CDN'S EXPERIENCES IN PRODUCING BONE CHAR

Written by
Catholic Diocese of Nakuru, Water Quality[1] and Kim Müller[2] (Eawag)

Reviewed by
Peter Jacobsen[3]

March 2007

[1] Catholic Diocese of Nakuru, Water Quality: Hillary Korir (Project coordinator 2006 - today, MSc Environment), Julius Kubai, Daniel Mbandu, Samuel Mburu, Gertrude Salano, Elizabeth Wanja, Esther Wanja, Nancy Wanjiku, Joshua Waweru and the workshop team, cdnwaterquality@yahoo.com
[2] Kim Müller: MSc Environmental Engineering ETH, Swiss Federal Institute of Aquatic Science and Technology (Eawag), kim.mueller@eawag.ch
[3] Peter Jacobsen: MSc Environment, Project coordinator at the Catholic Diocese of Nakuru, Water Quality, 1998 - 2006, cdnlab@yahoo.com

The following summary is based on the defluoridation experiences of the Catholic Diocese of Nakuru, Water Quality (CDN WQ).
This document has been prepared jointly by CDN WQ and the Swiss Federal Institute of Aquatic Science (Eawag) and aims at giving a summary of the current development stage. Further research and development of the described techniques and processes are still ongoing.

1 Introduction

Bone char is an effective material for removing fluoride, provided the bone char is of high quality. According to Dahi (2000) the bone charring process, “unless carried out properly, may result in a product of low defluoridation capacity and/or deteriorated water quality”. Hence the production of bone char is one of the most important steps for a future, successful defluoridation treatment.
The color of the bone char has been proven to be a simple indicator for its ability to remove fluoride (also reported in Jacobsen and Dahi, 1997)

- Grey-brownish bone char: Highest fluoride removal
- Black bone char: The bones still contain organic impurities, which cause odor and color to the treated water
- White bone char: Reduced fluoride removal capacity

In lab studies carried out by Albertus et al (2000) the fluoride removal capacity of 6 different types of bone char were analyzed and compared. According to these studies the bone char manufactured by CDN WQ had the best ability to remove fluoride.

Table 1-1 summarizes the different manufacturing steps from raw bones to high quality bone char, carried out by CDN WQ.

Table 1-1: Different steps in producing high quality bone char

Process	Duration per batch	Aim
Charring	Depends on the size of the kiln. In the current kiln 10-14 days of charring is required	To remove organic impurities with a minimal reduction of the defluoridation capacity
Crushing Sieving	~7 days, including sieving	To enable its use as a filter material To homogenize the size of particles to optimize both, flow rate and removal capacity
Washing	< 14 days	To remove dust and other impurities from the charring/crushing process
Drying	1-2 days	To enable safe storage

2 Charring of the bones

CDN WQ buys the bones at 5 KES per kg (0.07 USD) from several different suppliers. These are mainly cattle, goat, sheep and camel bones. The bones are stored under a roof to prevent them from getting wet as that would cause odors and impede the following charring process. In the past, CDN WQ has developed and constructed different types and sizes of kilns. In 2005, a new kiln was constructed to facilitate and enable the production of larger amounts of bone char (see Figure 2-1). The charring capacity amounts to ~10 tons of bones per batch. To enable optimal isolation, the walls of the furnace contain three different layers: An inner and outer wall made of bricks and between the two walls sand. 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 (see Figure 2-2). The cement used for constructing the inner wall has to be fire-resistant to avoid cracking of the walls.

A grate at the base of the kiln enables an equally distributed inflow of fresh air, whereas grids placed in the middle of the kiln enhance homogenous distribution of oxygen in the furnace. Temperature and oxygen content in the furnace are the most important parameters that determine the quality of the bone char. 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.

By means of different regulating tools, 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/or cracks.
- The oxygen content of the air inlet is regulated by mixing outlet air, which contains little oxygen, with fresh air. This reuse of waste air requires a cooling system (see Appendix) to reduce the temperature that enables the subsequent mixing. 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. The inflow of mixed, waste and fresh air is regulated by a plate at the inlet.

Evaluation of the charring process has shown that there are always places in the kiln where optimum charring conditions can not be achieved. Especially the bones placed close to the door of the kiln often are white in color due to the exposure to excess oxygen and elevated temperatures.

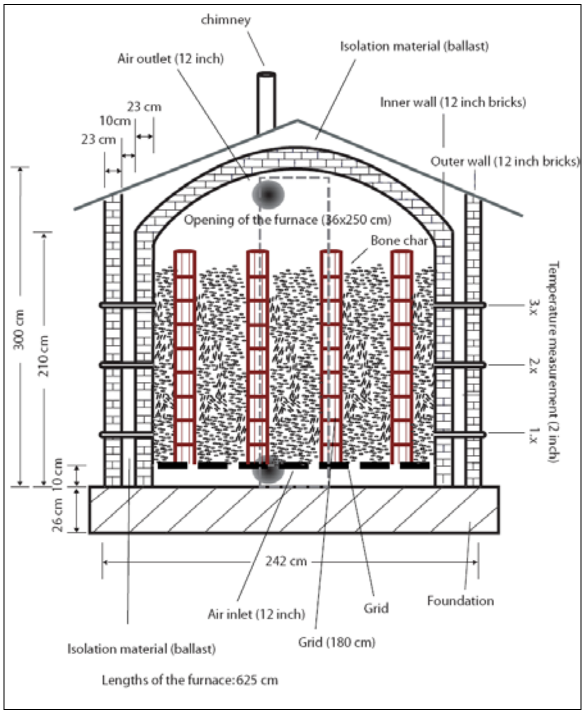
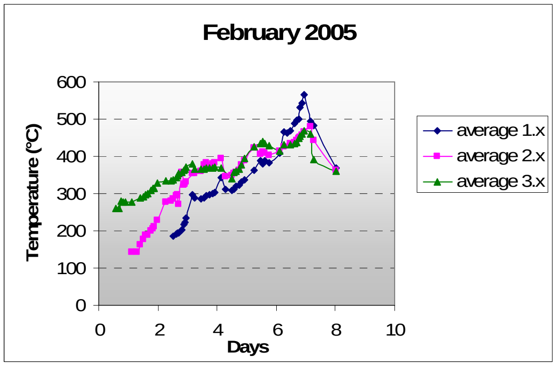


Figure 2-1: Sketch of the furnace that was designed and constructed by CDN WQ in 2005.

Figure 2-2: Storage of the bones and the charring process at its beginning.

The kiln contains 14 different monitoring points to measure the temperature in the furnace (at the inner wall). Additionally the temperature of the waste air is measured regularly. Temperature measurements are carried out with a slightly modified Testo 925 measuring instrument (see Appendix).

Temperature curves of a batch run in February 2005 and one run in November 2006 are shown in Figure 2-3. Best quality of bone char is produced at charring temperatures of 400°C for 1 to 5 days as experienced in November 2006. 80% of the charred bones were of high quality, 20% were white and almost none of them were black in color. Charring at higher temperatures (~ 500°C) can also lead to good quality bone char, but the charring time at high temperatures should not exceed 2 - 4 hours.



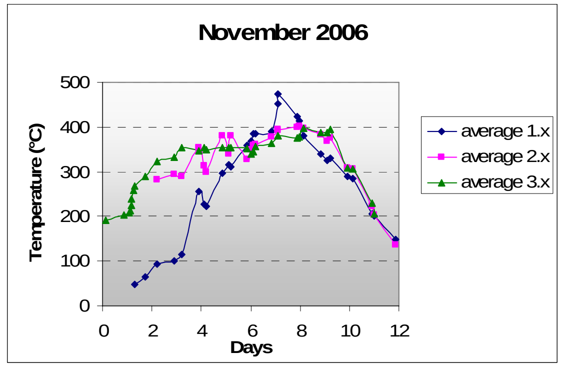


Figure 2-3: Temperature curves for charring batches carried out in February 2005 and October 2006. The blue line shows the temperature in the bottom, the purple line the temperature in the middle and the green line the temperature in the top layer of the bone char.

Example of a charring process:

The charring process normally takes between 10 to 14 days, depending on the bone properties, loading of the furnace and amount of black bone char that requires recharring. The following table gives a rough time table of a charring process.

Table 2-1: Example of a charring process

Charring	Activities/Observations
8 am	Starting the charring process: Around 10 t of bones have been placed in the furnace and piled up to the height of the grills (180 cm). One bucket of charcoal is placed in each corner, sprinkled with kerosene and ignited.
9 am	As soon as the bones have picked up fire, the furnace is closed. Especially at the beginning, the moisture content of the bone char plays an important role.
1 pm	The first 5 hours of the process requires careful observation. The color of the smoke indicates whether the charring process is satisfactory (dark color) or not (pale color). Another indicator for the charring is the temperature of the waste air that should exceed 180°C after ~ 5 hours. In some cases the bones do not catch up the fire and may be ignited again.
After 2-3 days	Cooling of the air outlet starts. While the chimney outlet is reduced, water passes to the specially constructed chimney that leads to a partial condensation of the smoke (see Appendix).
After 10 - 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.

The quality of the bone char depends on many parameters, mainly the charring conditions, packing of the furnace and the bone characteristics. The two observed charring batches (October and November 2006) produced 80% of high quality bone char and 20% of white ones.

3 Crushing and sieving

Before crushing the bone char is manually separated from metal pieces and separated according to its color. Black bone char is stored and added to the next charring batch, while white and grey-brownish bone char are crushed. Small quantities of white bone char are mixed with grey-brownish ones and used for defluoridation in community units (see “Draft of CDN’s defluoridation experiences on a community scale”). In 2000 the simple hand crush was replaced by a crushing machine, designed and constructed by CDN WQ (see Figure 8-3). Three sieves are attached to the crushing machine that enables the separation of 3 different particle sizes as summarized in Table 3-1.

Table 3-1: Different particle fractions and its use

Particles	Particle size	Percentage	Use
Powder and fine fraction	< 0.63 mm	40%	Used for the production of the calcium-phosphate pellets (contact precipitation) and as a mineral additive to animal feed
Middle	0.63 - 2 mm	30%	Filter medium in community and household filters
Coarse	2 - 4 mm	30%	Filter medium in community filters

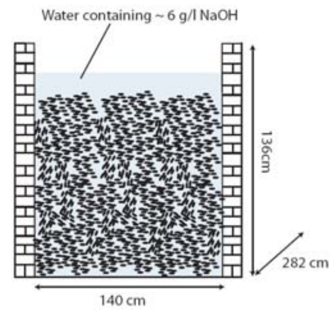
The powder fraction can’t be used directly as a filter medium due to clogging problems. Therefore part of it is sold to farmers as a mineral additive to animal feed at 18 KES per kg (0.25 USD).
Pictures of the crushing and sieving machines are attached in the Appendix.

4 Washing

3200 L of bone char is placed in one of the three 3 cement tanks. The different washing steps (see Table 4-1) can be conducted in each of the three tanks to enable parallel and separate washing of the different bone char fractions.

Table 4-1: Different washing steps

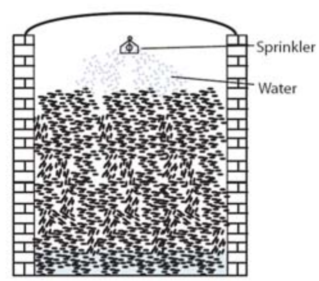
Removal of remaining organic impurities - washing with NaOH



- 3200 L of bone char is placed in a tank
- Washing tank is filled with 4000 L water containing the NaOH solution (~6 g/L NaOH, pH ~13)
- Once filled, the solution is continuously circled (by withdrawing the solution from the top and pumping it to the bottom of the tank) to enable maximum mixing
- Draining of the solution

This washing step takes ~24 hours

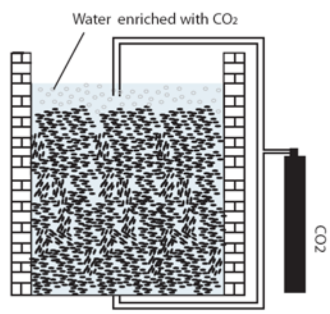
Flushing of residual NaOH and reducing color - washing with water



- Water is sprinkled over the bone char during 45 min at a flow rate of 40 L/min. CDN WQ experienced a more efficient washing process if the bone char is sprinkled and drained intermittently.
- The sprinkling process is stopped if the color of the treated water drops from 700/800 NTU[1] to less than 50 NTU (measurement in the lab)
- Draining of the water

This washing cycle takes ~9 hours

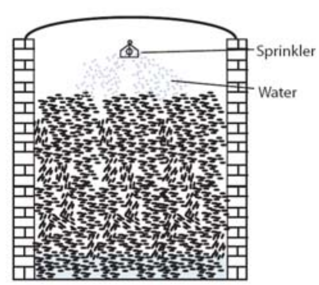
Reducing the pH - washing with CO_2 enriched water



- The tank is filled with fresh water
- While mixing, CO_2 is added to reduce the pH. In average, 1/4 of a gas cylinder (6 kg of CO_2) is used per washing batch.
- When pH < 8, the water is drained

This washing step takes ~18 hours

Reducing EC and color - final washing with water



- Water is sprinkled over the bone char and drained
- When NTU < 10 and EC[2] < 60 mS/m then the water is drained

This washing step takes ~24 hours

[1] NTU: Nephelometric Turbidity Units
[2] EC: Electrical Conductivity

5 Drying and packing

After washing, the bone char is placed on iron sheets for drying outdoor (see Figure 5-1). Depending on the climate and the particle size, drying takes 1 - 2 days (fine particle need more time for drying than coarser ones).
60 L of bone char are packed into white sacks and stored in a dry place. One sack of bone char costs 3000 KES (42 USD).

Figure 5-1: Drying the bone char and packed bone char ready for use.

6 Regeneration of saturated bone char

If the fluoride concentration in the treated water of a defluoridation unit exceeds 1.5 mg/L the bone char has to be either replaced or regenerated. Regeneration of saturated bone char, carried out according to the process developed by CDN WQ, has two main advantages: It's cheaper than replacement and, on a community scale, regeneration reduces the effort of emptying, transporting and refilling old/new filter medium.
Regeneration is carried out either on site, for community filters, or off site, for household filters (at the location of CDN WQ). Customers of household units bring the saturated bone char to CDN WQ where it is collected and regenerated in batches of 4000 L. Customers only pay half the prize for new bone char if bringing the saturated filter material to CDN WQ.
CDN WQ has carried out lab research on different kinds of regeneration media and concluded that regeneration with NaOH is preferable. Lab experiments also supported the optimization of the regeneration process in terms of amount of required chemicals, washing process, monitoring etc. Nevertheless, the regeneration process still is in development.
Currently the following steps for regenerating saturated bone char are carried out:

- Between 25 kg and 50 kg of NaOH is dissolved in a tank containing 650 L of water. This amount of NaOH is generally sufficient for regenerating 2500 L of saturated bone char, but depends on the amount of fluoride that is adsorbed on the bone char.

- Water is sprinkled intermittently over the bone char. CDN WQ experienced more efficient fluoride removal with this special washing technique compared to a continuous washing process.
- Water samples are taken every 2-3 hours. The pH is measured on-site with a pH meter whereas fluoride measurements are carried out at CDN WQ's laboratory. Due to the addition of caustic soda, the pH raises from approximately 8 to13. The high hydroxide concentration in solution leads to a desorption of accumulated fluoride on the bone char in exchange for hydroxide ion. This ion exchange reaction is facilitated due to the same charge and similar size of these two ions (Bregnhøj, 1995).
- The outlet of the filter is stored in a separate tank where $Ca(OH)_2$ or $CaCl_2$ is added. Due to this addition, fluoride precipitates as white flocks (CaF_2). These flocks are retained in a rapid sand filter and the eluate, now containing low fluoride, is reused for regeneration. At the beginning of the regeneration process the fluoride concentration in the outlet amounts to 200-300 mg/l and continuously decreases with time. The main advantages of this process are the reuse of NaOH and the formation of CaF_2 that reduces washout of fluoride to the groundwater due to its low solubility.
- After desorption, sprinkling with water is continued until the pH drops < 9.5.
- For further reduction of the pH, CO_2-enriched water is flushed through the filter until the pH amounts to < 8. The regeneration process now is complete and the filter can be taken into operation again.

The regeneration of a community filter takes around 4 to 8 days. Further improvements are still required to reduce regeneration time and to improve regeneration efficiency. Regeneration of a community plant containing 2500 l of bone char costs ~ 20'000 KES (280 USD).

7 References

Albertus J., Bregnhøj H. and Kongpun M. (2000) Bone char quality and defluoridation capacity in contact precipitation. *3rd International workshop on fluorosis prevention and defluoridation of water*. Chiang Mai,Thailand, 57-68.

Bregnhøj H. (1995) Processes and kinetics of defluoridation of drinking water using bone char, PhD thesis, *Institute of Environmental Science and Engineering.* Lyngby, Technical University of Denmark, 112.

Dahi E. (2000) The State of the Art of small community defluoridation of drinking water. *3rd International Workshop on Fluorosis and Defluoridation of Water*. Chiang Mai, Thailand, 137-167.

Jacobsen P. and Dahi E. (1997) Charcoal packed furnace for low-tech charring of bone. *2nd International Workshop on Fluorosis and Defluoridation of Water*. Nazreth, Ethiopia, 151-155.

8 Appendix

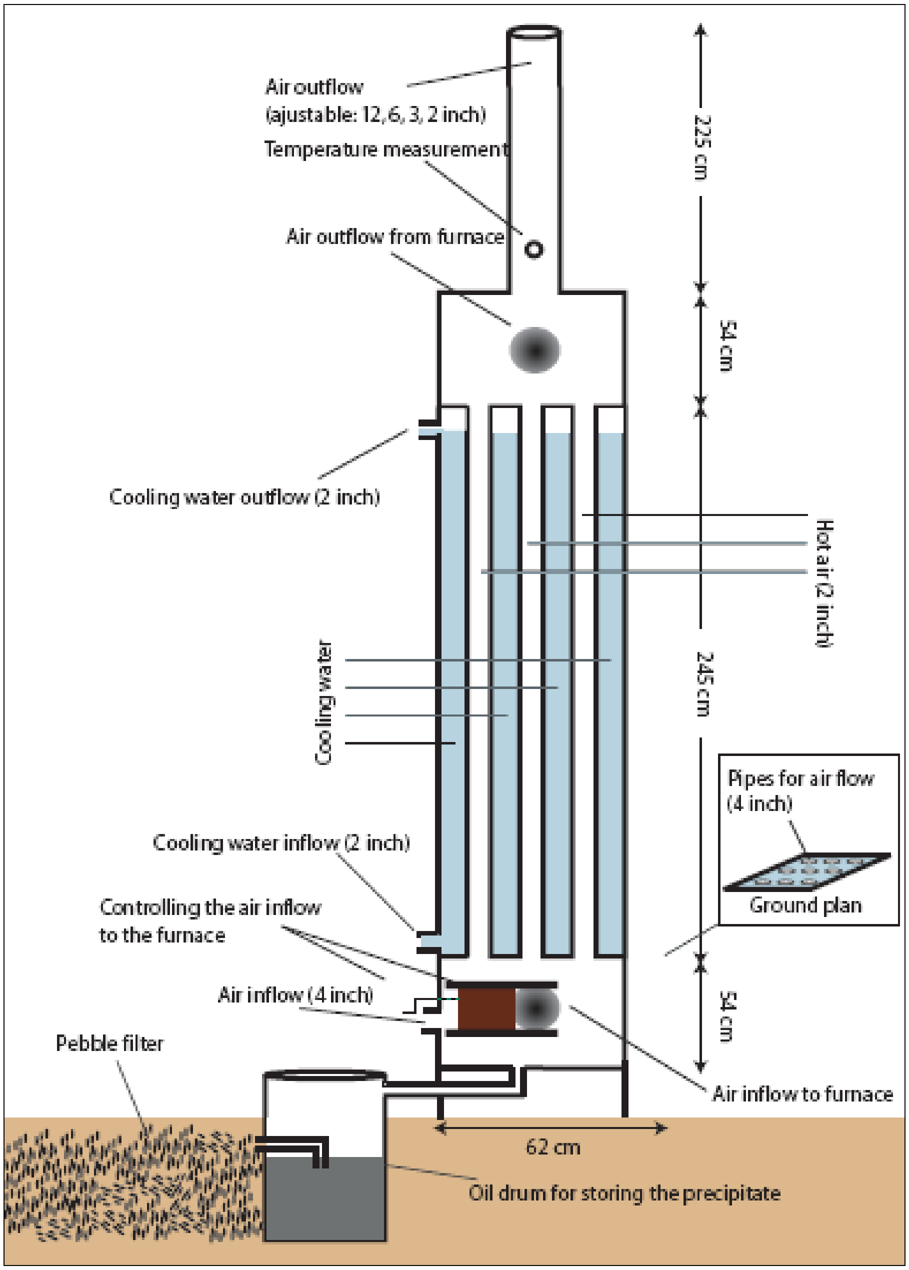


Figure 8-1: Sketch of the chimney with the specially designed cooling system for air flow regulation.

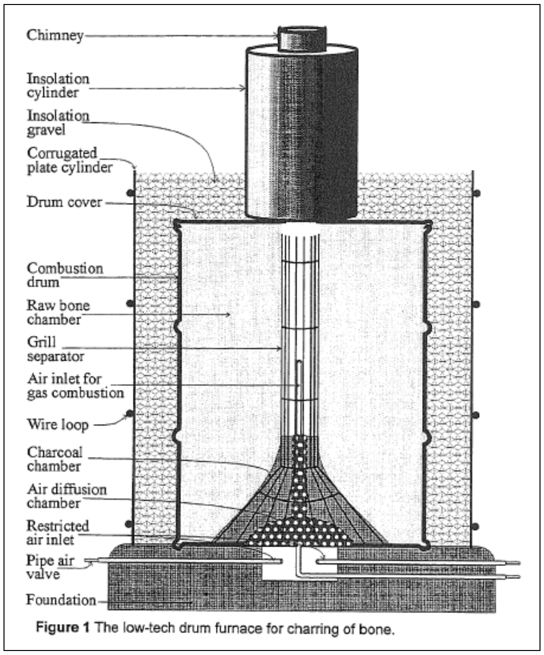


Figure 8-2: Design of a furnace first used in 1995 by Ngurdoto Defluoridation Research Station in Tanzania (Jacobsen and Dahi, 1997).

Figure 8-3: Crushing machine with attached sieving units and a separate sieving machine to facilitate and accelerate the sieving process.

Figure 8-4: Testo 925 to measure the temperature in the furnace. The wood and metal rod protect the delicate wire that transmits the information to the measuring equipment.