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TOWARDS THE MILLENNIUM DEVELOPMENT GOALS

Potential of activated carbon for manganese and iron removal

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GROUNDWATER REMAINS THE most important source of water in rural communities in Ghana. Currently, over 95% of domestic water supplies to small communities and towns are extracted from this source. However, high levels of metals have been identified as the most biggest constraint limiting the extent to which this resource can be exploited. In the Eastern Region of Ghana for instance, drilling records have revealed that between 20 to 30% of all boreholes drilled for domestic water supplies to rural communities and small towns contain manganese or iron or both in concentrations above the Ghana Standards Board permissible limits of 0-0.1 and 0–0.3mg/l respectively for drinking water

Manganese and iron occur naturally in most of the geological formations in Ghana. In the Eastern Region, the Togo Series, Buem, Dahomeyan, Tarkwaian and Voltaian formations are noted in particular for high levels of iron and manganese. 41.5mg/l of iron and 24.5mg/l of manganese have been detected in boreholes at Tortibo and Okyerekrom (two small communities in the Asuogyaman and Akwapim North districts in the Eastern Region, Ghana) respectively. Daily iron intake of 10mg for adult men and 15mg for adult women is adequate for growth (haemoglobin formation) and body metabolic processes (Languon, 2002). Whereas iron deficiency in the body is associated with anaemia and low intelligence quotient especially in children (Lozoff, 1997), excess level in domestic water supplies are connected with staining of clothes and utensils, blackening of food and bitter taste, whiles overload in the body is linked to hemochromatosis, a genetic disorder which causes diabetes, impotence and liver failure (Andrews etal., 1999). Between 2 to 3 mg daily intake of manganese is enough for formation of connective tissue and bone, growth and other body metabolism. Excess manganese consumption has been linked to malfunctioning of the central nervous system, reduction in haemoglobin regeneration,

Parkinsonism, abortion and stillbirth in women (WHO, 1981), and contributes to aesthetic defects similar to that of iron. Domestic water usage for drinking and cooking constitutes the highest sources of manganese and iron intakes into the body in the region. It is therefore important that the levels of these metals are reduced in domestic water supplies.

Manganese and iron removal technologies

The approach to solving the problem of high manganese and iron levels in water supplies from point sources, mainly boreholes and hand dug wells, focused on the use of plants designed to function as slow sand filters. In Ghana, in particular, the treatment plants normally referred to as 'iron removal plants' installed on boreholes to reduce the levels of these metals have not been efficient. Fine sand derived from riverbeds, and coarse aggregates of quartz or granite origin constitute the main filter materials. The major set backs related to these plants are that they are characterised with large sludge production, very little or no manganese removal, rapid clogging of filter media and rapid deterioration of filtered water quality resulting into short filter runs (or high frequency of rejuvenation) of average seven days. A study conducted on existing sand filters revealed that the communities soon become overburdened with the frequency of rejuvenation of the filter media leading to the systems either being abandoned or the community going back to the unsafe surface water sources.

Research into potential of activated carbon

Based on the low efficiency of the 'iron removal plants', research was intensified to identify appropriate filter media and mechanisms that can achieve improved water quality of the treatment plants and longer filter run – the most important factors critical for sustainable operation and management of the plants.

Granular Activated Carbon (GAC) prepared using charcoal, a porous form of carbon made from hardwood, as the base material has been identified, investigated and found capable of achieving a substantial iron and manganese removal from sample groundwater sources in a batch test. The choice of carbon as a filter medium for water treatment is increasingly becoming important as a result of the new knowledge acquired through research regarding its high capacity for removing manganese and iron, and other minerals through adsorption processes.

The batch test with carbon from charcoal

Charcoal is microcrystalline form of graphite, an allotrope of carbon. It is very reactive and possess high adsorptive properties. Unlike diamond the other allotrope of carbon, which is linked with a network of strong covalent bonds with no electrons, giving rise to its hardness and inert character, charcoal has a characteristic property, derived from its structure, which makes it possible to adsorb small molecules, and dissolved ions. When activated, its adsorptive properties increase tremendously (Kneen etal, 1984. Metcalf and Eddy, 1995).

Granular activated carbon (GAC), prepared from charcoal forms the most important filter material used for this research. 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 (or taboo for some ethnic groups), charcoal is universally acceptable even for application in traditional oral medicine.

Preparation of GAC

Improperly burnt wood and other impurities are isolated from the charcoal, followed by grinding or pounding into smaller particles. The grounded charcoal is then sieved using the appropriate sieve sizes to achieve particle size in the range 0.2 to 2 mm. The granular charcoal is heated to temperature above 150°C in an electric furnace for about 12 hours, and then cooled down to produce a more porous product called granular activated carbon. Heat activation ensures that improperly burnt wood is converted to charcoal, whiles the process results into increasing the pore sizes and therefore the surface area and adsorption sites of the carbon particles

Batch experimental set up

The objectives of the batch experiment were:

- Determine the relationship between adsorption of manganese and iron, and mass of GAC consumed.
- Determine the retention time (contact time) needed to achieve a substantial removal of manganese and iron from the source groundwater sample.
- Determine other effects of the GAC on the treated water quality.

Procedures for conducting the batch test

Accurately weighed quantities of the GAC of masses 26.25, 52.5, 105, 157.5, 210 and 262.5mg were each mixed with 10 litres of raw water collected from a borehole to achieve a GAC raw water concentrations of 2.625, 5.25, 10.5, 15.75, 21.0 and 26.25mg/l respectively. The tests were conducted for groundwater sources from Tortibo, Nkurankan (a small community in the Yilo Krobo District, Eastern Region, Ghana) and other communities in different geological formations. Only results for sources from Tortibo and Nkurankan are included in this publication.

The GAC raw water mixture was kept in plastic buckets (reactors) at temperature of 28°C, and other atmospheric conditions. Stirring was carried out initially, and thereafter every 10 minutes to ensure that uniform mixing was achieved. Samples from the batch reactors were taken for analysis after the first 5 to 10 minutes and thereafter every hour for pH, iron (ii), total iron and manganese salts. A sixth reactor was set up with 10 litres of the raw water without any GAC, and stored under the same conditions as others. Samples from this reactor were also analysed for pH, colour, turbidity, iron (ii), total iron and manganese every hour. The results of these tests are shown and discussed below.

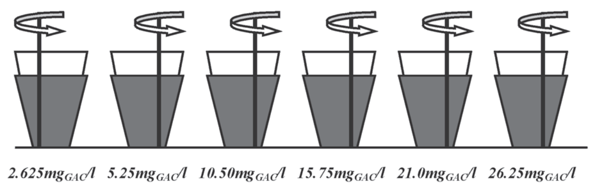

Figure 1. Batch reactors set up for different masses of GAC and groundwater source.

Discussion of results from the batch test

The most important mechanism identified to be responsible for the removal of iron and manganese from the raw groundwater samples was adsorption. Results in table 1 and figures 1 & 2 (Tortibo borehole source for 26.25mg/l concentration of GAC) clearly indicates that about 84% of iron (total) was adsorbed onto the carbon particles within a period of 10 minutes of contact, whereas a higher level of about 98% removal was achieved for the Nkurankan borehole source (table 2, for 26.25mg/l of GAC). Level of adsorption was observed to increase with retention duration, the highest occurring at hour six (see figures 2 & 3, and table 2). The variations in the removal levels for both metals indicate that the mass of the metals removed is related to the original concentration in the raw sample. Although the removal of manganese was also significant in the reactor, and follows same trend as for iron, the mass of manganese removed within the same period is lower compared to that of iron.

Table 1. Raw water quality data for groundwater sources from Tortibo and Nkurankan

Source water sample	Tortibo	Nkurankan
Manganese (mg/l)	2.75	5.75
Ferrous iron (Fe^{2+}) (mg/l)	21.0	4.25
Total iron (mg/l)	41.5	7.0
pH	6.4	6.4

Study of figures 2 & 3 revealed also that, manganese removal in the batch reactor increased much more rapidly after hour 3, only when a substantial quantity of iron was removed. Iron is therefore preferentially removed. From table 2, percentage levels of ferrous and ferric salts removed are identical and suggest that, to avoid production of iron and manganese flocs (sludge), treatment would be more effective under anaerobic conditions. Figure 4 displays the relationship between the mass of GAC, retention time and pH levels in the batch reactors. The graph indicates that GAC provides a medium, which is alkaline in character and affects therefore the adsorption process positively, and the pH of the treated water. This property of carbon is important, especially for water treatment processes where pH correction is necessary.

Water treatment is a continuous flow process. However, results of the application of design parameters such as 15.75 mg of GAC per litre of raw water 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 2m/hr in a new plant named Mwacafe indicates that performance of the plant is related to removal levels achieved in the batch test. Design of Mwacafe was based on this research findings and existing knowledge on the potential of iron oxide coated sand for iron and manganese removal. 20 Mwacafe plants installed in the Eastern and Greater Accra regions under a Danida funded project have been monitored to provide over four months filter run and iron, manganese and fluoride removal levels listed in table 3.

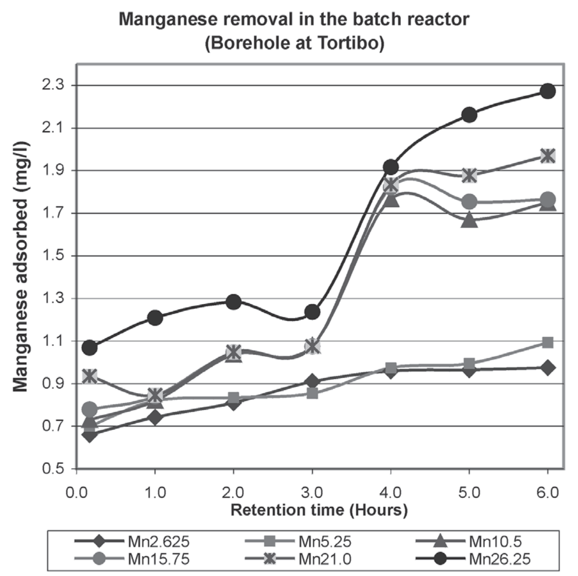

Figure 2. Manganese removal by GAC in the batch reactor for water sample from Tortibo.

Table 2. Results of the batch test for borehole source at Nkurankan.

Retention time (hours)	Conc. GAC (mg/l)	Mn pH	Fe^{2+} mg/l	Fe mg/l	total mg/l
0.17	5.250	6.4	3.345	1.83	3.45
	10.5	6.7	3.320	0.83	1.10
	15.75	6.8	3.145	0.59	0.70
	21.0	7.0	2.860	0.06	0.25
	26.25	7.1	2.260	0.09	0.15
1	5.250	6.4	3.286	1.31	1.930
	10.5	6.8	3.250	0.38	0.50
	15.75	6.9	2.612	0.08	0.13
	21.0	7.1	2.252	0.02	0.12
	26.25	7.2	2.134	0.01	0.08
2	5.250	6.6	3.189	1.06	1.55
	10.5	6.8	3.024	0.31	0.40
	15.75	7.0	2.524	0.03	0.08
	21.0	7.1	2.250	0.02	0.07
	26.25	7.3	2.125	0.01	0.06
3	5.250	6.7	3.153	0.96	1.32
	10.5	6.8	3.022	0.19	0.29
	15.75	7.0	2.424	0.01	0.04
	21.0	7.2	2.028	0.01	0.17
	26.25	7.4	2.011	0.00	0.01
4	5.250	6.8	3.154	0.56	1.22
	10.5	6.8	3.022	0.23	0.28
	15.75	7.0	2.225	0.00	0.02
	21.0	7.3	1.988	0.00	0.01
	26.25	7.4	1.866	0.00	0.01
5	5.250	6.7	3.144	0.55	1.04
	10.5	6.9	3.036	0.14	0.20
	15.75	7.0	2.224	0.00	0.01
	21.0	7.3	1.980	0.00	0.01
	26.25	7.4	1.950	0.00	0.01
6	5.250	7.1	3.143	0.53	0.71
	10.5	7.2	3.024	0.05	0.10
	15.75	7.3	1.966	0.00	0.01
	21.0	7.5	1.855	0.00	0.01

Table 3. Manganese, iron and fluoride removal levels achieved in the Mwacafe plant.

Parameter	Removal efficiency in the Mwacafe plant
Iron	90 – 100 %
Manganese	75 – 92 %
Fluoride	75 – 95%

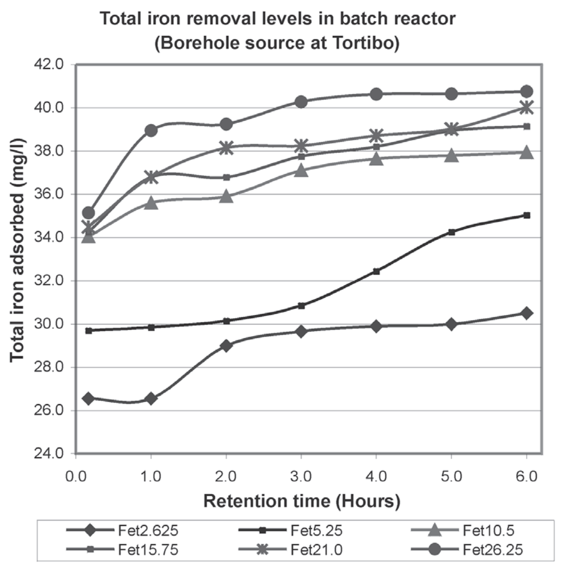

Figure 3. Total iron removal by GAC in the batch reactor for sample from Tortibo.

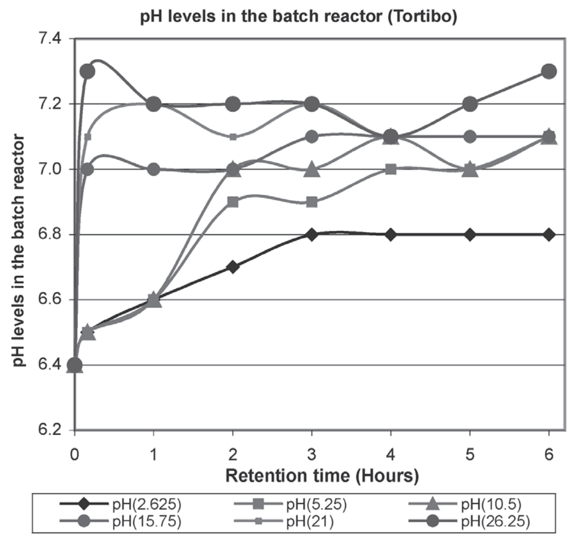

Figure 4. pH levels in the batch reactors for water sample from Tortibo.

Conclusion and recommendation

- GAC prepared from charcoal is effective for manganese, iron and fluoride removal.
- Iron is adsorbed faster and preferentially onto the carbon medium than manganese.
- The mass of iron or manganese removed from solution depends on the mass of the GAC used, retention time and concentration of metals in the raw water.
- Adsorption by GAC of ferrous iron is similar to that for total iron. Higher efficiency of the plant is likely if GAC medium is operated under anaerobic conditions because of the expected low sludge production.
- Conversion of iron (2+) salts to iron (3+) salts is slow, depending on several other ions that may inhibit the oxidation process. It is therefore important that design takes into account retention period, concentration of other ions present, initial pH of raw water and mass of GAC needed

References

KNEEN, W.R, ROGERS J.W. AND SIMPSON P., (1984). Chemistry, facts, patterns and principles, revised edition, pp 861.

LANGUON, S.Y, (2002). "Are you taking in enough iron", article published by the Mirror, a Ghanaian weekly newspaper, July 27, 2002.

LONZOFF, B., (1997). Functional significance of iron deficiency in children, (http://infonet.welch.jhu.edu),

METCALF AND EDDY., (1995). Wastewater Engineering, Treatment, Disposal and Reuse, third edition, pp 1334.

NANCY, ANDREWS., (1999 Diseases of iron metabolism, http://www.med.harvard.edu/). A publication by Harvard Medical School.

WHO, UNEP, and ILO., (1981). Environmental Health Criteria 17.

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