OPTIMISATION OF BONE CHAR PRODUCTION USING THE STANDARD DEFLUORIDATION CAPACITY PROCEDURE

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SUMMARY: The standard defluoridation capacity procedure was utilised to quantify the differences between the differently coloured bone chars, that are obtained in the charcoal packed furnace used in large scale production in Tanzania and Kenya. The highest defluoridation capacities were obtained with black and brown coloured bone char, while grey and white bone chars were the result of poor charring, with a deteriorated defluoridation capacity. Maintaining the bone char in black and brown may however introduce problems of discoloration, objectionable taste and smell, and elevated salinity. Post-treatment by means of mild acidification and water wash alleviated these side-effects, making it possible to produce a high quality bone char with respect to both the defluoridation capacity and the quality of the treated water.

Keywords: Acidification; Bone char; Bone char colours; Defluoridation; Kenya; Post-treatment acidification; Standard defluoridation capacity; Tanzania; Water wash.

INTRODUCTION

Most water defluoridation media need some kind of processing before they are ready for use. The processing may be an entire chemical synthesis, like the preparation of alumina from alum and the preparation of synthetic apatite, or a more simple physical preparation like the selection, heating, crushing, drying, sieving, and cleansing, in the case of the preparation of organic media from plant materials. In any case, one would need a simple procedure to test if the resulting product met expectations, in particular with respect to the defluoridation capacity and the quality of the treated water.

Recently, it was proposed to use the standard capacity test to determine the standard defluoridation capacity (SDC) of media, where the test would also allow a check of the quality of the water produced by the standard procedure itself.[1]

One quite promising and often discussed defluoridation medium is bone char. Apart from it originating from animal bone that may be subject to taboo constraints, bone char is also controversial with respect to its ability to produce water with an acceptable organoleptic quality.

Originally, bone char was reported to be prepared by pure pyrolysis, at 700ºC, in retorts, i.e., without the admission of oxygen.[2] In such a process, all the organic material in the bone cracks. Some of the organic carbon is lost as volatile smoke but the main part remains in the charred bone as graphite, i.e., active carbon. The graphite content gives the charred bone its characteristic black colour. Later, bone char was reported to change colour during heating from black to grey to white as the temperature increased from 300ºC to 600ºC.[3] In a previous study from the Defluoridation Technology Project, it was proven that this change of colour and

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the corresponding deterioration in the bone chars defluoridation capacity were due to more to the admission of oxygen than to the increase in temperature.[4]

In 1997, a charcoal/bone char packed furnace was developed, as a low-tech installation, suitable for the production of bone char in rural areas in developing countries.[5] Since then, this type of furnace, with minor modifications and up-scaling, has been the only installation used for the production of bone char, at least in Tanzania and Kenya. The furnace is run empirically with monitoring of the temperature. The two controllable variables in the furnace are the charcoal/bone ratio and the admission of atmospheric air (oxygen).

This paper describes some of the recent optimisations of the routine bone char fabrication used in the Defluoridation Technology Project in Tanzania.

MATERIALS AND METHODS

Bone char colours: Bone char from different firings were collected in four typical colourations designated: black, brown, grey, and white (Figure 1).

Figure 1. Cow bones fired at about 550ºC but with increasing oxygen admission, from left to right, resulting in a colour change from black, to brown, to grey, and to white.

The firings reached the same temperature level of about 550ºC, but differed in the length of time during which atmospheric air was admitted during cooling. After crushing the bones and sieving into a 2 mm wire mesh, the differences in their colours were less distinguishable. This may be due to the effect on the surface of the firings of the admission of more air (Figure 2).

Figure 2. The bones shown in Figure 1 after crushing and sieving.

Standard capacity test: About 20 g of the dry bone char were crushed and sieved in 2 mm size mesh. Then 0.500 g of the powder was transferred to 200 mL plastic bottles. 100 mL of a standard solution of 5.00 mg F/L were added. The mixture was then shaken efficiently, at half-hourly intervals until the end of the working day (approximately 10 times), allowed to settle overnight, shaken again once the following morning, and then allowed to settle for an hour before the determination of the residual fluoride concentration and thus the standard removal efficiency.[1]

Equilibrium water quality: The equilibrium water from the standard test was checked organoleptically. The waters colours were further determined using Hanna Instruments Multiparameter Bench Photometer HI 83200. The photometer allows for a direct reading in Platinum Cobalt Units, PCU.

Acidification: 20 g aliquots from each of the 4 types of bone powders were mixed with 100 mL of 3.6% hydrochloric acid. The mixtures were left for 24 hr. Thereafter, the mixtures were poured through a filter and washed 3 times with 100 mL distilled water. The powders were dried for 24 hr at 105ºC. The acid treated bone char powders were tested for their standard defluoridation capacities as above.

RESULTS

Standard defluoridation capacity (SDC): The black bone char, with the highest SDC, was the most capable of removing the fluoride from water (Figure 3). When the black bone char turned brown, it still retained about 97% of its original defluoridation capacity. In contrast, when the bone char turned grey and then white, the SDC dropped to 66% and 44%, respectively, of the black bone char capacity.

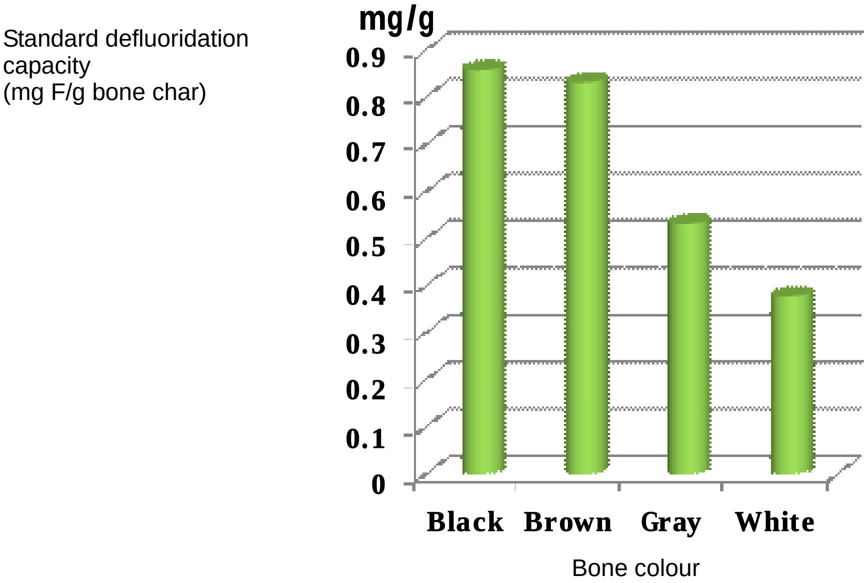


Figure 3. The standard defluoridation of bone chars with different colours.

Total dissolved solids (TDS): Along with the change in the bone char capacity, as the colour changed from black to white, there came a stripping of the bone char minerals to the water. Although even black bone char released some dissolved solids to the water, about 75 mg/L or 15 mg/g, as the black bone char turned brown, grey, and white, more solids were dissolved in the SDC-procedure, 16, 19, and 23 mg/g, respectively.

Total dissolved solids (TDS)
in mg TDS/L

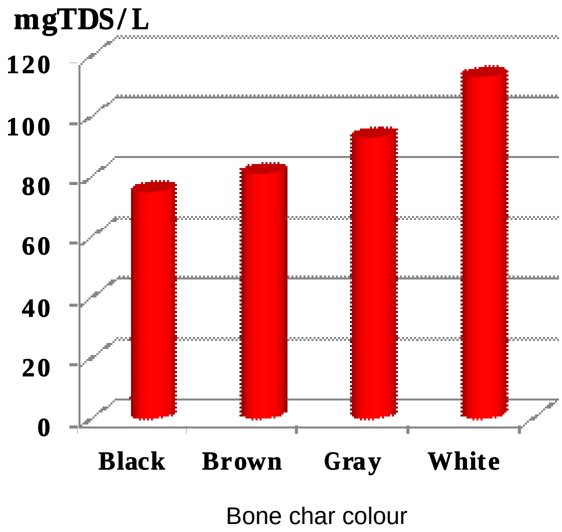


Figure 4. The salinity (total dissolved solids) of equilibrium water in the standard defluoridation capacity test for the bone chars with different colours.

Organoleptic quality of equilibrium water: The equilibrium water from a SDC-test resembles the water treated at first in a defluoridation column. This water may have an objectionable smell, taste, and colour, especially if the charring process runs out of control. The less the charring is, in terms of a lower temperature or a shorter charring time, the more objectionable are the smell, taste, and colour. It is seen that the bone char produces water that is coloured, in this case the PCU is about 100, approximately 10 times more than what is organoleptically acceptable for drinking waters (Figure 5). In addition to the taste and smell being objectionable, an unacceptable pH and slightly elevated salinity are often observed with bone char treated waters that are coloured (Figures 6 and 7).

Acidification: The colour of the SDC-equilibrium water can be removed significantly by a simple acid treatment of the bone char (Figure 5). The acidification would also bring about a more acceptable pH but the salinity would increase significantly although this does cause any deterioration of the defluoridation capacity (Figures 6 and 7). On the contrary, an acid wash seems, in addition to lowering the pH and increasing the TDS of the equilibrium water, to improve the defluoridation capacity of the bone char (Figures 8–11).

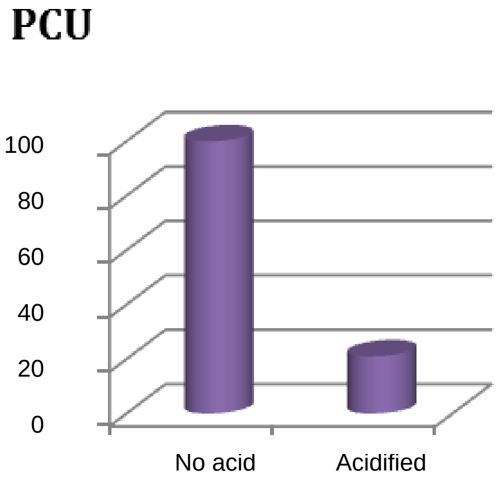


Figure 5. The colour, in platinum-cobalt units (PCU) on the platinum-cobalt colour scale, of the equilibrium waters of bone char before and after acidification.

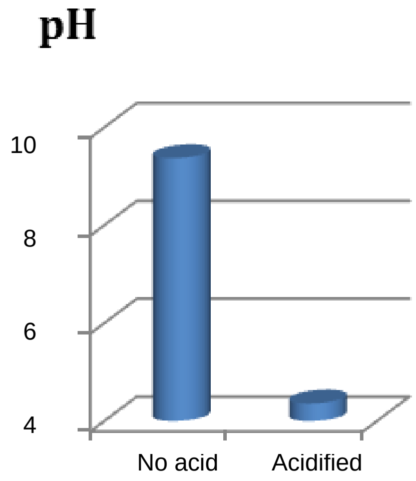


Figure 6. The pH of the equilibrium waters of bone char before and after acidification.

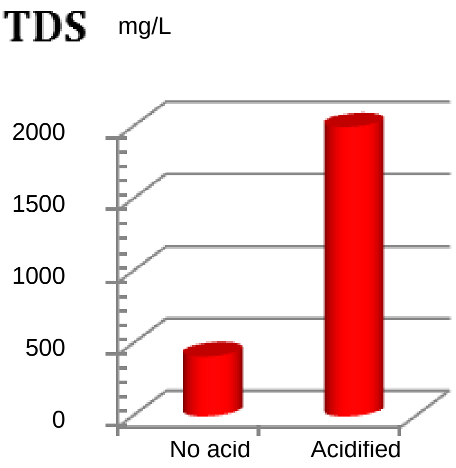


Figure 7. The total dissolved solids (TDS) in mg TDS/L of the equilibrium waters of bone char before and after acidification.

Figure 8. The pH of the equilibrium waters for bone char before and after water- and acid-wash.

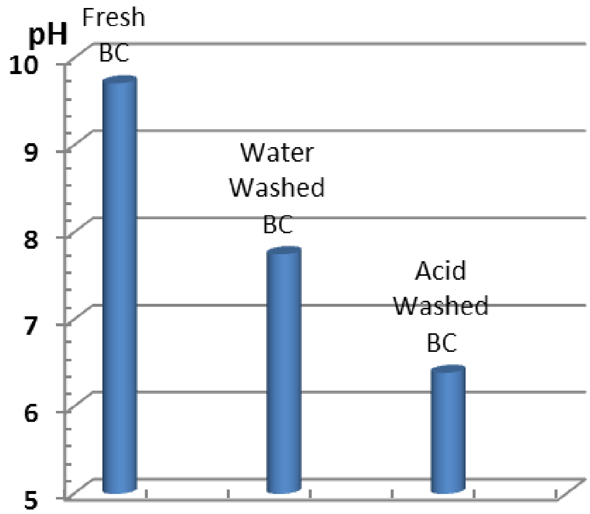


Figure 9. The total dissolved solids (TDS) in mg TDS/L for the equilibrium waters of bone char before and after water- and acid-wash.

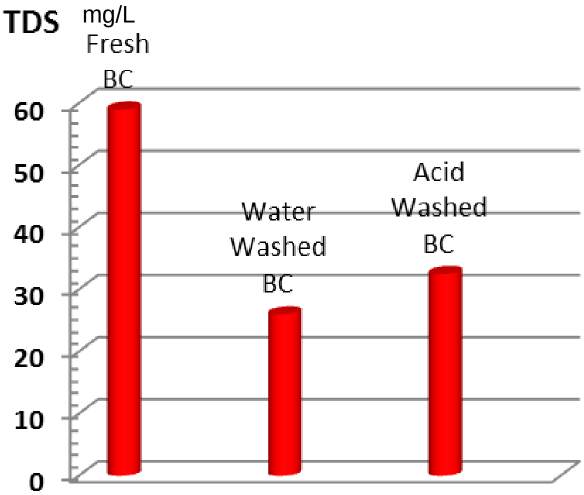
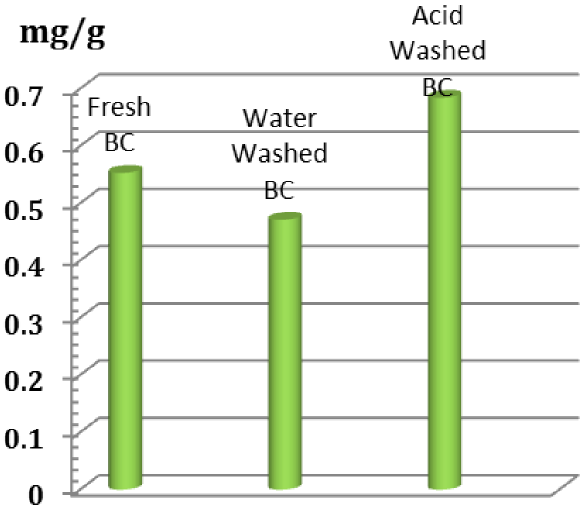


Figure 10. The standard defluoridation capacity (SDC, mg F/g bone char) of the equilibrium waters for bone char before and after water- and acid-wash.



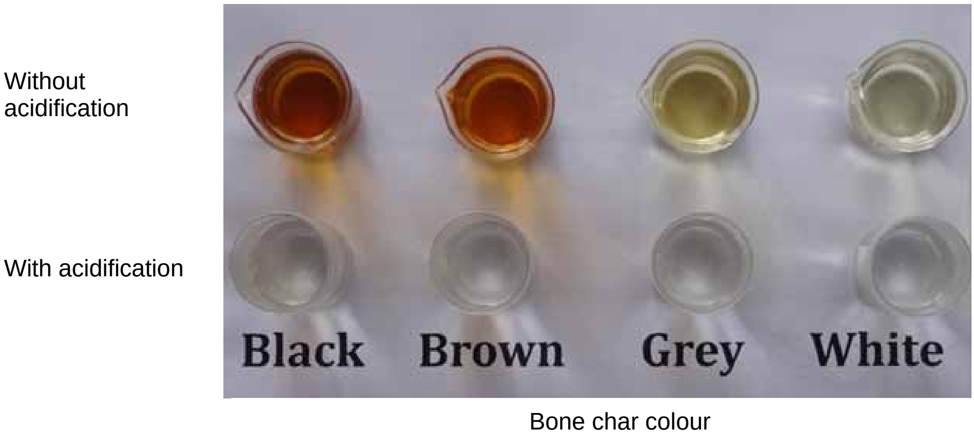


Figure 11. The standard defluoridation capacity (SDC) test without- (upper row) and with- (lower row) acidification for bone chars with different colours

DISCUSSION

Bone char colour and quality: The bone changes in colour when charred in the charcoal packed furnace. Black, brown, grey and white pieces or parts and particles may be produced in the same charring batch, i.e., from bone which has been heated to the same temperature for the same duration. This has been found to depend on the availability of oxygen during charring and that it is the oxygenation process that determines the resulting bone char colour rather than the temperature reached during charring.[4]

Black and brown bone char provide the maximum defluoridation capacity, while grey and white bone char have a lesser defluoridation capacity. Thus, the colour of the charred bone may be used as an indicator of the defluoridation capacity that can be quantified through the standard defluoridation capacity procedure.

On this colour scale, the black bone char is a product of true pyrolysis and the white bone char is a product of calcination. The calcination is associated with high pH values and a high content of total dissolved solids in the SDC-equilibrium water and thus in the water treated at first by grey or white bone char. On the other hand, black or brown bone char may produce coloured water that has a repulsive smell, taste, and colour.

In order to produce good quality bone char one should therefor aim at a pyrolysis process, that preserves the defluoridation capacity, but where the accompanying poor smell, poor taste, and discolouration are removed by a post-treatment of the charred bone. Even minor washing removes a significant portion of the minerals (Figure 9).

Mineralisation of defluoridated water: Defluoridation of water by means of bone char produces some salinity or mineralisation, at least in the equilibrium water of the SDC-procedure and in the first treated water. This mineralisation may be advantageous in fluorotic regions that in most cases are in deficit of calcium hardness in the water. On the other hand, the mineralisation may contribute to the growth of algae when there is exposure to light. This present study shows that black and brown bone char add fewer minerals than is the case with calcined bone (grey and white bone char). The mineralisation effect may be quantified through the SDC-test.

Acidification: Acidification of the charred bone has a significant effect on its defluoridation capacity. It also reduces the pH in the initially treated water towards neutral and more acceptable levels. In addition, acidification reduces the discoloration from poorly charred bone. Depending on the severity of the acidification, the initially treated water may contain elevated concentrations of dissolved solids. Thus, mild acidification can be used to improve the quality of bone char in general and it is recommended that it is followed by a water wash in order to remove the acidity and the added salinity before its use in water treatment.

CONCLUSIONS

The standard defluoridation capacity procedure is a useful tool in the optimisation of bone char production. The colour of the charred bone indicates the quality of the medium with respect to its defluoridation capacity. Black and brown bone char are most capable in removing fluoride from the water, while grey and white bone char are less effective and the result of poor firing. Black bone char, in particular, may produce coloured water. while white bone char may produce water with an elevated pH and increased concentrations of dissolved solids. An acid wash followed by a water wash may alleviate these negative effects on the quality of the treated water. In addition, acidification may further improve the defluoridation capacity of the bone char.

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