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**ACCESS TO SANITATION AND SAFE WATER:
GLOBAL PARTNERSHIPS AND LOCAL ACTIONS**

Aeration and its application in groundwater purification

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Aeration is an important process in water treatment on boreholes fitted with hand pumps and on small to large conventional water treatment systems. Aeration aids the removal of some pollutants such as iron and manganese, and similarly colour, turbidity, odour and taste. Studies have shown that water treatment levels predicted during aeration may not be achieved for iron and manganese if some other oxygen consuming substances are present in the raw water. Manganese removal is noted to be generally inefficient if aeration and filtration are the only processes applied during water purification. It has been observed also that, for such systems, pH of the effluent reduces as the water treatment process progresses. This results in dissolution of manganese and iron flocs formed and a short filter run.

Background

Aeration is one of the most common and important water treatment processes applied during water purification on boreholes fitted with hand pump for small communities, and on small to large conventional water treatment plants for towns or cities. Cascade aerator for instance is designed to combine the turbulence created when the raw water to be treated is transported along a number of weirs or steps. The turbulence created as the water falls from one step to the other allows dissolution of the oxygen component of air in the effluent. The dissolved oxygen of the effluent increases subsequently and is available for the conversion of most unstable organic and inorganic substances into stable forms that can be removed later in the other treatment processes. Dissolved oxygen concentration in other types of aerators (example spray types) is dependent on the size of the film of water created as the raw water is separated into smaller particles through spraying or passage of effluent through engineered perforations.

Oxygen consuming substances in raw water

Many organic and inorganic substances, and micro-organisms are present in raw water from surface or ground sources. Most of these substances are unstable, produce taste, colour, odour and turbidity, which are objectionable to water consumers. Iron and manganese compounds for instance are soluble at pH lower than 5 (Siabi, 2004) and produce taste, colour as well as odour when available in quantities above guideline limits of World Health Organization (WHO, 2004). These substances may be converted into stable ones when oxygen is available. When dissolved oxygen is generated in raw water (effluent) during aeration, it oxidizes several compounds including iron, manganese, ammonium and organic substances. Similarly, gases such as carbon dioxide, carbon monoxide, hydrogen sulphide and hydrocarbons, which may be trapped in the raw water, are desorbed. During the design stage of a gas transfer component, the levels of oxidation and desorption are estimated. However based on the quantities of pollutants present in the raw water, the oxidation processes may not be efficient for the removal of the target substances.

Objectives of this paper

In this paper, results from studies undertaken, which are related to oxygen generation and its application for oxidation and removal of iron, manganese and ammonium salts are compared for a water treatment system designed for a borehole fitted with hand pump and for a conventional water treatment plant.

Oxidation of pollutants during aeration

The chemical reactions, which explain how some pollutants are stabilized through oxidation during aeration processes, are as follows.

Organic compounds

Organic substances often found in water sources have elements including carbon, hydrogen, oxygen and nitrogen. When oxygen is present, the organic substance is broken down according to the reaction,



Ammonium compound is formed as an intermediary and is further broken down into nitrites and nitrates, with the help of the bacteria, nitrosomonas and nitrobacter.



In this reaction, 3.56g of oxygen is consumed per gram of ammonium compound.

Inorganic substances

Oxidation of iron



In this reaction, 0.14g of oxygen is consumed per gram of iron.

Oxidation of manganese



In this reaction 0.29g of oxygen is consumed per gram of manganese. This is double the oxygen demand for oxidation of iron II Oxide. Reactions (1) to (4) indicate that hydrogen ions are produced in excess. If enough bicarbonate ions are unavailable to neutralize these hydrogen ions, the effluent becomes more acidic, and may affect iron/manganese flocs formation if the pH dropped below 5.

Dissolved oxygen generation on cascade aerator; theoretical perspective

According to Metcalf and Eddy, (1995), if raw water (effluent) is transported on a cascade aerator, dissolved oxygen generated can be estimated using the following equations and assumptions.

$$K = 0.36(1 + 0.046T) H \quad (5)$$

[This is equivalent to $K = a(b + cT)h$, where a, b & c are constants, $H = 0.5\text{m}$, $Co = 3.0\text{mg/l}$]

$$Ce = Co + K(Cs - Co) \quad (6)$$

Where,

K = Efficiency coefficient for the cascade at the temperature, T (oC).

T = Water Temperature during aeration

H = Step or weir height

Ce = Oxygen concentration expected after aeration (mg/l)

Co = Initial oxygen concentration of effluent (mg/l)

Cs = Saturation concentration of oxygen, mg/l ($Cs = 9.65\text{mg/l}$).

Cascade aerator at Abaam

A water treatment system was installed to purify groundwater for Abaam, a small town in the Kwaebibirem District of the Eastern Region, Ghana. Included in the water treatment components is a six-step cascade aerator. The raw groundwater contained excessive iron, manganese and colour (compared with the permissible limits of the Ghana Standard Board Standard of 0.3mg/l (iron), 0.1 mg/l (manganese) and 15 Hazen (colour)). The six-step (weir) cascade aerator installed was designed based on the model proposed by Metcalf and Eddy (equations 5, 6 and the assumptions). The dissolved oxygen predicted to be generated in the effluent during aeration according to the design is tabulated in Table 1. After the installation of the cascade aerator, series of water quality tests were carried out and the average levels measured is tabulated also in Table 1.

Comparison of dissolved oxygen generation

The model proposed by Metcalf and Eddy suggests that oxidation would start at the end of the aeration process. However, it was observed that even though the entire transportation time of the effluent on the cascade is short, some oxygen generated have been consumed and is explained by the increasing levels of colour and turbidity of the effluent from steps 1 to 6. The difference between dissolved oxygen predicted and that measured during operation may account for that consumed by pollutants in the effluent during aeration.

Table 1: Measured quality of raw groundwater on cascade aerator at Abaam during aeration and as predicted during design

Step ID	Colour (Hazen)	Turbidity (NTU)	Temperature (oC)	Fe 2+ (mg/l)	Manganese (mg/l)	Dissolved oxygen (mg/l)	Predicted dissolved oxygen (Ce), mg/l
Step 1	40	3.6	23	0.85	0.55	6.21	5.46
Step 2	49	8.6	23	0.80	0.55	7.36	7.01
Step 3	55	10.3	23	0.67	0.54	7.65	7.99
Step 4	72	10.6	23	0.56	0.52	7.82	8.61
Step 5	83	13.7	23	0.54	0.50	8.03	8.99
Step 6	86	16.5	23	0.43	0.49	8.24	9.24
Settling tank	35	3.6	23	0.09	0.26	7.40	N/A

Table 2: Water quality parameters of raw groundwater source at Gyakity before treatment:

Water Quality Parameter	Measured Level
pH	6.4
Colour (Hazen)	0.6
Turbidity (NTU)	1.88
Manganese (mg/l)	2.11
Ferrous iron (mg/l)	12.85
Total iron (mg/l)	23.55
Ammonium Salts (mg/l)	0.2
Dissolved oxygen of aerated raw water (mg/l)	7.25

Table 3: Test run results of water treatment system with spray aeration on borehole fitted with hand pump at Gyakity

Test duration (Hours)	pH	Colour (Hz)	Turb. (NTU)	Mn (mg/l)	Fe (total) mg/l	NH4+(mg/l)
1	6.4	1.62	1.46	1.565	0.34	0.34
2	6.3	1.51	1.26	1.540	0.30	0.20
3	6.1	1.50	1.14	1.542	0.28	0.10
4	6.0	1.50	1.15	1.554	0.25	0.10
5	5.8	1.46	1.14	1.666	0.22	0.01
6	5.6	1.44	1.00	1.660	0.22	0.01
7	5.6	1.42	0.90	1.652	0.23	0.01
8	5.5	1.40	0.80	1.654	0.25	0.10

9	5.5	1.50	0.90	1.655	0.25	0.10
10	5.5	1.50	0.90	1.657	0.27	0.10
12	5.4	1.52	0.92	1.697	0.34	0.10
14	5.3	1.54	0.94	1.723	0.46	0.10
16	5.2	1.54	0.99	1.725	0.61	0.10
18	5.2	1.61	1.10	1.880	0.67	0.10
20	5.1	1.61	1.20	1.880	0.76	0.10

Oxygen demands by iron, manganese salts

According to Table 1, an estimated 0.42mg/l (49%) of iron II Oxide was converted to iron III oxide while 0.06mg/l (11%) of manganese was probably converted into the stable MnO₂ state and deposited, thus the reduction in manganese concentration. These reactions occurred during aeration on the cascade. It is deduced that ferrous iron easily stabilizes into the ferric iron when oxygen is available. Manganese however is much more stable than iron in the reduced states. After retention in the settling tank for one and half hours, 0.29mg/l of manganese (53%) was removed. Manganese therefore requires long retention if aeration is applied for removal. In this particular treatment plant, pre-chlorination was applied afterwards to ensure that all the manganese is oxidised and removed in the other treatment components.

Aeration and water treatment on hand pump

The effectiveness of aeration on a water treatment system designed for borehole fitted with hand pump was observed to be similar to that discussed under cascade aeration for conventional water treatment systems. Aeration on this water treatment system is similar to that of spray type. The water delivered through the spout of the hand pump falls on flat perforated trays arranged in series. There were 2 to 4 trays depending on the hand pump type used. As the water flows through the small perforations, oxygen gets dissolved into it. Dissolved oxygen generated during aeration on this plant is 7.25mg/l even though the contact time of the effluent with air was limited.

Test run on the Gyakity plant

Table 2 shows water quality of the raw groundwater source. Results of test run carried out on this plant are presented in Table 3. It was observed that, even though enough oxygen was generated during aeration, manganese removal in the sand filters remained negligible [maximum of 0.57mg/l removed (27%)] compared with the iron [maximum of 23.33mg/l removed (99%)]. This suggests further that oxidation of manganese was ineffective. It is concluded that long retention is required if manganese removal can be achieved when aeration process is applied as an important component in the overall water treatment process. It was also noted that ammonium salts easily get oxidized compared to iron and manganese, and depletes faster the dissolved oxygen of the effluent.

pH of effluent during oxidation

It was noted during the test run on the borehole at Gyakity that, while the levels of iron and manganese in the filtered water increased gradually after six hours of test run, the pH of effluent also reduced gradually (Table 3). This confirms the products of reactions (1) to (4). Hydrogen ions generated during the oxidation processes have not been completely neutralized, as should have been the case when bicarbonate ions are present. This is responsible for increasing acidity of the filtered water. It was also observed that at pH lower than 5, the flocs of iron and manganese formed re-dissolved.

Conclusions

Aeration is very useful in water treatment when iron, manganese, colour, odour and turbidity are excessive in the raw water. When manganese is available in high concentrations it is important that the water treatment process is monitored to ensure that the removal levels predicted are achieved. The following observations have been made.

1. Manganese requires larger amounts of oxygen for oxidation during aeration compared to iron.

2. Iron is easily oxidized than manganese during aeration.
 3. Longer retention time is required for the removal of manganese if aeration and filtration are the only water treatment processes to be applied.
 4. pH reduction follows oxidation of iron, manganese and ammonium salts, and may affect floc formation and removal during water treatment.
 5. Iron and manganese flocs formed re-dissolves when pH of the effluent reduces to about 5 or lower during water treatment
 6. When ammonium salts are present in raw water it is important that additional oxidizing agents are applied during treatment in order to avoid depletion of the dissolved oxygen.
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