



Bone Char Production

Fluorosis Mitigation with Innovative Technologies



Table of Contents

1	Purpose	2
2	Scope	2
3	References	2
4	Terms/Definitions	Error! Bookmark not defined.
5	Principal Responsibilities.....	2
6	Method	3
6.1	Raw Material Procurement	3
6.1.1	Work Instruction - Activity.....	3
6.1.2	Work Instruction - Recording.....	3
6.1.3	Data Analysis – Documenting	4
6.1.4	Auditing	4
6.2	Charring.....	4
6.2.1	Work Instruction – Activity.....	4
6.2.2	Work Instruction - Recording.....	6
6.2.3	Data Analysis – Documenting	7
6.2.4	Auditing	7
6.3	Sorting/Crushing/Sieving	7
6.3.1	Work Instruction – Activity.....	7
6.3.2	Work Instruction - Recording.....	7
6.3.3	Data Analysis – Documenting	7
6.3.4	Auditing	7
6.4	Washing.....	7
6.4.1	Work Instruction – Activity.....	7
6.4.2	Work Instruction - Recording.....	9
6.4.3	Data Analysis – Documenting	9
6.4.4	Auditing	9
6.5	Drying/Packing/Storage	9
6.5.1	Work Instruction – Activity.....	9
6.5.2	Work Instruction - Recording.....	10
6.5.3	Data Analysis – Documenting	10
6.5.4	Auditing	10

1 Purpose

Objective of the bone char production procedure is to guarantee uniform and good quality of the final product. In addition, the procedure shall allow a continuous learning process to further improve the quality and reduce the costs of bone char intended for the use of drinking water defluoridation. Bone char quality is defined as: (I) high fluoride uptake capacity, (II) low content of remaining organic matter which could change color and taste of treated water and (III) no fecal contamination of the bone char during production or storage.

The production steps of bone char involves collection of bones, packing in furnace and charring, crushing and sieving, washing and finally packing. The charring step in the furnace that takes around 10 days is the limiting step in the production process.

OSHO has been producing bone char since 2011 with one furnace constructed with the support of Swiss Church Aid (HEKS). To increase the production capacity OSHO proposed the construction of the second furnace that was financed by USAID.

This version of the production manual is reproduced for the purpose of USAID reporting and various forms and checklists are excluded.

2 Scope

This procedure covers the whole bone char production circle including quality control measures and auditing check-lists. The production circle starts when the raw materials (mainly raw bones) are delivered to Modjo production facilities and ends when the final product is sold and taken out of the storage. Following production steps are described in detail: (I) raw material procurement, (II) charring, (III) sorting, crushing, sieving, (IV) washing and (V) drying, packing and storing. The procedure is designed in a way that allows back-tracking from the final product to the raw materials used.

3 References

CDN, Mueller K. and Jacobsen P. (2007) CDN's experiences in producing bone char. Technical report, <http://www.wrq.eawag.ch>

4 Principal Responsibilities

The lead in bone char production and in keeping up-to-date the production procedures is within the responsibility of the quality control supervisor. However the project manager should approve significant changes in the production procedure.

Other departments directly involved:

Production supervisor → Purchasing, charring, crushing, packing
Accountant → Purchasing
Store Keeper → Purchasing, packing

5 Method

5.1 Raw Material Procurement

5.1.1 Work Instruction - Activity

The production on bone char requires following raw materials:

- Raw bones
- Charcoal, kerosene, fire wood (for the ignition process)
- Sodium hydroxide, NaOH
- Carbon dioxide, CO₂
- Bags and thread
- Sand (for closing the furnace opening)
- Water (for cooling and washing)
- Electricity

Rawbones from cattle, sheep and goats are bought from slaughterhouses and transported to the bone char production site through a middleman. The bones are stored under a roof to prevent them from getting wet as that would impede the following charring process. The storage is protected with corrugated iron sheets to prevent wild animals and dogs to access the bones.

Note: *when raw bones are stored for a certain time in a roofed shelter, they will dry up and flies and other insects will partially remove the remaining organic material from the bones.*

Good quality raw bones are clean of meat and fur, dry, big in size (with some smaller bones to ensure dense packing in the furnace) and free of stones, sand, metal or plastics.

When working with raw bones the production technicians are wearing gloves. After working with raw bones eyes the hands have to be washed with soap.

The sodium hydroxide is stored in a clean and dry place.

5.1.2 Work Instruction - Recording

Whenever raw bones are purchased, the store keeper records the amount and costs using the **'Bone Char - Raw Bone Procurement Form'**. The price for raw bones includes costs for the bones, transportation to the production site in Mojo, the weighbridge fee and daily laborers needed for unloading the lorry.

Whenever sodium hydroxide, carbon dioxide or bags are purchased, the procurement date, quantity, costs (incl. transportation) and contact details of the supplier are recorded by the accountant using the **'Bone Char - Raw Material Procurement Form'**.

The main water meter readings and the electricity meter readings are recorded end of every month using the **'Bone Char–Water and Electricity Form'**.

The costs of charcoal, kerosene, firewood, thread and sand can be neglected and are therefore not monitored.

5.1.3 Data Analysis – Documenting

The accountant enters the data into Office Excel.

Following information is of interest:

- Quantity of raw bones purchased
- Price of raw bones (and its changes over time)
- Quality of raw bones
- Expenditures for sodium hydroxide, carbon dioxide, bags, water and electricity

5.1.4 Auditing

The project manager is auditing the whole bone char production every six months. For auditing the raw material procurement the '**Bone Char - Raw Material Check-List**' is used.

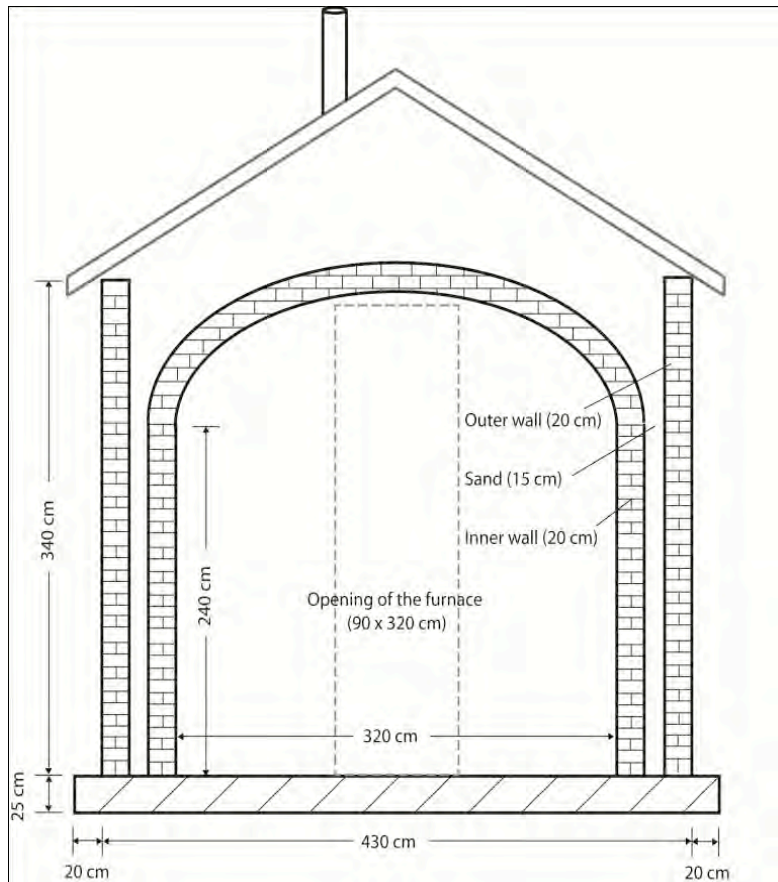
5.2 Charring

5.2.1 Work Instruction – Activity

Around 10'000 kg of raw bones are piled up well packed on a metal grate inside the furnace up to the height of the grids (180 to 200 cm), the total filling volume amounts to 26.2 – 29.4 m³ and the filling density to around 350 kg/m³. To enable optimal isolation, the walls of the furnace contain three different layers: An inner and outer wall made of bricks (each 20 cm) and the space between the two walls is filled with sand (15 cm). The kiln can be entered and loaded through an opening that is closed by placing two layers of metal sheets above each other and filling the space in between with sand.

Note: During the charring process roughly 50% of the loading weight gets lost through steam and smoke.

One bucket of charcoal (15 kg) and some firewood are placed in four to six places (a minimal distance of 50 cm to the walls and of 100 cm to the door in the front), sprinkled with kerosene and ignited. As soon as the bones have picked up fire, the furnace is closed. The first 5 hours of the process require careful observation as the fire might extinguish due to high moisture content of the raw bones or other reasons. The color of the smoke indicates whether the charring process is satisfactory (dark color) or not (pale color). In some cases the bones do not catch up the fire and may be ignited again. Cooling of the air outlet starts after 2 to 3 days. While the chimney outlet is reduced, water passes to the specially constructed chimney that leads to a partial condensation of the smoke. After 10 to 14 days the charring process normally stops on its own due to limiting organic matter. If not, closing of the chimney will suffocate the fire.



Length outside: 615 cm

Length inside: 505 cm

Loading height: 180 - 200 cm

Loading volume*: 26.2 – 29.4 m³

* The volume of 20 metal grids placed inside the furnace (diameter 32 cm, total volume 2.9 m³) is subtracted

Sketch of the bone char furnace

Temperature and oxygen content in the furnace are the most important parameters that determine the quality of the bone char.

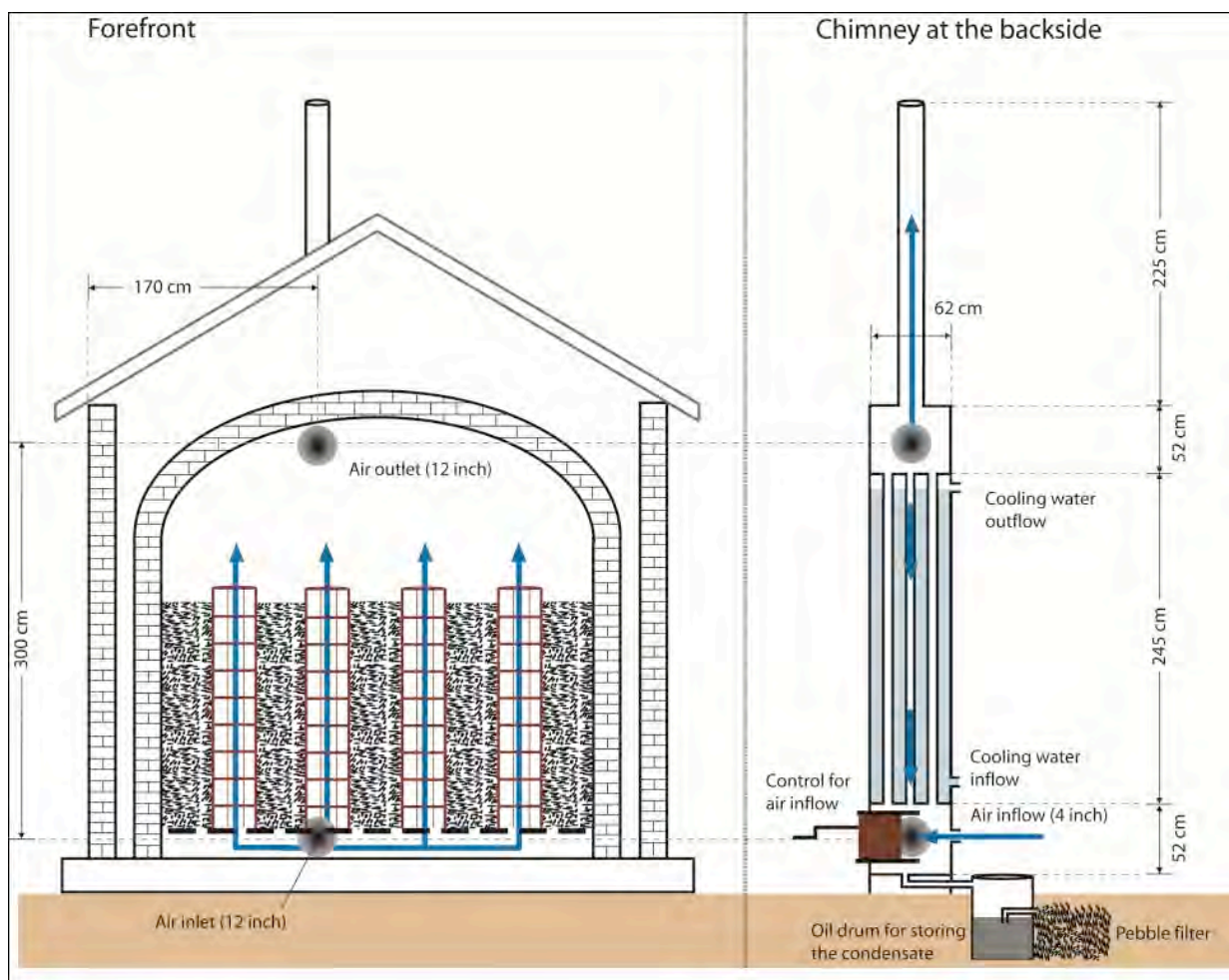
A grill roast at the base of the kiln enables an equally distributed inflow of fresh air, whereas 20 metal grids (200 cm height) placed in the middle of the kiln enhance homogenous distribution of oxygen in the furnace. Oxygen content and air speed also play a role in the vertical movement of the fire within the bones. At a moderate air speed and high oxygen content, the flames tend to move downwards in channels that cause inhomogeneous charring within the furnace. Low concentrations of oxygen enables horizontally uniform charring, but due to the slow movement of the front of the flames the bones may be exposed for a long time to high temperatures and hence will turn out to be white in color with reduced adsorption capacity for fluoride. Evaluation of the charring process has shown that there are always places in the kiln where optimum charring conditions cannot be achieved.

Temperature and oxygen content in the furnace can be controlled:

- *The size of the outlet of the chimney* regulates the flow of fresh air to the furnace. Controlling the outlet of the air is more efficient than controlling its inlet as fresh air may also enter the furnace through gaps and cracks.
- *The position of the prime valve.* The oxygen content of the air inlet is regulated by mixing outlet air, which contains little oxygen, with fresh air. The inflow of mixed, waste and fresh air is regulated by a plate at the inlet (prime valve).
- *Cooling of the chimney with water.* The velocity of waste air in the chimney is slowed down. The reduced temperature of the waste air enables the subsequent mixing of fresh and waste

air. A positive side effect of cooling the waste air is a reduction of the odor problems caused by the charring process, due to smoke condensation.

- *Opening/closing temperature measuring holes.* Generally all temperature measuring holes are closed and only opened for taking the temperature measurements. However, some of them can be opened to enable a higher oxygen supply at some places in the furnace. Normally the two holes in the front of the furnace are left open during the first day of charring.
- *Cracks* will lead to higher and uncontrolled oxygen supply and to changes in the furnace performance. Regular maintenance of the furnace is required.
- *The packing density of raw bones* influences the charring process. Loosely packed bones have more oxygen in contact with bone surface. This leads to short-term, high temperatures instead of a slow charring process at constant temperature.
- *The position of the metal roasts* at the bottom of the furnace can be changed by giving more inter-space by putting bricks below the roasts. This would increase the ventilation/ air flow from the inlet.



Airflows in the furnace of RVDWP

5.2.2 Work Instruction - Recording

For every charring batch, the temperatures, activities and the quality of the produced bone char are recorded with the **'Bone Char- Charring Form'** by the production manager and the production technicians.

5.2.3 Data Analysis – Documenting

The quality control manager enters the recorded data into Office Excel. The documentation includes following information:

- Number of charring batches per month
- Reasons for trends in white/grey ratio and production quantity
- Average duration and temperatures of a charring batch
- Lifespan of furnace (charring batches during life)

5.2.4 Auditing

The production manager is auditing the whole bone char production every six months. For auditing the bone charring the '**Bone Char - Charring Check-List**' is used.

5.3 Sorting/Crushing/Sieving

5.3.1 Work Instruction – Activity

When the charred bones are removed from the furnace they are pre-sorted according to their color. Grey and white charred bones are put each in a separate room. Black bones are piled up next to the opening of the furnace to be filled in the furnace again for the next charring batch. Before crushing, the charred bones are manually separated from remaining metal pieces and stones and they are again separated according to their color. White and grey-brownish bones are crushed and sieved. Four different fractions are expected to be distinguished: bone dust (< 0.2 mm) and bone char fine (0.2 – 1 mm), medium (1 – 2 mm) and coarse (2 – 4 mm). However the current crusher and sieve does not insure this particle sizes and it needs further improvement to have uniform sorting of bone char according to the particle sizes.

5.3.2 Work Instruction - Recording

All data of interest are recorded when packing the final products.

5.3.3 Data Analysis – Documenting

All data of interest are documented according to the packing records.

5.3.4 Auditing

No specific check-list is applied.

5.4 Washing

5.4.1 Work Instruction – Activity

The sieved bone char is placed in a cement washing tank and washed with a 10 g/L caustic soda solution (also named sodium hydroxide, NaOH).

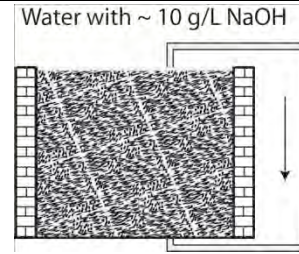
Note: *This process removes remaining organic impurities.*

After the sodium bicarbonate solution is drained the bone char is sprinkled with piped water from Modjo town water supply line (containing 0.01 mg/L fluoride).

Bone Char Washing Steps

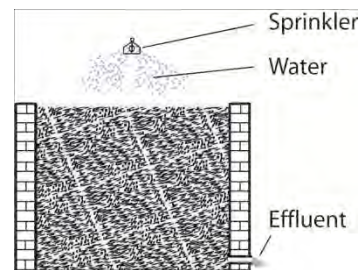
(I) Removal of remaining organic impurities - washing with NaOH (caustic soda)

- Sieved bone char is placed in a tank (4'000 L)
- Water (2'500 L) and caustic soda (25 kg) are mixed in a separate plastic tank (pH ~13) and filled from bottom-up into the washing tank.
- The NaOH concentration should always be 10 g/L even if less bone char and water is filled into the washing tank.
- Once filled, the caustic soda solution is continuously circled (by withdrawing the solution from the bottom and pumping it to the top of the tank) to enable maximum mixing.
- Draining of the solution after 24 hours
- A water **sample** is taken from the drained water.



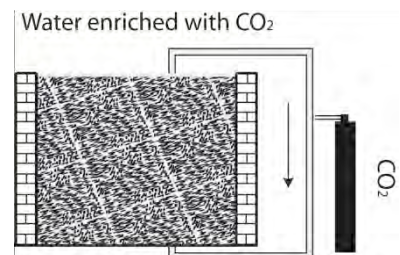
(II) *Sprinkling for removal of residual NaOH - washing with water*

- 1 eBV of water is sprinkled over the bone char.
- After every second sprinkling event a water **sample** is taken (at the time when the sprinkling is stopped)
- This process is repeated 8 times. At this point the pH is expected to be below 10. If not, the sprinkling is continued.



(III) *Reducing the pH - washing with CO₂ enriched water*

- The tank is filled with fresh water from bottom-up (1 eBV)
- The water is circulated slowly bottom-up for three consecutive days. CO₂ is inserted continuously (1 L/min) (total per day: 1'440 L = 3'000 g = 68mol)
- A water **sample** is taken daily.

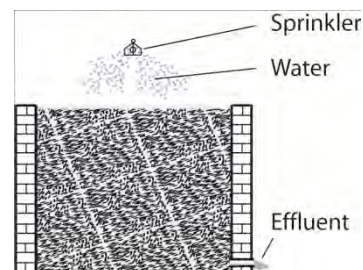


(IV) *Final sprinkling*

- 1 eBV of water is sprinkled over the bone char.
- This process is repeated 2 times
- After the second sprinkling event a water **sample** is taken (at the time when the sprinkling is stopped)

The water sample has to meet the quality requirements.

- Quality requirements for final water sample:
 - pH < 8.5
 - EC < 100 mS/m
 - Color < 15 TCU
- If the quality does not meet the requirements the quality control manager decides on the further washing process. Good documentation is essential.
- If it meets the desired quality, the washing is stopped, the bone char is removed from the tank and put on metal trays for drying.



EC: Electric conductivity, NTU: Nephelometric turbidity unit

5.4.2 Work Instruction - Recording

For each washing batch the '**Bone Char - Washing Form**' is used for recording the amount of water used and the quality of the effluent water. Each washing batch is given an identification number. *Note: raw water quality measurements are part of the procedure.*

5.4.3 Data Analysis – Documenting

The quality control manager enters the data into Office Excel. The documentation includes following information:

- Number of completed washing batches
- Amount of water, sodium hydroxide and carbon dioxide used per batch
- Time required per washing batch
- Quality of effluent water at known intervals (pH, color, turbidity, EC)

5.4.4 Auditing

The production manager is auditing the whole bone char production every six months. For auditing the bone charring the '**Bone Char - Washing Check-List**' is used.

5.5 Drying/Packing/Storage

5.5.1 Work Instruction – Activity

After washing, the bone char is placed on iron trays for drying outside. Depending on the climate and the particle size, drying takes around 2 days. Approximately 50 kg bone char is filled on one tray. Bone char of different washing batches are kept separately.

Three buckets (à 21 L) of bone char (63 L) are packed into different colored bags: white bags for bone char white, yellow bags for bone char grey and red bags for bone dust. The sacks are weighted, labeled with a waterproof pen and stored in a dry and clean place (animals including birds have no access to the store). Labeling includes: Date, identification number and particle size. *Note: the content of the bag can be determined by its color (white = white bone char, yellow = grey bone char, red = bone dust).*

Before sealing the bags two spoons of bone char are put aside in a plastic box. This is done for all bags filled with bone char from the same washing batch and the same type (total ca. 1'000 g). The plastic box is labeled with packing date and washing batch ID. Parts of the material is used for the quality control test, the rest is stored in the lab for at least two years.

Quality control test 100 gram of the material is filled into a column. 20 L of tap water spiked with sodium fluoride (fluoride concentration of 10 mg/L) are pumped through the column at a constant flow rate. The fluoride content of the raw water is measured. *Note: it is important that the flow rate is the same for each quality test because it can influence the fluoride uptake capacity.*

30 minutes after starting the pump a water sample of the effluent is taken for pH analysis. After pH measurement the sample is poured back into the effluent collection plastic container. When all water has passed through the column the fluoride content in the collection container is measured.

5.5.2 Work Instruction - Recording

The '**Bone Char - Packing Form**' is used by the production technicians for recording the weight of all packed bone char bags. The production and operation manager fills the '**Bone Char – Selling Form**' whenever bone char is taken out of the store for its use in community or household filter. *Note: The two forms can be used to easily monitor the number of bone char bags in store.*

The quality control manager records the results of following quality control tests carried out with the product sample taken during packing using the '**Bone Char – Quality Form**'.

5.5.3 Data Analysis – Documenting

Following information are of interest:

- Number of bags produced (by different types of products)
- Number of bags sold
- Volume / Weight of one average bag
- Product quality (results of quality test)

5.5.4 Auditing

The production manager is auditing the whole bone char production every six months. For auditing the bone charring the '**Bone Char –Packing/Storing Check-List**' is used.