REBUILDING CIVILIZATION

Water and sanitation

Obtain, purify, distribute water, and manage excreta and wastewater.

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Contents

Water purification

Remove pathogens and contaminants from water: heat, filtration, chemicals and sun, from household to industrial scale.

WATER AND SANITATION › WATER PURIFICATION

Boiling water

Boil water to kill pathogens, with time adjusted for altitude, safe cooling and storage, and fuel consumption.

N1 · Pottery and farming · Draft · Machine translation · civilizationrebuild.org/en/01-agua-y-saneamiento/potabilizacion/hervido-del-agua/

> **Machine translation.** Its structure and figures have been automatically checked against the Spanish original, but no person has reviewed it.

> **Draft without technical review.** It may contain errors: double-check figures and procedures before applying them. It contains 6 figures marked “verificar” (to be verified).

Summary

Boiling water destroys practically all the bacteria, viruses and protozoa (including their cysts and oocysts) that cause disease, using only fire and a container. It is the most reliable biological purification method and the easiest to verify by eye (just seeing it at a rolling boil) when there is no chlorine, certified filters or laboratory available. Expected, measurable result: starting from water with no visible turbidity, a batch of up to ~10 L becomes microbiologically safe in 15-35 minutes (lighting the fire, heating and boiling), plus 30-60 minutes of cooling before it is comfortable to drink, at a cost of between 1.5 and 2.2 kg of dry firewood (or 0.4-0.6 kg of charcoal) per 10 L over an open fire. Boiling does **not** remove chemical products, heavy metals or turbidity, and boiled water is not protected against later recontamination: safety depends as much on how the water is boiled as on how it is cooled and stored.

Prerequisites

- **Knowledge:** none is essential to carry out the procedure as described here. It helps to have already decided how the water is collected (the clearest source available) and, if the goal is to reduce fuel use, to compare with solar disinfection (SODIS) and with filtration, articles planned for this same folder.
- **Materials:**
  - Water to be treated, as clear as possible: 2-3 L per person per day just for drinking (more in heat or with physical work).
  - Fuel: dry firewood (moisture <20 %, it snaps with a crack instead of bending), or charcoal, or any other sustained heat source (gas, electric stove, embers).
  - A tightly woven cotton cloth (a sari-type cloth folded 4-8 times works; see “How it works”) to pre-filter the water if it is turbid.
  - A clean, narrow-mouthed container with a lid and, if possible, a tap, kept exclusively for drinking water, for later storage.
  - A thick cloth or oven mitt to handle the hot container.
- **Tools:**
  - An open-air fire or a hearth (N0: three stones and firewood are enough).
  - A container that can be set directly over the flames and withstand repeated boiling without cracking or releasing toxic substances. **This is where this article's technological level is decided:** it is set at `nivel: 1` because the main procedure (container placed directly over the fire) requires fired ceramic (N1 minimum) or metal (N2); a purely N0 container — raw hide, bark, waterproofed basketry, wood — burns, warps or loses its seal if brought near direct fire. A genuine N0 route does exist, slower and with greater losses: heating stones red-hot in the bonfire and dropping them into water held in a container that resists water but not direct fire (“hot-rock boiling”). Because it is less efficient and carries a greater risk of burns, it is documented as a lower-resource variant (see “Variants”), not as the main procedure.

  - A thermometer and/or a WAPI indicator are optional (needed only for the lower-temperature pasteurization variant, see "Variants").
- **Time and people:** one person is enough. Per batch of up to 10 L: 5-10 min to prepare the fire, 10-20 min to bring the water to a boil (depending on fire strength and volume), 1-3 min of sustained boiling, and 30-60 min of cooling before it is comfortable to drink (it can be drunk warm before that, already safe, if there is urgency).

How it works

Why heat kills pathogens

Heat denatures the proteins and enzymes of microorganisms and damages their nucleic acids; above a certain temperature, sustained for long enough, the pathogen stops being viable or infectious. Thermal sensitivity varies by type of organism:

- **Bacteria in vegetative form** (*E. coli*, *Vibrio cholerae*, *Salmonella*, *Shigella*): inactivated in seconds from about 60 °C upward; at boiling temperature, destruction is practically instantaneous.
- **Enteric viruses** (rotavirus, norovirus, hepatitis A): somewhat more resistant than bacteria, but likewise inactivated in under 1 minute at boiling temperature.
- **Protozoan cysts and oocysts** (*Giardia*, *Cryptosporidium*): the most heat-resistant organisms of sanitary concern among those commonly transmitted by water. *Cryptosporidium* oocysts are inactivated in under 1 minute above 70 °C, and *Giardia* cysts almost instantly from that same temperature.
- **Bacterial spores** (e.g. *Bacillus*, *Clostridium*): boiling at 100 °C does **not** reliably destroy them; autoclave temperatures (~121 °C under pressure) or very long times are needed. In practice, however, they are not the usual cause of waterborne illness, which is why boiling remains the reference method for household use, with this honest caveat.

Taken together, a sustained rolling boil comfortably exceeds the temperature and time that any common enteric pathogen needs to be inactivated.

Boiling versus pasteurization

It is not necessary to reach 100 °C to kill pathogens: pasteurization uses lower temperatures (60-72 °C) for longer to achieve the same effect with less fuel. The reference study (Ciochetti and Metcalf, 1984) found that fecal coliforms in river water were inactivated from 60 °C upward, and that keeping water above 65 °C leaves it, for at least one hour, above the pasteurization temperature of milk (62.8 °C), considered sufficient to inactivate the enteric pathogens of concern. Boiling (100 °C, 1-3 min) is simpler to verify without a thermometer — just seeing it bubble is enough — and gives a wider safety margin against variations in altitude, turbidity or uneven heat distribution in the container; that is why WHO/UNICEF and the CDC recommend it as the default method. Lower-temperature pasteurization (the WAPI variant, see "Variants") is preferable when fuel is the scarcest resource.

Altitude adjustment

Water boils when its vapor pressure equals atmospheric pressure; at lower atmospheric pressure (higher altitude), water boils at a lower temperature. This does not invalidate the method — even at high altitude the boiling temperature stays well above the 70 °C that suffice for the pathogens mentioned above — but it reduces the safety margin, which is why WHO/UNICEF and the CDC recommend extending the boiling time above 2000 m (~6500 ft):

Altitude (m)	Boiling point (°C)	Rolling-boil time
0 (sea level)	100.0	1 minute
610	97.8	1 minute
1219	95.7	1 minute
1829	93.6	1 minute
~1980 (6500 ft, WHO/CDC threshold)	~93.0	**3 minutes** from here on
2438	91.6	3 minutes
3048	89.6	3 minutes
4572	84.7	3 minutes

Rule of thumb: **1 minute of rolling boil below 2000 m; 3 minutes from 2000 m upward.**

Why settle and filter before boiling

Heat does not remove turbidity or suspended matter, and sediment can shelter pathogens protected from the heat inside it (larger particles take longer to reach the lethal temperature at their core), besides wasting fuel by heating matter that is not water. Filtering through a tightly woven cotton cloth also has a documented effect of its own: a field study in Bangladesh (Colwell et al., 2003) showed that a sari-type cloth folded 4-8 times forms a filter with an effective mesh of about 20 microns, able to retain the zooplankton and phytoplankton that *Vibrio cholerae* usually attaches to, and cut cholera cases by 48 % in the villages where it was used. Settling and filtering before boiling is therefore a step that reduces fuel use and adds an extra barrier, not a substitute for boiling.

What boiling does NOT remove

- **Dissolved chemicals:** pesticides, solvents, nitrates, excess arsenic or fluoride are not destroyed or meaningfully evaporated by boiling; if the water is boiled for a long time, letting a significant fraction of it evaporate, the concentration of what does not evaporate (salts, heavy metals) can even rise slightly.
- **Heavy metals** (lead, mercury, cadmium, arsenic): not removed by boiling.
- **Turbidity, color, salty taste or mineral off-odor:** boiling does not clear the water or remove salty tastes; only settling, filtration or distillation act on this.
- Because of the above, if the water is suspected of contamination by fuel, solvent or industrial chemicals, **it must not be boiled for drinking**: another source must be found.

Procedure

1. **Prepare the water.** If there is visible turbidity, let it settle undisturbed in a container for 30-60 min and pour off only the clear water from the top without stirring up the sediment, or filter it through a tightly woven cotton cloth folded 4-8 times (sari-type, effective mesh of ~20 microns) tied over the mouth of another clean container. *Success criterion:* the water looks transparent (text is legible through a 10 cm layer of it) and leaves no visible sediment after 10 minutes at rest in a glass.
2. **Choose the container.** Fired ceramic without lead glaze, or metal, with a capacity of at least 1 L per person per serving, with no cracks or leaks, and that has never held fuel, paint or pesticides. *Success criterion:* after filling it with water and leaving it for 5 min, no drips appear and no rust stains rub off to the touch.
3. **Fill the container between 2/3 and 3/4 of its capacity**, leaving room for the boil without overflowing. *Success criterion:* a gap of at least 5 cm between the water surface and the rim.
4. **Cover** with a lid or a flat object that does not release substances (another pot, a clay plate) and place over the fire at maximum power. *Success criterion:* no continuous jet of steam is seen escaping from the sides before it starts to boil (covering it saves fuel, see “Calculations”).
5. **Heat until it reaches a rolling boil**: large bubbles rising continuously from the bottom that do not stop when stirred. *Success criterion:* visible bubbling across the whole surface (not just at the edge) for at least 10 consecutive seconds.
6. **Keep it at a rolling boil** for 1 minute if the site's altitude is below 2000 m; 3 minutes if it is at or above that. *Success criterion:* time it from the moment step 5's criterion is met; the boil does not stop at any point during the interval.
7. **Remove from the fire** with a thick cloth or tongs (the container and any metal handle are above 90 °C) and uncover it while keeping face and hands away from the jet of steam. *Success criterion:* no one makes direct contact with the container or gets hit by the steam.
8. **Cool** it covered, out of children's reach, until it is comfortable to drink. *Success criterion:* the outside of the container is lukewarm (≤ 35-40 °C to the touch), not hot.
9. **Aerate to improve the taste (optional).** Pour the water back and forth between two clean containers 5-10 times from a height of ~30 cm. *Success criterion:* fine air bubbles appear and the water loses the “flat” taste typical of boiled water (caused by the loss of dissolved air during boiling).
10. **Store** it in the narrow-mouthed container, covered, with a tap if possible, without putting hands, cups or ladles into the water. *Success criterion:* the water is only served by pouring directly or through the tap, never by dipping a utensil in.

Verification

- **Visual:** the water is transparent, with no sediment or film on the surface, and the only smell or taste that differs from the original is the “flat” taste typical of boiling (which aeration in step 9 fixes).
- **Process-based, not product-based:** there is no simple field test that can confirm afterward that boiled water is free of pathogens; the guarantee comes from having met the time and temperature requirements (steps 5-6), not from a later check. If a thermometer is available, it can confirm that a rolling boil (not just hot water) was reached before timing starts.

- **Important:** unlike chlorination, boiling leaves no protective residual. Correctly boiled water can be contaminated again 5 minutes later if it is served with dirty hands or in a dirty container; the real verification that it is still safe to drink is that it has been handled following step 10 at every moment since it was boiled.

Common mistakes

Symptom	Likely cause	Solution
Someone who drinks "boiled" water still gets sick	Recontamination during cooling or storage (hands, ladle, dirty container)	Use a narrow-mouthed container with a lid/tap; serve without dipping utensils in; wash the container daily
The water tastes "flat" or unpleasant	Loss of dissolved air during boiling	Aerate it by pouring between two containers before drinking (step 9)
Much more fuel is used than expected	Uncovered container, fire exposed to wind, damp firewood	Cover the container; shield the fire from wind; use firewood with under 20 % moisture or an efficient stove
The water is still turbid after boiling	Water with sediment was boiled without settling or filtering it first	Settle and/or filter with cloth before boiling (step 1); boiling does not clear the water
Strange or metallic taste after using a certain container	Unsuitable container: plastic not rated for heat, lead-glazed ceramic, or a container that held fuel/pesticide	Use only fired ceramic without lead glaze, or metal kept exclusively for water (see "Safety")
The boil does not give enough safety margin at high altitude	Time was not adjusted for altitude	Boil for 3 minutes instead of 1 above 2000 m (see altitude table)

Safety

- **Burns and scalds (the main hazard of this procedure):** steam at 100 °C causes deeper burns than liquid water at the same temperature, because it releases a large amount of extra heat as it condenses on the skin. Always use a thick cloth or oven mitt to move the container; uncover it while keeping face and hands away from the jet of steam; make sure the container sits stable over the fire and cannot tip over; keep children out of reach of the fire and the hot container at all times, including during cooling.
  - **What to do for a burn:** cool it immediately with lukewarm or cold (not iced) running water for 10-20 minutes; do not apply ice directly, toothpaste or home remedies to the burn; do not pop blisters; cover with a clean, non-stick cloth. Seek medical attention if the burn is bigger than the palm of the hand of the person who suffered it, if it affects the face, hands, skin folds or genitals, or if extensive blisters appear.
- **Smoke poisoning:** if firewood or charcoal is used to boil in a closed or poorly ventilated space, there is a risk of carbon monoxide poisoning, which is odorless and can be fatal. Always boil outdoors, under a smoke outlet, or with assured cross-ventilation.
- **Valid containers:** fired ceramic without lead or cadmium glazes (some old or handcrafted glossy glazes contain them, and heat and acidity make them more likely to leach into the water), or metal (stainless steel, aluminum, iron) kept exclusively for food use.
- **Invalid containers:**
  - Plastic not certified for direct contact with heat: it can warp, burn or release compounds into the water.
  - Any container that has held fuel, solvent, paint or pesticide: boiling does not remove those chemical residues even if the water ends up free of pathogens.
  - Ceramic with lead or cadmium glaze.
  - Galvanized metal for repeated, prolonged boiling: the zinc coating can degrade with continued use and leach into the water in excess (verificar: the size of the risk depends on the condition of the coating and how many times it is reused).
- **Stones for the hot-rock boiling variant (see "Variants"):** never use river stones, porous stones, or ones that have been wet on the inside: steam trapped in their pores can make them explode violently when heated, throwing off fragments. Use dense, dry stones with no visible cracks, and always heat them well away from the face.
- **Reminder:** boiling does not protect against chemicals or heavy metals (see "What boiling does NOT remove" in "How it works"); if that kind of contamination is suspected, boiling alone is not enough.

Variants

- **With fewer resources (N0, no ceramic or metal): hot-rock boiling.** Dense, dry, non-porous stones are heated red-hot in the fire for 20-30 min, and dropped in one at a time with green-wood tongs or a forked stick into the water, which is held in a container that withstands water but not direct fire (raw hide, sewn tree bark, a very tightly woven basket waterproofed with clay or resin, a hollowed-out log). Roughly 3-5 fist-sized stones (~0.5 kg each) are needed per liter of water to reach a boil, replacing stones as they cool (verificar: exact figure depends a great deal on the type of stone and the size of the fire). It is a technique with a documented history of use in cultures that had no fire-resistant containers. *What is lost:* energy efficiency (a lot of heat stays in the stones that never fully submerge), more time and labor, and a higher risk of burns from splashing and of porous stones exploding. *What is gained:* not depending on fired ceramic or metal.
- **With more resources (N2 upward):** a metal kettle with a tight-fitting lid and a heat-insulated handle; a gas or electric stove with power control, which reaches the boil sooner and without smoke; from N3 onward, an electric kettle with automatic shutoff at boiling (less supervision needed); at industrial scale (N3-N4), continuous-flow pasteurizers with a heat exchanger that recovers part of the heat from the already-treated water to preheat the incoming water, cutting fuel use per liter considerably.
- **Lower-temperature pasteurization variant with an indicator (WAPI):** instead of bringing the water to a boil, it is heated (over a fire, in a box-type solar cooker, or over embers) and held at 65 °C using a WAPI indicator — a polycarbonate tube with a wax plug calibrated to melt at that temperature, developed by Fred Barrett and Dale Andreatta for Solar Cookers International — or, without a WAPI, with a thermometer. The basis for this (Ciochetti and Metcalf, 1984) is that fecal coliforms are inactivated from 60 °C upward, and that keeping the water above 65 °C comfortably exceeds the pasteurization temperature of milk (62.8 °C), sufficient for the enteric pathogens of concern. *Advantage:* it saves a significant part of the fuel compared with boiling, since there is no need to reach 100 °C or sustain a boil. *Disadvantage:* it requires controlling the temperature more precisely than just "seeing it boil"; it does not destroy heat-resistant bacterial spores (of little relevance in drinking water); making a WAPI requires N3-N4-level materials and calibration, although an already-made WAPI can be reused thousands of times. Recommended when fuel is the scarcest resource and there is a reliable way to control temperature.
- **Scaling up to a village:** boiling in communal cauldrons of 20-200 L over a shared fire or in a community kitchen, in shifts. The larger the cauldron, the smaller its surface-to-volume ratio, which reduces relative heat losses and fuel use per liter compared with boiling in small batches. In exchange, the risk of recontamination rises (more people dipping ladles or containers into the same cauldron), and it becomes necessary to organize distribution into individual narrow-mouthed containers and to ensure a centralized fuel supply, which is usually the real bottleneck: WHO/UNICEF point to the high cost and fuel consumption as the main limitation of large-scale boiling compared with centralized chlorination, which works out far cheaper per liter. Where possible, reserve communal boiling for those without access to chlorine, and treat it as a transitional solution.

Calculations

Theoretical energy to boil 10 L of water

Data: specific heat of water c = 4.186 kJ/(kg·°C); mass of water m = 10 kg (10 L); initial temperature 20 °C, final 100 °C (at sea level); ΔT = 80 °C.

Minimum energy the water must receive (not counting losses or the time of sustained boiling):

```
Q = m × c × ΔT = 10 kg × 4.186 kJ/(kg·°C) × 80 °C = 3349 kJ ≈ 3.35 MJ
```

In practice, most of a fire's heat is lost to the air and surroundings rather than passing into the water, so considerably more fuel is needed than this theoretical figure.

With an open three-stone fire (real thermal efficiency 10-15 %, verificar)

```
Firewood energy needed = 3.35 MJ / 0.10 to 0.15 = 22.3 to 33.5 MJ
```

With air-dried firewood (calorific value ≈ 15 MJ/kg):

```
Firewood mass ≈ 22.3/15 to 33.5/15 = 1.5 to 2.2 kg per 10 L (≈ 150-220 g per liter)
```

With an improved rocket-type stove (efficiency 25-40 %)

```
Firewood energy needed = 3.35/0.25 to 3.35/0.40 = 8.4 to 13.4 MJ
Firewood mass ≈ 0.56 to 0.9 kg per 10 L (≈ 56-90 g per liter)
```

That is, between 2 and 3 times less firewood than with an open fire, consistent with fuel savings on the order of 40-60 % cited by field comparisons between three-stone fires and rocket stoves (verificar: exact figure varies by study).

With charcoal (28-30 MJ/kg) and a "jiko"-type stove (efficiency 20-30 %, verificar)

```
Energy needed = 3.35/0.20 to 3.35/0.30 = 11.2 to 16.75 MJ
Charcoal mass ≈ 0.37 to 0.6 kg per 10 L (≈ 37-60 g per liter)
```

Effect of the lid

Covering the container reduces fuel use for boiling by 20-35 % compared with boiling uncovered (a general estimate from cooking physics, not specific to water purification). Applied to the open three-stone fire, this could bring consumption down to approximately 1-1.8 kg of firewood per 10 L.

Honesty note: all the fuel-mass figures in this section are order-of-magnitude estimates based on published efficiencies for different fire/stove types; actual consumption depends heavily on the moisture of the firewood, wind, fire size, the shape of the container and the experience of the person tending it. They are marked as estimates, not as an exact, reproducible value.

Sources

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Related: Solar disinfection (SODIS) (p. 9) Chemical disinfection of water with chlorine and iodine (p. 17) Slow sand filter and charcoal biofilter (p. 27) Ceramic and carbon filters (p. 37)

WATER AND SANITATION › WATER PURIFICATION

Solar disinfection (SODIS)

Disinfect clear water in PET bottles in the sun: turbidity, exposure times by cloud cover, what it doesn't remove, storage and verification.

N0 · Natural materials · Draft · Machine translation · civilizationrebuild.org/en/01-agua-y-saneamiento/potabilizacion/desinfeccion-solar-sodis/

Machine translation. Its structure and figures have been automatically checked against the Spanish original, but no person has reviewed it.

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Summary

Solar disinfection (SODIS, short for *solar water disinfection*) consists of filling clear plastic PET bottles of 2 L or less with clear water and leaving them lying in direct sun for a full day (at least 6 hours including midday), or two consecutive days if the sky is more than half covered. UV-A radiation and the heating of the water inactivate most of the bacteria that cause diarrhea and cholera, and some of the viruses and protozoa. It uses no fuel or chemical products and works with recovered bottles, which makes it the starting option when there is no firewood or chlorine. Expected, measurable result: with water of turbidity below 30 NTU and good sun, a reduction of fecal bacteria of around 3 logarithms (99.9 %) in 1 day, at a rate of 2 L per bottle exposed (Meierhofer and Wegelin, 2002). It does **not** sterilize, does **not** remove chemicals or turbidity, is weak against *Cryptosporidium* and many viruses, and does not work with continuous rain or for baby-bottle water.

Prerequisites

- **Knowledge:** none essential. It helps to know boiling water (p. 3), which is the mandatory alternative for infants, sick people and rainy days, and filtration (slow sand filter (p. 27)) as a pretreatment for turbid water.
- **Materials:**
  - Clear, colorless PET bottles (or with a slight blue tint), 0.3 to 2 L, with a screw cap that seals tight. Guideline amount: **4 bottles of 2 L per person** (2 in the sun and 2 ready to drink), following Eawag's guidance (Meierhofer and Wegelin, 2002); with frequent cloudy skies more are needed, or boiling as a supplement (see "Calculations"). How to identify PET: see step 1.
  - Soap or ash and a brush or a handful of clean sand for the first wash.
  - A support to lay the bottles flat in the sun: corrugated metal sheet (the best), a roof, aluminum sheet or any dark or reflective surface free of shadows.
  - A newspaper or paper with large print (headlines) for the turbidity test.
  - A tightly woven cotton cloth or a sand filter if the water is turbid.
  - Optional: thermometer, WAPI indicator and an *E. coli* test kit (see "Verification").
- **Tools:** none manufactured. **Technology-level decision:** set at `nivel: 0` because the main procedure does not require manufacturing anything: sun, water and recovered PET bottles suffice, which will be abundant in the first years after a collapse (phase F0). PET cannot be manufactured until N4, so the method is sustainable only for as long as recovered bottles last; its manufacturable substitute is clear glass bottles (N2), with the caveats explained in "Variants". A purely N0 container (gourd, hide, ceramic) is opaque to UV-A and does not work for SODIS; with it, only boiling or pasteurizing is possible.
- **Time and people:** one person. It requires daily work filling, placing, retrieving and marking bottles, plus 6 h to 2 days of waiting without attention; the 2016 manual only describes it as a "relatively high daily work demand" and gives no minutes per bottle: time it during the first week to plan (see "Calculations"). Eawag's recommendation: that at least 2 people in each household know how to apply it and one is responsible for it every day (Meierhofer and Wegelin, 2002).

How it works

Two effects of the sun and their synergy

1. **UV-A radiation (320-400 nm) and visible violet.** The UV-B that reaches the ground kills microorganisms by directly damaging their DNA, but PET absorbs almost all of it. What does pass through the bottle is UV-A, which

generates **reactive oxygen species** in the water (singlet oxygen, hydrogen peroxide, hydroxyl radical) from dissolved oxygen and photosensitive substances; these damage the membranes, enzymes and DNA of pathogens (Luzi et al., 2016, chap. 2.1). This is why disinfection depends on light penetrating (clear water, shallow depth) and on dissolved oxygen being present.

2. **Heat (infrared).** The water in the bottle heats up. On its own, heat inactivates pathogens in 60 minutes at temperatures between 45 °C (*Vibrio cholerae*) and 63 °C (enteroviruses) (Luzi et al., 2016, chap. 2.2.7).
3. **Synergy above 45-50 °C.** Together, the two effects add up to much more than separately. At 30 °C a dose of about **555 Wh/m²** is needed (350-450 nm, equivalent to about 5-6 h of midday summer sun at mid latitudes: ~5 h according to Wegelin et al., 1994 and table 5 of Luzi et al., 2016; ~6 h according to Meierhofer and Wegelin, 2002, p. 12) to reduce fecal coliforms by 3 logarithms; at 50 °C about 140 Wh/m² is enough, on the order of 1 h of exposure (Wegelin et al., 1994; Meierhofer and Wegelin, 2002). The 2016 manual summarizes this by saying that at 50 °C the dose or time needed is reduced **by up to two thirds** (Luzi et al., 2016, chap. 2.2.7). Below about 45 °C the temperature dependence is weak.

Practical consequence: the synergy explains why SODIS works better in warm climates, but **the 2016 manual does not recommend shortening the exposure time**: water temperature changes throughout the day, a single reading does not prove how long it stayed above 50 °C, and the 6 h or 2 day rule already carries a built-in safety margin (Luzi et al., 2016, chap. 2.2.7 and box 6).

Variables that matter, and their margin

Variable	Recommended value	What happens outside the margin
Solar intensity	≥ 500 W/m² (full spectrum) for about 5-6 h	With a fully overcast sky UV-A drops to ~1/3: 2 days need to be accumulated (Meierhofer and Wegelin, 2002)
Turbidity	< 30 NTU	Particles absorb and scatter UV-A and shield microbes: pretreat (step 3)
Water depth	≤ 10 cm	With water at 26 NTU, at 10 cm depth only ~50 % of the UV-A gets through (Sommer et al., 1997)
Bottle volume	≤ 2 L	In China, 2.5 L glass bottles left only 72 % of samples free of coliforms; with 1.25 L PET, 99.2 % (Meierhofer and Wegelin, 2002)
Material	Colorless transparent PET	Colored bottles (brown, green) block UV-A; 2 mm window glass barely lets it through
Dissolved oxygen	Aerated water (≈ saturation)	At 50 % saturation, *E. coli* inactivation runs at half speed (Reed, 1997, cited in Luzi et al., 2016)
Color and dissolved organic matter	As little as possible	Heavily colored water (tea, peat) lengthens the time needed; there is no simple test to measure it

Suitable latitudes

- **Most favorable region:** between 15° and 35° latitude (north and south): semi-arid areas with plenty of direct radiation and little cloud.
- **Second most favorable:** between the equator and 15° latitude: plenty of radiation, but more cloud cover and diffuse radiation (Meierhofer and Wegelin, 2002, chap. 2.3).
- **Beyond 30-35°** (all of mainland Spain, between 36° and 44° N; the Canary Islands, around 28° N, do fall within the favorable band): Eawag warns that its exposure guidelines **do not apply** beyond 30° N/S (Luzi et al., 2016, box 6). There is no official guideline for these latitudes. At altitude (the Bolivian Altiplano, the Chinese plateau) SODIS has worked well despite the cold because UV is intense.
- **Criterion proposed by this project for high latitudes (extrapolation, not an Eawag guideline):** table 5 of the 2016 manual estimates a threshold dose of ≈ 5.7 kWh/m² of full-spectrum radiation accumulated during

exposure. From this, the following monthly guideline is derived, according to the **mean daily global irradiation on a horizontal surface** (monthly values in AEMET's solar radiation atlas or in PVGIS):

Mean daily global irradiation for the month	Guideline
> ≈ 6 kWh/m²	1 full day on clear days; 2 days if there is more than 50 % cloud
≈ 3 to 6 kWh/m²	2 consecutive full days as the rule, only with mostly clear days
< ≈ 3 kWh/m²	Do not use SODIS: boil or pasteurize

The thresholds of 3 and 6 kWh/m² are the project's own reasoning without field validation (verificar). They are not fully conservative: in winter the UV-A fraction of global radiation is even lower than in summer and the water barely heats up, so in months close to the lower limit boiling is advisable, and before adopting SODIS at these latitudes it should be checked with an *E. coli* test (“Verification”).

What it eliminates and what it does not

Typical reductions after 6 h in a PET bottle in tropical countries, with water below 40 °C (Luzi et al., 2016, tables 1-4). LRV = log reduction value (1 log = 90 %, 2 log = 99 %, 3 log = 99.9 %).

Organism	LRV in 6 h	Comment
E. coli	2-5	Indicator of fecal contamination; ~1 day for 3 log
Vibrio cholerae	3-5	Very sensitive: ~3 h for 3 log
Salmonella, *Shigella*	2-4	*Salmonella* can regrow after treatment
Campylobacter jejuni	> 4	Sensitive
Bovine rotavirus	0.5-1	> 20 h for 3 log
Poliovirus, adenovirus, coxsackievirus	Very low	Almost unaffected in PET (the bottle filters out UV-B)
Giardia cysts	2 to > 3	Similar to bacteria
Cryptosporidium oocysts	0.3 to > 0.4	**Resistant:** 10-70 h for 3 log
Acanthamoeba	—	Only inactivated above 50 °C
Ascaris eggs	1	Not very effective

WHO (GDWQ 4th ed., 2011, table 7.8) assigns solar disinfection reference reductions of 3 log for bacteria, 2 for viruses and 2 for protozoa, with maximums above 5, 4 and 4 log. Those figures cover all protozoa together: *Cryptosporidium* falls well below (0.3 to > 0.4 log in 6 h, table above).

SODIS **does not remove**: chemical products (pesticides, fuels, solvents, nitrates, arsenic, fluoride, heavy metals), turbidity, color, salt or bad tastes. Nor does it sterilize: harmless environmental algae and bacteria can survive and even grow in the bottle (Meierhofer and Wegelin, 2002).

Regrowth

Some studies have observed *E. coli* or *Salmonella* multiplying again in the 18-24 h following insufficient exposure; others see no regrowth. To be safe, Eawag recommends keeping the water in the same bottle, in a cool place, and drinking it within a few hours and at most 1-2 days (Luzi et al., 2016, chaps. 2.2.8 and 2.4).

Procedure

1. **Choose the bottles.** Clear, colorless or with a very slight blue tint, 2 L or less, with no deep scratches, no cloudiness or yellowing, with a cap that seals. Identify PET: it usually carries the recycling symbol “1” or “PET”. **Discard** PVC (bluish sheen at the cut edge; symbol “3”; if in doubt, the flame test from “Safety”), polycarbonate (symbol “7”, rigid water-cooler jugs or old baby bottles: can release bisphenol A) and, in general, any plastic other than PET that is not certified for drinking water (Luzi et al., 2016, chap. 2.2.4); also colored bottles, ones that held fuel, pesticide, solvent or industrial oil, and jugs over 2 L. *Success criterion:* filled and turned upside down for 1 minute it does not drip; looking through it, text reads without distortion or whitish haze.
2. **Wash the bottle the first time.** Remove all paper or plastic labels (they cast shade). Wash the inside with water, soap (or ash) and a handful of clean sand, shaking for 30 s; scrub the neck thread and the inside of the cap with a small stick or brush, where the most dirt collects. Rinse 2 times. *Success criterion:* no smell, no film to the touch inside the cap and no visible residue on the thread.
3. **Check the water's turbidity.** Fill the bottle to the top, stand it **in the shade** on the headline of an ordinary newspaper and look at it vertically from the mouth of the full bottle, through the whole column of water (Luzi et

al., 2016, chap. 2.2.5). *Success criterion:* the letters can be read → turbidity below 30 NTU, suitable. With Eawag's original template (15 cm SODIS logo), if the fine rays of the drawing can also be made out, turbidity is below 20 NTU (Meierhofer and Wegelin, 2002, p. 15). If they **cannot** be read, pretreat the water before continuing:

- Let it settle for **1 day** in a covered container and pour off the clear part without stirring up the sediment; or
- filter it through a tightly woven cotton cloth folded several times, or through a sand filter; or
- clarify it by coagulation and flocculation (aluminum sulfate or crushed *Moringa oleifera* seeds; article planned for this folder). Repeat the test. If it still cannot be read after pretreating, **do not use SODIS**: boil or pasteurize.

4. **Aerate and fill.** Fill the bottle to 3/4, close it and shake it hard for about 20 s; then fill it to the top and close it tightly. The 2002 guide always recommended this; the 2016 one considers it unnecessary because the water already gets oxygenated when poured. It is essential with stagnant, oxygen-poor water (ponds, cisterns, wells): there, shake it or pour it several times between two containers from ~30 cm. *Success criterion:* the bottle is filled to the neck, with at most one small bubble, the cap tight and no dripping when tilted.
5. **Set up the exposure site.** Choose a spot that gets direct sun **from early morning to mid-afternoon with no shade at all** throughout the day (trees, eaves, walls, the back of a chair). Place a corrugated metal or aluminum sheet on it, or use a metal roof or a dark ground surface. Prefer a waist-height support over climbing onto roofs. **Solar time without a watch:** drive a vertical stick into level ground; solar noon is the moment its shadow is shortest. “9 h” and “15 h” solar time are roughly 3 h before and after that moment (a test day with any kind of watch, or counting the sun's passage, serves to calibrate it). *Success criterion:* checked at 9 h, 12 h and 15 h solar time, the spot is still in the sun.
6. **Expose.** Lay the bottles **flat** (horizontal or slightly tilted), with the long side facing the sun, without stacking them or shading one another, in the grooves of the sheet so they do not roll. Start as early as possible in the morning. Not behind a window pane (blocks UV-A). Do not move or shake them during exposure. *Success criterion:* all the bottles receive sun along their whole length and are lukewarm or hot to the touch at midday.
7. **Time it according to the sky.** Estimate cloud cover in mid-morning and at midday:

Sky during exposure	Minimum time
Clear or with clouds covering **less than 50 %**	1 full day: **at least 6 h including midday** (e.g., from 9 h to 15 h solar time)
Clouds covering **more than 50 %** or fully overcast sky	**2 consecutive full days**, without opening the bottle in between
Continuous rain or very dense fog	**Do not use SODIS.** Drink stored SODIS water, collect rainwater or boil

   Never shorten the time, even if it is very hot or the water is very hot (Luzi et al., 2016, chap. 2.2.7 and box 6). At latitudes above 30°, also apply the monthly criterion from “Suitable latitudes”. *Success criterion:* the time in the table has been met and the bottle was never in the shade at any point.
8. **Retrieve and mark.** Collect the bottles at the end of the afternoon without opening them and place them in a cool, shaded spot, separate from the untreated water bottles. Mark the treated ones (a different-colored cap, a notch, or separate “raw” and “ready” shelves). *Success criterion:* anyone in the household can tell a treated bottle from an untreated one without hesitation.
9. **Drink.** Drink straight from the bottle or pour into a clean glass, **without transferring** it to open jugs or containers. Consume it the same day or at most within 1-2 days. If another container has to be used, it should be clean, narrow-mouthed, covered, with a clean tap or ladle. *Success criterion:* the treated bottle is not opened until the moment of drinking and no one puts fingers or utensils into it.
10. **Maintain the bottles.** Wash the cap and thread every week: this is a routine recommended by this project, not an Eawag guideline; the source only documents that a dirty thread recontaminates the treated water (Sacabamba, Bolivia; Meierhofer and Wegelin, 2002, p. 27). Each month, hold every bottle up to the light and **replace** any that are scratched, cloudy, yellowed, deformed or have a leaking cap: scratches and plastic aging reduce UV-A transmission. *Success criterion:* every bottle in use passes the step 1 inspection.

Verification

- **There is no visible sign that the water is disinfected.** Treated water looks the same as raw water. The guarantee comes from having followed the process (turbidity, bottle, time, sun with no shade). Keeping a simple log (date, cloud cover, time put out and time retrieved) helps catch failures.
- **Temperature (if a thermometer is available):** measure, in the early afternoon, the water of a control bottle exposed alongside the rest. If it exceeds 50 °C, the synergy is working with a good margin, but **that is no reason to shorten the time** (step 7). In warm climates it usually stays around 40-45 °C (Luzi et al., 2016), which is normal and does not invalidate the 6 h.
- **WAPI indicator** (a tube with wax that melts at pasteurization temperature, see boiling water (p. 3)): if the wax melts inside the bottle or container, the water reached pasteurization temperature regardless of the UV. It is a test of **sufficiency**, not of insufficiency: if it does not melt, that does not mean SODIS has failed.
- **Microbiological testing (the only one that confirms the result):** count of *E. coli* or fecal coliforms in raw and treated water with a field kit (membrane filtration and incubation at 44 °C for 16-18 h; Meierhofer and Wegelin, 2002). Desirable result: 0 *E. coli* per 100 ml in the treated water; in the WHO risk classification cited by Eawag, 1-10 per 100 ml is low risk, 10-100 intermediate, 100-1000 high and over 1000 very high. Do this when introducing the method, when changing water source or bottle type, and each season. **Not valid as indicators:** total coliforms or total bacteria count, because harmless environmental bacteria and algae grow in the bottle in the sun. The absence of *E. coli* also does not guarantee the absence of *Cryptosporidium* or viruses, which are more resistant. Field methods without a laboratory will be covered in the planned article "Basic water quality testing".
- **Validation test for new bottles (glass or doubtful plastic):** requires an *E. coli* kit. Expose in parallel, with the same water, a reference PET bottle and the candidate bottle, and compare *E. coli* after the normal time. The candidate is only adopted if it gives the same result. **Without a kit there is no possible validation:** the candidate bottle is not adopted for SODIS.

Common mistakes

Symptom	Likely cause	Solution
There is diarrhea in the family despite using SODIS	Bottles in the shade part of the day (tree, eave, chair back)	Check the spot at 9 h, 12 h and 15 h; use a metal sheet in an open spot (step 5)
"Treated" water with *E. coli*	Dirty thread and cap contaminate the water when drinking	Scrub the thread and the inside of the cap (steps 2 and 10)
Treated water contaminated when tested at home	It was transferred to an open jug or container and served with a ladle or hands	Drink from the bottle itself; if transferring, use a narrow-mouthed container with a lid and tap
Water is drunk right after it was put out or at midday	Impatience, or 2 batches are treated in one day with the same bottles	Always keep a reserve (see "Calculations": more bottles for cloudy spells); never shorten the time
Poor effectiveness with standing bottles	Vertical placement: light must pass through up to 30 cm of water	Lay them flat, with the long side facing the sun (step 6)
Poor effectiveness with river or pond water	Turbidity > 30 NTU or heavily colored water	Headline test (step 3); let settle for 1 day, filter or flocculate first
Worse results with certain bottles	Scratched, cloudy, labeled or colored bottles	Remove labels; replace aged bottles; only colorless ones
Bottles deformed or warped after exposure	Water above ~65 °C in PET (a very effective collector or box)	Remove the reflector on very hot days or use glass for pasteurization
Bottles cold at midday or covered in dust	They are not put out daily; they are filled just before drinking	Assign a responsible person and a fixed schedule
Water tastes or looks greenish after several days stored	Algae and environmental bacteria grow in water stored in the sun or for a long time	Store in the shade and consume within 1-2 days

Safety

- **What can kill: a false sense of security.** SODIS greatly reduces the risk, but does not eliminate it. Cholera, dysentery and dehydration from diarrhea kill quickly, especially young children. If someone gets diarrhea, start oral rehydration immediately (if there are no ORS sachets, WHO's homemade recipe: **1 L of clean water—boiled and cooled—, 6 level teaspoons of sugar and 1/2 level teaspoon of salt**, stirred until dissolved; do not add more salt, prepare fresh daily and discard after 24 h; Rehydration Project), switch the whole household to boiling water, and seek medical care if there is blood in the stool, high fever, vomiting that prevents drinking, or signs of dehydration (dry mouth, little urine, sunken eyes, lethargy).

- **Groups that should NOT drink SODIS water** (Meierhofer and Wegelin, 2002, chap. 3.4): use only boiled water for
  - infant formula, baby porridges and drinking water for infants and children under ~18 months;
  - people who are severely ill or malnourished;
  - immunocompromised people (advanced HIV/AIDS, chemotherapy): *Cryptosporidium*, barely affected by SODIS, causes them severe, prolonged diarrhea;
  - people with chronic digestive diseases.
- **Chemical contamination:** SODIS removes nothing chemical. Do not treat water that smells of fuel, solvent or pesticide, nor water from mining or industrial areas without testing it: find another source. Do not reuse bottles that held toxic substances.
- **Substances from the plastic:** the available studies find no significant risk from migration of substances from PET into SODIS water: the plasticizers measured (DEHA, DEHP) were at levels similar to bottles stored in the dark and well below WHO guideline values (Schmid et al., 2008, cited in Luzi et al., 2016). Antimony from PET only migrates appreciably **above 60 °C or with very long storage times**: do not deliberately heat PET above that temperature (very efficient collectors) or store water for weeks in the heat. **Never** use polycarbonate (symbol 7).
- **Flame test to tell PET from PVC:** PVC releases irritant, toxic smoke (hydrochloric acid). If this test must be done, burn only a 1 cm² piece outdoors, with tongs, without inhaling the smoke and away from children. PET burns more easily and its smoke smells sweetish; PVC's is acrid (Meierhofer and Wegelin, 2002).
- **Falls:** carrying full bottles (2 kg each) onto roofs causes falls. Prefer a waist-height frame with sheet metal; if a roof is used, always have the same adult do it, with a stable ladder.
- **Contact burns:** a metal sheet at midday sun can burn to the touch; pick up bottles by the cap or with a cloth and do not rest hands on it or let children sit on it.
- **Glass:** glass bottles break easily and cause cuts; do not use them on roofs or within reach of small children.
- **Mixing up bottles:** a child may drink from an untreated bottle. Always mark the treated ones (step 8) and keep the raw ones separate.

Variants

- **With fewer resources (no PET bottles):**
  - Without a container transparent to UV-A there is no SODIS. The N0-N1 alternatives are boiling and pasteurization in ceramic pots over a fire: see boiling water (p. 3).
  - **Clear polyethylene bags** (recovered): trials showed very high disinfection thanks to their shallow depth and larger surface area, but Eawag does not recommend them because they are hard to handle and break more easily than bottles (Meierhofer and Wegelin, 2002, p. 24). Only as an emergency resort: follow the general rule of water depth ≤ 10 cm (variables table; Sommer et al., 1997), lay them flat without folds that cast shade, and apply the same exposure time.
  - Without a metal sheet: any dark ground or flat stone in the sun; the improvement from sheets and dark backgrounds is under 30 %, so lacking one does not require a longer time (Luzi et al., 2016, chap. 2.2.3).
- **N2: glass bottles.** Glass does not scratch or warp with heat, but it is heavy, breaks, and its UV-A transmission depends on the **iron oxide content**: 2 mm window glass barely lets UV-A through, while the colorless commercial beverage bottles tested by Eawag transmitted comparably to PET and gave the same effectiveness (Luzi et al., 2016, box 7). That box only backs **commercial** beverage bottles and recommends measuring the UV transmittance of locally available glass. N2 artisanal glass is usually greenish from the iron in the sand, and at N2 there is no *E. coli* kit to validate it with (comparative test in “Verification”): **without an analysis kit, artisanal glass is not adopted for SODIS; it is used only for solar pasteurization with temperature control** (below). If a kit becomes available later, candidate glass must be colorless when viewed edge-on, as thin-walled as possible, and in bottles of ≤ 2 L.
- **Solar pasteurization (with more resources or cold climates).** Instead of relying on UV, it relies on heat: bottles or containers with the lower half painted black, inside a box with aluminum foil or a solar cooker, until the water is kept above 65 °C (Ciochetti and Metcalf, 1984; time and criterion in the boiling water (p. 3) article),

with a WAPI or thermometer as a check. In a test at 32° N, a half-blackened bottle went from 21 °C to 42.5 °C in the open air and to 66.5 °C inside an aluminum-lined box between 9 h and 14 h (Green, Lifewater, cited in Meierhofer and Wegelin, 2002). Advantage: it also inactivates protozoa and viruses that UV-A barely touches, and it works in opaque containers. Disadvantages: PET warps above ~65 °C (use glass or dark metal), and it requires checking the temperature. The 2016 guide no longer promotes painting bottles black for standard SODIS; at altitude, where the water does not heat up, a fully transparent bottle is preferable. Details on pasteurization and the WAPI are in boiling water (p. 3).

- **With more resources (N3-N4):** reflectors or compound parabolic collectors that concentrate light (acceleration typically under 50 %; Luzi et al., 2016, chap. 2.3); electronic or chemical UV indicators that warn of the dose received; *E. coli* kits to monitor quality; combination with filtration (ceramic and carbon filters (p. 37)) for turbid water, or with chlorine (p. 17) when residual protection or effectiveness against viruses is needed.
- **Scaling up to a village:** SODIS is a **household** method: it scales by multiplying bottles and homes, not by enlarging containers. It requires an organized supply of PET bottles, communal exposure points (metal roofs of the school or the health center) and, above all, training and follow-up visits: in the field, without follow-up, use drops sharply once promotion ends (in Nepal and Indonesia, around 21 % use years later; Luzi et al., 2016, chap. 3.1.2). See "Calculations".
- **Scaling up to a city:** not suitable. Large-volume solar reactors (a few hundred liters a day) are technically complicated to build, clean and maintain, and cannot compete on cost with centralized chlorination (Luzi et al., 2016, chap. 2.3). In a city, SODIS only makes sense as a household backup during outages or emergencies.

Observed health effectiveness

Results from field trials (Luzi et al., 2016, table 8; CDC, 2008): in children aged 5-16 in Kenya, an odds ratio for diarrhea of 0.66 (Conroy et al., 1996); in children under 6, during a cholera outbreak, 3 cases among 155 who used SODIS versus 20 among 144 who did not (odds ratio 0.12; Conroy et al., 2001; table 8 of Luzi et al., 2016 summarizes it as 81 % less cholera in children under 5, a discrepancy with the title of the original article); in Bolivia, no significant effect with only 32 % compliance (Mäusezahl et al., 2009). The CDC summarizes diarrhea reductions of 9 to 86 % across four controlled trials. The difference is made by **consistent and correct** use: drinking even 5-10 % untreated water can cancel out almost all the benefit (Brown and Clasen, 2012, cited in Luzi et al., 2016).

Calculations

Bottles for a family

Data: 5 people; minimum drinking water of about 2 L per person per day in mild conditions, up to 4.5 L with heat and physical work (Howard and Bartram, 2003). 3 L/person/day is used.

```
Daily water = 5 people × 3 L = 15 L
2 L bottles that must finish their exposure each day = 15 L / 2 L = 7.5 → 8 bottles

Sunny regime (1 day of exposure):
  8 bottles in the sun + 8 treated ready to drink at the same time = 16 bottles

Cloudy regime (2 days of exposure):
  for 8 bottles to finish each day, 2 alternating batches must be in the sun at once:
  8 (batch on its 1st day) + 8 (batch on its 2nd day) + 8 treated ready to drink = 24
bottles
```

With only 16 bottles, in a cloudy spell only 8 bottles come out every 2 days, i.e. 8 L/day against the 15 L/day needed: **either 24 bottles are kept, or boiling supplements the shortfall during cloudy spells**. Eawag's guideline of 4 bottles per person (20 for this family) does not fully cover the 2-day regime at 3 L/person/day either.

Exposure surface

Measure the available bottles lying flat and add about 2 cm of spacing between them. Worked example with a bottle that, lying flat with its spacing, takes up 12 cm × 32 cm:

```
Surface per bottle ≈ 0.12 m × 0.32 m ≈ 0.038 m²
Family, sunny regime (8 in the sun)  ≈ 8 × 0.038  ≈ 0.31 m²  → a 1 m × 0.5 m sheet is more
```

```
than enough
Family, cloudy regime (16 in the sun) ≈ 16 × 0.038 ≈ 0.61 m²  → 1 m × 0.7 m sheet
```

Village of 200 people

```
Drinking water = 200 × 3 L = 600 L/day
Bottles in the sun = 600 / 2 = 300 bottles/day
Surface = 300 × 0.038 ≈ 11.5 m²  (≈ 6 corrugated sheets of 2 m × 1 m)
Inventory, sunny regime = 300 in the sun + 300 to drink = 600 bottles
Inventory, cloudy regime = 600 in the sun + 300 to drink = 900 bottles (or boil during
cloudy spells)
Surface, cloudy regime = 600 × 0.038 ≈ 23 m²
Labor = 300 bottles/day × (minutes per bottle timed in the first week)
```

There is no published figure for minutes per bottle (the 2016 manual only speaks of a "relatively high daily work demand"): time it in practice before organizing shifts.

That is why in a village it helps for each household to treat its own water at home (spreading the labor and avoiding transfers) and to reserve communal exposure for schools and health centers.

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Related: Boiling water (p. 3) Slow sand filter and charcoal biofilter (p. 27) Ceramic and carbon filters (p. 37) Chemical disinfection of water with chlorine and iodine (p. 17)

WATER AND SANITATION › WATER PURIFICATION

Chemical disinfection of water with chlorine and iodine

Bleach, calcium hypochlorite and iodine doses per liter and per tank, contact times, residual chlorine, limits and safe handling.

N1 · Pottery and farming · Draft · Machine translation · civilizationrebuild.org/en/01-agua-y-saneamiento/potabilizacion/desinfeccion-quimica-del-agua-con-cloro-y-yodo/

> **Machine translation.** Its structure and figures have been automatically checked against the Spanish original, but no person has reviewed it.

> **Draft without technical review.** It may contain errors: double-check figures and procedures before applying them.

Summary

Adding a measured dose of chlorine (bleach or calcium hypochlorite) or iodine to clear water and waiting a contact time inactivates bacteria, viruses and most *Giardia* cysts, without fuel and for any volume: from a 20 L jerrycan to a tank of several cubic meters. Expected, measurable result: with clear water at 15-30 °C, 20 L are disinfected with about 1.6 mL of 5 % bleach (4 mg/L) waiting 60 min at 15 °C or 45 min at 30 °C (30 min is enough for bacteria and viruses), and the water afterward keeps a **free chlorine residual of 0.2-0.5 mg/L** that protects it from recontamination during storage, something neither boiling nor solar disinfection achieves. Honest limits: chlorine and iodine at field doses **do not inactivate *Cryptosporidium***, work poorly in turbid water and do not remove chemical contaminants. Iodine is only suitable for emergency use lasting a few weeks.

Prerequisites

- **Knowledge:** none essential. It helps to know how to clarify the water beforehand (settling and filtering through cloth, see “Procedure”, step 1) and to know the alternative methods for when the reagent runs out or *Cryptosporidium* is suspected: Boiling water (p. 3), solar disinfection (SODIS) and ceramic or sand filters, in this same folder.
- **Dependence on technological level (read before planning):** the *procedure* is N1 — measuring volumes with ceramic containers, counting drops, waiting — which is why the article carries `nivel: 1`. But the *reagent* is not: bleach and calcium hypochlorite are products of industrial chemistry (N3-N4), and iodine tincture or iodine crystals are too. In a reconstruction scenario the reagent will be **recovered** from existing stock (supermarkets, swimming pools, pharmacies, agricultural stores) and runs out; its local manufacture (e.g. hypochlorite by electrolysis of brine) is a separate chemistry topic. While stock lasts, this is the cheapest method per liter; once it runs out, one must go back to boiling, sun or filtration. That is why it is worth storing mainly **granular calcium hypochlorite**, which lasts years, rather than liquid bleach, which degrades within months (see “How it works”).
- **Materials (depending on the option chosen):**
  - **Bleach** (sodium hypochlorite) **with no additives**: no fragrance, no detergent, no thickeners (“gel”). In Spain, look on the label for “suitable for disinfecting drinking water” and the concentration in grams of active chlorine per liter. **Not suitable:** “bleach-free bleaches”, “active oxygen” products or “color-safe” bleaches (these are peroxides, not chlorine).
  - **Granular calcium hypochlorite** at 65-70 % (HTH, pool “granular chlorine”) with no stabilizer (cyanuric acid) or added algaecides. 100 g treat about 17 m³ at 4 mg/L.
  - **Iodine** (alternative): 2 % iodine tincture, 10 % povidone-iodine (Betadine and similar), 5 % Lugol's solution, or resublimed iodine crystals (4-8 g) in a 30-60 mL glass bottle with a lid.
  - Enameled ceramic, glass or food-grade plastic containers for the water; **never metal** for concentrated solutions (chlorine and iodine corrode them).
  - Tightly woven cotton cloth for pre-filtering.
  - Optional: vitamin C (ascorbic acid) powder or charcoal to remove the taste.
- **Tools:**
  - A **calibrated** dropper (N3-N4 if plastic; in N1 a thin reed or a straw cut at an angle): count how many drops fill a known measure. Reference: 20 drops ≈ 1 mL, but it varies between 16 and 24 depending on the dropper (WMS 2024, table 7).
  - A set of ceramic or gourd volume measures marked out (a “cup” and a pot or pitcher whose capacity has been counted in cups). With these, 1:100 dilutions can be made without instruments (N1).

  - Optional (recovered N4): free chlorine DPD kit with color comparator or test strips; 1 and 10 mL syringes; kitchen scale for the HTH.
- **Time and people:** one person. Preparing the stock solution: 15-30 min every 2-7 days (see B.2 and C.5). Dosing a jerrycan: 2 min. Contact time: from 30 min (warm, clear water) to 4 h (water at 5 °C with a low dose).

How it works

How chlorine kills, and which variables matter

Sodium hypochlorite (bleach) and calcium hypochlorite (HTH) dissolve in water and form **hypochlorous acid (HOCl)** and hypochlorite ion (OCl^-). Both oxidize the enzymes, membranes and nucleic acids of microorganisms. Together they are measured as **free chlorine**. Disinfection depends on the **C·t** product (free chlorine concentration in mg/L times contact time in minutes): less chlorine can be used by waiting longer, or more chlorine by waiting less. Four factors modify it:

1. **Type of microorganism.** For a 99.9 % reduction (WMS 2024, table 4): *E. coli*, C·t ≈ 0.016 mg·min/L (seconds); enteric viruses, C·t ≈ 0.5-30; *Giardia* cysts, C·t ≈ 77-153 depending on temperature and pH (ameba cysts, ≈ 35); *Cryptosporidium* oocysts, C·t ≈ 10,400-15,300 (20 mg/L for 8-13 h: **impractical** in drinking water).
2. **Temperature.** Cold slows the reaction down. Oxfam's field rule: 30 min at 25 °C and **double the time for every 10 °C less**. This rule gives shorter times than table 2 (at 5 °C, 120 min versus 180 min with 4 mg/L): **if they do not match, table 2 governs**, being the more conservative one.
3. **pH.** HOCl is much more effective than OCl^- (tens of times), and the proportion of HOCl falls as pH rises: 92 % at pH 6.5, 52 % at pH 7.5 and 26 % at pH 8 (at 25 °C, with pKa 7.54); at pH 9 barely 3 % is left (same calculation). That is why WHO requires pH < 8 to accept the standard residuals. Practical rule in alkaline waters: **if it gets close to pH 8, double the contact time; between 8 and 9, also raise the residual to ≥ 0.4-0.6 mg/L and extend the contact; above 9 chlorination is not reliable** (Oxfam calls for ≥ 0.4 mg/L with pH > 8; the pH 9 limit is derived from the 3 % HOCl calculated above). In N1 no one measures pH: in waters known to be very hard (they leave a lot of white scale in pots), apply directly double dose and double time.
4. **Chlorine demand and turbidity.** Organic matter, ammonium, iron, manganese and particles **consume** chlorine before it acts, and particles shield microbes inside them. The part left over after covering that demand is the **free chlorine residual**: this is what disinfects and what is measured. Above 10 NTU chlorination loses effectiveness and requires double dose; above 100 NTU the water must be clarified first (Oxfam). Test without a turbidimeter: **single dose** only if in a transparent glass, held against the light, no turbidity at all is visible (a person starts to see turbidity around 5 NTU, WMS 2024; that is, under roughly 5-10 NTU). If it looks somewhat turbid but printed text can be read through 10 cm of water, **double dose** (under roughly 30 NTU, the criterion used for solar disinfection). If the text cannot be read, **clarify first**.

Target dose

- **Clear water of doubtful origin (surface water, open well):** 3-4 mg/L of chlorine (WMS 2024, table 5). CDC/EPA instructions (2 drops of 5-9 % bleach per liter) give in practice about 5-9 mg/L.
- **Good-quality water (protected well, unreliable piped supply):** 2 mg/L. The CDC/WHO Safe Water System uses 1.875 mg/L for water under 10 NTU and 3.75 mg/L for 10-100 NTU (Lantagne et al. 2018).
- **Turbid, colored or very cold water:** double dose, 4-8 mg/L (CDC: water "cloudy, murky, colored, or very cold"; WMS 2024, table 5). The EPA no longer calls for a double dose for turbid water: only settling and filtering first.
- **Ceiling:** WHO sets 5 mg/L as the guideline value for chlorine in lifetime consumption; most people notice the taste well before that (from about 3 mg/L, WMS 2024). Exceeding it briefly in an emergency is not dangerous ("chlorine has no known toxicity at the concentrations used for disinfection", WMS 2024), but it makes the water unpleasant and people reject it, which is a real health risk.

Target free chlorine residual

Moment	Free chlorine	Source
After ≥ 30 min of contact (pH < 8)	≥ 0.5 mg/L	WHO
At the point of consumption	≥ 0.2 mg/L (≥ 0.4 mg/L if pH > 8)	WHO, Oxfam
Reasonable maximum at consumption	≤ 2 mg/L for taste; never > 4-5 mg/L	Lantagne 2018, Oxfam

Why bleach loses strength and HTH not so much

Sodium hypochlorite in solution decomposes continuously into chloride and chlorate. The rate **increases with temperature, with concentration, with light and with metal ions**: a 15 % solution decomposes about 10 times faster than a 5 % one, and at 45 °C about 5 times faster than at 25 °C (Solenis). With heat, household bleach loses strength within months: if it is old or has been in the sun, check the residual or, without a kit, double the dose when the bleach's chlorine smell is weak. The EPA recommends using bleach that has been stored at room temperature for **less than a year**. Solid, dry calcium hypochlorite is much more stable: 3-5 years closed, cool and dry (Oxfam). Practical consequences: check the residual (or at least the smell) when the bleach is old, and prepare diluted stock solutions frequently.

How iodine works and why it is only for emergencies

Elemental iodine (I_2) and hypoiodous acid (HOI) oxidize microorganisms like chlorine does. Advantages: it is less affected by pH, reacts less with nitrogenous organic matter and works somewhat better in poorer-quality water (WHO 2018). Disadvantages: it needs higher doses (4-8 mg/L), **it is ineffective against *Cryptosporidium*** and, above all, it is physiologically active: the thyroid gland concentrates it. Drinking 3 L a day with a residual of 2-4 mg/L means 6-12 mg of iodine per day; with the 4-8 mg/L doses from table 4, 12-24 mg/day (WMS 2024 calculates 16-32 mg/day with tablets). That is many times more than the recommended intake of 0.15 mg/day for an adult and the tolerable upper limit of 0.6-1.1 mg/day (WHO 2018; WMS 2024). That is why WHO recommends it only for short-term emergency use; WMS 2024 limits it to “short periods (months)” and calls for a thyroid check for anyone who will use it a long time, and the CDC advises against drinking iodinated water for more than a few weeks. This article adopts the prudent limit of **3 weeks to 1 month**, knowing that no time limit has a firm experimental basis (Backer and Hollowell, 2000). Tincture and Lugol's solution also carry iodide, which does not disinfect but does add iodine to the body. Colorless iodine solutions (iodide only) **do not work**.

Procedure

A. Chlorinating a jerrycan with bleach (20-25 L, household use)

1. **Clarify.** If the water is turbid, let it settle for 30-60 min and pour off the clear part without disturbing the sediment, or filter it through a cotton cloth folded 4-8 times. *Success criterion:* in a transparent glass, held against the light, no turbidity at all is visible (under roughly 5-10 NTU, WMS 2024): single dose in step 4. If it looks somewhat turbid but printed text can be read through 10 cm of water (under roughly 30 NTU), double dose. If the text cannot be read, do not chlorinate yet: clarify more or boil.
2. **Identify the bleach's concentration.** Read the label. If it comes in g/L of active chlorine, divide by 10 to get it in %: 40 g/L = 4 %. If it comes in % sodium hypochlorite, use it as is (the error of this approximation is under 15 %, well below the dose margin). *Success criterion:* you have a figure C in % and have confirmed it carries no fragrance, detergent or “active oxygen”. If the label of a bleach suitable for drinking water gives its own dose (drops per liter), follow it and check it against table 1: if they differ a lot, re-read the concentration. If there is no label, assume 3 % and check the residual (step 7).
3. **Measure the container's volume.** Count how many known measures (a 1.5 L bottle, a marked saucepan) fit up to the fill mark. *Success criterion:* volume V known within ±10 % and marked with a line on the container so the measurement need not be repeated.
4. **Calculate and add the dose.** Use table 1 or the formula `mL of bleach = V (L) × dose (mg/L) ÷ (C (%) × 10)`. Dose 4 mg/L for clear water at 10 °C or above; 8 mg/L for turbid, colored water or water below 10 °C. Pour the bleach **onto the water** (not into the empty container), with a calibrated dropper or syringe. *Success criterion:* the dose added is noted or remembered; the freshly dosed water clearly smells of chlorine when the nose is brought close to the container's mouth.
5. **Mix.** Cover and shake, or stir with a clean rod for 30 s; if the container has a tap or screw cap, let some water run out through it so the thread is also disinfected. *Success criterion:* 30 s of mixing and the tap or thread wetted with chlorinated water.
6. **Wait the contact time** per table 2, covered and in the shade. If the water's temperature falls between two columns, use the **lower** temperature column closest to it (water at 12 °C with 4 mg/L: the 5 °C column, 180 min). Absolute minimum: 30 min. *Success criterion:* the timed interval (clock, or a calibrated candle or shadow mark) has been met.
7. **Check the residual.**
   - *With a DPD kit:* see “Verification”. Target 0.5-2 mg/L free chlorine.

- *Without a kit (minimum criterion, EPA):* the water should have **a slight chlorine smell**. If there is no smell at all, repeat the same dose, wait **15 more minutes** and smell again. If it still does not smell after the second dose, the water has high demand (organic matter, iron): clarify it better or boil it. *Success criterion:* a slight chlorine smell is perceptible (or a DPD reading in range).

8. **Serve and store** without putting hands or ladles in, in the same covered container. *Success criterion:* the water still smells slightly of chlorine 24 h later; if it no longer does, drink it that same day or re-chlorinate at half dose.

Table 1. Bleach dose by concentration (1 drop = 0.05 mL; chlorine in g/L ≈ C % × 10)

Bleach	mg of chlorine per drop	Drops per liter, clear water (resulting dose)	Drops per liter, turbid or cold	mL per 20 L, clear (4 mg/L)	mL per 20 L, turbid (8 mg/L)	mL per 1000 L, clear (4 mg/L)
1 % (or 1 % HTH stock solution)	0.5	8 (4.0 mg/L)	16 (8.0 mg/L)	8.0	16.0	400
3 %	1.5	3 (4.5 mg/L)	5 (7.5 mg/L)	2.7	5.3	133
5 %	2.5	2 (5.0 mg/L)	3 (7.5 mg/L)	1.6	3.2	80
6 %	3.0	2 (6.0 mg/L)	3 (9.0 mg/L)	1.3	2.7	67
8.25 %	4.1	1 (4.1 mg/L)	2 (8.3 mg/L)	1.0	1.9	48

Comparison with the CDC's simplified rule: **2 drops per liter** of 5-9 % bleach in clear water and **4 drops** in turbid, colored or very cold water; with 1 % bleach, 10 drops per liter. The EPA also gives 2 drops per liter of 6 % or 8.25 % bleach, but for turbid water it only asks to settle and filter it first. That rule is valid and easy to remember, but with 8.25 % bleach in turbid water it gives about 16 mg/L: safe short-term, but very strong tasting. For volumes of 1-2 L drops are imprecise: if possible, treat at least 5-10 L at a time.

Worked example. Bleach labeled "40 g/L active chlorine" (C = 4 %). 25 L jerrycan with clarified river water, at 8 °C. Being cold: dose 8 mg/L. `mL = 25 × 8 ÷ (4 × 10) = 200 ÷ 40 = 5 mL` ⟶ a level teaspoon of 5 mL, or 100 drops. Contact time (table 2, 5 °C column, 8 mg/L): 60 min. After 60 min it should smell slightly of chlorine.

Table 2. Minimum recommended field contact time, chlorine or iodine (WMS 2024, table 6; calculated for *Giardia* cysts, well above what bacteria and viruses need)

Halogen concentration	5 °C	15 °C	30 °C
2 mg/L	240 min	180 min	60 min
4 mg/L	180 min	60 min	45 min
8 mg/L	60 min	30 min	15 min

Practical rule: warm, clear water with 4-5 mg/L, 30 min is the CDC/EPA minimum and is enough for bacteria and viruses; if *Giardia* is a concern (mountain water, livestock upstream) or the water is cold, use the table. In alkaline waters apply the pH rule from "How it works" (close to pH 8, double the time; between 8 and 9, more residual and more time; above 9, do not rely on chlorine); without measuring pH, in known very hard waters, double dose and double time.

B. Stock solution without instruments (1:100 dilution, N1 level)

Useful for dosing many containers with ceramic measures instead of drops.

1. **Prepare the stock solution (~500 mg/L chlorine).** In a clean, enameled ceramic or glass pitcher, pour in **1 measure of bleach** and the **measures of clear water** indicated in table 3. Stir with a wooden or glass rod. *Success criterion:* a strong chlorine smell on uncovering it; the liquid is transparent.
2. **Label and store** covered, in the shade, in a cool place, out of children's reach, with a visible mark (e.g. an engraved cross) that distinguishes it from the drinking-water pitchers. Prepare only enough solution for a few days: 2-4 in a hot climate, 7 at most in a cool, dark place. Dose with it only if it smells clearly of chlorine on uncovering; with a DPD kit, check the residual of the treated water. *Success criterion:* an unmistakable container, a known preparation date and a clear chlorine smell before use.
3. **Dose: 1 measure of stock solution per 100 measures of clear water** (≈5 mg/L), or **2 per 100** if the water is turbid or cold (≈10 mg/L). Example: 1 cup of 200 mL per 20 L. Mix, wait and check as in A.5-A.8. *Success criterion:* a slight chlorine smell after the contact time.

Table 3. Measures of water per measure of bleach to obtain ~500 mg/L

Bleach	Measures of water per 1 of bleach
3 %	60
4 %	80
5 %	100
6 %	120
8.25 %	165

C. Granular calcium hypochlorite (HTH 65-70 %)

1. **Prepare the 1 % stock solution (10 g/L chlorine).** Wearing gloves and goggles, outdoors, pour **14 g of 70 % HTH** (≈2 heaping teaspoons: the EPA gives ≈7 g, ¼ ounce, per heaping teaspoon; if you have a scale, weigh it the first time, since the granular product's density varies) **into 1 L of water** in a plastic or glass container. **Always the product onto the water, never the water onto the product.** Stir 1 min with a non-metallic rod. *Success criterion:* the granules have dissolved except for an insoluble white residue (normal: calcium carbonate and hydroxide).
2. **Decant.** Let it settle for 30-60 min and pour the clear liquid into an opaque bottle with a non-metallic cap. *Success criterion:* transparent liquid with no particles; the residue is disposed of diluted in plenty of water, away from water sources and crops.
3. **Dose** as with the 1 % bleach in table 1: 8 drops/L (4 mg/L), 8 mL per 20 L, 400 mL per 1000 L. *Success criterion:* the same as A.7.
4. **Alternative without a scale (EPA):** 1 heaping teaspoon (≈7 g, ¼ ounce) of HTH in 2 gallons (≈7.6 L) of water gives a stock solution that the EPA rates at ≈500 mg/L (with real 65-70 % HTH it comes out around 600-650 mg/L); it is dosed at **1 part per 100 parts of water** (≈5-6.5 mg/L). Example: 1 cup of 200 mL of solution per 20 L. *Success criterion:* a slight chlorine smell after 30 min.
5. **Storage:** the 1 % stock solution degrades faster than the solid. Prepare solution for 2-4 days (Oxfam); in an opaque, cool bottle it can last longer, but then check the residual of the treated water or the chlorine smell of the solution with each batch. Solid HTH, well closed, lasts 3-5 years.

D. Tanks, cisterns and reservoirs

D.1. Calculate the volume (WHO/WEDC, technical note 3):

- Rectangular: `V (L) = length (m) × width (m) × water height (m) × 1000`.
- Vertical cylinder: `V (L) = 3.14 × diameter² (m²) ÷ 4 × water height (m) × 1000`.

D.2. Chlorinate the stored water (routine treatment).

1. Calculate the volume of water (not that of the empty tank). *Success criterion:* a figure in liters.
2. Dose 4 mg/L (8 mg/L if turbid or cold): `g of chlorine = V (L) × dose (mg/L) ÷ 1000`; with bleach, `mL = g of chlorine × 100 ÷ C (%)`; with 70 % HTH, `g of HTH = g of chlorine ÷ 0.7`. *Success criterion:* the amount calculated and checked by a second person.
3. Dissolve the product first in a 10 L bucket of water taken from the tank itself (decant the HTH, in addition) and pour it spread over the surface or through the inlet opening while the tank is being filled. *Success criterion:* no lumps left at the bottom of the bucket.
4. Mix (stirring with a long pole, or recirculating with buckets for 5-10 min) and wait per table 2. *Success criterion:* free chlorine 0.5-2 mg/L in a sample taken from the outlet tap.

Worked example. Rectangular reservoir of 2.0 × 1.5 m with 1.2 m of clear water at 18 °C. `V = 2.0 × 1.5 × 1.2 × 1000 = 3600 L`. Chlorine at 4 mg/L: `3600 × 4 ÷ 1000 = 14.4 g`. With 6 % bleach: `14.4 × 100 ÷ 6 = 240 mL`. With 70 % HTH: `14.4 ÷ 0.7 = 20.6 g`. Contact: 60 min (table 2, 15 °C, 4 mg/L).

D.3. Shock disinfection of an empty tank (before first use, after contamination or after cleaning; WHO/WEDC technical note 3): 0. **Safety inside the tank** (WHO/WEDC technical note 3, box 3.2): open lids and manholes and ventilate before entering; gloves, boots and goggles; **never enter alone**: always another person outside, at the opening, who can see or hear you. **Do not enter cisterns or underground tanks** if there is a smell of gas or rot, or if a lit candle lowered on a rope goes out: there may be gases that suffocate without warning. *Success criterion:* tank ventilated, candle lit at the bottom, gear on and a helper at the opening.

1. Empty, scrape and scrub the walls with a brush, water and soap; rinse until no foam remains. Use only tanks that have held water or food-grade liquids, **never** fuel, pesticides or wastewater. *Success criterion:* no slippery biofilm to the touch and no residue in the corners.
2. Fill 1/4 of the capacity with clean water and add **80 g of HTH per 1000 L of total capacity** (≈55 mg/L chlorine). Do not sprinkle it in: dissolve the granules first in a bucket with 10 L of water (product onto the water), let it settle 5-10 min and pour in the liquid. Equivalent with 5 % bleach: 1.1 L per 1000 L (80 g × 0.7 = 56 g chlorine; 56 g ÷ 50 g/L = 1.12 L); with 35-40 g/L bleach, 1.4-1.6 L. *Success criterion:* product dissolved, no lumps at the bottom of the bucket, and spread evenly.
3. Finish filling, close and leave for **24 h**. If urgent, **double dose (160 g/1000 L) and 8 h**. If it has a pump and hoses, recirculate the chlorinated water through them for 1 h. *Success criterion:* time met and a strong chlorine smell on opening.
4. Empty the shock water **away from homes, rivers and ponds** (it kills fish and plants), fill with potable water, leave for 30 min and empty again. *Success criterion:* the rinse water smells at most slightly of chlorine; the tank is ready.

E. Iodine (alternative for short emergencies)

1. **Clarify** as in A.1. *Success criterion:* the same.
2. **Dose according to the product** (table 4). *Success criterion:* the water takes on a very faint straw-yellow tint (with 4-8 mg/L).
3. **Wait** per table 2 (the same one used for chlorine): 30 min minimum in warm, clear water (EPA); at 5 °C, 60 min with 8 mg/L or 180 min with 4 mg/L. *Success criterion:* time met.
4. **Remove the taste (optional), only after the contact time:** a small pinch of vitamin C powder per liter (WMS 2024). Stoichiometrically very little is needed: about 20 mg for 8 mg/L of chlorine and about 6 mg for 8 mg/L of iodine; a little extra does no harm. It converts iodine into iodide and chlorine into chloride, with no color or taste. **It removes taste and color, not the iodine:** the body still absorbs the iodide, so the contraindications and the week-based limit still apply. Drink the water that same day, since no residual is left. *Success criterion:* colorless water with no medicinal taste.

Table 4. Iodine dose per liter (WMS 2024, table 7; WHO 2018, table 6)

Product	For 4 mg/L (clear water, not cold)	For 8 mg/L (turbid or cold)
2 % iodine tincture	0.25 mL = 5 drops	0.5 mL = 10 drops
10 % povidone-iodine	0.4 mL = 8 drops	0.8 mL = 16 drops
Saturated iodine crystal solution	13 mL	26 mL
5 % Lugol's solution (a calculation made for this article, no published recommendation)	≈0.08 mL ≈ 2 drops	≈0.16 mL ≈ 3 drops
Tetraglycine hydroperiodide tablets	½ tablet	1 tablet

The WMS counts 20 drops per mL (it varies from 16 to 24). The EPA gives the simplified rule: **5 drops of 2 % tincture per liter, 10 if the water is turbid or colored**, and wait at least 30 min. The Lugol's figure is a calculation made for this article (no published recommendation) from its free-iodine content (50 mg/mL at 5 %): use it only if there is nothing else. **Watch the strength:** pharmacies often sell 1-2 % Lugol's, and with those drops the dose would fall 2.5-5 times short. Check the label to confirm it is 5 % iodine; if it is 2 %, use the 2 % tincture doses; if the strength is not stated, do not use it. 5 % Lugol's also carries 10 % potassium iodide, which adds about 76 mg/mL of iodine as iodide, 1.5 times the free iodine: it does not disinfect, but it does add iodine to the body.

Crystal method (Polar Pure type).

1. Put 4-8 g of resublimed iodine crystals in a 30-60 mL glass bottle with an airtight lid; fill it with water, cap it and shake for 30-60 s. Wait **1 h**. *Success criterion:* a brownish-orange liquid over the crystals, which do not fully dissolve.
2. Pour only the liquid into the water to be treated (13 mL per liter of clear water, 26 mL if it is cold or turbid), **without letting any crystal fall in**. Iodine's solubility drops with cold: refill and shake the bottle at pocket temperature (about 20-25 °C); if the bottle is cold (< 10 °C), use double the volume. Refill the bottle with water for next time. *Success criterion:* no crystal in the drinking water; bottle refilled. The crystals last hundreds of refills before dissolving completely (WMS 2024, table 7).
3. Wait per table 2. *Success criterion:* time met.

Verification

- **Smell (minimum criterion, no equipment):** after the contact time, chlorinated water should have a slight chlorine smell (EPA). No smell = insufficient or no residual: re-dose (step A.7). A strong smell that stings the nose = overdose: let it stand for a few hours in the shade, covered only with a clean cloth, aerate it by pouring it between containers, or mix it with already treated water that has no smell. The sense of smell is imprecise and quickly becomes accustomed: have someone who has not handled the bleach do the smelling.
- **Free chlorine DPD kit (if available):** fill the comparator cell with 10 mL of treated water (or the volume the kit specifies), add a DPD No. 1 tablet, crush it and mix. **Read the pink color right away** (in under 1 min) against the scale. Good range: 0.5-2 mg/L after 30 min; ≥ 0.2 mg/L at the time of drinking. Water with a lot of chlorine (> 10 mg/L) can **bleach out** the reagent and give a falsely low reading: if the color appears and then disappears, dilute the sample by half with chlorine-free water (e.g. boiled and cooled water) and multiply the reading by 2, per the kit's instructions.
- **4-bucket demand test (village level, with DPD kit; Oxfam):** 4 buckets of 10 L with water from the source; doses of 1, 2, 3 and 4 mg/L (1, 2, 3 and 4 mL of 1 % solution, or 0.2, 0.4, 0.6 and 0.8 mL of 5 % bleach); after 30 min measure the free chlorine in each. The correct dose is the lowest one that leaves ≥ **0.5 mg/L** at 30 min. Repeat if the source changes (rains, dry season / low flow).
- **Iodine with starch (N1, indicative):** boil a chopped potato or a handful of rice in a little water and keep the cooled broth. A few drops of that broth in some iodinated water turn **blue-violet** if free iodine is present. This is an indicative test: a negative result (no color) does not prove that no iodine remains.
- **What none of these tests verify:** the absence of *Cryptosporidium*, chemical contaminants or metals. The residual proves that there was enough disinfectant, not that the water is entirely harmless.

Common mistakes

Symptom	Likely cause	Solution
The water does not smell of chlorine after 30 min	Old or overheated bleach; water with a lot of organic matter or iron	Repeat the dose and wait 15 more minutes (EPA); clarify better; use fresher bleach or HTH
Diarrhea in someone who drinks “chlorinated” water	Turbid water not clarified; short contact time in cold water; *Cryptosporidium*; recontamination	Clarify; follow table 2; boil or filter if cryptosporidiosis is present in the area; serve without dipping utensils in
Taste and smell so strong that people will not drink it	Overdose (drop rules with very concentrated bleach)	Calculate by table 1; use 2 mg/L doses in good water with more time; aerate or add vitamin C after the contact
Strong “fishy” or medicinal taste	Chloramines or chlorophenols: chlorine reacting with ammonium or phenols in the water or container	Clarify; clean containers with no chemical residue; charcoal after the contact
White residue in the HTH solution	Normal insoluble residue	Decant and use only the clear liquid
The water tastes of perfume or foams	Bleach with additives	Discard that water and use bleach with no additives
Water treated with iodine stays strongly brown	Overdose or an iodine crystal fell into the water	Remove the crystal; do not drink; treat fresh water again with the dose from table 4
The residual disappears within hours in the tank	Uncovered tank, in the sun, with biofilm	Cover, shade, shock cleaning (D.3)
Very different doses between jerrycans	Uncalibrated dropper or assumed container volume	Calibrate drops per mL; measure and mark the volume of each container

Safety

- **Never mix bleach or HTH with acids or with ammonia.**
  - With **acids** (vinegar, muriatic acid or hydrochloric acid, descalers, bathroom and limescale cleaners, concentrated lemon juice) **chlorine gas** is released: a yellowish-green gas with a suffocating smell.
  - With **ammonia** or ammonia-based products (glass cleaner, some cleaners, accumulated urine) **chloramines** are released.

  - Both gases burn eyes, throat and lungs; at high concentration, in an enclosed space, they can **kill** or cause pulmonary edema that sometimes appears **hours after** an exposure that seemed mild.
  - *What to do:* leave immediately for the open air and ventilate from outside; remove soaked clothing; wash eyes and skin with plenty of water for 15 min; rest in a half-upright position; seek medical attention if there is persistent cough, difficulty breathing, wheezing or chest pain, and keep under medical observation for 24 h even if symptoms improve.
- **Calcium hypochlorite (HTH): oxidizer and reactive** (ICSC 0638).
  - It does not burn, but it **feeds fire** in anything nearby. In contact with oil, grease, diesel, brake fluid, glycerin, sugar, sawdust, paper or rags it can **start a fire or an explosion**. It reacts violently with acids, ammonia and amines, and with many metals. It decomposes from about 100 °C onward and rapidly above 175 °C, releasing chlorine and oxygen.
  - *Storage:* in its original container, well closed and dry, in a cool, ventilated place, in the shade, **kept away from fuels, acids, fertilizers, paint and food**, out of children's reach and never inside the home. Do not return leftover product to the container, and do not use wet or dirty scoops (a few drops of water or organic matter inside the container can cause heating and decomposition).
  - **Never mix HTH with stabilized chlorines**: trichloroisocyanuric acid (pool “tablets” and “multi-action” products) or sodium dichloroisocyanurate (NaDCC, “fast” granular chlorine and water disinfection tablets). Together they react violently: heat, fire or explosion and toxic gases. Not in the same bucket, nor the same dosing device, nor with the same scoop, nor on the same shelf. When recovering pool stock, read every label and keep the containers separate; an unlabeled container is not used or mixed with anything.
  - *Handling:* gloves, goggles, outdoors, **product onto the water**, never water onto the product.
  - *Spill:* collect it dry with a clean shovel into a separate, clean, dry container, and dilute the remains with plenty of water; do not sweep with sawdust or rags.
  - *Fire involving HTH* (ICSC 0638): water in large amounts, from a distance; **do not use dry chemical** powder extinguishers; cool exposed containers with water. Do not try to smother it with blankets or dirt: HTH supplies its own oxygen and keeps burning.
- **Accidental ingestion of bleach or of concentrated solution.** Diluted household bleach (≤ 5-6 %) usually causes irritation of the mouth, throat and stomach, vomiting and pain; concentrated bleach, the HTH stock solution or the granules can cause **corrosive burns** of the esophagus and stomach, shock and death.
  - *What to do:* rinse the mouth; **do not induce vomiting**; do not give vinegar, baking soda or “neutralizers”. Only if the person is conscious, swallows without difficulty and is not vomiting or drooling: a glass of water in sips (≈200 mL in an adult; in children, a few sips, ≈50-100 mL) (ICSC 0638: “rinse the mouth and give one or two glasses of water to drink”; Spain's Servicio de Información Toxicológica (Toxicological Information Service) advises against giving liquids without medical assessment, hence the limited amount). If there is drooling, difficulty swallowing or vomiting, **nothing by mouth**. Seek urgent medical attention, more so if there is drooling, difficulty swallowing, chest pain, vomiting blood or difficulty breathing.
- **Eyes and skin:** bleach and the HTH solution cause chemical burns, and in the eyes they can leave permanent damage. Wash with plenty of water for 15 min, removing contact lenses; seek medical attention if pain, redness or blurred vision persist.
- **Mixed-up containers:** the most common cause of serious poisoning is drinking from a water or soda bottle refilled with bleach or stock solution. **Never** store chlorine solutions in beverage containers; mark stock-solution pitchers unmistakably and keep them out of children's reach.
- **Iodine: contraindications.** Do not use for drinking water in: **pregnancy** (risk of goiter and hypothyroidism in the newborn); current or past thyroid disease, even if controlled; strong family history of thyroid disease; **allergy or hypersensitivity to iodine**; people from areas with chronic iodine deficiency (WMS 2024; CDC). As an additional precaution from this article (not found in those guidelines), also not during **breastfeeding** nor for infants: iodine passes into breast milk. No one should drink iodinated water **for more than a few weeks in a row** (CDC); this article's prudent limit, 3 weeks to 1 month; WMS 2024 speaks of “months” and calls for a thyroid check if use will be prolonged. Signs of excess to watch for: lumps in the neck, abnormal tiredness and feeling cold, palpitations or nervousness: stop the iodine and switch to chlorine, boiling or filtration.
- **Iodine crystals:** toxic and corrosive if swallowed; a single ingested crystal is a poisoning, not a dose. Well-closed glass bottle, out of children's reach, and care when decanting.
- **Disinfection by-products (risk context).** Chlorine reacts with the water's natural organic matter and forms trihalomethanes (such as chloroform) and other compounds; old or heated hypochlorite solutions build up

chlorate. WHO sets guideline values (chloroform 0.3 mg/L; chlorate 0.7 mg/L, provisional) calculated for **lifetime** consumption, and their risk is small compared with drinking undisinfected water, which can kill within days from cholera or dysentery. WHO insists that disinfection **must not be compromised** for the sake of controlling by-products. To reduce them without losing effectiveness: clarify before chlorinating (removes organic matter), do not overdose, and use fresh bleach and stock solutions kept cool.
- **What this method does not solve:** *Cryptosporidium* (outbreaks of persistent watery diarrhea despite chlorinating: boil or filter), water suspected of fuel, pesticides, metals or industrial residue contamination (do not drink: find another source).
- **Out of scope:** the production of chlorine gas and its use in water treatment plants is not documented here due to its hazard. The manufacture of hypochlorite by electrolysis of brine belongs to a chemistry article.

Variants

- **With fewer resources:**
  - *No dropper or syringes:* method B (1:100 dilutions with ceramic measures). Precision is lost (±30 %), which is enough given the margin between 2 and 8 mg/L.
  - *No reagent:* there is no chemical substitute equivalent that is simple to make (WMS 2024). 3 % hydrogen peroxide, citrus juice or silver **do not** work as a primary disinfectant. One must switch to boiling (p. 3), solar disinfection or filtration.
  - *Chlorinated lime or old-style "chloride of lime"* (bleaching powder with ≈25-35 % available chlorine when fresh): used like HTH, recalculating with its strength and decanting. It degrades quickly: check it by the residual or smell and adjust the dose.
- **With more resources:**
  - *Sodium dichloroisocyanurate tablets* (NaDCC, e.g. Aquatabs): exact dose, stable for years, lightweight; follow the dose on the package. Store them away from HTH and never mix them with it (see "Safety").
  - *Chlorine dioxide* in tablets or two-component form: it does act on *Cryptosporidium*, but needs 2-4 h and leaves no lasting residual (WMS 2024).
  - *DPD kit and pH meter:* allows lowering the dose to what is strictly needed (better taste, fewer by-products) and checking each batch.
  - *Prior filtration* (ceramic, slow sand) followed by chlorination: a reference combination, because the filter removes turbidity and resistant parasites and the chlorine provides a residual.
  - *Local manufacture of hypochlorite by electrolysis of brine* (salt, water and direct current): gives independence from recovered stock; to be covered in a chemistry article.
- **Scaling up:**
  - *Family:* 20-25 L jerrycans with a tap, bleach or stock solution, smell as the check.
  - *Village:* batch chlorination in a communal tank (1-10 m^3) or **chlorine dispensers next to the source** (a tank of 1 % solution with a valve that releases a fixed dose per bucket). This requires a responsible person, a 4-bucket demand test whenever the season changes, a DPD kit, a log of doses and residuals, and a reserve of HTH. Clarify first if the sources are surface water.
  - *City:* continuous dosing with pumps or hypochlorinators proportional to flow, a contact tank sized by C·t, turbidity control (ideally < 1 NTU) and pH, a residual of 0.2-0.5 mg/L at the taps, periodic microbiological testing and trained operators. Chlorine gas is used by large industrial plants under specific regulation, outside the scope of this article.

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Related: Boiling water (p. 3) Solar disinfection (SODIS) (p. 9) Slow sand filter and charcoal biofilter (p. 27) Ceramic and carbon filters (p. 37)

WATER AND SANITATION › WATER PURIFICATION

Slow sand filter and charcoal biofilter

Household (biosand) and community slow sand filter, with biological layer, sizing and cleaning; granular charcoal bed.

N1 · Pottery and farming · Draft · Machine translation · civilizationrebuild.org/en/01-agua-y-saneamiento/potabilizacion/filtro-lento-de-arena-y-biofiltro-de-carbon/

Machine translation. Its structure and figures have been automatically checked against the Spanish original, but no person has reviewed it.

Draft without technical review. It may contain errors: double-check figures and procedures before applying them. It contains 5 figures marked “verificar” (to be verified).

Summary

A slow sand filter passes water at a very low velocity (on the order of 0.1 m/h) through a fine sand bed 0.5 to 0.9 m deep. On the surface a biological layer (*schmutzdecke*) grows that traps and digests most bacteria, protozoa and helminths and leaves the water clear (turbidity below 1 NTU). This article covers the intermittent-flow household version (*biosand* type, 24 to 72 L/day per filter) and the continuous-flow community version (1 m² of bed gives about 2400 L/day). After the sand there can be a granular charcoal bed that improves taste, odor and color and retains part of the organic contaminants. **Neither one replaces final disinfection**: the filtered water is boiled, chlorinated or exposed to the sun before drinking.

Prerequisites

- **Knowledge:** measure volumes and times with a graduated container and by counting seconds; disinfect the filtered water (see Boiling water (p. 3) and the related articles on chemical and solar disinfection). Making charcoal: there is no article yet; section F gives a minimal method.
- **Materials (household filter):**
  - 1 watertight container 90 to 100 cm tall and 25 to 35 cm inside diameter: unglazed fired-clay jar or one with lead-free glaze, a wooden barrel, a concrete or food-grade plastic bucket.
  - Sand: about 40 L already sieved and washed (start with 60 to 80 L raw: washing and sieving remove part of it).
  - Separating gravel (0.7 to 6 mm): about 4 L. Drainage gravel (6 to 12 mm): about 4 L.
  - 1 outlet pipe 1 to 2 cm inside diameter: bamboo or reed cane with no internal nodes, fired-clay, copper or plastic pipe.
  - Sealant for where the pipe passes through the wall: clay with resin or beeswax (N1), lime mortar (N2) or cement (N3).
  - 1 diffuser: thin board, fired-clay plate or sheet metal, with holes about 3 mm.
  - 1 lid and 1 clean container with lid to collect the filtered water.
- **Materials (household charcoal biofilter):** 25 to 30 L of already crushed, sieved and washed hardwood charcoal; 1 container of 35 to 40 L with the same type of raised outlet pipe.
- **Tools:** buckets of 10 to 20 L (N1), woven-fabric or basketry sieves (N1), mortar or stones for crushing (N0), ruler or knotted cord with knots every 1 cm (N1), counting seconds (N0). For the community version: hoe and shovel (N1), clay (N1) or masonry (N2), sluice gate or wooden plug (N1).
- **Time and people:** household filter, 2 people for 1 to 2 days (mostly sieving and washing the sand), plus 2 to 4 weeks of ripening. Community filter of 2 m², 6 to 10 people for 1 to 3 weeks depending on the terrain, plus ripening.

How it works

What the sand retains. Water crosses the gaps between grains (in fine sand, a few tenths of a millimeter). Particles are caught by straining at the surface, by settling inside the pores and by sticking to the grains. That retains turbidity, helminth eggs and protozoan cysts, but lets through many bacteria and almost all viruses.

The biological layer does the fine work. In the top 1 to 2 cm a sticky film of algae, bacteria, protozoa and organic matter forms over weeks (*schmutzdecke*, German for “dirty layer”). There pathogens get stuck, are devoured by protozoa or die from lack of food. That layer needs:

1. **Contact time:** WHO/IRC recommends designing for **0.1 m/h**, with an accepted range of **0.1 to 0.4 m/h** (Visscher et al. 1987; Global WASH Cluster). Faster than that, pathogens cross the bed.
2. **Oxygen:** it arrives dissolved in the water or, in the household filter, by diffusion through a layer of standing water **5 cm** deep (CAWST 2009). More water on top suffocates the layer; less, and it dries out from heat.
3. **Not drying out or being poisoned:** if the bed is left without water or chlorinated water is poured in, the layer dies.

Grain size. The **effective size** (d10) is the sieve opening through which 10 % of the weight passes; the **uniformity coefficient** is CU = d60/d10. For a slow sand filter: **d10 = 0.15 to 0.30 mm** and **CU < 5, preferably < 3** (Visscher et al. 1987; Pennsylvania gives 0.15 to 0.35 mm and CU 1.5 to 3). Coarser sand: water passes too fast. With many fines (silt, clay): it clogs within days. Too little uniformity: fine grains fill the gaps between coarse ones and the flow rate collapses.

Why the outlet rises above the sand. The discharge point sets the minimum water level inside the filter (communicating vessels). If it is above the sand, the bed never empties and the layer never dries out. But if the pipe drops too far outside it can **siphon**: it keeps pulling water down below the elbow's level and leaves the sand exposed to air. This is the part most often done wrong.

What the charcoal does. Charcoal has an enormous internal pore surface where organic molecules are **adsorbed**: those that give taste, odor and color, pesticide residues and other organics. It also **destroys free chlorine**. The higher the carbonization temperature and the finer the grain, the greater the capacity: charcoal made at ≥ 850 °C in a gasifier worked well, though commercial activated carbon outperformed it by a factor of 2 to 34 (average 15) (Kearns et al. 2021).

Contaminant	Does the charcoal bed retain it?
Taste, odor, color	Yes, well
Residual free chlorine	Yes (that's why disinfection happens **after** the charcoal)
Pesticides and other organics	Partly; depends on the charcoal and it gets exhausted
Bacteria, viruses, protozoa	**Not** reliably; bacteria can grow inside the bed
Salts, nitrates, fluoride, hardness	**No**
Metals (arsenic, lead, etc.)	Generally **no**, or very little
Turbidity	Little, and it clogs: that's why it goes **after** the sand

Order of the treatment train: (settling if the water is turbid) ⟶ sand ⟶ charcoal ⟶ disinfection ⟶ covered storage.

What to expect from a ripened sand filter. A 1-log reduction is 90 %, 2-log is 99 %, 3-log is 99.9 %.

Pathogen or parameter	WHO 2011, table 7.7 (slow filtration)	Community (Global WASH Cluster)	Biosand (CAWST 2009)
Bacteria	0.2 to 2 log	> 95 %	up to 96.5 % in the laboratory; 87.9 to 98.5 % in the field
Viruses	0.25 to 4 log	> 95 %	70 to > 99 % in the laboratory
Protozoa	0.3 to > 5 log	> 99 %	> 99.9 % in the laboratory
Helminths	—	—	up to 100 % (assumed by size)
Outlet turbidity	—	< 1 NTU	95 % reduction, down to < 1 NTU

WHO's lower figures correspond to poorly operated filters (unripened, freshly scraped, too fast): retention drops a lot. Even 95 % lets through 50 bacteria out of every 1000: it greatly reduces diarrhea, **it does not guarantee safe water**. Hence the need for final disinfection.

Inlet limits: recommended turbidity up to 10 NTU, with peaks of up to 50 NTU in the community filter (Global WASH Cluster); the biosand accepts up to 50 NTU (CAWST 2009). Above that, settle it first.

Procedure

A. Sizing

1. **Calculate demand.** If capacity is scarce, filter only drinking and cooking water: **7.5 L per person per day**. If all household water is filtered, basic access is around **20 L per person per day** (Howard and Bartram 2003). *Success criterion:* a liters/day figure written down.
2. **Choose the type.** A biosand gives 24 to 72 L/day in 4 batches of 12 to 18 L (CAWST 2009).
   - Up to ~70 L/day: **1 biosand** (at 7.5 L/person/day, up to 9 people: 9 × 7.5 = 67.5 L).
   - Between 70 and ~290 L/day: **2 to 4 biosands in parallel**, one per 70 L/day (4 × 72 = 288 L).
   - More than ~300 L/day or collective use: **continuous-flow community filter**. *Success criterion:* type and number of filters decided.
3. **Community filter area.** Area (m^2) = flow rate (m^3/h) / velocity (m/h), at 0.1 m/h and 24 h/day. So, 1 m^2 gives 0.1 m^3/h = 2400 L/day: 120 people at 20 L/day or 320 at 7.5 L/day. **Worked example:** village of 200 people at 20 L/day.
   - Demand: 200 × 20 = 4000 L/day = 4 m^3/day = 4 / 24 = 0.167 m^3/h. Area: 0.167 / 0.1 = 1.67 m^2.
   - **2 identical units** to clean one without cutting off supply: 2 × 0.9 m^2 (0.95 × 0.95 m). Under normal operation they run at 0.167 / 1.8 = 0.093 m/h; with one stopped, the other runs at 0.167 / 0.9 = 0.19 m/h, within 0.1 to 0.4 m/h.
   - Flow rate to measure: 167 L/h = 2.8 L/min total, 1.4 L/min per unit: a 10 L bucket in about 7 min.
   - For drinking and cooking only (7.5 L): 1500 L/day = 0.0625 m^3/h ⟶ 0.63 m^2 ⟶ 2 × 0.32 m^2 (0.57 × 0.57 m). Visscher et al. (1987) give 5 to 200 m^2 per unit: the 0.3 to 0.9 m^2 units are below what's typical. They work, but are scraped from the edge, without stepping inside. *Success criterion:* area, units and flow rate per unit recorded.
4. **Household filter flow rate.** Maximum load **600 L/h per m^2** (CAWST 2009): maximum flow rate (L/h) = area × 600. Container of 30 cm: area = 3.14 × 0.15^2 = 0.0707 m^2; maximum = 42 L/h = 0.7 L/min. The CAWST v10 filter works at **0.4 L/min** maximum with a full reservoir. Since 0.7 L/min is 1.75 times that value, **aim for 0.4 to 0.5 L/min**. *Success criterion:* target flow rate for your container recorded.
5. **Household filter heights** (bottom to top; layers according to CAWST 2012 and Global WASH Cluster):

Layer	Thickness	Material
Drainage gravel (surrounds the pipe mouth)	5 cm	6 to 12 mm
Separating gravel	5 cm	0.7 to 6 mm
Filter sand	45 to 50 cm	< 0.7 mm, no fines
Standing water layer	5 cm (4 to 6 cm)	—
Gap to the diffuser	just enough that it doesn't touch the water (5 cm in the calculation)	—
Reservoir above the diffuser	whatever a 12 L batch occupies	—

   For a 30 cm diameter, 12 L occupies 12,000 cm^3 / 707 cm^2 ≈ 17 cm. Total ≈ 5 + 5 + 50 + 5 + 5 + 17 + 5 cm of freeboard ≈ **92 cm**. *Success criterion:* a scale drawing with the measurements, including the outlet elbow's height = sand surface + 5 cm.
6. **Check the pore volume.** Each batch must fit within the sand's pores so it stays inside the bed during the pause. Porosity of silica sand = 1 − bulk density / grain density = 1 − 1560 / 2650 ≈ 0.41 (values from Thames Water 2005). Pore volume = 0.0707 m^2 × 0.50 m × 0.41 = 0.0145 m^3 = 14.5 L ≥ 12 L. *Success criterion:* batch ≤ pore volume; if not, reduce the batch size.

B. Obtaining, sieving and washing the sand and gravel

1. **Choose the source.** In order of preference (CAWST): **crushed rock**, dry quarry sand and river sand taken high on the bank. River sand usually carries organic matter and pathogens from excrement. Look for hard quartz grains that don't crumble when rubbed. Avoid beach sand (salt and shells), sand near latrines, dumps or mine tailings, and clayey sand. *Success criterion:* a squeezed handful of damp sand does not form a ball that keeps the imprint of the fingers (if it does, it carries too much clay).
2. **Sieve out the coarse material** through a sieve of about **0.7 mm**. Without proper sieves: cloth, mosquito netting or regularly woven basketry; opening ≈ (10 mm / threads per cm) − thread thickness (10 threads/cm with 0.3

mm thread ⟶ 0.7 mm). Also a thin board or leather perforated with hot wire of known thickness. Keep what is retained for the gravels. *Success criterion:* the sieved material passes the measurement in step 3 and, at the end, the flow-rate test (C.7).

3. **Measure the grain size without sieves.** Line up grains touching each other along 1 cm and count them: average diameter ≈ 10 mm / number of grains. Look for typical grains of 0.2 to 0.5 mm (20 to 50 grains per cm), consistent with d10 = 0.15 to 0.30 mm and CU < 3. Do this with 3 samples from different spots in the pile. *Success criterion:* all 3 give 20 to 50 grains/cm, without two very different populations (dust plus coarse grains).
4. **Remove fines by decantation.** In water at 20 °C, a natural quartz grain falls at about **7.5 mm/s if it measures 0.1 mm** and at about **10 mm/s if it measures 0.12 mm** (Ferguson and Church 2004). Practical rule, valid for any container: **after stirring, wait 1 s for every cm of water above the sand** (30 cm ⟶ 30 s) and pour off the turbid water. What settles at less than 10 mm/s is removed: grains smaller than about 0.12 mm, below the target d10. In water at 10 °C the viscosity is 30 % higher and grains fall more slowly: wait 36 to 40 s per 30 cm. Procedure: fill the container with one third sand and the rest water (Thames Water 2005); measure the height of water above the sand with the knotted cord; stir vigorously for 10 s; wait according to the rule; pour off without dragging the sand off the bottom; repeat. *Success criterion:* after stirring and waiting, the water lets you see the sand at the bottom and no longer carries dust when poured off.
5. **Check the silt content without over-washing.** Bottle test (Pyper and Logsdon 1991, in Thames Water 2005): 100 mL of sand in a clear jar, water up to 200 mL, shake hard and let it settle for 20 min. Turbid water, a silt band and the sand form. Silt (%) = silt height / sand height × 100; wash it if it exceeds 1 % (Visscher et al. 1987). In the biosand, don't wash more than necessary: sand that is too clean lets water through too fast, and the final call is made by the flow-rate test (C.7). *Success criterion:* silt band barely visible, ≤ 1 % of the sand height.
6. **Prepare the gravels.** Sieve what was retained in step 2 into two fractions: **0.7 to 6 mm** (separating) and **6 to 12 mm** (drainage), checking the largest grains in each pile with the ruler. Wash both until the water runs clear. *Success criterion:* wash water clear on the first pour; no flat or elongated stone larger than 12 mm.
7. **Store the fractions** separately and labeled, covered, on a clean surface. *Success criterion:* 3 identified piles, free of soil, leaves or animal droppings.

C. Building the household filter (biosand, N1)

1. **Prepare the container.** Fired clay: fill it with water for 24 h to check for leaks. Wood: untreated and non-toxic, let it swell with water for 2 to 3 days until it stops seeping. *Success criterion:* no visible leaks and the water level does not drop more than 1 cm in 24 h.
2. **Place the outlet pipe.** Two ways:
   - **Internal (preferable):** a vertical pipe inside the container, with its lower mouth 1 to 2 cm from the bottom, running up against the wall, passing through it at the height "sand surface + 5 cm" and exiting through an elbow.
   - **External:** a hole near the bottom and a pipe that runs up outside to that height and then exits. **Avoid siphoning:** after the elbow, the spout must drop only a little (**5 cm at most**) or have a **small hole (2 to 3 mm) at the top of the elbow** to let air in. Seal the pass-through in the wall with clay and resin or wax (N1), lime mortar (N2) or cement (N3), inside and out. Cover the lower mouth with cloth or mesh so gravel cannot get in. *Success criterion:* with the container full of water, water flows out of the spout and stops when the inside level reaches exactly the elbow's height, without dropping further over the next 10 min; no leaks from the seal after 12 h.
3. **Fill with water first and pour the media into the water**, so as not to leave air pockets. Mark the levels on the wall beforehand. Pour in 10 to 15 cm of clean water, add the drainage gravel up to 5 cm, level it, and add the separating gravel on top up to 5 cm. *Success criterion:* flat layers (± 1 cm) with water always above them.
4. **Add the sand** by handfuls inside the water, adding water as needed, up to 45 to 50 cm. Level it with your flat hand, without pressing. *Success criterion:* flat surface 5 cm (4 to 6 cm) below the elbow.
5. **Place the diffuser**, with holes about **3 mm** spread over its whole surface, resting on a ledge, on wedges or on the wall, **above the standing water layer** without touching it. *Success criterion:* when a 10 L bucket is poured all at once, the sand shows no crater or channels.
6. **Put on the lid** and, under the spout, the collection container on a stand, covered around it with a clean cloth. *Success criterion:* the stream falls inside without splashing or touching the rim.
7. **Flow-rate test.** Fill the reservoir with the full batch (12 L). As soon as it starts to come out, time how long it takes to fill a glass of known volume. Flow rate (L/min) = volume (L) × 60 / seconds. Example: 1 L in 150 s ⟶

0.4 L/min. *Success criterion:* 0.4 to 0.5 L/min in a 30 cm container (≤ 0.4 in a CAWST v10), and no less than half that value so the family doesn't tire of waiting.

- **Too fast:** sand is coarse or over-washed. Replace the top 5 to 10 cm with finer or less-washed sand and repeat.
- **Too slow:** too many fines. Remove the top 5 to 10 cm, wash them more (B.4) and repeat.

8. **Check the standing water layer.** When water stops coming out, measure the height of the water above the sand. *Success criterion:* 5 cm (4 to 6 cm; CAWST 2009). If not, correct the sand's height (not the pipe's); if it drops below 4 cm with the sand well leveled, the pipe is siphoning (see Common mistakes).

D. Ripening and daily use

1. **Use the filter every day** with the same water source from day one; changing sources reduces performance (CAWST 2009). *Success criterion:* daily log of batches (one mark per batch).
2. **Ripen the biological layer:** up to **30 days** in the biosand (CAWST 2009); in the community filter, up to **3 weeks** with new sand (Visscher et al. 1987), longer in cold water. During that time the water comes out clear but **is not treated**: always disinfect it. *Success criterion:* the flow rate drops somewhat and stabilizes, and a slightly sticky brown or greenish film appears on the sand.
3. **Respect the pause between batches: at least 1 h** from when water stops flowing; 6 to 12 h is recommended and 48 h is the maximum (CAWST 2009). Typical pattern: 4 batches per day. *Success criterion:* it's never refilled while still dripping; never more than 2 days pass without a batch.
4. **Pretreat turbid water.** Above 50 NTU, strain through a folded cloth or let it settle (CAWST 2009). Without a turbidimeter, **CAWST's bottle test (2009)**: fill a clear 2 L plastic bottle with the water and set it over large printed letters; if they can be read looking down through the bottle from above, it's probably below 50 NTU. *Success criterion:* the letters can be read; if not, settle it first.
5. **Never pour in chlorinated water, soap or hot water**: they kill the biological layer. *Success criterion:* the incoming water does not smell of chlorine.

E. Maintenance

Household filter: "swirl and dump" (CAWST). Only when the flow rate no longer meets the household's needs or drops below **0.1 L/min** (CAWST manual), not on a schedule.

1. If the filter is empty, pour in about **4 L** of water (CAWST). Remove the lid and the diffuser. Wash your hands.
2. Stir in circles with your palm, only the sand surface, without pushing your fingers down toward the gravel.
3. Scoop out the dirty water with a cup and dump it away from the source and the filter. Repeat until the flow rate recovers.
4. Level the sand, put the diffuser and lid back on. Clean the spout **on the outside** with water and soap or chlorinated water, without letting it get into the filter. *Success criterion:* the flow rate returns close to that of the initial test. For a few days the filter retains less well while the layer rebuilds (CAWST 2009): disinfect as always.

Community filter: scraping

1. **When:** when, with the outlet fully open, the flow rate falls below the design value or the water reaches the overflow. This ranges from several weeks to a year depending on the water (Global WASH Cluster).
2. **Partially drain it:** close the inlet and lower the level to about **10 cm below the sand surface** (Global WASH Cluster). *Success criterion:* the visible top sand is moist, not dry.
3. **Scrape** the top **1 to 3 cm** with a flat shovel or board (Thames Water 2005), in strips and evenly, removing it in baskets. On units smaller than about 2 m², work from the edge; on larger ones, step only on boards. Do it in a single day. *Success criterion:* clear, uniform sand appears underneath.
4. **Refill from below** with **already filtered** water: open the connecting pipe to the twin unit (H.6) and let the water rise through the drain. If there is no filtered water, do not fill from below with settled water (it seeds pathogens into the drain): fill from the top instead, slowly, pouring onto the flat stone (Thames Water 2005). *Success criterion:* the level rises a few cm per minute, without bubbles or craters, until it covers the sand.
5. **Re-ripen:** after scraping, allow **at least a few days**, and more after adding new sand (Global WASH Cluster; Visscher et al. 1987 gives 1 to 2 days after scraping and up to 3 weeks with new sand). Meanwhile, dump the water or disinfect it. *Success criterion:* outlet turbidity and flow rate back to their usual values.
6. **Wash and store the scraped sand** (B.4) in a covered pile.
7. **Recharge** the bed when it drops to **0.5 to 0.6 m** (Visscher et al. 1987; Global WASH Cluster), every few years. **Trench technique** (Thames Water 2005, from Huisman and Wood 1974): remove the old sand down to the gravel in a strip, put washed sand at the bottom and the old sand on top, and continue strip by strip. The old

sand, already colonized, ends up on top and shortens re-ripening. *Success criterion:* bed back to 0.8 to 0.9 m, level, and design flow rate recovered.

F. Preparing the charcoal for the filter

This also serves for the charcoal cartridge of household ceramic filters.

1. **Wood.** Hard, dense and dry (holm oak, oak, beech, fruit trees or coconut shell). Never treated, painted, particle-board or varnished. *Success criterion:* firewood with no rotten bark that sounds dry when struck.
2. **Carbonize it.** The best charcoal for water comes from a **TLUD gasifier** (*top-lit updraft*: lit from the top, with rising draft; sheet-metal drum, N2-N3): the one made at ≥ **850 °C** adsorbed much better than low-temperature charcoal (Kearns et al. 2021). Without sheet metal, **minimal N1 method in a pit or mound** (FAO 1983, chap. 5 and 6):
   - Stack the firewood tightly, filling gaps with thin sticks, in a pit or around a central pole. Cover with leaves and **10 to 20 cm of sandy soil**; leave a gap at the top and air inlets at the base (6 to 10 in a 4 m diameter mound).
   - Light it by dropping embers through the top gap. **Thick white smoke**: the fire has caught. Cover with soil any crack from which flame escapes.
   - When the smoke **decreases and turns bluish and then almost transparent** (days, in a 4 m mound), carbonization is finished and what is burning is now the charcoal itself: **seal** all inlets and the top gap with soil or clay.
   - Let it cool sealed (2 to 3 days in that mound). Good-practice yield: 1 kg of charcoal per 4 kg of air-dried firewood. This charcoal is made at a lower temperature (about 550 °C in an improved mound, according to FAO) and unevenly: **it adsorbs less than gasifier charcoal and will remove less taste and odor**. Set aside the under-carbonized pieces from near the smoke outlet. *Success criterion:* pieces black inside, with no brown core, that ring metallically when struck, leave little soot, and break with a shiny fracture.
3. **Cool without air.** If you put it out with water, do so outdoors and away from the steam (see Safety). Spread the charcoal in the shade. *Success criterion:* plunging a hand into the pile shows no heat anywhere, and none the next day either; only then bag it.
4. **Crush it.** Dampen the charcoal so it doesn't raise dust and crush it in a mortar or between stones inside a sack. *Success criterion:* almost all of it in grains the size of a pea or smaller.
5. **Sieve it.** Aim for grains of **4 to 8 mm**. Kearns et al. (2021) model a full-scale adsorber (bed 58 cm in diameter and 30 cm deep) with **4.5 mm** grains and **2.5 h** of contact time; Thailand's community system, in use since 2008, uses **7.5 mm** grains with about **18 h** of contact time. Finer grain adsorbs more (going from 0.165 to 0.059 mm multiplied capacity by 3.5 to 3.9 in the laboratory), but it clogs and is lost during washing. Crush again what doesn't pass through 8 mm and discard the dust that passes through a mosquito net. *Success criterion:* grains of similar size, with no dust when a dry handful is rubbed.
6. **Wash and saturate.** In a bucket with water, stir, wait 30 s and pour off the black water along with whatever floats. Repeat until it comes out nearly clear. Leave it soaking at least overnight so water fills the pores. *Success criterion:* rinse water light gray and almost all the charcoal at the bottom; discard whatever keeps floating.
7. **Decolorization test** (useful for comparing charcoals and for monitoring the bed, G.6): in two identical glasses put 200 mL of water with 1 drop of vegetable ink or strong tea; add to one a handful of the charcoal being tested and to the other an equal handful of reference charcoal; shake for 10 min and let it settle. *Success criterion:* the good charcoal leaves the water noticeably clearer than the reference, or the same if the reference is new charcoal.
8. **Steam activation (optional; when in doubt, skip it).** Industrial activation works between 700 and 1000 °C and opens more pores by burning part of the charcoal. There is no reliable data on how much it improves charcoal already made at high temperature: if it comes from a gasifier, it probably isn't worth it. If you do it (N2), read Safety first:
   - Use an iron container, never clay, filled with grains up to 2/3, with a lid pierced by a short **vent** and by an **iron pipe at least 1 m long with a funnel on top** to add water far from the fire.
   - Heat until the container is red-hot (cherry red to orange, ≈ 800 to 900 °C, verificar) and keep it there for 1 to 2 h (verificar). Light the gas coming out of the vent.
   - Pour very little water through the funnel each time (about 50 mL every 5 to 10 min, verificar), with your face turned away from the vent and the funnel, because steam comes out in bursts.
   - **Stop adding water at least 15 min before finishing** and keep heating until **there is no flame at the vent** (gas exhausted). If you sealed it with gas still inside, air entering as it cooled could ignite the mixture, blow off the lid and throw embers.

- Only then remove it from the fire, **seal the vent and the funnel with clay or damp sand** and let it cool.
- **Do not open it until you can rest your hand on the lid.** *Success criterion:* lighter, more porous grains (weigh before and after) that, once washed, outperform the same unactivated charcoal in the decolorization test (step 7).

G. Assembling and using the charcoal biofilter

1. **Place it after the sand**, never before. *Success criterion:* the water entering the charcoal is already clear.
2. **Size it by contact time.** The beds described (model and field) work with 2.5 to 18 h of contact (step F.5). In the intermittent filter, make sure **each full batch stays inside the charcoal during the pause** (6 to 12 h): bed pore volume ≥ batch size. Measure the porosity between grains: fill a 1 L jar with already-saturated charcoal, add water to the brim and measure how much went in; porosity = liters of water / 1 L. Example with 0.45: 12 / 0.45 ≈ **27 L of charcoal**, which in a 30 cm container occupies 27,000 cm^3 / 707 cm^2 ≈ 38 cm. *Success criterion:* porosity measured, bed calculated and container chosen.
3. **Assemble the container like the biosand, but simpler:** 5 cm of drainage gravel around the pipe mouth, the charcoal on top and the outlet elbow above the surface of the charcoal, with the same precaution against siphoning (C.2). On top, a cloth or perforated plate. Fill with water first and pour the charcoal in. *Success criterion:* with the filter at rest, a visible layer of water remains above the charcoal and nothing floats.
4. **Rinse before use:** run through 2 or 3 batches and discard them. *Success criterion:* it comes out with no gray color or particles.
5. **Always disinfect after the charcoal**: boil, chlorinate or SODIS. If you chlorinate, do it **at the outlet** of the charcoal, which removes chlorine. *Success criterion:* the stored water smells slightly of chlorine, or was boiled.
6. **Replace the charcoal** when the taste or odor it used to remove comes back, or when, in the **monthly decolorization test** (F.7) with a handful taken from the top layer of the bed, it decolorizes clearly less than freshly prepared new charcoal. There is no published interval: Thailand's system has gone through several replacement cycles, but Kearns et al. (2021) do not give months. Do not reuse charcoal used for water without reactivating it; burn it outdoors, away from people. *Success criterion:* loading date and result of each monthly test recorded on the container.

H. Building the continuous-flow community filter (N1-N2)

1. **Choose the site:** above the flood zone, downhill from the intake and uphill from the reservoir, and at least **30 m** from latrines and cesspits (Sphere 2018), farther from animal pens if the terrain drains toward the filter. *Success criterion:* water flows from the intake to the filter and to the reservoir by gravity.
2. **Excavate or build the tank.** Height: **0.3 to 0.5 m** of drain and gravel + **0.8 to 0.9 m** of sand
   - supernatant water + **0.2 to 0.3 m** of freeboard (Visscher et al. 1987; Thames Water 2005). WHO/IRC recommends **1 m** of supernatant water; with less it can still work, but there is less head to push the water through and it must be scraped more often. Waterproof it with puddled and compacted clay in layers (about 5 cm per layer, verificar) or with masonry set in lime mortar (N2). *Success criterion:* full of water, the level does not drop more than 1 cm/day aside from evaporation; if it drops more, add another layer of clay.
3. **Drain:** pipes 6 cm in diameter spaced 1 m apart (Visscher et al. 1987), of fired clay laid end to end with the joints slightly narrower than the finest stones of the gravel layer covering them, or a channel of flat stones, with a slight slope toward the outlet. *Success criterion:* water poured in at the high end reaches the outlet without pooling.
4. **Support gravel**, bottom to top (Visscher et al. 1987, in Thames Water 2005): **16 to 23 mm, 15 cm**; **4 to 5.6 mm, 10 cm**; **coarse sand 1 to 1.4 mm, 10 cm**. Wash them until the water runs clear. *Success criterion:* flat layers; a handful of filter sand poured with water onto the top layer does not disappear between the grains.
5. **Sand:** 0.8 to 0.9 m initial thickness (Visscher et al. 1987), poured into the water as in C.3-C.4. Mark the initial and minimum level (0.5 to 0.6 m) on the wall. *Success criterion:* flat surface (± 2 cm).
6. **Outlet and connection between units:** the drain leads to a chamber whose weir sits **slightly above the sand surface** (Huisman and Wood 1974, in Thames Water 2005), so the bed never empties; in front, a wooden plug or gate regulates the flow. Connect the drains of the two units with a **6 cm pipe with a plug** so one can be filled from below with filtered water from the other. *Success criterion:* with the inlet closed, water stops coming out and stays above the sand; with the plug closed, no water passes from one unit to the other.
7. **Inlet:** an overflow in the wall at the maximum supernatant water level returns the excess to the stream; the inlet pours onto a slab or flat stone. *Success criterion:* with the inlet fully open, the level stabilizes at the overflow and the sand does not move.

8. **Initial filling from below** with already-filtered water (from the twin unit through the connecting pipe, or from another filter poured into the chamber with the gate open), until it covers the sand; if only unfiltered water is available, fill from the top over the flat stone (Thames Water 2005). Afterward open the normal inlet. *Success criterion:* the level rises a few cm per minute, with no bubbles.
9. **Set the design flow rate** with the gate, measuring with a bucket and a clock (A.3: 10 L in about 7 min per unit). Check it **every day** (Visscher et al. 1987) and open it up little by little as the layer slows the flow; a large sudden adjustment worsens the water quality (Thames Water 2005). *Success criterion:* the bucket fills in the design time at the daily check.
10. **24 h operation** toward a **covered reservoir** of at least **40 %** of daily production (Visscher et al. 1987; in the example, 1.6 m³), from which water is drawn with a tap. During ripening, dump the water or disinfect it. *Success criterion:* the reservoir never runs empty and the filter never stops.
11. **Cover the filter** with a small roof of branches, reed matting or boards: light favors algae, which clog the filter sooner (Pennsylvania manual). *Success criterion:* no floating algae or excrement in the water.

Verification

With N1 means, no laboratory:

- **Clarity:** the filtered water looks clearly cleaner than the inlet water. Sharply seeing a black mark through 30 cm of water indicates improvement, **not** that 1 NTU has been reached; a turbidimeter is needed for that.
- **Odor and taste:** no rotten or moldy smell. If it smells rotten, the layer is oxygen-starved: check the standing water layer (5 cm) and the maximum pause (48 h).
- **Flow rate:** record it every week. A slow decline is normal; a sudden increase indicates a disturbed bed, a crack or a channel next to the wall (water is not being filtered).
- **Standing water layer** of 5 cm (4 to 6 cm) in the biosand; sand always covered in the community filter.
- **Charcoal:** monthly decolorization test (F.7).
- **Health:** diarrhea decreasing in the household or village compared with before (a delayed but real indicator).

With more resources (N3-N4):

- **Turbidity** of the outlet < 1 NTU with a turbidimeter.
- **Hydrogen sulfide test** (paper strip in a 20 mL jar): incubate at **25 to 35 °C** and read at 24 and 48 h; if it turns black, fecal contamination is likely. Below about 20 °C it takes much longer and can give false negatives (Pillai et al. 1999).
- ***E. coli*** by membrane filtration or chromogenic substrate: WHO's target is 0 in 100 mL (WHO 2011, table 7.10), which in practice **is only achieved with final disinfection**.
- **Charcoal exhaustion:** pour water that smells of chlorine **directly onto the charcoal bed**, never through the biosand (D.5). If the outlet of the charcoal smells of chlorine, it is exhausted.

Common mistakes

Symptom	Likely cause	Solution
Water comes out almost as fast as it's poured in	Coarse or over-washed sand; channel next to the wall	Replace the top 10 cm with finer sand; pack damp sand against the wall
Very slow flow rate from day one	Sand with too many fines or clay	Remove the top layer and repeat decantation (B.4)
Flow rate drops within a few days	Turbid inlet water	Settle or strain it first; "swirl and dump" or scrape
Sand with dry patches or cracks	Outlet below the sand surface	Raise the elbow or the weir above the sand
Standing level < 4 cm despite well-leveled sand	The pipe is siphoning: the spout drops too far and keeps pulling water	Shorten the spout's drop to ≤ 5 cm or open a 2 to 3 mm hole at the top of the elbow
Water smells of rotten eggs	Oxygen-starved layer: more than 5 cm of standing water, pauses longer than 48 h	Adjust the sand height; use it daily
Crater in the sand under the stream	Diffuser missing, broken or submerged	Reinstall the diffuser above the water layer

Symptom	Likely cause	Solution
Improves and worsens depending on the day	Change of water source; chlorinated or soapy water	Always use the same source; don't add chlorine or soap
Sand in the outlet water	Separating gravel absent or too coarse	Redo the gravel layers
Gray water after the charcoal	Poorly washed charcoal dust	Wash more; discard the first batches
The charcoal floats and comes out	It wasn't saturated with water	Soak it until it sinks before loading it
The bad taste comes back	Exhausted charcoal	Replace the charcoal
Diarrhea despite the filter	Unripened filter, recent scraping, re-contamination during storage, or no disinfection	Always disinfect; use a covered collection container with a tap or spout

Safety

- **False sense of safety (the main risk).** A ripened filter retains most pathogens, not all of them; during ripening and after every cleaning, much less. Charcoal does not retain pathogens and can grow them. **Always disinfect the filtered water.** With water from an obviously fecal source (a river below a settlement, a pond with livestock), an undisinfected batch can transmit cholera, typhoid fever, hepatitis A or rotavirus, which kill small children through dehydration.
- **Chemical contaminants.** Neither sand nor charcoal removes salt, nitrates (dangerous for infants under 6 months), fluoride, arsenic or most metals. If the source is near mines, tailings, heavily fertilized fields or industries, or there are tooth stains or frequent skin lesions in the area, look for another source. Exhausted charcoal can release what it has adsorbed: replace it.
- **Containers.** Old or traditional glazed pottery can leach lead: use unglazed clay or lead-free glazes. Do not use drums that held fuel, pesticides or chemical products, nor treated wood.
- **Dust.** Sieving dry sand raises silica dust, which causes silicosis over time: sieve it wet or outdoors, with a damp cloth over nose and mouth. Charcoal dust irritates eyes and lungs: crush it damp.
- **Carbonization and freshly made charcoal.** The mound and the pit give off smoke with carbon monoxide: work upwind (with the wind at your back) and never near homes. Stepping on a lit mound can sink you into embers: don't climb on it. Putting out red-hot charcoal with water releases steam and some carbon monoxide and hydrogen: do it outdoors and upwind. Charcoal can reignite hours later and burn down storage: don't bag it hot. Natural-fiber clothing, water on hand and an area clear of dry leaves.
- **Steam activation (optional: when in doubt, don't do it).** Risks: steam bursting out and burning the face; combustible and **toxic** gas (carbon monoxide and hydrogen); flame flashback if air enters with gas still inside, blowing off the lid and throwing embers. Therefore: only outdoors; water through a pipe at least 1 m long and little at a time, never with your face above the vent or the funnel; stop adding water 15 min before and heat until there is no flame before sealing (F.8); do not open until you can touch the lid; never in clay containers: they burst. Keep children and animals away.
- **Carbon monoxide poisoning. It has no smell and cannot be seen.** Symptoms: headache, dizziness, nausea, fatigue, confusion. At the first sign, **move upwind, out of the smoke**, and move others away too. If someone is unconscious but breathing, place them in the **recovery position** outdoors; if not breathing, give **rescue breathing** (and chest compressions if you know how) and call for help. **No one returns to the area until the fire is out and it has been ventilated.**
- **Community filters and wells.** A tank with water or a pit near the river is a drowning risk for children: fence it or cover it. In sandy ground, pit walls collapse: don't go into a pit deeper than waist height without shoring or sloping it. To scrape it, use boards and never work alone.
- **Maintenance hygiene:** the water from “swirl and dump” and the scraped sand carry pathogens. Dump that water and that sand away from sources, wells and raw-vegetable gardens, and wash your hands with soap.
- **Frost.** Frozen water kills the biological layer and cracks clay containers: protect or bury the filter.

Variants

- **With fewer resources (N0):**
  - **Riverbank well (bank filtration):** dig a shallow pit in sandy ground 5 to 10 m from the channel (verificar) and draw the water that seeps in; the ground acts as a filter. It greatly improves turbidity, but flow velocity is not controlled: always disinfect. Fence it or cover it and watch for collapse (see Safety).

  - **Bark containers, basketry waterproofed with clay, or leather:** work the same if the 5 cm water layer, the raised siphon-free outlet and the maximum flow rate are respected; they don't last as long.
  - Without charcoal: the improvement in taste and odor is lost, not the removal of pathogens (which the charcoal never provided anyway).
- **With more resources:**
  - **N2:** masonry tank with lime mortar, glazed clay pipes, perforated sheet-metal diffuser, sheet-metal TLUD gasifier for the charcoal, iron container for activating it.
  - **N3:** concrete filter with a steel mold (CAWST v10, 70 to 75 kg, service life of more than 30 years according to CAWST 2009); standardized sieves for d10 and CU; **gravel prefilters** for more turbid water.
  - **N4:** commercial granular activated carbon (on the order of 15 times the capacity of good charcoal; Kearns et al. 2021); turbidity and *E. coli* monitoring; molded plastic filters (about 3.5 kg).
- **Scaling up:**
  - **Family:** 1 biosand (24 to 72 L/day) + 1 charcoal bed of ~27 L + disinfection + container with a tap.
  - **Village (100 to 1000 people):** 2 or more continuous-flow units; 5 to 200 m² per unit is typical (Visscher et al. 1987), though small ones under 1 m² serve small groups if scraped from the edge. Covered reservoir, a trained caretaker who measures the flow rate daily and staggers the scrapings.
  - **City:** dozens of beds (the municipal slow sand filter has been used since 1829 in London), with prior settling, mechanical sand washing, final chlorination and a laboratory. The slow sand filter takes up **up to 10 times** more area than a rapid one (Global WASH Cluster): beyond a certain size, coagulation with rapid filtration takes over.

Sources

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Related: Boiling water (p. 3) Ceramic and carbon filters (p. 37) Chemical disinfection of water with chlorine and iodine (p. 17) Solar disinfection (SODIS) (p. 9)

WATER AND SANITATION › WATER PURIFICATION

Ceramic and carbon filters

Make, test and use silver-impregnated ceramic pot filters, candle filters and a carbon stage; what they remove and what they do not.

N1 · Pottery and farming · Draft · Machine translation · civilizationrebuild.org/en/01-agua-y-saneamiento/potabilizacion/filtros-de-ceramica-y-carbon/

> **Machine translation.** Its structure and figures have been automatically checked against the Spanish original, but no person has reviewed it.

> **Draft without technical review.** It may contain errors: double-check figures and procedures before applying them. It contains 13 figures marked “verificar” (to be verified).

Summary

A ceramic pot filter is a vessel of porous fired clay of about 10 l that hangs inside a receptacle with a lid and tap. Water passes through the wall by gravity (1-2 l/h when the filter is new) and leaves behind dirt, almost all bacteria, protozoa and worm eggs. If the ceramic is impregnated with silver, more bacteria die and less biofilm grows. A family thus obtains 10-25 l/day of filtered water, depending on turbidity, without spending firewood to boil it, with a filter that lasts 1-3 years. **It does not retain viruses well** (typical reduction of 90 %, sometimes less) nor does it remove dissolved chemical substances (arsenic, nitrates, fluoride, salts). If the source water may have fecal contamination (river, pond, open well) or there are outbreaks, disinfect after the filter. A granular carbon stage improves taste and odor and retains chlorine and part of the organic matter, but **it does not disinfect**. This article also covers ceramic candle filters.

Prerequisites

- **Knowledge:** knowing how to work clay and fire it in a ceramic kiln (topic “Ceramic kilns”, not yet an article). To disinfect after the filter: Boiling water (p. 3), Chemical water disinfection with chlorine and iodine (p. 17) or Solar disinfection (SODIS) (p. 9). Preparing granular carbon (crushing, sieving, washing, activation) is covered in Slow sand filter and carbon biofilter (p. 27).
- **Materials (RDIC recipe, ≈ 6 filters per batch):**
  - 30 kg of dry, powdered clay. Brick clay or red earthenware (terracotta) pottery clay both work, as long as they pass the tests in step 1. With 8.9-10 kg of burnout material and 12.5 l of water this adds up to ≈ 52 kg of paste, which yields ≈ 6 blocks of 8.0-8.2 kg (RDIC, p. 33).
  - 8.9-10 kg of ground and sieved burnout material: rice husk, untreated sawdust, coffee husk. Particle size between 0.5 and 1 mm.
  - 12.5 l of clean water.
  - For silver (optional, recommended): 100 g of $AgNO_3$ (≥ 99 %) for 1.5 l of concentrate, enough for about 900 filters. For every 60 filters: 100 ml of that concentrate and 18 l of distilled or rainwater. **Do not dissolve all the nitrate in the working water** (you would apply 13-14 times the dose). Alternative: commercial colloidal silver (step 17).
  - For each finished filter: a receptacle of 20-40 l with a lid (food-grade plastic, unglazed clay or clay with a lead-free glaze, or wood sealed with beeswax or left unsealed; **not** paint or varnish), a tap, a support ring for the rim of the pot and a soft-bristle brush.
  - Kiln fuel: RDIC burns about 1.5 m³ of dry firewood per firing of 96 filters.
- **Tools:**
  - 0.5 mm and 1 mm sieves (wire mesh, N2; tightly woven cloth or a fine basket, N1, with less precision).
  - Tamper or mallet to crush the clay (N0-N1). Scale or matching buckets to measure by volume (N1).
  - Two-piece mold (male and female) made of wood, fired clay or metal, with a lever or jack press. Without a mold, a potter's wheel (N1).
  - Ceramic kiln with a chimney draft that reaches 850-900 °C (N1). Pyrometric cones or a thermocouple if available (N3-N4).
  - 1 l graduated container and a clock or hourglass timed to 1 h (N1).
  - Gloves, goggles and a dust/silver mask (N1-N4 depending on type).
- **Time and people:** about 3-4 weeks from mixing to a finished filter: 1 day of mixing and pressing, 1-3 weeks of drying, 1-2 days of firing and cooling, 1 day of soaking and flow-rate testing, 3-8 days of drying and silver

painting. A workshop of 3-4 people with a press produces about 50 filters a day (Potters for Peace). On the wheel, a potter makes far fewer, with a less uniform wall.

How it works

Why water passes through and microbes do not. RDIC gives pore sizes of 0.2-3 µm (p. 9; on p. 8, 0.6-3 µm citing Lantagne). A bacterium measures around 1-3 µm, a protozoan cyst about 4-15 µm and a helminth egg about 45 µm. Other measurements give larger pores: van Halem, an average of 40 µm by bubble point; Oyanedel-Craver and Smith, 0.02-15 µm. In other words, retention is not just sieving: sedimentation, diffusion and adsorption on the pore walls also act, and all of that needs **residence time**. That is why a filter with a higher flow rate retains worse. A virus measures about 0.02 µm and only a fraction is retained, by adsorption.

Water alone through plain clay would pass too slowly. That is why the clay is mixed with a **burnout material** (sawdust or husk), which burns away in the kiln and leaves gaps that shorten the path through the dense clay. As long as they do not form continuous channels from side to side, filtering is still done by the clay between them. From this come the variables that matter most:

Variable	If overdone	If insufficient
Proportion of burnout material	Connected voids: high flow rate, bacteria pass through, fragile piece	Flow rate < 1 l/h: the family stops using the filter
Burnout material particle size	Large pores: more flow with the same mass and worse retention	Low flow rate
Firing temperature	> 950 °C: the clay begins to vitrify, pores close and flow drops (`verificar`)	< 600 °C: it slakes (falls apart) in water. Between 600 and 800 °C it does not fall apart, but stays soft, with a black core and unburned carbon (`verificar`): surviving 1 h in water is not enough to pass
Wall thickness	Lower flow rate	Higher flow rate and less strength

Flow rate serves as quality control. You cannot see a 1 µm pore, but you can see how many liters cross the wall in an hour. A too-high flow rate reveals cracks, large pores or connected voids, and shortens the residence time and the contact time with the silver. In a Potters Without Borders study (2013), filters that started above 1.7 l/h fell below 99 % coliform reduction, and it recommends not going below 53 % clay in the mix (without specifying whether by mass or by volume).

Silver. Silver ions (Ag^+) damage bacterial membranes and enzymes. When the filter is painted with silver nitrate, the ions are reduced inside the ceramic to metallic silver particles, which gradually release traces that inactivate bacteria on contact and slow biofilm growth. Studies do not agree on how much it contributes:

- Oyanedel-Craver and Smith (2008): silver improved *E. coli* retention; the amount applied mattered more than the way it was applied.
- van Halem (2006): filters from Nicaragua without silver removed coliforms from canal water just as well as treated ones; with high *E. coli* loads, silver did improve the result. Filters without silver retained the MS2 bacteriophage **better**.
- Brown (2007), cited by RDIC (p. 8): in the field, filters painted with silver performed similarly to those without it.

Practical conclusion: silver is a **reinforcement**, not the basis of the filter. A well-made filter without silver is still useful, but disinfecting afterward is advisable.

Expected effectiveness. The row in WHO table 7.8 is “Porous ceramic and carbon block filtration” and also groups candles and industrial blocks together (LRV = log reduction value: 1 LRV = 90 %, 2 = 99 %, 4 = 99.99 %):

Group	Reference LRV (ordinary product)	Maximum LRV (well made and used)
Bacteria	2 (99 %)	6
Viruses	1 (90 %)	4
Protozoa	4 (99.99 %)	6

Locally made pots usually fall **below 1 LRV for viruses**. In the field, RDIC measured an average *E. coli* reduction of 95.1 %, up to 99.99 %, and among its users there was 46 % less diarrhea (Brown and Sobsey, 2006, cited by RDIC). In the laboratory, van Halem obtained 4-7 LRV for *E. coli* and 0.5-3 LRV for MS2 (a virus indicator); Lantagne (2001) measured 1.8-4.9 LRV of *E. coli*. **Viruses are the weak point**: do not take their retention for granted.

Carbon. Activated carbon has an enormous internal surface where organic molecules are adsorbed: taste and odor compounds, residual chlorine, part of the pesticides and solvents. **It does not kill microbes.** It retains organic matter that feeds bacteria, so biofilm grows inside it and the water can come out with more heterotrophic bacteria than went in (WHO, *Heterotrophic Plate Counts*, 2003). It hardly retains salts, nitrates or fluoride, and ordinary charcoal barely retains arsenic (`verificar`). In a household filter it improves taste and reduces certain organic chemicals, but it adds no microbiological safety.

Procedure

The main procedure is the pot filter, in seven parts: A) raw materials and recipe, B) shaping, drying and firing, C) quality control, D) silver and assembly, E) use and maintenance, F) ceramic candle filters and G) carbon stage.

A. Raw materials and recipe

1. **Check the clay.** Wet a handful, make a coil about 1 cm thick and close it into a ring of about 2.5 cm. Also make a bar of 10 × 2 × 1 cm with two marks exactly 10 cm apart. Dry it in the shade for 7 days and fire it with the next firing. Find out whether the clay comes from an area with arsenic in the groundwater: you will need this in step 13. *Success criterion:* the ring does not crack when closed. The bar comes out whole, with no cracks or warping, and after firing the distance between the marks is still between 8.8 and 9.2 cm (total shrinkage of 8-12 % (`verificar`)). If it cracks or shrinks more, mix in fine sand or grog (ground fired clay) in 10 % increments until it passes. If it crumbles or does not bind, mix it with a more plastic clay.
2. **Dry and grind the clay.** Dry it completely in the sun (clods that break dry and do not squash like modeling clay). Break them up with a tamper on clean ground and pass them through a sieve of about 1-2 mm, outdoors, wearing a mask and with your back to the wind (see Safety). *Success criterion:* loose powder with no lumps bigger than 2 mm, no roots and no stones.
3. **Prepare the burnout material.** Grind the husk or sawdust if needed and sieve it: use what passes through 1 mm and stays on 0.5 mm. Always use the same source and the same sieving, because larger particles give more flow for the same mass. No treated, painted or particle-board sawdust. *Success criterion:* visibly uniform particles, with no splinters bigger than 1 mm and no large amount of fine dust.
4. **Test mixes (only the first time or when changing material).** RDIC's reference recipe is 30 kg of powdered clay, 8.9-10 kg of ground rice husk and 12.5 l of water: 23-25 % burnout material by dry mass. Potters for Peace works by volume, between 60:40 and 50:50 (clay:sawdust); Potters Without Borders advises against going below 53 % clay. Start at 55:45 or 60:40 and treat 50:50 as the limit. Without a scale, measure with the same bucket. Make 3 mixes 5 points apart (for example 55:45, 60:40 and 65:35), make 3-5 filters from each and carry them through step 11 (and step 14 if possible). *Success criterion* (this article's practical rule): keep the recipe in which at least 4 out of every 5 pieces give 1.0-2.0 l/h in the first hour.
5. **Mix.** First mix dry for 10 min (with a shovel on a tarp), covering your mouth. Add the water gradually with a watering can and knead for another ≥ 10 min; then throw the paste against the tarp to remove air. Divide into blocks of 8.0-8.2 kg (RDIC's measure for its mold; adjust to yours with about 5 % extra). *Success criterion:* uniform color, no streaks of sawdust or dry lumps. A 5 cm ball squeezed in the hand keeps its shape, does not crack at the edge and does not stick to the palm.

B. Shaping, drying and firing

6. **Shape the pot.**
   - *With a press and mold (Potters for Peace, RDIC):* line both pieces of the mold with thin plastic bags. Place the block and close until clay overflows through the relief holes; remove the excess and open. Reference dimensions of the Potters for Peace filter: about 28-30 cm across the mouth by about 25 cm high, about 10 l capacity and a wall 10-12 mm thick (Potters for Peace; Engineering for Change).
   - *On the wheel (N1):* throw a pot of the same shape and the same 10-12 mm wall. Check the thickness with a marked needle at 5-6 points on the base and walls: more than 2 mm of difference creates preferential flow zones.
   - In both cases, smooth the rim with a wet brush, fill gaps with clay, smooth the inside with a soft rib and mark the date and batch. After 3-4 h in the shade (or overnight), scrape the smooth inner skin to open up pores. *Success criterion:* symmetrical shape, firm rim with no cracks, wall of equal thickness at every point measured. A deformed piece goes back into the mass: it can be recycled while unfired, no longer once fired.
7. **Dry.** Dry in the shade the first day and then on ventilated shelves, covered if it rains. RDIC needs 7-15 days in the dry season and 15-18 in the wet season; Potters for Peace, 1-3 weeks. Judge by the pieces at the bottom, which

dry more slowly. *Success criterion:* uniform light color, not cold to the touch against the cheek, and it sounds dry when tapped.

8. **Fire.** Load the kiln with clay spacers; the pots can be stacked in towers of 3-5, mouth to mouth and base to base. Close the door with bricks and seal the gaps with clay. Place test pieces where they can be seen through the peephole:
   - If available, small Orton pyrometric cones: RDIC uses 014 as a warning and 012 as the endpoint (≈ 866 °C; pp. 41 and 44).
   - If not, **test rings** of the same clay, about 3 cm, strung on an iron rod (N2) or a previously fired clay rod, that can be pulled out through the peephole with a hook.

   Follow this curve:
   - **Dehydration:** low fire, vents open, up to ≈ 100 °C; hold it for 2 h. Without a thermometer: the smoke comes out white and damp, and a cold sheet of metal, a shard or a piece of glass held in the chimney fogs up; keep going until it stops fogging (`verificar`). Rising faster bursts the pieces from the steam.
   - **Rise:** add firewood gradually. Reaching the final temperature takes 8-10 h.
   - **Final temperature: 850-900 °C.** RDIC fires at 866 °C; Potters for Peace, at about 860-900 °C. Without cones, look for **light cherry red (≈ 850-900 °C)**, viewed with the kiln shaded or at night; do not wait for orange, which is already hotter. Then pull out a ring, let it cool for 5 min and break it. If it has a black core or scratches with a fingernail, keep the fire going for 30-60 more minutes and pull out another; repeat.
   - **End of firing and cooling** (RDIC, p. 44, no soak): once cone 012 melts or the ring passes, remove the fuel, close the dampers and leave the kiln closed for 9 h. Then open it and let it cool for 24 h before unloading.

   Record firewood, hours and color, and **keep rings from a firing that produced good filters** to compare color, sound and hardness in the next ones. *Success criterion:* the broken ring has the same color inside as outside, with no black core (unburned carbon), does not scratch with a fingernail, and sounds like the reference rings. The pots **ring like a bell** when knuckled and do not stain the hand. Not softening in 1 h of water is necessary but not sufficient.

C. Quality control of each filter

9. **Inspection and sound test.** Look inside each pot with a flashlight and tap it with a knuckle at 4 points on the rim and 2 on the base. *Success criterion:* a clear, sustained sound at every point and no visible crack. A dull or cracked sound reveals a crack even if unseen: discard the piece. Also do not accept cracks in the rim longer than 1 cm, because they grow with use.
10. **Soaking.** Fully submerge the pots in clean water for **at least 5 h**; overnight is normal. This saturates the pores so all of them are measured the same way. *Success criterion:* no bubbles come out when removed and the surface looks uniformly dark.
11. **Flow-rate test (on every filter, without exception).** Place the saturated pot on a stand that lets it drip into a clean container. Fill it **to the rim**, top it off if it has dropped, and start the clock. At **1 h**, measure the water collected with the graduated container (or how much the level has dropped, using a T-shaped ruler calibrated liter by liter on a waterproofed pot from the same mold). *Acceptance criterion* (the same throughout the article):
    - **Accept 1.0-2.0 l/h** in the first hour.
    - **Between 2.0 and 2.5 l/h**, only if the batch's bacteriological test (step 14) gives ≥ 99 %. Without a test, reject.
    - **Reject above 2.5 l/h** (large pores, connected voids or a crack) **and below 1.0 l/h** (it filters too little and will end up unused).

    Context: RDIC sets an optimum of 1.8-2.5 l/h and accepts 1.5-3.0 (4.6, p. 46); Potters for Peace designs for 1-2 l/h (Oyanedel-Craver and Smith, p. 927); Potters Without Borders saw coliform reduction fall below 99 % above 1.7 l/h; the CMWG gives 1-3 l/h. These factory figures are measured in the first hour with the filter full and saturated, and are not the average flow rate in use, which is lower (van der Laan et al., 2017). If a batch produces more high-flow-rate rejects than usual, adjust the recipe (less burnout material or finer particles); if more low-flow-rate rejects, the opposite.
12. **Localized-leak test.** During the flow-rate test, watch the outside at 10-15 min. *Success criterion:* the wall dampens evenly and drips are spread out. A trickle, a darker wet line or a concentrated drip indicates a crack: discard. Break or pierce the base of rejected pieces so no one uses them as a filter.

13. **Arsenic and metals from the clay itself.** van Halem measured in the water of a Cambodian filter ≈ 200 µg/l of arsenic in the first week and still 17 µg/l at 12 weeks (WHO guideline value: 10 µg/l). A study on filters from Kandal (Cambodia) estimated ≈ 43.5 mg of arsenic released per filter, 80 % in the first 100 l, and found that washing reduces it ("Arsenic leaching from ceramic water filters", 2018). Therefore:
    9. If the clay comes from a region with arsenic in the groundwater and you cannot test it, **do not use that clay**. van Halem recommends testing leaching before choosing the clay.
    10. If there is no alternative, discard at least the first 100-200 l filtered by each filter (`verificar`): for example, keep it full in the workshop for 3-4 days at 2 l/h before drying and painting it.
    11. If testing is available, measure the filtered water after washing.
    12. It is a **chronic** risk (years of exposure). A few weeks above 10 µg/l weigh far less than drinking water with fecal contamination: do not abandon the filter over this if there is no other safe water.

    Success criterion: transparent filtered water, with no clay taste; where testing is available, arsenic < 10 µg/l.
14. **Batch bacteriological test (where resources allow).** From each firing, pass river or pond water through 2-3 randomly chosen filters and analyze *E. coli* or thermotolerant coliforms in 100 ml of the inflow water and of the filtered water. Without a laboratory, the H_2S presence/absence test detects serious failures, but does not give a percentage. *Success criterion:* reduction ≥ 99 % relative to the inflow water and, better still, absence of *E. coli* in 100 ml. The analysis method is a topic for the planned article "Basic water quality testing".

D. Silver and assembly

15. **Dry the approved pieces** lying on their side for 3-8 days. *Success criterion:* they have returned to the light color of dry clay.
16. **Prepare the silver nitrate solution (RDIC recipe, p. 49).** With gloves and goggles, away from children and food.
    15. **Concentrate:** dissolve the 100 g of $AgNO_3$ in 500 ml of distilled water and make up to 1500 ml. Store it in a tightly closed opaque plastic bottle: light breaks it down. This is enough for ≈ 900 filters.
    16. **Working solution:** 100 ml of concentrate + 18 l of distilled or rainwater = 18.1 l, for about 60 filters. Prepare only as much as you will use.

    Check calculation: 100 ml of concentrate contains 6.67 g of $AgNO_3$, and silver makes up 63.5 % of that mass (108/170): 4.23 g of Ag. In 18.1 l that gives ≈ 234 mg of Ag per liter. Each filter receives 300 ml, i.e. ≈ 70 mg of Ag: ≈ 47 mg inside (200 ml) and ≈ 23 mg outside (100 ml). If you dissolved the 100 g in 20 l instead, each filter would receive ≈ 950 mg. *Success criterion:* transparent, colorless liquid. If it turns yellow, becomes cloudy or forms dark sediment, it has spoiled (light or water with chlorides): prepare another batch with distilled water.
17. **Paint.** Fill a cup marked at 300 ml and at 100 ml. Paint the inside with a brush, spreading it evenly over the base and walls, until the level drops to the 100 ml mark; paint the outside with the rest. Do not dip it: silver is wasted and the inside needs a higher dose. *Success criterion:* the whole volume absorbed, with no puddles or drips, and the pot dry in the shade within a few hours. Darkening with light is normal.
    - **With colloidal silver:** van Halem (2006) describes 2 ml of 3.2 % colloidal silver in 250 ml of water (≈ 64 mg of Ag per filter); Potters for Peace also uses 1 ml in 250 ml (≈ 32 mg). In the laboratory, a 45 s dip in 800 mg/l has been used (Oyanedel-Craver and Smith, 2008). Commercial concentration varies: read the label and calculate for 30-70 mg of Ag per filter (Potters for Peace 32-64 mg; RDIC 70 mg).
    - **Without silver:** the filter still mechanically retains most bacteria and protozoa, but with less margin and more biofilm. Always disinfect afterward and clean the receptacle more often (step 22).
18. **Assemble the unit.**
    15. **Tap:** on the receptacle (20-40 l; RDIC's holds 38 l and stores ≈ 26 l with the filter in place), 3-5 cm from the base (`verificar`) so sediment stays below it, with a rubber or leather gasket and a nut on the inside.
    16. **Ring:** on the mouth of the receptacle, a support ring (plastic, wood or wrapped rope) that spreads the weight (the full filter weighs about 16 kg), **closes the gap** between the pot and the receptacle, and slopes outward, so any splash on the rim falls outside the filtered water.
    17. **Filter and lid:** seat the filter and put on the lid.

    Success criterion: with the receptacle filled up to the tap and the pot empty, nothing drips from the tap or the gasket in 30 min. A glass of water poured over the ring does not enter the receptacle.

19. **First loads.** On first use, ≈ 30 % of the applied silver comes out; RDIC discards the first 33 l (p. 48). Fill the filter 3-4 times and **discard that water** (≥ 33 l; more if step 13 requires it). *Success criterion:* the water comes out clear and with no clay or metallic taste.

E. Use and maintenance

20. **Daily use.**
    20. **Turbid water:** if you cannot read text through 10 cm of water in a glass, let it settle for 12-24 h and decant, or strain it through cloth. Above about 50 NTU, pre-settling is needed (SSWM); if turbidity is habitual, it should not exceed 25 NTU (Emergency WASH).
    21. **Loading:** fill the pot 2-3 times a day without touching the inside with your hands.
    22. **Location:** covered, in the shade, on a stand at least 30 cm high, out of animals' reach.
    23. **Serving: only through the tap**, with a clean cup; never hands or ladles in the receptacle.
    24. **Final disinfection:** if the water comes from a river, pond or open well, or there are outbreaks of hepatitis or diarrhea, add chlorine to the filtered water (dose in the chlorine and iodine article) or boil it.

    Success criterion: transparent water, with no odor, and cool; the receptacle is only opened to clean it. **Calculation.** WHO/WEDC (technical note 9) gives 2.5-3 l/person/day for drinking and 7.5-15 l in total. For 5 people: 15 l/day for drinking and ≥ 37.5 l/day counting cooking and basic hygiene. The 1-2 l/h flow rate is that of a new filter in the first hour; in use it drops as the level falls and as clogging occurs, and settles at ≈ 0.5-1.5 l/h on average (`verificar`). With canal water, van Halem saw all her filters drop below 0.5 l/h within 12 weeks. Thus:

    - **Clear water** (≈ 1 l/h on average, pot refilled 2-3 times): 15 l in ≈ 15 h ⟶ **1 filter** for the drinking water of 5 people.
    - **Turbid water** (≈ 0.5 l/h): 15 l takes ≈ 30 h ⟶ **2 filters or mandatory pre-settling**.
    - For ≈ 37.5 l/day: 2-3 filters, or a 20 l container inverted above the pot (an RDIC variant) that keeps it full and makes use of the night.

21. **Clean the pot (when flow rate drops noticeably, or every 1-4 weeks with turbid water).**
    20. Wash your hands with soap and cover the receptacle meanwhile.
    21. Lift the pot by the rim and rest it by the rim on a clean basin, with the base in the air, **without touching the outer base**.
    22. Scrub the **inside** with a soft-bristle brush and the unfiltered water: no soap or bleach (they clog the pores or leave a taste) and no metal scourer or sand (they wear down the wall and the silver).
    23. Rinse with source water, empty it and put it back in place. Do not scrub the outside; if it needs cleaning, use filtered or boiled water and a cloth kept just for that.

    Success criterion: the inside regains the color of the clay and the flow rate rises noticeably. According to van Halem, the effect is temporary and the flow rate falls again with turbid water.

22. **Clean the receptacle and the tap (every 1-3 months, or if slime or an off-taste appears).**
    20. Take out the pot as in step 21 and empty the receptacle through the tap.
    21. Scrub the inside of the receptacle with chlorinated water: 15 ml (1 tablespoon) of plain 5 % bleach with no additives in 10 l of water gives ≈ 75 mg/l, on the order of the shock disinfection dose in the chlorine and iodine article (≈ 55 mg/l, WHO/WEDC technical note 3). The CDC gives, for surfaces, 1 tablespoon per gallon (≈ 15 ml in 3.8 l, ≈ 200 mg/l with 5 % bleach). Without bleach, use freshly boiled water.
    22. Open and close the tap with that water inside.
    23. Rinse with chlorinated drinking water or boiled water (not just filtered water) and dry upside down.

    Success criterion: no slimy film when running a finger over it and no moldy smell.

23. **Service life and signs of failure.** Replace the pot at whichever comes first:
    - **Time:** every **2 years** (RDIC); Oyanedel-Craver and Smith give a typical life of 2-3 years. SSWM recommends every 1-2 years and Emergency WASH 6-12 months with poor-quality water.
    - **Breakage:** visible crack, cracked sound, a chip at the rim, or a flow rate that suddenly **rises** without having been cleaned.
    - **Wear from cleaning:** after many brushings the wall thins. If damp spots appear on the outside when filled that stand out before the rest, treat it as a localized leak (step 12).
    - **Filtered water that is turbid or has an odor.**

A broken pot **is not repaired** with clay, cement or glue: it is retired. *Success criterion:* a knuckle tap gives a clear sound and, right after cleaning, the first-hour flow rate (step 11) is **no higher than 2.5 l/h** nor higher than what the filter had when new (recorded on its sheet).

F. Ceramic candle filters

24. **What they are.** Hollow ceramic cylinders with a threaded nozzle, made of fine clay or diatomaceous earth, with finer pores than the pot (on the order of 0.2-1 µm according to manufacturers (`verificar`)), sometimes with silver or a carbon core. They are mounted in **two stacked buckets**:

    24. The candle hangs inside the upper bucket and passes through its base with a rubber gasket and nut.
    25. Water enters from outside to inside the candle and drips through the nozzle into the lower bucket, which has a tap.

    Each candle gives ≈ 0.1-1 l/h (SSWM), so 2-4 are fitted. Its weak point is **the gasket**: if it leaks, unfiltered water gets through. *Assembly success criterion:* with the upper bucket full and the candles replaced by a blind plug (or with the nozzle blocked from below), nothing drips into the lower bucket in 1 h.

25. **Use and cleaning of the candles.** The first 2-3 loads are discarded. When the flow rate drops to half:

    24. Unscrew the candle with clean hands, holding it by the nozzle.
    25. Scrub the outer surface with a soft scourer or brush under **filtered or boiled** water, without wetting the inside of the nozzle, until the original color reappears.
    26. Reassemble it.

    Replace it if it has cracks, has lost thickness (some manufacturers give a minimum diameter gauge) or, if it contains carbon, when a bad taste returns. Making candles locally requires very fine, uniform clay, cast in a plaster mold or pressed, and the same controlled firing: it is harder than the pot and best left to experienced workshops. *Success criterion:* after cleaning, the flow rate returns to more than 80 % of the initial value and the water comes out transparent.

G. Carbon stage in the household filter

Preparing granular carbon (crushed to 0.5-2 mm, sieved, washed and activated) is covered in Slow sand filter and carbon biofilter (p. 27). This section only explains how to integrate it.

26. **Set up a carbon bucket before the ceramic (recommended option).** Carbon goes **before** so the ceramic can afterward retain the bacteria its biofilm sheds. A bag of carbon put inside the pot does not work: water leaves through the walls and base without passing through it, and it also blocks filtering surface.

    26. **Bucket:** one of food-grade plastic or clay, with the base pierced with holes of ≈ 3-5 mm, that rests firmly on the mouth of the receptacle or on two crossed slats, and drips into the pot. The set's lid moves to the bucket.
    27. **Bed:** at the base, a tightly woven cotton cloth or 2-3 cm of washed fine gravel, and on top of it washed granular carbon in a layer ≥ 10 cm thick (`verificar`), covering the whole base from wall to wall.
    28. **Volume:** do not load into the bucket more water than fits free in the pot (≤ 10 l with the pot empty), so it does not overflow.
    29. **Contact time:** time = bed volume ÷ flow rate through the bed; aim for ≥ 5 min (`verificar`). Example: a bucket 25 cm in diameter with 10 cm of carbon ⟶ a bed of ≈ 4.9 l. If 10 l takes 10 min to come out (1 l/min), the time is ≈ 5 min. If it comes out faster, plug holes with wooden pegs or add more carbon.

    Success criterion: water leaves the bucket **only through the holes**, after passing through the bed (it does not run along the sides of the bucket or overflow the top), no black grains fall into the pot, and the pot does not overflow with a full load.

    - **Secondary option, after the ceramic:** a carbon cartridge at the tap or a chamber between pot and receptacle. It gives better taste, but the carbon stays **on the clean side** and breeds bacteria. Use it only with disinfection afterward (boiling, or chlorine added to the cup and not to the receptacle, because the carbon would remove it) or by changing the carbon often.
    - A bag of carbon inside the receptacle or the pot only improves the taste slightly by contact; it does not count as a treatment stage.

27. **Maintain the carbon.** Wash new carbon until the water comes out clear, so the black dust does not clog the ceramic. Change it when the taste or odor it used to remove returns, or every 2-3 months (`verificar`).

Spent carbon is regenerated by heating it (see the biofilter article) or discarded. *Success criterion:* water with no chlorine, mold or pond smell.

Verification

From simplest to most demanding:

1. **By sight and smell.** A glass of filtered water and another of source water, against a white background. The filtered one must be **clearly more transparent**, with no particles or odor. If it is just as turbid, there is a crack or side leak.
2. **Monthly flow rate.** With the pot filled to the rim, measure the liters collected in the first hour (step 11) and record them on a sheet attached to the filter. If it **drops**, cleaning is needed. If it **rises** above 2.5 l/h or above the flow rate it had when new without having been cleaned, or rises suddenly, a crack is likely: retire the pot.
3. **Sound test** at every cleaning (step 9).
4. **H_2S presence/absence test** (strips or bottles with culture medium) on 100 ml of filtered water, every 1-3 months. A color change to black in 24-48 h at 25-35 °C indicates probable fecal contamination.
5. ***E. coli* count** (membrane filtration or chromogenic substrate): **0 CFU in 100 ml** of filtered water. With inflow water ≥ 1000 CFU/100 ml, also measure the reduction: ≥ 99 % (2 LRV), better ≥ 99.9 %.
6. **Chemicals (with a laboratory):** arsenic < 10 µg/l in new filters made of clay of doubtful origin. Silver: WHO sets no guideline value, but considers up to 0.1 mg/l tolerable. In Oyanedel-Craver and Smith's tests (2008), the water came out above 0.1 mg/l at the start and below it after 200 min of continuous use.

None of these tests verifies virus retention. That is provided by subsequent disinfection.

Common mistakes

Symptom	Likely cause	Solution
Flow rate > 2.5 l/h in a new filter (or 2.0-2.5 without a bacteriological test)	Too much burnout material, coarse particles or a crack	Discard the piece; adjust the recipe (−5 points of burnout material or a finer sieve)
Flow rate < 1 l/h in a new filter	Too little burnout material, particles too fine, thick wall or overfiring	Raise burnout material by 5 points (without going below 53 % clay), thinner wall, lower final temperature
Very different flow rates within the same firing	Poorly homogeneous mix, uneven thickness, cold spots in the kiln	Mix longer; measure thickness; record the position of each piece in the kiln
Pieces cracked coming out of the kiln	Incomplete drying or a fast rise above 100 °C	Dry completely; hold at ≈ 100 °C for 2 h
Black core, scratches or stains the hand	Insufficient firing (even if it does not fall apart in water)	Do not use as a filter; extend the firing and compare with reference rings
Filtered water tastes of clay weeks later	Low firing or clay with a lot of organic matter	Retire it; improve firing or change clay
Filtered water is turbid	Crack, gap at the ring, water entering at the rim	Sound and leak test; seal the ring; replace the pot
Flow rate falls below 0.5 l/h within weeks	Turbid water clogging the pores	Pre-settle; brush the inside; second filter
Slime or bad odor in the receptacle	Biofilm from lack of silver, hands or ladles inside	Clean with chlorine (step 22); serve only through the tap
Silver solution turned yellow or with sediment	Light or water with chlorides (tap, brackish well)	Store in an opaque container; prepare with distilled or rainwater
Carbon does not remove the bad taste	Spent or unactivated carbon, thin bed, water running along the sides	Change or regenerate it; bed ≥ 10 cm wall to wall; fewer holes
More bacteria after adding carbon at the tap	Biofilm in the carbon, on the clean side	Put the carbon before the ceramic or disinfect afterward

Safety

- **False security: the most serious risk.** A cracked, poorly fired filter, or one with a gap at the ring, lets contaminated water through with an almost clean appearance. Diarrhea, cholera or typhoid fever can **kill**, especially young children. Measure the flow rate and do the sound test regularly. With heavily contaminated water, during outbreaks, or for infants, always disinfect after the filter.

- **Viruses.** A significant portion of viruses get through: hepatitis A and E, rotavirus, norovirus, poliovirus. Hepatitis E is especially dangerous in pregnant women. In areas with these outbreaks, **chlorine or boiling after the filter is mandatory**.
- **Chemicals it does not remove.** Neither the ceramic nor the charcoal reliably removes arsenic, nitrates, fluoride, salt or heavy metals. If the source is suspect (areas with known arsenic, mines, fertilized fields), the filter does not make it safe.
- **Arsenic from the clay itself.** Some clays release arsenic for weeks: do not use clay from arsenic-affected areas if you cannot test it, and if there is no alternative, discard the initial water (step 13).
- **Lead from the receptacle.** Never use traditional glazed pottery of unknown origin to store drinking water: low-temperature glazes often contain lead and can leach it. Use unglazed clay or glaze known to be lead-free. Wood should be sealed with beeswax or left unsealed, never painted or varnished.
- **Clay dust (crystalline silica).** Breathing it for months or years causes **silicosis**, irreversible, and is linked to lung cancer. Crush and mix dry outdoors, with the wind at your back, wearing a mask (ideally FFP2/FFP3 or N95; at minimum several layers of damp cloth, much less effective) and goggles. Dampen the ground, sweep wet, and do not let children nearby.
- **Silver nitrate.** Corrosive and oxidizing. In the eyes it can cause serious injury and blindness; on the skin it leaves black stains for weeks and burns if concentrated. Ingested it is toxic, and it is very toxic to aquatic life.
  - **Prevention:** gloves and goggles; do not store it near fuel, wood or paper; opaque, labeled bottle, away from food and children.
  - **Eyes:** rinse with clean water for **15 min** without stopping, with the eyelid open, and seek medical attention.
  - **Skin:** wash with plenty of water. **If swallowed:** rinse the mouth, give sips of water, do not induce vomiting, and seek medical attention.
  - **Waste:** do not dispose of it in rivers or wells. Precipitate it with common salt (silver chloride, insoluble) and let the sediment dry in a closed container.
- **Silver in drinking water.** With the dose from step 16 and discarding the first loads, silver stays below the level that concerns WHO. A dilution error (dissolving the 100 g directly in the working water) multiplies the dose by 13-14. Taking excess silver for years causes **argyria**, a permanent bluish-gray skin discoloration. Do not add "extra" silver, and do not drink colloidal silver solutions.
- **Kiln.** Burns from pieces or ashes: thick gloves, closed footwear and do not unload before 24 h. In enclosed spaces the smoke carries **carbon monoxide**, which kills without warning: fire the kiln outdoors or under an open roof, with a tall chimney and away from dwellings. A damp piece can burst: do not look through the peephole during the initial rise.
- **Loads and crushing.** A block weighs 8 kg and a full filter about 16 kg: lift with your legs and with two people if needed. Presses crush fingers: only one person operates it and no one puts their hands in the mold.
- **Bleach.** Never mix it with vinegar, ammonia or other cleaners: it releases toxic gases. See the chlorine and iodine article.

Variants

- **With fewer resources (N0-N1, no draft kiln):**
  - *Firing in a bonfire or pit.* Reliably reaching 850 °C and holding it throughout the piece is not guaranteed (`verificar`): soft filters come out, with a black core and erratic flow. If there is no alternative, fire in a pit covered with shards and plenty of firewood, apply the ring, sound and flow-rate tests without exception, and **always treat the filtered water as unsafe**: the filter only clarifies it, and it is boiled or chlorinated afterward.
  - *Without silver.* See step 17: this is compensated for with subsequent disinfection and more frequent cleaning.
  - *Receptacle without plastic.* An unglazed clay jar (well fired, washed and covered), or glazed only if the glaze is known to be lead-free. Never use traditional glazed pottery of unknown origin to store drinking water: it can leach lead. Wooden lid and a clay or cane spout with a wooden plug as a tap. Without a tap, a long-handled ladle reserved for this purpose that never touches the ground; it is worse, because hands end up touching the water.
  - *Without sieves.* Sift with a fine-weave basket and cotton cloth as a second sieve; the flow rate will come out more variable, so make more test pieces.
- **With more resources (N2-N4):**

  - Hydraulic press and a two-piece metal mold (RDIC, Potters for Peace): identical wall thickness on every piece. Hammer mill and mechanical mixer.
  - Orton cones 012-014 or a thermocouple. With a thermocouple, firing can include a soak: Oyanedel-Craver and Smith fired at 900 °C with a 3 h soak (p. 928).
  - Calibrated T-shaped ruler to measure the flow rate of dozens of filters at once.
  - Silver nitrate made from metallic silver and nitric acid (N3; releases NO_2: only outdoors or under a fume hood; this is a chemistry topic and is not detailed here).
  - An in-house *E. coli* laboratory to release batches and analyze arsenic.
  - Iron oxides (laterite, goethite) in the mix to try to adsorb viruses: RDIC tested this and abandoned it because it could not confirm the effect.
  - Industrial candles with silver and a carbon core. For viruses, ultrafiltration with pores ≤ 0.02 µm (≈ 20 nm) or with a certified virus reduction rating under WHO's classification for household treatment (N4). Fibers of 0.1-0.2 µm, like ceramic, need disinfection afterward against viruses.
- **Scaling up:**
  - *Family:* one pot filter is enough for the drinking water of 5 people with clear water; two with turbid water or if it is also used for cooking (calculation in step 20). Keep a spare pot at home.
  - *Village:* a workshop of 3-4 people with a press, 1 kiln of ≈ 100 pieces and a stand for flow-rate tests supplies hundreds of families a year. What decides success is **consistent quality**: a flow-rate test on every piece, batch records, and teaching each family how to use it; RDIC insists that training matters as much as manufacturing. Selling at cost price favored the purchase of replacements in Cambodia.
  - *Schools and health centers:* a 20 l container inverted above the pot to get ≈ 30 l per load, or banks of 4-6 filters in parallel.
  - *City:* the household filter does not scale to a network. For a large population, centralized treatment is used (coagulation, rapid or slow sand filtration and chlorination), and the ceramic filter remains as point-of-use protection when the network is not reliable.

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