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Application of Mwacafe plant for the removal of Iron and Manganese

W. K. Siabi, Ghana

High concentration of manganese and iron in groundwater above limits permissible for domestic water supply is becoming the most important challenge facing the rural water sector in Ghana. Up to 30% of drilled wells contain high levels of manganese, iron, arsenic and fluoride. A third of boreholes containing these substances are abandoned, while the rest are marginally used. This translates to about \$ 900 lost of resources on every borehole drilled in the affected regions. Iron and manganese removal plants developed in the 1990s are ineffective, the major set back being short filter run. Recent research revealed that activated carbon prepared using charcoal, and iron oxide or manganese oxide coated quartz sand have high adsorption properties, which aid the removal of iron and manganese. Based on results of this study, the Mwacafe plant was developed. Available data on performance of Mwacafe indicate that a filter run of between 3 to 12 months is achieved.

Background

Groundwater resource development has become the alternative solution to the high cost of treating surface water sources for small communities and towns in Ghana. Currently, over 95% of domestic water supplies for small communities are extracted from this source (Siabi, 2003). In recent years however, groundwater has gone through various degrees of deterioration in quality through pollution, resulting from improper waste management, and geo-chemical changes in the geological formations. Unacceptably high levels of manganese, fluorides, arsenic and iron compounds in the groundwater reserves are becoming a constraint and challenge that limits the extent to which this resource can be exploited (Siabi, 2003).

Studies in Ghana have already revealed that up to about 30% of drilled wells contain these substances at levels unacceptable for domestic use (Siabi, 2003). High concentrations of iron and manganese are noted in the groundwater of six (6) out of ten (10) regions in Ghana namely Eastern, Volta, Greater Accra, Central, Western and Ashanti, while fluoride compounds have similarly been detected in concentrations above permissible limits in groundwater in the Upper East, Upper West and Northern regions. Ongoing research at the Kwame Nkrumah University of Science and Technology in Kumasi, Ghana indicated that the detection of high levels of arsenic in groundwater in Ashanti, Western, Brong Ahafo, Northern, Upper West and Upper East regions pose the most serious emerging treat to the choice of groundwater source in the affected areas.

In spite of the many advantages offered by some of these substances, especially iron, recent research reveals that they have serious health consequences when consumed in large quantities. Iron overload in the body has been linked to he-

mochromatosis, a genetic disorder, which causes diabetes, impotence and liver failure (Andrews et al., 1999). Excess manganese consumption has been associated with malfunctioning of the central nervous system, low intelligence quotient especially in children, reduction in haemoglobin regeneration, parkinsonism, abortion and stillbirth in women (WHO, 1981). Even though no research findings are available on these health problems, it cannot be ruled out completely that these health risks and fears are relevant, especially where levels of these substances in water supplies are high.

Estimated lost of investment on projects

It has been estimated by W. Siabi in 2002 that in Ghana, between 20 to 40% of point sources, especially boreholes, which have water quality problems, especially iron and manganese above permissible limits, are abandoned by the beneficiary communities, while the remaining 60 to 80% are used marginally for purposes other than for drinking, cooking and laundry. This translates approximately to about nine hundred US Dollars (\$900) lost of resources on every borehole drilled in the affected regions in Ghana. Whereas this loss in investment funds may create uncertainty for future investments, the health consequences resulting from the continuous use of water facilities that have high levels of the metals would further deepen the already high poverty levels and health risks in the communities.

Performance of existing iron removal systems

Several types of small water treatment plants have been installed on boreholes to reduce manganese and iron levels during implementation of rural water and sanitation projects

in small rural communities. The design of these small water treatment plants often referred to as ‘iron removal plants’ are based on aeration and slow sand filtration mechanism. Test runs conducted on some of these plants indicate low efficiency. In particular, the plants are characterised by short filter runs, low pH of about 5, and rapid deterioration of the filtered water, especially colour and turbidity. It has been determined that the iron or manganese flocs produced clog the filter media bed and thus shortens the duration of rejuvenation. Very often, the flocs dissolve when the pH falls to about 5 or lower. In most of these plants, manganese removal is negligible.

During the last three years, research has been carried out on water quality management of point sources in small communities in Ghana by W. Siabi to find new techniques for dealing with the emerging water quality challenges. The study focussed on achieving the following objectives:

- *Collect information on the perception of communities on water quality, especially high iron and manganese levels in their water supplies, and performance of the ‘iron removal plants’ installed on the boreholes.*
- *Test run existing ‘iron removal plants to determine their efficiency.*
- *Develop a new technique for the management of water quality in small communities.*

Water quality acceptability study

Information on the perception of communities on the quality of water from ground sources was collected on the above study covering hundred (100) respondents in ten (10) communities using iron removal plants. The ten communities are located in five (5) districts namely Yilo Krobo, Manya Krobo, Asuogyaman, Fantekwa and East Akim in the Eastern Region, Ghana. The results indicated rapid deterioration of the treated water quality a few days after installation of the plants. In most of the communities studied, there is little knowledge of the effects of poor water quality. In some communities the bitter taste, staining of clothes and blackening of food, which are characteristics of high concentrations of iron and manganese, have often been linked to superstition. The systems had been abandoned in most of the communities studied.

Test run results of existing iron removal systems

One of the measures employed for measuring the efficiency of the ‘iron removal plants’ was to test run identical systems on boreholes with different water quality to determine their filter run for specific minerals (or metals) present in the raw groundwater. Focus was placed mainly on removal levels achieved for specific water quality parameters (especially iron and manganese) above the Ghana Standards Board, and World Health Organization (WHO) permissible limits for drinking water supply. The test run involved:

- Rehabilitation of the plants selected for the test run to restore their performance to expected designed capacity.
- Hourly water quality testing of the filtered water from the plants for pH, total iron, manganese, colour and turbidity, and weekly testing of the raw groundwater quality.
- Application of Ghana Modified India Mark 2 hand pump and electric driven submersible pump on boreholes to determine pump type and discharge effect on the performance of the iron removal plants.

Results from the test run were similar for the different pumps for similar discharges. However, the submersible pump provided a more regular discharge and consistent test results. Iron concentration in the filtered water was about 1.0 mg/l within a period of 13 hours (refer to figure 1), for a raw groundwater total iron and manganese concentrations of 41.5 and 3.75 mg/l respectively. This test run duration is equivalent to a period of 2 days operation of plant (water usage in the communities was noted to be about 6 hours

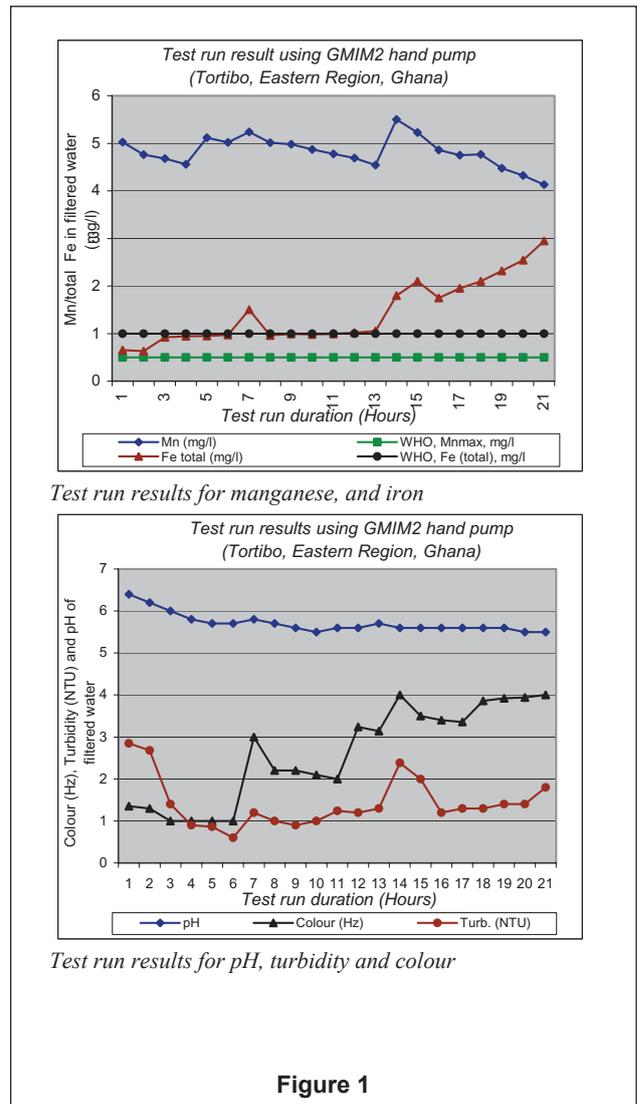


Figure 1

daily). Manganese concentration was almost constant in all the plants studied especially where quartz coarse aggregate was used as filter media. Where granite was used as coarse filter medium, the manganese concentration increased steadily in the filtered water with time, even far above the levels recorded in the raw groundwater. This suggests that the filter media contributes manganese to the raw water during the treatment processes (Figure 1).

Figure 1 displays the relationship between colour, turbidity and pH of the treated water and time during the test run using the Ghana Modified India Mark 2 hand pump. It was noted that whiles colour and turbidity increased with time as a result of deterioration in the treated water quality, the pH of the water decreased steadily, thus creating acidic conditions. The pH level dropped in most cases to 5 or lower, a condition suitable for dissolution of the flocs deposited in the filter media back into solution. This condition results into increasing the reduced forms of iron and manganese compounds in the filtered water. One of the major challenges facing the continuous use of these small water systems is finding an answer to the low pH, common with the filtered water and the short filter run associated with the plants.

Research into activated carbon

Granular Activated Carbon (GAC) prepared using charcoal, a porous form of carbon made from hardwood has been investigated and found to provide properties capable of achieving a substantial removal of iron and manganese compounds from groundwater samples in a batch test. The result generated from the batch test indicated preferential adsorption of iron ahead of manganese by the GAC, whenever the two metal compounds exist (Siabi, 2003). It was also noted that, adsorption of the two metals is time dependent as well as the mass of the GAC used. This new knowledge forms the basis for the development of a new plant called Mwacafe. The paper titled 'Potential of Activated Carbon for manganese and iron removal' (Siabi, 2003.) is useful for deciding on the assumptions used for the design of Mwacafe, and the conclusions drawn from the test results on the plant.

Design of Mwacafe

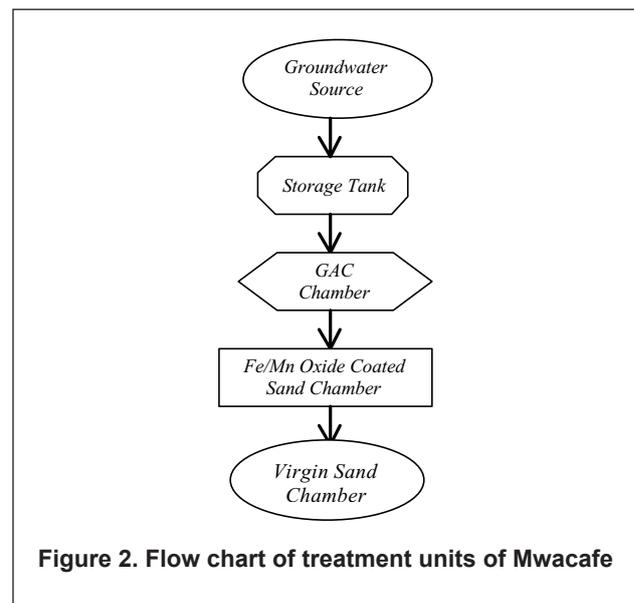
Granular activated carbon (GAC), iron and manganese oxides coated quartz sand constitutes the main filter media of the Mwacafe plant. Charcoal has been chosen as the raw material for the preparation of the GAC based on several advantages it has over the other sources or types of carbon namely:

- Charcoal is made from hardwood mostly in rural communities in Ghana, and is available in large quantities.
- The product is less expensive compared to carbon from other sources.
- Unlike carbon prepared especially from animal bones, which may be rejected based on tradition and cultural beliefs, charcoal is universally acceptable even for application in traditional oral medicine (Siabi, 2003).

The assumptions considered for the design of Mwacafe are:

- Application of 15.75 mg of GAC per litre of raw groundwater to be treated, or higher depending on levels of iron and manganese in raw water.
- Retention period of 10 to 20 minutes and filtration rates of about 1 to 2m³/m²/hr.
- Removal of manganese and iron by GAC is related to levels achieved in the batch test (75-100%) under limited oxygen supply (Siabi, 2003).
- 20 litres/day optimum per capita water consumption of beneficiaries (CWSA, 2003).
- Iron oxide or manganese oxide coated quartz sand also used as filter media under limited oxygen supply to aid manganese and iron removal (Metcalf & Eddy, (1995)., Sharma et al, (1997).

Manganese and iron removal in the Mwacafe plant is achieved during treatment in four stages as shown in the flow chart (figure 2). The plant is designed to operate under limited oxygen supply. Greater removal is achieved in the GAC chamber, whiles residual manganese and iron compounds are further reduced in the other chambers.



Performance of Mwacafe

The results on a test plant constructed at Tortibo, a small community in the Eastern Region of Ghana indicated high efficiency of Mwacafe in the range of about 75 to over 99% for manganese and iron removal. Levels of total iron, manganese and pH in the raw groundwater, the treatment chambers of Mwacafe, and the filtered water were measured weekly within a four month period. The levels of the three parameters measured were compared to determine the degree of treatment as the raw water is transported through the treatment chambers. It is noted from figure 3 that pH

was stabilised between 6.8 to 7.3 (pH of treated water from Mwacafe normally ranges from 6 to 8 in most cases).

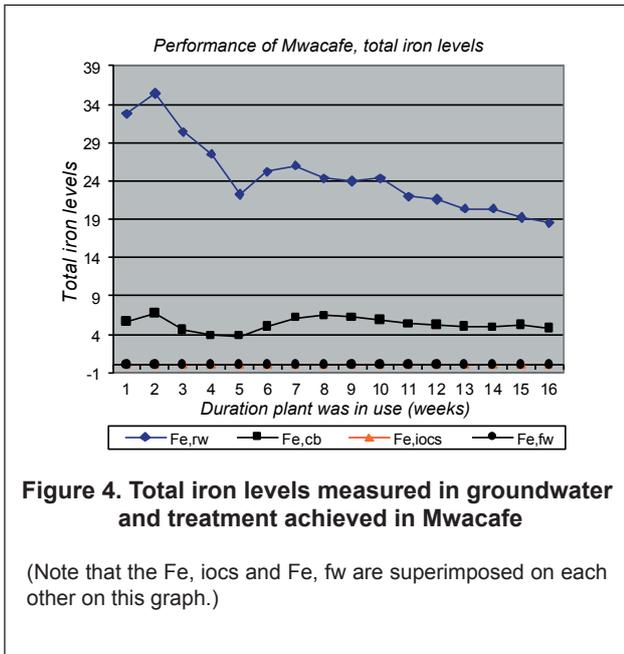
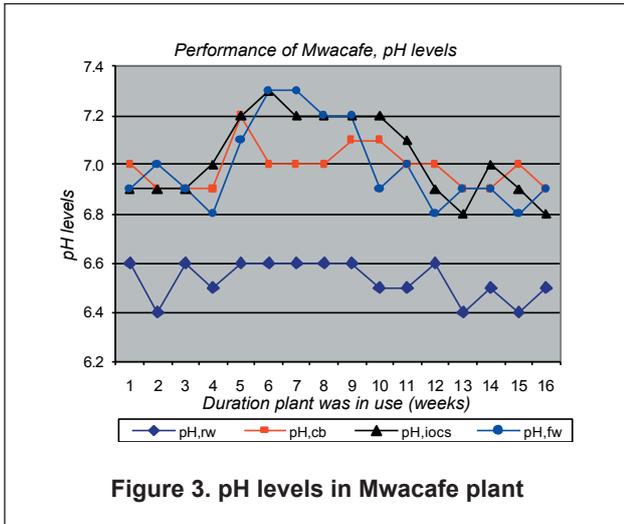
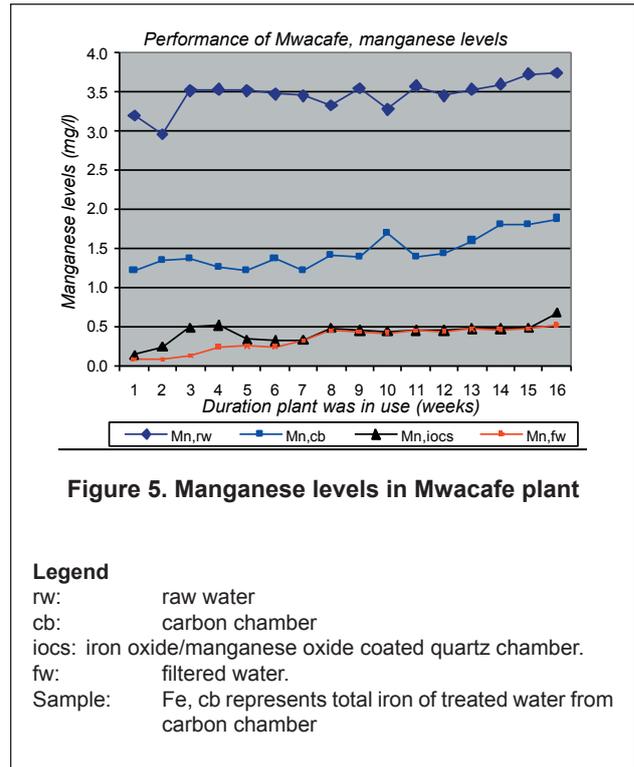


Figure 5 shows a near zero iron concentration in the filtered water within the four month monitoring period. This amounts to over 99% efficiency of plant for iron removal (figure 3). It was also observed from figures 3,4 & 5 that removal of the metals in the treatment chambers of Mwacafe are related to their concentrations in the raw water. Manganese level in the filtered water remained below 0.5mg/l over the four months monitoring period. This constitutes about 86% removal. As predicted in the batch test, iron is always preferentially removed ahead of manganese, even in cases where manganese concentration is much lower (Siabi, 2003). Depending on the quality of the raw groundwater, rejuvenation of the filter media may become necessary between three (3) to twelve (12) months. Mwacafe was observed to also remove



odour producing substances, colour and turbidity from water sources during treatment. Figures 3, 4 & 5 compared to 1 and 2 explain advantages Mwacafe has over other plants.

Cost, operation and maintenance of Mwacafe

The installation cost of Mwacafe is three thousand US Dollars (\$3000), about \$1000 cheaper than other plants. Operation and maintenance of Mwacafe is similar to that of slow sand filters. The sand filters of Mwacafe require rejuvenation within 3 to 12 months, depending on the raw water quality. 20mm valves connected to the treatment chambers are used to flush out deposited flocs from the storage tank and aid the rejuvenation process. Weekly flushing of the storage tank and rejuvenation of the iron oxide or manganese oxide coated quartz media is necessary to minimise the passage of flocs on to the filters, whilst ensuring that the oxides coated quartz is available to enhance adsorption of the metal compounds. The weekly maintenance of the plant takes about 20 minutes. The GAC chamber may be rejuvenated after a year or more after installation.

Cost of maintenance of the Mwacafe and the other plants depend on the frequency of rejuvenation. Where the community is unable to provide communal labour for rejuvenation, about \$ 28 may be needed to engage trained artisans. The 10 kg of GAC that is needed yearly would cost \$30. Other cost areas of maintenance are replacement of pipefittings when damaged, and the quartz grains filter media, which may be gradually lost during cleaning. A maximum of \$126 may be needed annually for the most frequently rejuvenated

Mwacafe plant whiles \$70 may be spent on a plant rejuvenated once a year. Rejuvenation of the filter sand of other plants is similar but is carried out regularly, very often weekly or two times in a month. This gives a minimum rejuvenation frequency of 24 in a year. The community therefore require a minimum amount of \$ 684 for maintenance if trained artisans are engaged.

Conclusion and recommendation

- GAC prepared from charcoal is effective for manganese and iron adsorption under limited oxygen condition in the Mwacafe plant.
- Iron slows down manganese adsorption onto granular activated carbon during treatment.
- GAC normalises the pH of acidic groundwater during treatment in Mwacafe.
- Mwacafe achieves 75 to over 99% efficiency for the removal of iron and manganese.
- The use of granite as filter medium or in the construction of boreholes should be avoided in view of the likelihood of high manganese concentration.
- Groundwater quality changes with seasons.

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