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drinking water systems
ADVANCING THE SCIENCE OF SELF-RELIANCE

Five-Gallon Bucket Filter for Rooftop Harvested Rainwater

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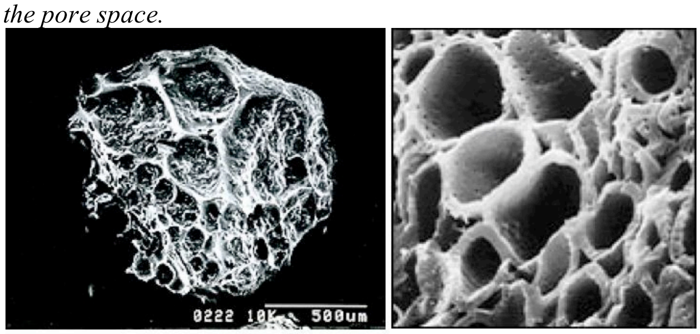
Many households would benefit from using rooftop harvested rainwater as a self-reliant source of drinking water. However, some concerns exist over contamination of the rainwater as it runs over roofing materials such as asphalt shingles.

The US EPA, the World Health Organization and several academic studies identify granular activated carbon (GAC) as the best available technology for the control of hydrocarbons and many synthetic organic chemicals in drinking water.[i, ii, iii, iv] Granular activated carbon is relatively inexpensive and can be purchased on-line or from aquarium supply shops. This paper presents a simple DIY (Do-It-Yourself) design for a five-gallon bucket charcoal filter that can provide a household of five people drinking water for up to six months.

Charcoal Filtration

Charcoal consists of elemental carbon in its graphite configuration. Carbon has been used for water purification for centuries, possibly dating back as far as ancient Egypt and India.[v] Carbon, in the form of graphite, exhibits an exceptionally high surface area per volume: one gram of industrially produced activated carbon may have a surface area of 400 – 1500 m^2 (a football field is about 5000 m^2). Non-polar organic molecules dissolved in water are strongly attracted to this surface and bind due to van der Waals (induced dipole) interactions. Carbon filters are employed in commercial home water treatment systems (to improve water taste, for example) as well as in large-scale municipal treatment facilities.

Scanning electron microscope images of GAC. The grain on the left is about 1 mm across. The right image shows a close-up of the pore space.



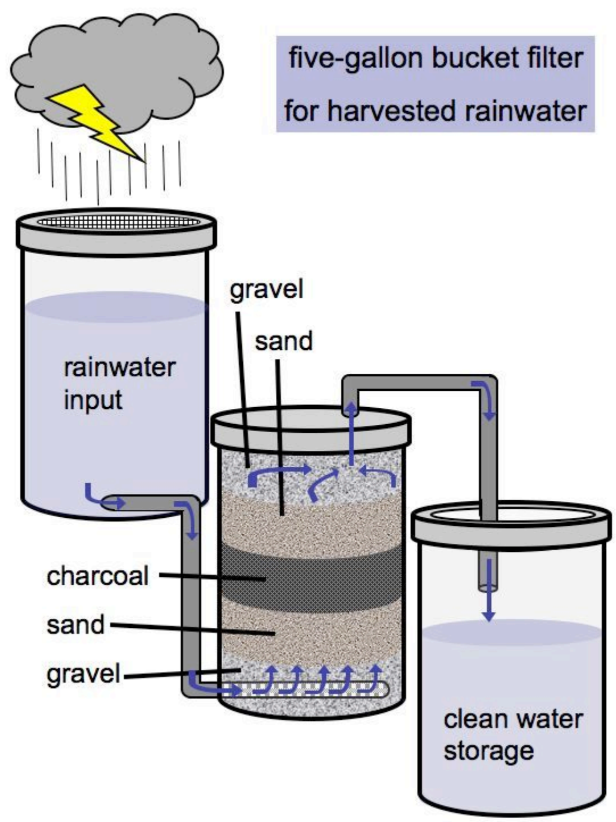
Carbon filters are effective for removing chlorine, mercury, iodine, and some inorganic compounds as well as many problematic organic contaminants such as hydrogen sulphide (H_2S), formaldehyde (HCOH), and volatile orgnanic compounds (VOCs). Activated carbon does not bind well to certain chemicals including lithium, alcohols, glycols, ammonia, strong acids and bases, metals, and most inorganic substances such as sodium, lead, iron, arsenic, nitrates and fluoride.

As a general rule, carbon will bind non-polar materials while polar materials will tend to remain in aqueous solution. Most pesticides are organic and strongly non-polar and thus should display an affinity for adsorption onto the carbon surface.

Water contaminants that can be reduced to acceptable standards – according to EPA National Drinking Water Standards – by activated carbon filtration include: organic arsenic, chromium and mercury complexes as well as inorganic mercury, benzene, endrin, lindane, methoxychlor, 1,2-dichloroethane, 1,1-dichloroethylene, 1,1,1-trichloroethane, trihalomethanes, toxaphene, 2,4-D, 2,4,5-TP (Silvex), and p-dichlorobenzene. [vi]

Charcoal Bucket Filter Design

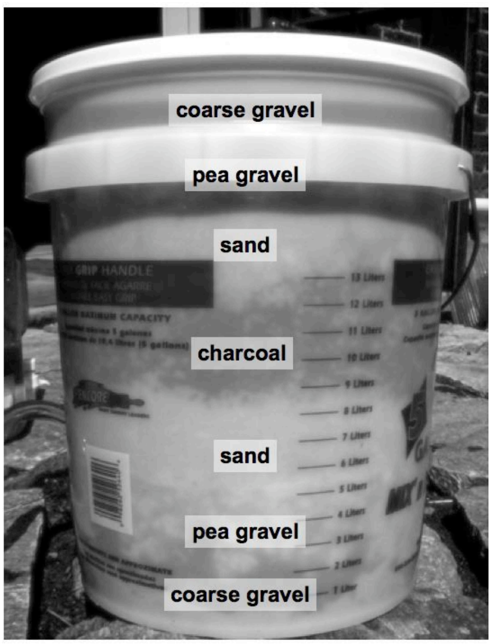
This design is for a charcoal bucket filter meant to serve a household of about five people who want to drink harvested rainwater but are concerned about contamination from roofing materials such as asphalt shingles.



Microbial contamination – primarily from fecal coliforms - is not a big concern since the rainwater runs only across a roof (unless there are a lot of bird droppings). But some microbes will likely be picked up, and charcoal provides an excellent surface for colonies to attach to.

It's doubtful that a slow sand filter could generate sufficient biological action in a short period of time on such a small scale as a five-gallon bucket, as used here. However, fine sand can still act as an adequate filter by occluding microorganisms that cannot fit through the pore spaces between sand grains. Thus, this design does not rely on a mature *schmutzedecke* to perform decontamination and degradation as in full-scale bio-sand filter designs.[1]

Design Specifications



This bucket filter uses a multi-layered design, with a bed of charcoal "sandwiched" between two layers each of fine sand and gravel. The charcoal filter medium used here is a commercial activated charcoal, or filter carbon, which can be purchased in bulk from any aquarium supply shop or via the internet.

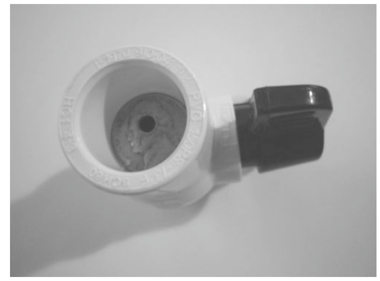
Since the filtered water will be used for drinking, we make conservative estimates about the quantity of filter carbon needed to purify a given volume of rainwater. For this design, we assume that 1g of activated charcoal is necessary to purify 1L of rainwater. One gram of activated charcoal is probably adequate to purify 10L of rainwater; our design specifications use the 1g to 1L ratio as a measure of precaution since the water is for drinking, and because charcoal is relatively inexpensive.

Assuming a household of 5 people and each person's drinking water intake at 2L per day (US EPA guideline), then to purify enough drinking water for a period of 6 months (183 days) requires 1830g (1.83kg) of activated charcoal. The density of charcoal is about 500g/L. Thus 1.83kg of charcoal occupies about 3.66L of volume, or a little less than a gallon. After 6 months approximately 1,830L have passed through the filter and the charcoal must be replenished.

The filter uses an upflow design for economy of construction and ease of use. A single valve installed between the

[1] *Schmutzedecke* – German, literally "scum layer." So-called bio-sand filters rely on a layer of microorganisms living in the top few centimeters of sand to perform most of the decontamination. In the filter design presented here, the sand functions simply as a strainer, physically occluding microorganisms from passing though the media. More information on bio-sand filtration can be found on the Aqueous Solutions website – www.aqsolutions.org.

rainwater collection bucket and the filter bucket controls flow through the system.



A flow restrictor is fabricated by drilling 1 – 3 holes, 9/64 inch in diameter, in a nickel or other suitable disk-shaped material. A nickel fits snugly into a ½ inch ball valve housing and so is a convenient choice of material for this purpose. One 9/64 inch hole should provide a flow rate of 1 – 1.5 L/min. The flow rate should not exceed 4 L/min to ensure adequate contact time between the rainwater and the charcoal filter medium.

A pea gravel and rock underdrain support the layers of filtration media and keep the sand from backing up into the influent pipe. From the bottom up, the sequence of filter media should be: coarse gravel, pea gravel, sand, charcoal, sand, pea gravel, coarse gravel. Each layer of sand or gravel should be 2 – 3 inches deep; the media should completely fill the filter bucket. The sand should be fine-grained and thoroughly washed; pre-washed play sand works well, but needs additional washing to remove the finest fraction of silt. The pea gravel and coarse gravel should also be thoroughly washed before use in the filter.

The charcoal should also be washed prior to use in the filter. This is easily done by using a 3ft x 3ft piece of window screen to bundle up about ½ gallon of charcoal at a time, tying the bundle securely with twine, and then dunking vigorously several times in an ample volume of clean water. The blackened water is discarded and the charcoal dunked again in clean water until most of the fine charcoal particles are removed.

The filter pipe assembly (see photograph below) is fabricated by drilling several 9/64 inch diameter holes into a 9 inch long section of pvc pipe. This helps to disperse the flow of water into the filter bucket and encourages even distribution and laminar flow through the layers of filter media.

Holes ¾ inch in diameter are drilled near the base of each bucket and in the lid of the filter bucket using a spade bit. Plumbing joints installed in these holes use rubber washers to provide a snug fit and prevent leaks. All threaded pvc connections are taped with Teflon to provide a good seal and prevent leaks. PVC slip fittings can probably be made hand-tight and will not leak; this avoids the need for pvc glue, which is unpleasant to work with.

Parts and Tools Inventory

Part Number	Description	Quantity, Amount, Size, etc.	Approximate cost
1	commercial activated carbon; filter carbon	1 gallon	$35/gallon
2	5 gallon plastic bucket with lid	2 buckets, 2 lids	$8.50 each
3	1/2 inch ball valve	1	$2.50 each
4	teflon tape	3 - 4 feet	$1/roll
5	1/2 inch inner-diameter rubber washers	6 - 10	$1 - $2 total
6	1/2 inch pvc elbow fitting, threaded and slip	2	$3.50 each
7	1/2 inch male threaded pvc insert connector	1	$0.75 each
8	1/2 inch female threaded pvc insert connector	2	$0.75 each
9	1/2 inch pvc end-cap slip	1	$1.75 each
10	1/2 inch inch pvc bushing, threaded	2	$3.50 each
11	1/2 inch pvc adapter; male threaded, female slip	1	$2 each
12	1/2 inch inner-diameter vinyl or Tygon tubing	6 ft	$0.30 per ft
13	sand	2 gallons ~ 30 lbs	$5 for 50 lbs
14	pea gravel	1 gallon ~ 15 lbs	$5 for 50 lbs
15	coarse gravel	1 gallon ~ 15 lbs	$5 for 50 lbs
16	1/2 inch pvc pipe, 2 1/2 inches in length	2	$3 for 6 ft
17	1/2 inch pvc drainpipe, 9 inches in length	1	$3 for 6 ft
18	nickel	1	$0.05
19	window screen	15 x 15 inch	$5 per roll

Tools needed are: drill; 3/4 inch spade drill bit; 9/64 inch sheet metal drill bit; sandpaper - medium to coarse grade; boxcutter or exacto knife; scissors; pocket knife; pliers; saw to cut pvc; window screen - 3ft x 3ft; twine - 6 ft; measuring cup - 1L size or larger.

The rainwater input bucket (see photograph below) is fabricated by cutting an 8 inch circle out of the bucket lid, and using the rim of the lid to secure a 15 inch x 15inch piece of window screen over the mouth of the bucket. This assembly screens out debris in the source rainwater to help prevent clogging of the system.

The lid of the filter bucket should fit snugly to prevent leaking during filter operation. If leaking occurs, Teflon tape can be applied in the gap in the lid to create a seal with the rim of the bucket mouth. If leaking still occurs, some soft silicone sealant can be used to seal the lid to the bucket rim. (Use soft silicone so that the lid can be easily removed using a boxcutter or exacto knife later when it's time to change the charcoal.)

Total expenses for all parts and filter media should not exceed $90 – a good scavenger could acquire most of these materials at much less cost. Thus, for a household of 5 people, for the first 6 months of operation the cost should be less than $3 per person per month, or less than $0.05 per liter. For subsequent 6-month periods over the lifetime of system, the cost should drop below $0.02 per liter, or $1.30 per person per month.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GALLON


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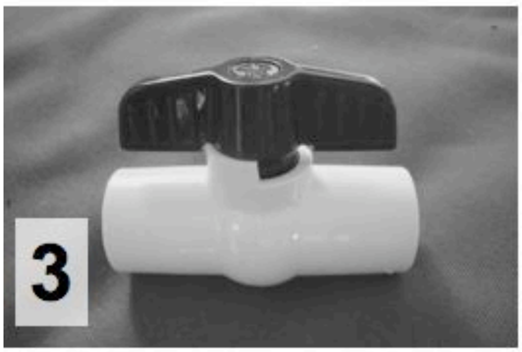
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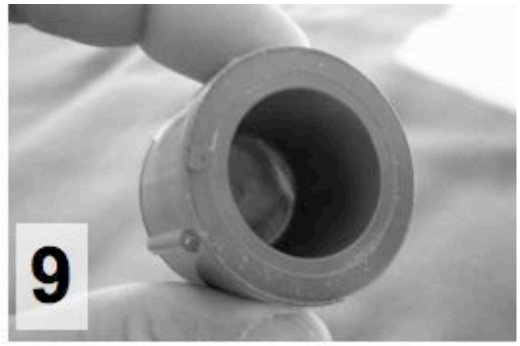
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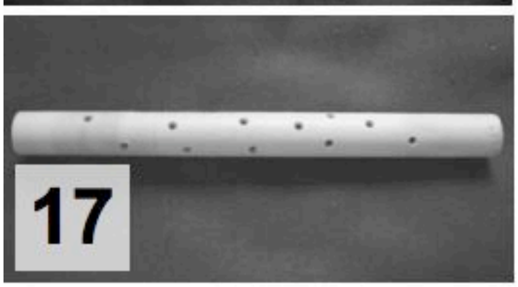
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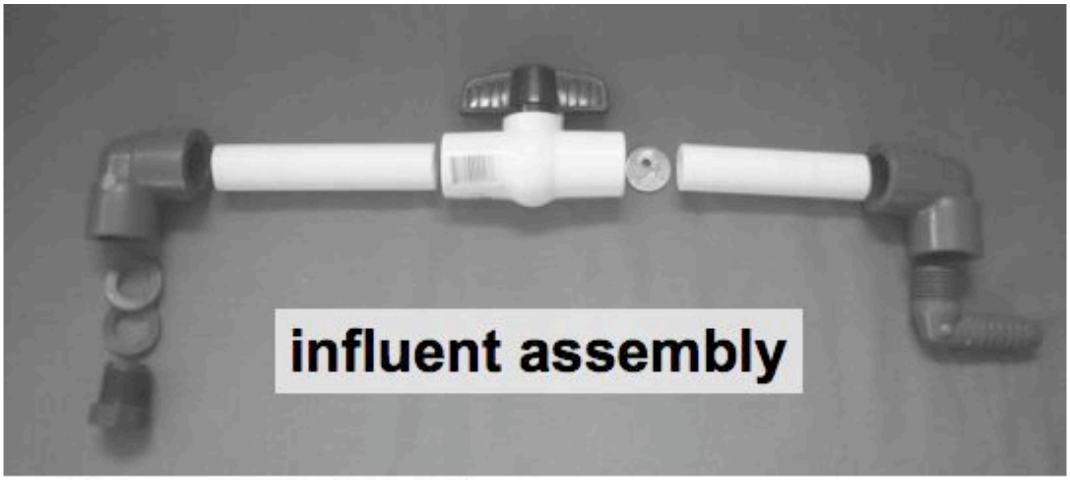
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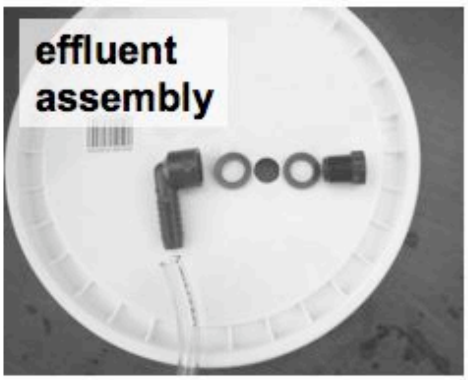
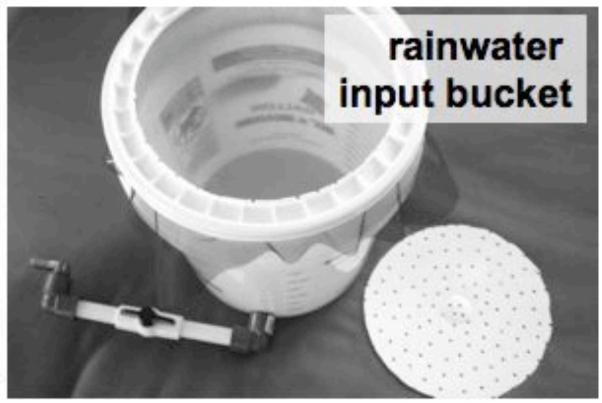
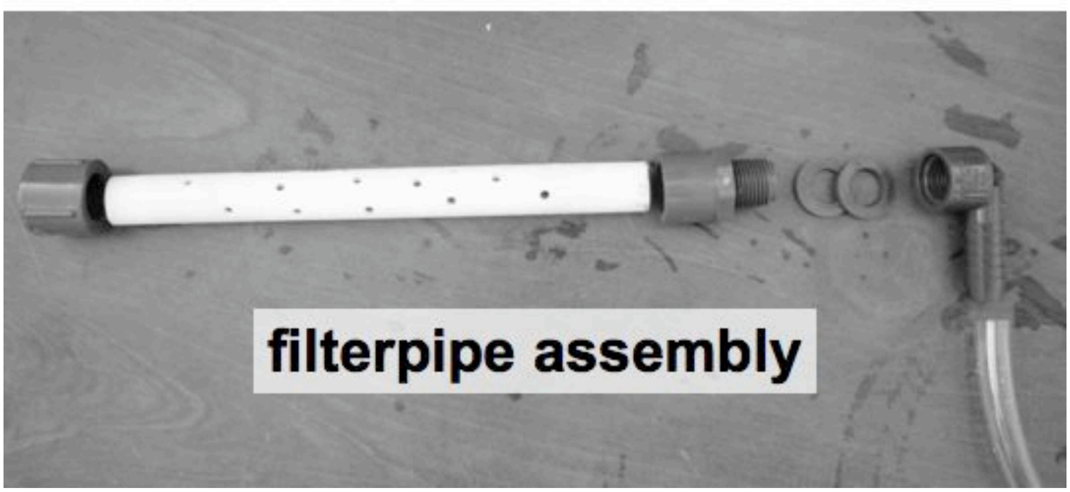

effluent
assembly


rainwater
input bucket


filterpipe assembly

For more information on sustainability and self-reliance in drinking water filtration, see our website:

aqsolutions.org

References

[i] US EPA. National primary drinking water regulations; final rule. Federal Register, 30 January 1991. 1991; 56 20: 3526 3597.

[ii] World Health Organization website: (http://www.who.int/water_sanitation_health/dwq/wsh0207/en/index6.html) section 2.3 Charcoal and activated carbon adsorption

[iii] Pontius F. An update of the federal drinking water regs. J AWWA 1995; 87: 48-58.

[iv] Pesticide Adsorption by Granular Activated Carbon Adsorbers. 1. Effect of Natural Organic Matter Preloading on Removal Rates and Model Simplification. Matsui Y, Knappe DRU, Takagi R. Environ. Sci. Technol. 2002, 36, 3426-3431.

[v] Wikipedia: http://en.wikipedia.org/wiki/Carbon_filtering

[vi] Water Quality Association, 1989. Recognized treatment techniques for meeting the National Primary Drinking Water Regulations with the application of point-of-use systems.; and, Water Quality Association, 1989. Recognized treatment techniques for meeting the National Secondary Drinking Water Regulations with the application of point-of-use systems. See also Seelig B, Bergsrud F, and Derickson R. Treatment Systems for Household Water Supplies: Activated Carbon Filtration. February 1992. (http://www.ag.ndsu.edu/pubs/h2oqual/watsys/ae1029w.htm)