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Original Research Article

# Sustainable Treatment for High Iron Concentration in Groundwater for Irrigation Purposes

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**Abstract**

**Groundwater contamination has major complications on the environment and can pose serious threat to agriculture and human health. Since the industrial revolution, one of the major concerns regarding the contamination of groundwater is the precipitation and accumulation of heavy metals. The metals like magnesium, calcium, iron and manganese however are necessary to sustain the vital plants function in trace amounts. Iron and manganese are occurring naturally in groundwater (Tredoux et al., 2004) where both elements are present in anoxic environment (Ebermann et al., 2010). Therefore World Health Organization has approved the treatment of water if concentrations of iron and manganese are higher than 0.3mg/L and 0.1 mg/L respectively. The issue of higher concentrations of iron and manganese in groundwater wells at Farafra oasis, Egypt is unbearable since iron levels from 4.9ppm to 8.8ppm and manganese levels from 0.2ppm to 0.43ppm. Several techniques were applied to remove iron and manganese from groundwater. The aim of this investigation was to focus on reducing these high levels of iron and manganese to some safe levels for irrigation purposes. The relationships between oxygen levels and precipitation rates of iron and manganese are the main key in solving this problem. Instead of some well-known chemical treatments, an innovated technique would help in resolving such problem. The idea is to subject the groundwater to as much air as possible to maximize participation of these two elements of iron and manganese. Iron and manganese concentrations after aeration followed by filtration came down to 0.11, 0.05 mg/L respectively in all cases. These low levels are still subjected to further improvement.**

**Keywords**: Groundwater, Sustainable Treatment, High iron Concentration, Irrigation Purposes, Air-water close contact.

## INTRODUCTION

Groundwater contamination has major implications on the environment and can pose serious threat to agriculture and human health. Since the industrial revolution, one of the major concerns regarding the contamination of groundwater is the precipitation and accumulation of heavy metals. The metals like magnesium, calcium, iron and manganese however are necessary to sustain the vital plants function in trace amounts. Iron and manganese are occurring naturally in groundwater where both elements are present in anoxic environment. Therefore World Health Organization has approved the treatment of water if concentrations of iron and manganese are higher than 0.3mg/L and 0.1 mg/L respectively (NGU, 2008). Iron is a common water contaminant that is not considered a health hazard; however, its presence at elevated levels can cause aesthetic problems on ornamental plants, buildings and structures, and its accumulation on irrigation equipment can lead to clogged emitters.

### *Problem Definition*

The issue of higher concentrations of iron and manganese in groundwater wells at Farafra oasis, Egypt is unbearable

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due to high iron levels from 4.9ppm to 8.8ppm and manganese levels from 0.2ppm to 0.43ppm. These high levels of iron and manganese make a lot of problems such as deposits in pipelines and service laterals, clogging of water meters and drippers, reduction in pipe diameter resulting in higher power and higher energy costs. Ferrous iron provides a food supply for the growth of bacteria in the distribution system, reduces well capacity and service life, well redevelopment expense, staining and formation of a reddish brown or white gelatinous slime and stringy masses that can slough off causing a variety of problems. Iron mainly exist in two different forms: ferrous iron; iron(II) or $Fe2+$ and ferric iron; iron(III) or $Fe3+$ (Mayer and Jarrell, 2000). Ferrous iron can become ferric iron by oxidation. A commonly applied oxidizer in water treatment is oxygen, mostly easily abstracted from air.

***Objective***

The aim of this investigation was to focus on reducing these high levels of iron and manganese to some safe levels for irrigation purposes. The relationships between oxygen levels and precipitation rates of iron and manganese are the main key in solving this problem. To minimize the usage of chemicals required using some well-known chemical treatments which are described as highly expensive treatments; an innovative technique is warranted to help in resolving these problems. The idea is to subject the groundwater to as much air as possible to maximize oxidation and participation of these two elements.

## MATERIAL AND METHODS

Groundwater with high levels of iron (7.014 mg/L) and manganese (0.307 mg/L) is the only water resource in farafra oasis for irrigation purposes. Engineering treatment approach must be practical, feasible and economical. Aeration followed by sand filtration is the main target towards reducing these high levels of these contaminates. The farafra location is about 2550 fed (1071.5 ha). Thirteen wells covers the irrigation responsibilities in that area. Waterfall is created to aerate the water after pumping out from these wells and let it pass over the waterfall. Figure (1) shows the design of installed waterfall. Filtration station is provided to filter water from all impurities in the lake, especially insoluble iron and manganese.

Water aerating system has been evolving in terms of the methods and conventional technology, where the modifications are done to optimize the factors or parameters that affect the efficiency of the system. It consisted by a series of waterfall on a concrete cascade using the potential energy of the gravitational pull of the water at the water inlet of the system. In cascade aeration, the available fall height is subdivided into several steps. During each step the water falls over a weir into the next step. When water passes over the weir, an interface between air and water is created, where gas transfer can take place. More relevant in cascade aeration is the entrained air. The falling water jet enters the water body in the lower cascade chamber and air is entrained in the form of bubbles. Due to turbulence during entraining, a mixture of air and water is provided, in which gas transfer will occur. The cascade aerating depends on the early level of dissolved oxygen, the concentration of dissolved oxygen that is needed and the temperature of the treated water.
At the end of the aeration system by cascading, iron and manganese concentration were measured.

Water samples were taken from thirteen water wells and the following table shows their water analysis:

| Well No. | pH | Temp. (°C) | T.D.S (ppm) | Cations | | | | Total (meq/L) | Anions | | | Total (meq/L) | Fe (ppm) | Mn(ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Na | K | Ca | Mg | | Cl | $So_4$ | $HCO_3$ | | | |
| 1 | 6.7 | 41 | 228 | 22 | 7 | 17 | 7 | 2.55 | 46 | 20 | 55 | 2.62 | 6.4 | 0.3 |
| 1 R | 6.4 | 48 | 103 | 22 | 6 | 18 | 13 | 3.06 | 37 | 70 | 40 | 3.14 | 5.8 | 0.24 |
| 2 | 6.3 | 41 | 131 | 21 | 6 | 16 | 6 | 2.34 | 40 | 25 | 48 | 2.42 | 5.8 | 0.25 |
| 3 | 6.8 | 45 | 100 | 16 | 5 | 16 | 5 | 2.02 | 29 | 20 | 55 | 2.12 | 7.1 | 0.35 |
| 4 | 6.2 | 40 | 214 | 35 | 7 | 23 | 11 | 3.75 | 70 | 40 | 62 | 3.81 | 5.4 | 0.28 |
| 5 | 6.2 | 40 | 176 | 14 | 6 | 15 | 6.6 | 2.04 | 28 | 18 | 52 | 2.01 | 6.9 | 0.34 |
| 6 | 6.4 | 42 | 171 | 14 | 7 | 15 | 7 | 2.1 | 29 | 20 | 55 | 2.12 | 6.7 | 0.32 |
| 7 | 6.5 | 41 | 216 | 18 | 8 | 19 | 9 | 2.67 | 42 | 25 | 62 | 2.72 | 4.9 | 0.32 |
| 9 | 6.6 | 39 | 101 | 17 | 5 | 13 | 4 | 1.255 | 25 | 22 | 47 | 1.92 | 8.8 | 0.43 |
| 10 | 6.5 | 42 | 100 | 20 | 6 | 13 | 6 | 2.17 | 30 | 25 | 52 | 2.22 | 8.6 | 0.3 |
| 11 | 6.5 | 42 | 100 | 20 | 6 | 13 | 6 | 2.17 | 30 | 25 | 52 | 2.22 | 8.6 | 0.3 |
| 12 | 6.9 | 42 | 101 | 17 | 5 | 14 | 5 | 1.97 | 23 | 20 | 48 | 1.84 | 8.4 | 0.34 |
| 12 R | 6.9 | 41 | 101 | 17 | 5 | 14 | 5 | 1.97 | 23 | 20 | 48 | 1.84 | 8.4 | 0.34 |
| 13 | 6.4 | 42 | 130 | 11 | 3 | 15 | 6 | 2.1 | 28 | 35 | 46 | 2.27 | 6.4 | 0.2 |

ppm: Parts per million
meq/L: milliequivalents of solute per liter

Waterfall is created to aerate the water after pumping out from these wells and let it pass over the waterfall. The waterfall is built by concrete material. The total height of the waterfall is 7.00 meters with 3 steps. The height of the first step is 2.50m with 8.00m width and 8.00m length. The height of the second step is 2.00m with 8m width and 6m length. The height of the third step is 2.50m with 8.00m width and 5.30m length. The thickness of the upstream waterfall's wall is 0.40m and thickness of the two wall sides of waterfall is 0.40m. Barriers and weirs in the third step were formed from local materials that existed in the project location.

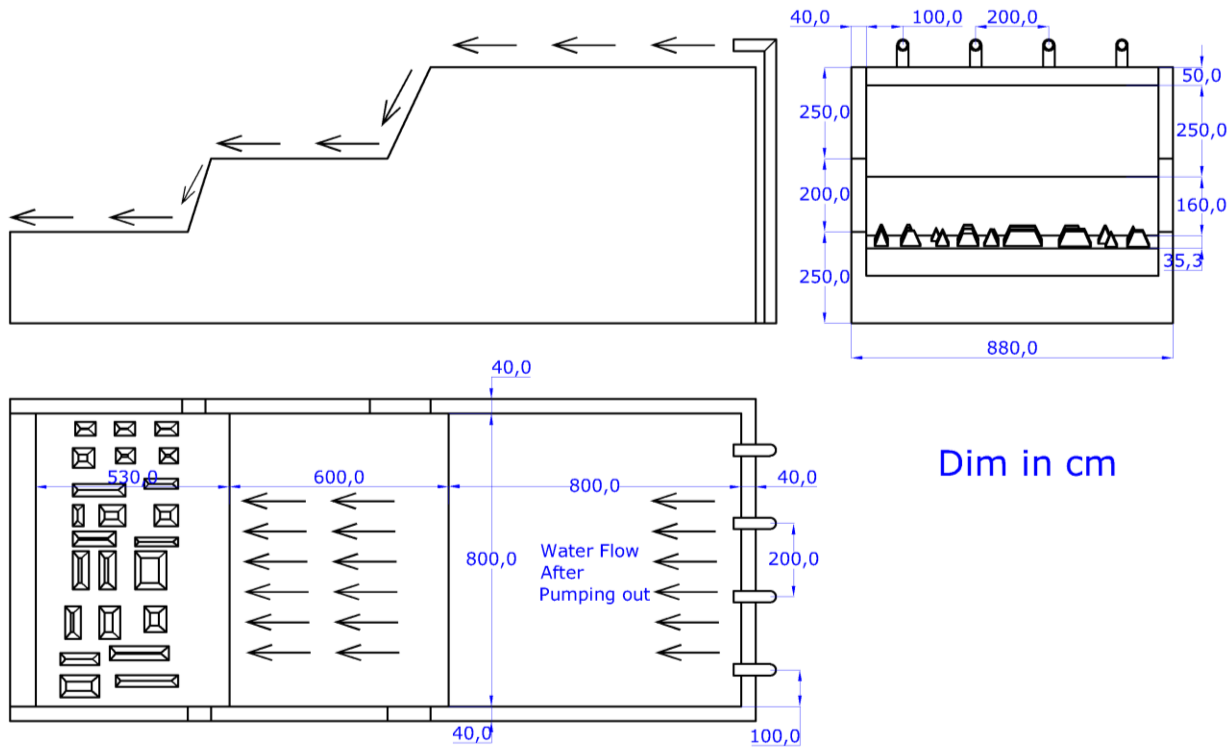


**Figure (1) Schematic of the field work, Dimensions in cm**

The groundwater was pumped out through well pipes and carried to the waterfall by carrier pipes. Polyvinyl chloride (PVC) is the material of carrier pipes with diameter 315mm. The discharge was measured by means of a flow meter followed by a flow control valve installed on the discharge pipe. The distance between these pipes is 2.0m and between the pipe and the wall thickness of waterfall is 1.0m.After the waterfall, there is a basin (storage lagoon) to receive the water, precipitate ferric iron and storage water for irrigation. The volume of this basin is 90000 m3 and its area is 5.50 feddan (2.3hectares) with height 5.0m.After the sedimentation and precipitation of iron, the water is pumped to the irrigation system by pump station. The pump station's components are three pumps and one spare pump. Pumps with Inverter to regulate the flow at the same pressure (50m3/hr to 1200m3/hr at 5 bars). Filtration station is provided to filter water from all impurities in the basin especially insoluble iron and manganese. The filtration station is consisted of twenty sand (gravel) filters with size 48" and four screen filters with size 8". The average discharge of this filtration station is 1050 cubic meter per hour. The daily operation time of this project is twenty hours per day. The daily irrigation water requirements of 380 fed is 21000 cubic meter per day. To treat this amount of groundwater per day, an effective treatment is needed. This whole system was installed to treat these amounts of water. At that time, the optimum design of aeration or iron oxidation was not asked. However, this study would help to approach the academic investigation that help putting the design concept in prospective.

The aeration process starts when the water gets out from the pipe. The aeration process brings water and air into close contact by exposing thin sheets of water to the air. Variations in flow rate, contact time, pH were tested to find their effects on the efficiency of aeration along with different iron concentrations and wind speed. Special attention is given to continuous monitoring of the main factors affecting the phenomena such as pH, temperature, iron concentration and over all time during the treatment stage.

Raw groundwater was obtained from wells by the carrier pipes. The samples were analyzed in the field and in laboratory according to The Environmental Protection Agency (EPA) standards in order to determine the characteristics of the groundwater. The physical and chemical characteristics of raw groundwater are shown in the previous table. The concentration of iron varied from 4.9 mg/ L to 8.8 mg/L and the concentration of manganese varied from 0.2 mg/L to 0.43 mg/L. The average water temperature is 41.8 °C from 39 °C to 48 °C. pH values were from 6.2 to 6.9. The groundwater was pumped from the wells through a PVC pipes to the upstream step. The discharge was measured by means of a flow meter followed by a flow control valve installed on the discharge pipe. The upstream cascade plan area is 8.00 m x 8.00 m with a drop of 2.50 m, the second cascade plan area is 8.00 m x 6.00 m with a drop of 2.00 m and the downstream cascade plan area is 8.00 m x 5.30 m with a drop of 2.50 m.

Groundwater samples were collected upstream & downstream the stepped cascade and at the inlet of the filtration station. The following parameters were tested for each groundwater sample: - Dissolved oxygen concentration (DO) – iron concentration - Total dissolved solids (TDS) - Temperature of water- pH. The dissolved oxygen was measured by the portable meter CyberScan DO100 Model for three sampling points; upstream, downstream the cascade. The dissolved oxygen (DO) meters were daily calibrated as recommended by the manufacturer. pH is an important indicator and temperature is an important parameter since it is in a direct relation with the iron concentration and the dissolved oxygen concentration. Dissolved oxygen refers to the amount of oxygen that is contained in water. While dissolved oxygen concentrations are necessary to carry out the iron concentration. Iron level in groundwater was measured by the laboratory in the project. An efficiency term was introduced to quantify how the iron oxidation was improved by the following:

Oxidation Efficiency=1-(iron concentration after oxidation)/(iron concentration before oxidation)

## RESULTS AND DISCUSSION

Results have shown that iron and manganese concentrations after aeration followed by filtration came down to 0.34, 0.05 mg/L respectively. These low levels are still subjected to further improvement. Figure (2) shows that the aeration efficiency increases with the increase of height step. Efficiency of oxidation calculated by the concentration of oxygen in water before and after the step. The increase of step height will increase efficiency of oxidation. It also illustrates the highest efficiency of oxidation can be obtained at 2.2m height of step. Concentration of oxygen increased in water by falling water from the upstream to downstream over the step. The 100% oxygenation efficiency does not mean that all percentage of iron would be oxidized. However, more oxygen is needed to oxidize the rest of the iron concentration.

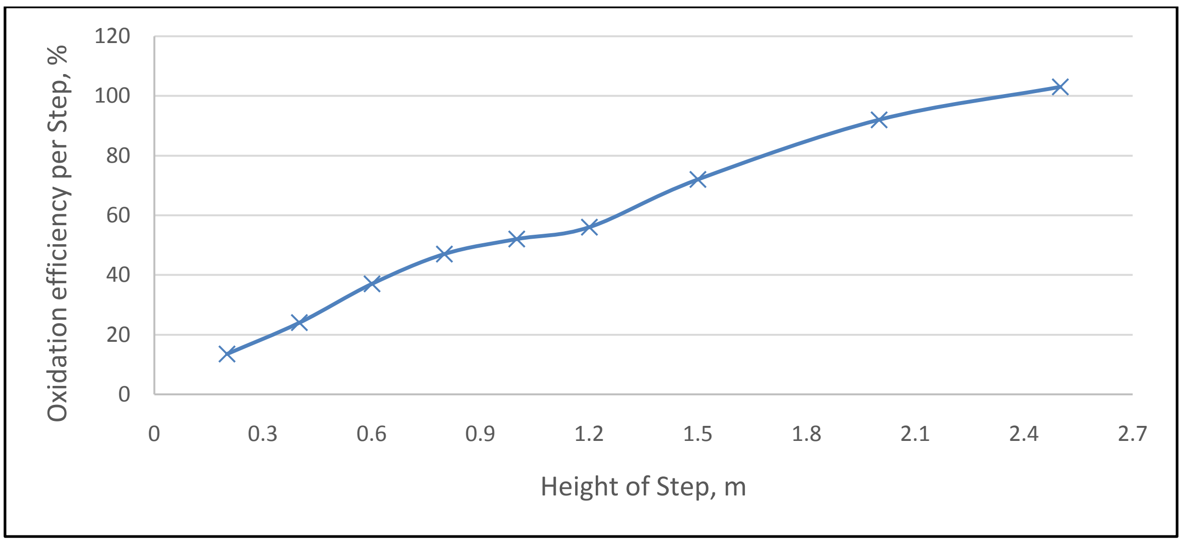


**Figure (2) Oxidation efficiency per step with the step height**

Oxygenation rate of ferrous iron is proportional to iron concentration and is strongly influenced by pH. Figure (3) shows the variation of the concentration of iron with time at different values of pH. It shows also that the rate of decreasing of that concentration depends on the pH level. The higher the value of the pH, the higher the rate of reduction in iron concentration would be. Figure (3) shows the decrease of iron with different pH values. The concentration of iron is 1.95 mg/L (35 * 10-6 mole/L). This concentration may decreased to allowable concentration with different pH values 6.59, 6.84, 6.96, 7.02 and 7.26. The concentration of iron is reduced to 0.3 mg/L (allowable concentration) after 10 minutes with pH 7.26. Figure (3) illustrates the increase of pH value, the decrease of iron concentration in a short time. The reduction would take longer time when pH deviate to more acidity values. This also explained as given by (Stumm and Lee,1961).

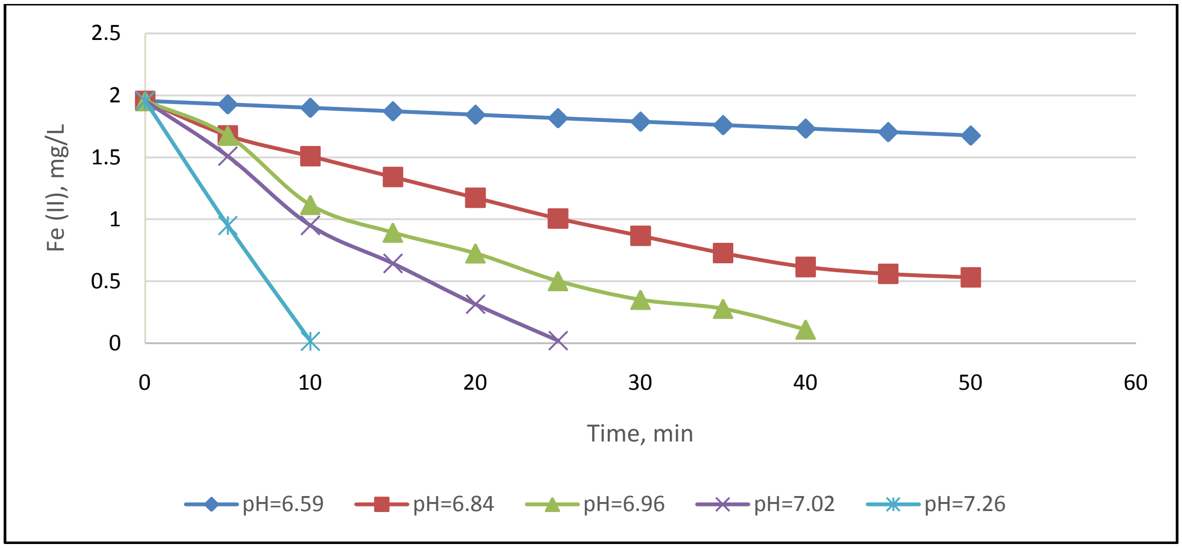


**Figure (3) Oxygenation rate of ferrous iron is proportional to Fe(II) strongly influenced by pH**

About 0.14 mg of oxygen is required for the oxidation of 1 mg of iron (II). A low pH will decrease the reaction rate, a high pH will increase the reaction rate. In case the pH of the groundwater is low, the pH has to be increased and an aeration step will be chosen that removes a lot of CO2. This will result in a higher pH and thus a higher oxidation rate.

**Figure (4)** shows the increasing of oxidation efficiency with time and pH .Figure (4) shows the influence of pH on the oxidation rate. It also illustrates the highest oxidation efficiency of iron at pH=8. Iron is removed after 60 sec compared to the corresponding time at pH=7. This also explained as given by (K.Teunissen, 2007).

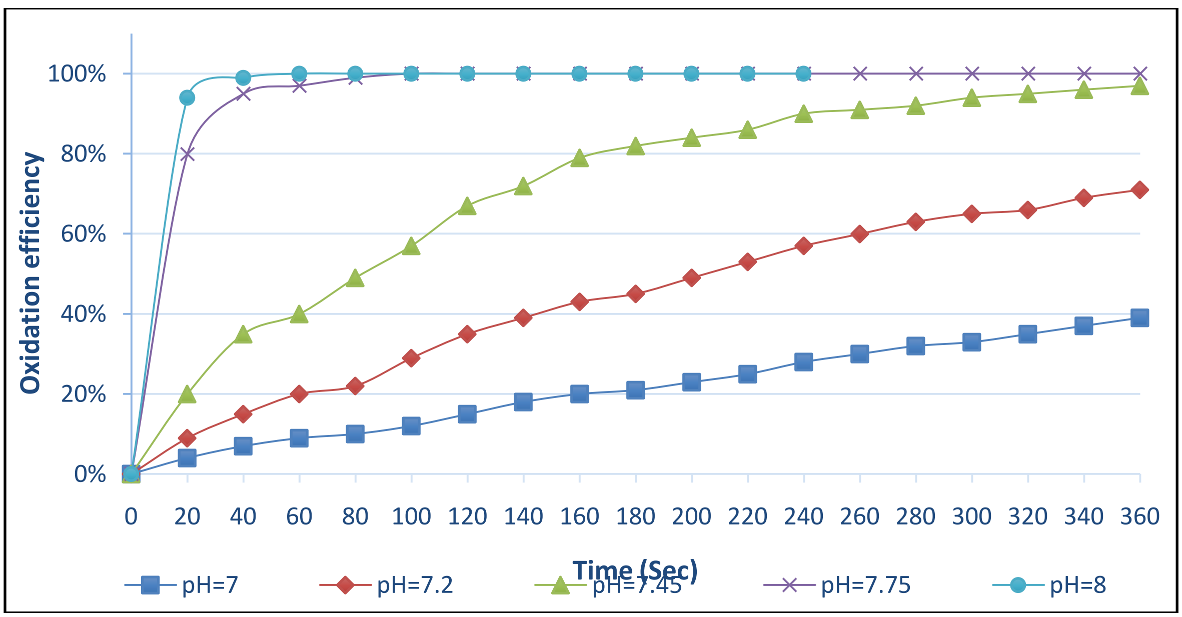


**Figure (4) Oxidation efficiency of iron as a function of time at different pH values**

**Figure (5)** shows the observed aeration efficiency values as affected by wind speed for the six different flow rates 10, 20, 30, 40, 50 and 60 m3/hr. The results indicated that flow rate and wind speed are important parameters influencing the aeration efficiency. The aeration efficiency increased with the increase of the wind speed and flow rate. This can be explained that higher wind speed increase the turbulence which lead to greater bubble penetration into the groundwater layer. It is evident from figures (5) that there is no significant wind effect on the aeration efficiency for wind speed below 4 m/sec, while higher wind speed (4 m/sec to 9 m/sec) increases the aeration efficiency similar to the findings of Yu and Hamrick (1984).Figure (5) illustrates that for a flow rate of 60m3/hr, the aeration efficiency increases from 27% to 35% for a wind speed increase from 1.3 m/sec to 4.2 m/sec, while it increases from 35% to 55% for a wind speed increase from 4.2 m/sec to 7.7 m/sec. For a flow rate of 10 m3/hr, the aeration efficiency increases from 5% to 14% for a wind speed increase from 1.3 m/sec to 4.2 m/sec, while it increases from 14% to 30% for a wind speed increase from 4.2 m/sec to 7.6 m/sec.

## CONCLUSION

Iron concentration reduction is mainly affected by pH and contact time. Iron concentration reduction is mainly affected by pH, time, atmospheric temperature, water temperature, flow rate, wind speed, and design of aerating system. Engineering treatment is feasible in the range of pH from 6.9:9.Required air for oxidation increases as temperature and flow rate. As vertical steps increases, this would imply the increase of DO in water. Height of step of one meter can easily treat the concentration of ferrous in ground water. As number of vertical steps increases, oxidation efficiency will increase and a number of six steps would be satisfactory. Turbulence of air with high speed would increase oxidation efficiency. Instead of some well-known chemical treatments, an engineering treatment is used in resolving high iron concentration in groundwater. More research has to be done to design a cascade aerator that is highly efficient to benefit the powers of the gravity that is not only cheap, but also free and flexible.

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