Dissolved Iron Oxidation in Inclined Aerator

Bibhusa Mishra, Iswar Man Amatya

Department of Civil Engineering, Central Campus - Pulchowk, IOE, Tribhuvan University

Corresponding Email: bibhusachhetri@yahoo.com, iswar@ioe.edu.np

Abstract: Aeration is simple water treatment unit for removal of dissolved iron from groundwater. High concentration of iron content in ground water source is one of the main undesirable water qualities in Kathmandu valley. Therefore, an attempt was made to reduce higher dissolved iron concentration only by aeration followed by sedimentation using corrugated sheet. A small scale gravity inclined aerator was built which aerates water by natural gravity flow down an inclined, transversely corrugated surface. A study was carried out for angle of inclination 5° to 50° with an interval of 5° and 60° also, at different flow rates of 0.06, 0.08 and 0.1 lps respectively with reference to dissolved iron, contact time and dissolved oxygen.

The study with inclined aerator revealed that the maximum dissolved iron oxidation rate was 3.31ppm (34.66%) for discharge 0.06lps. Similarly the minimum oxidation rate was noted 0.29 ppm (3.04%) for discharge 0.1 lps. For angle 50° and 60° dissolved iron oxidation rate was 3.00ppm (31.31%), 2.48ppm (25.79%), 2.19ppm (22.84%) and 2.54ppm (26.52%), 2.07ppm (21.53%), 1.87ppm (19.55%) for discharge 0.06, 0.08 and 0.1 lps respectively.

The dissolved oxygen was also observed 6 mg/l for 45° at lower discharge of 0.06 lps whereas the effectiveness declines to 1.94 mg/l for 5° at discharge 0.1 lps. The dissolved oxygen rate decreases above angle 45°. The results showed that the dissolved iron oxidation rate was highest at the lower discharge of 0.06 lps for angle 45°. The optimum angle of inclination for discharge 0.06 lps was found to be nearly 35°, for discharge 0.08 lps the optimum angle was nearly 31° and for discharge 0.1 lps, the optimum angle was found to be around 28°.

Keywords: iron concentration, inclination, oxidation, dissolved oxygen, and discharge

1. Introduction

1.1 Background

Water is one of the inevitable components in every day's life, which is not only used to cook food but also to drink and clean. In accordance to World Health Organization (WHO) that 97.5 percent of water on the earth is salty and the remaining 2.5 percent is fresh water. It also indicated that 70 percent of the fresh water is frozen in the polar icecaps and the other 30 percent is either as soil moisture or in underground aquifers. This leads to an estimate of less than 1 percent of the world's fresh water is readily accessible for direct human use (G.Shanmugam.et.al, 2004).

Water also has become a serious problem for the people of Kathmandu both in terms of quantity and quality due to rapid growth of population and urbanization .The present drinking water demand in Kathmandu is 320 MLD and Kathmandu Upatyeka Khanepani Limited (KUKL) is able to supply only 151 million liters daily in wet season whereas the supply is only 80-90 MLD during the dry period and the annual growth in water demand is 6 MLD (NWSC, 2010).

Available source of water i.e. groundwater of the Kathmandu valley (KTM) generally contains large amounts of iron, manganese, ammonium, suspended solids, etc. Concentration of iron is 0.3mg/l to 7.4mg/l, (JICA, 1990).

The maximum concentration of iron noted in Kathmandu valley is 11.01mg/l and minimum concentration is 0.12mg/l (Gharana, 2009). But as per Nepal water quality standard value and WHO Guideline, the limiting value of iron concentration for human health and domestic use is 0.3 mg/l. Excess amount of iron concentration may cause problems like reddish or brown stains on clothes, deposits in the pipes and leads blocking of pipes, damage on plumbing fixtures and become unpleasant in taste. The presence of iron in excess quantities will produce gastrointestinal disturbances (Jha,2009). So, its removal is quite significant to minimize its adverse effect.

Though the aerators followed by slow sand filter, pressure filter, roughing filter, settling tank; one of these or combination of two or more of these options has been seen in Valley (Jha, 2009). Design parameters like inclination and required length are not clearly mentioned.

2. Objectives of the Study

The objective of study work is to determine the dissolved iron oxidation rate in inclined aerator focused

- to determine oxygen transfer with respect to angle of inclination.

- to determine dissolved iron oxidation for various discharge condition and contact time.

3. Literature Review

Gas transfer for aerators is governed by Two-Film Theory (developed from Fick's Law of diffusion) that is accepted as a valid interpretation in which a gas dissolves into a liquid. The theory reasonably postulates the resistance to movement between the phases initially proposed by Lewis and Whitman in 1924 (Howard.et.al, 1985).

In 2000, Agrawal conducted comparative study of aeration (spray and cascade aerator). The study mainly focuses on effect of mesh sizes and sprays heights in spray aeration and for rise and tread ratio for cascade aerator. (Agrawal,2000)

In 2009, Bidur Jha conducted study on aeration using geo-textile. Study of aeration unit was carried out with reference to turbidity, total iron, dissolved oxygen and pH for tray aerator and aerator with geo-textile for discharge of 0.1 lps, 0.15 lps, 0.20 lps, 0.25 lps and 0.3 lps for detention time of 30 minutes for sedimentation. The geo-textile was used to increase the contact time for aeration.

3.1 Iron in Groundwater

Dissolved iron in groundwater supplies is a common problem. The recommended level of concentration as per WHO is < 0.3 mg/l. The problems created by high iron concentrations are mainly aesthetic. Water containing more than 0.3 mg/l of iron will cause yellow to reddish-brown stains of plumbing fixtures or almost anything that it contacts. If the concentration exceeds 1 mg/l, the taste of the water will be metallic and the water may be turbid.

Iron (III) compounds are not dissolving in water as long as there is oxygen present. In anaerobic condition, insoluble iron (III) is converted to soluble iron (II), which may be leached away. High amounts of iron (II) in groundwater are due to a limited amount of dissolved oxygen and a high level of carbon dioxide is present. However, in river water that is well aerated, iron is always present as insoluble (suspended) iron (III). Oxidation of ferrous iron is expected to occur rapidly at pH values exceeding 7.2 (Ghosh et al., 1966).

3.2 Inclined gravity aerator

In inclined aerators, the water is allowed to flow downward over an inclined surface which causes the water to fall in thin layers from one level to the other. This result in increasing the area-volume ratio and the exposure time for mass transfer. These aerators are used mainly for gas transfer. The velocity can be calculated by using Manning's equation as in Eq.1.

$$V=\frac{1}{N}R^{2/3}S^{1/2} \qquad \text{Eq. 1.}$$

The time of contact for inclined aerator can be calculated as in Eq.3.2.

$$t = L/V \qquad \text{Eq. 2.}$$

Where,

V= Velocity of flow, m/s

N= Manning's coefficient,

S= slope

t = time of contact, sec

L= length of aerator, m

The Eq. 1 shows that velocity and slope are directly proportional i.e. with increase in angle of inclination, velocity also increases. Whereas Eq. 2 shows that with increase in velocity, time of contact decreases.

4. Methodology

The research focuses on the aeration process to determine the iron oxidation for inclined aerator using corrugated sheet with the expectation of providing more contact time. The iron was measured after sedimentation of 30 minute at outlet water. The iron content before and after sedimentation was measured. The aeration followed by sedimentation was expected to oxidize more iron. Discharge was selected as mentioned in literature review. The study mainly focuses the angle from 5° to 45° and study was also carried out for 50° and 60° angle for the limited time period of 10 days, only to check the trend of iron oxidation above angle 45°.

Experimental Setup

The experimental model was set up including the provision of corrugated sheet with the expectation to improve the efficiency of oxygen absorption during the aeration so that maximum dissolved iron can get oxidized.

In order to accomplish the work throughout the entire study period:

- The study was conducted with 5° interval for angle of inclination 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° and 45°.The study was conducted for angle 50° and 60° also to check the trend of iron oxidation.
- Water from inlet and outlet of the aerator was collected for the study.

- Water sample from the outlet was collected after 30 minutes of sedimentation.
- The discharge of water was maintained at 0.06 lps, 0.08lps and 0.1lps.
- The total area of inclined corrugated sheet is 1m^{2}. The design details of aeration unit are presented in Table 1. The configuration of inclined aerator is shown in Figure 1.

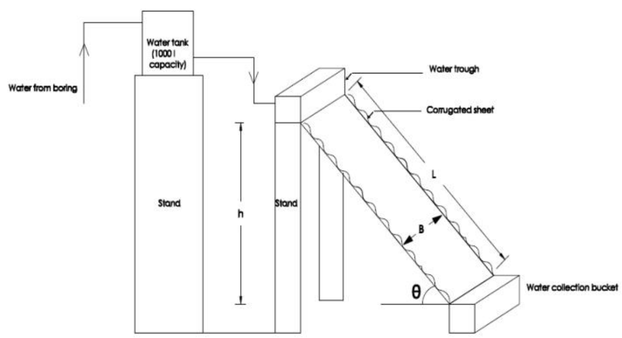

Figure 1: Schematic diagram of experimental model

Table 1: Design detail of aerator used for research

S.N.	Angle of Inclination (θ)	Height (h) (m)	Length (L) (m)	Width (B) (m)
1	5	0.174	2	0.5
2	10	0.347	2	0.5
3	15	0.517	2	0.5
4	20	0.684	2	0.5
5	25	0.845	2	0.5
6	30	1.000	2	0.5
7	35	1.147	2	0.5
8	40	1.286	2	0.5
9	45	1.414	2	0.5
10	50	1.532	2	0.5
11	60	1.732	2	0.5

The analysis was done as per the methods described in Standard Methods (Arnold et.al, 1992).

5. Results and Discussions

5.1 Iron Concentration of Influent and Effluent

The influent and effluent iron concentrations were measured for all discharges 0.06 lps, 0.08 lps and 0.1 lps at different angle of inclination. The details of measured concentration and results obtained have been presented in Figures 2, 3 and 4. Influent iron concentration was found to vary from 9.28 ppm to 9.85 ppm for 5° to 45°. Effluent iron concentration varied from 6.07 ppm to 9.54 ppm.

For discharge of 0.06lps and angle of inclination 5°, 10°,15°, 20°, 25°, 30°, 35°, 40° and 45°, average effluent iron were found to be 9.16, 9.04, 8.66, 8.46, 8.19, 7.98, 7.40, 6.82 and 6.25 ppm respectively. And for angle 50° and 60°, effluent iron concentration are 6.59 and 7.05 ppm respectively results are shown in Figure 1. Influent and effluent iron concentrations followed a linear path.

In Figure 1., the difference in effluent iron concentration is observed more above angle 30° than below 30°. And for angle 50° and 60° the effluent iron concentration comes more than that of angle 45°. So, angle of inclination below angle 30°and above angle 45°does not seems to be effective for inclined aerator.

For discharge 0.08 lps, effluent iron concentrations were 9.22, 9.05, 8.76, 8.47, 8.27, 7.99, 7.60, 7.21 and 6.83 ppm respectively for angle 5° to 45° and for angle 50° and 60° are 7.12 and 7.53 ppm respectively which are shown in Figure 2.

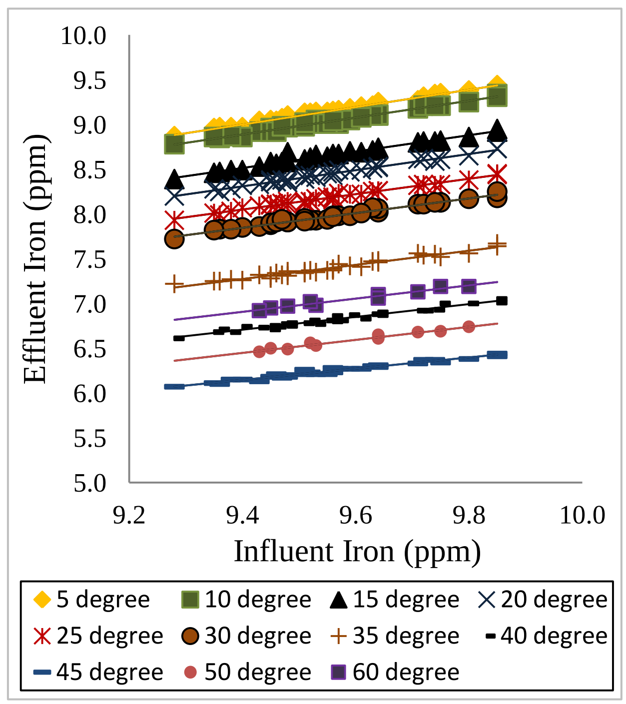

Figure 2: Iron Concentration for Discharge 0.06 lps

In Figure 2, the influent and effluent iron concentration followed a linear path with the more difference in effluent concentration above angle 30°, whereas effluent concentration has less difference below angle 30°. Also the difference in effluent concentration above angle 45° is more. Thus angle between 30° to 45° was observed more effective.

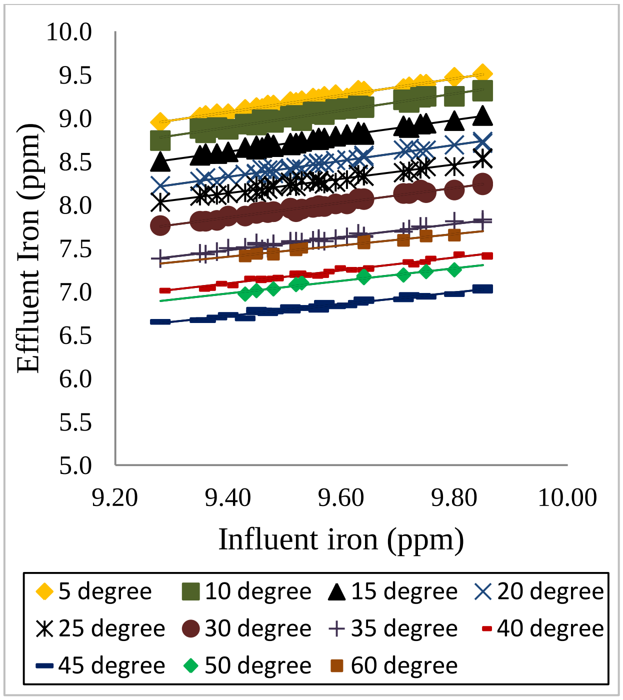

Figure 3: Iron Concentration for Discharge 0.08 lps

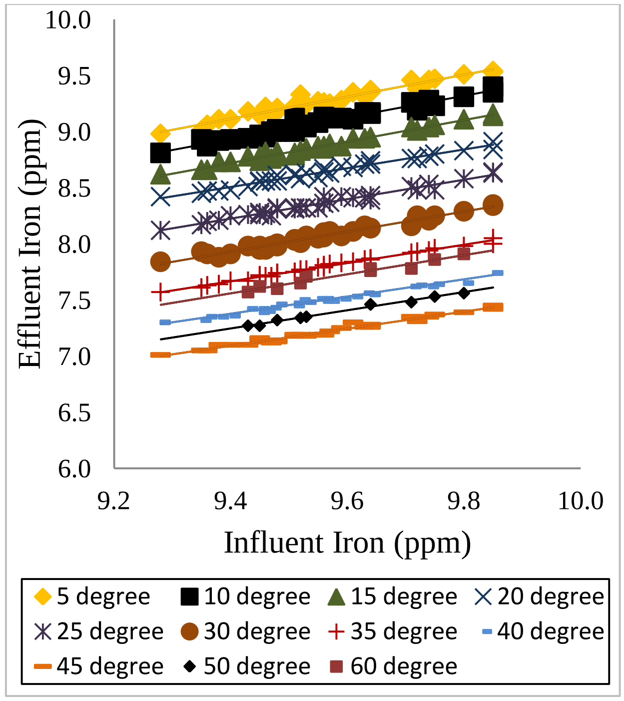

Figure 4: Iron Concentration for Discharge 0.1 lps

Similarly for discharge 0.1 lps, effluent iron concentration were 9.27, 9.09, 8.88, 8.64, 8.37, 8.07, 7.80, 7.50 and 7.21 ppm respectively for different angle of inclination that varies from 5° to 45°. Whereas for angle 50° and 60°, the effluent concentrations are 7.40 ppm and 7.72 ppm. The results are shown in Figure 3. Here also the angle effectiveness is seen between 30 ° to 45°.

Thus the Figures 2-4 showed that concentration of dissolved iron at effluent decreases compared to influent iron for different angle of inclination at various discharge condition. The concentration of dissolved iron in influent for 5° to 60° was found to vary from 9.28 to 9.85 ppm during the study period. The concentration of dissolved iron in effluent water was seen quite higher than the guideline values and unacceptable for consumption.

Again talking about dissolved iron concentration at outlet, the results showed that average effluent iron concentration for discharge 0.06 lps is 6.25 ppm and for discharge 0.1 lps is 7.21 ppm at 45° and at 5° the results obtained are 9.16 ppm and 9.27 ppm respectively for 0.06 lps and 0.1 lps. So, the concentration of dissolved iron at effluent is decreasing as the discharge decreases. For all three discharge conditions in inclined aerator, the relation of influent iron concentration with effluent iron concentration was found to follow a linear pattern.

Similarly in case of angle 50° and 60°, the relation of influent and effluent iron also follows the linear trend. The average effluent concentration at 0.06 lps is 6.59 ppm and 7.05 ppm and at 0.1 lps is 7.40 ppm and 7.72 ppm respectively for angle 50° and 60°. Though with decrease in discharge the effluent iron also seems to decrease but the effluent iron concentration at 50° and 60° was found to be more compared to angle 45°. Thus angle between 30° and 45° was observed effective during the study period.

5.2 Iron Oxidation after Aeration

The effect of inclined aerator for dissolved iron oxidation at different angle i.e. 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50° and 60° for various discharge 0.06 lps, 0.08 lps and 0.1 lps were studied before and after 30 minutes of sedimentation time. The total iron concentration values are seen lesser than that of dissolved iron after 30 minutes of sedimentation. So, the results obtained for dissolved iron concentration are only considered after 30 minutes of sedimentation because here the suspended iron was settled out and gave more percentage of dissolved iron oxidation and are presented in Figure 5, 6 and 7.

The dissolved iron oxidation rate were 0.41 ppm(4.25%), 0.52 ppm(5.43%), 0.90 ppm (9.45%), 1.11 ppm(11.57%), 1.37ppm(14.35%), 1.58 ppm(16.57%), 2.1ppm(22.58%), 2.74 ppm(28.66%), 3.31 ppm(34.66%), 3.00 ppm(31.31%) and 2.54 ppm (26.52%) for discharge 0.06lps at angle 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50° and 60° respectively. The results are presented in Figure 5.

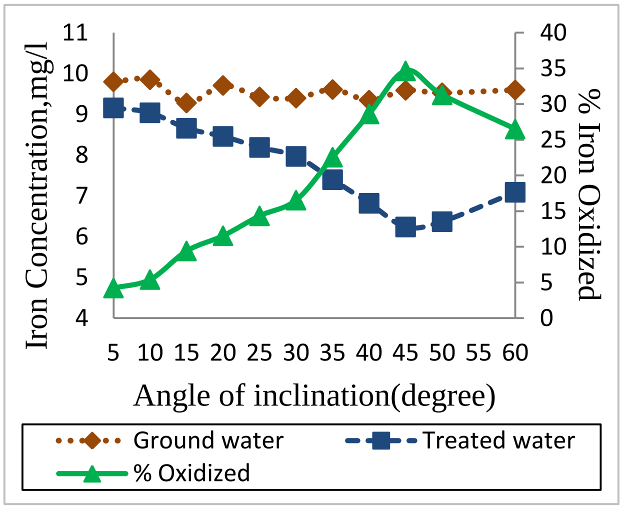

Figure 5: Profile of Iron Concentration in Ground water, Treated water and Percentage of Iron Oxidation for Discharge 0.06 lps

Similarly, dissolved iron oxidation rate for discharge 0.08 lps at angle 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50° and 60° were 0.34 ppm(3.54%), 0.51 ppm(5.35%), 0.80 ppm(8.37%), 1.09 ppm(11.42%), 1.29 ppm(13.54%), 1.57 ppm(16.44%), 1.96ppm (20.51%), 2.35 ppm(24.55%), 2.73 ppm(28.58%), 2.48 ppm(25.79%) and 2.07ppm(21.53%) respectively. The results are shown in Figure 6.

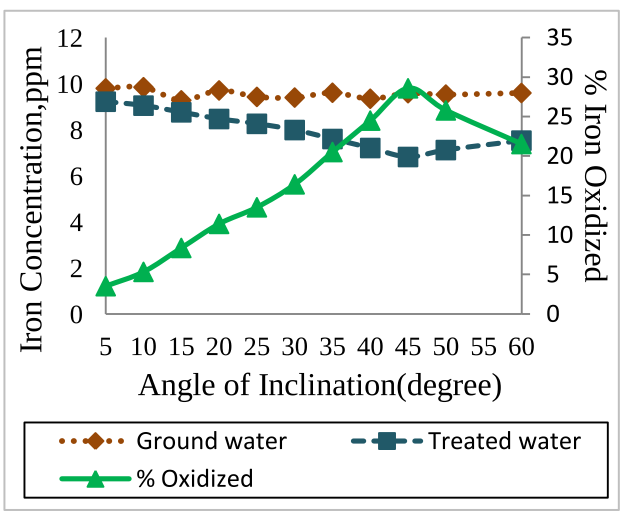

Figure 6: Profile of Iron Concentration in Ground water, Treated water and Percentage of Iron Oxidation for Discharge 0.08 lps

Also dissolved iron oxidation rate for discharge 0.1 lps at 5° to 60° angle were 0.29 ppm(3.04%), 0.47 ppm(4.92%), 0.68 ppm(7.16%), 0.92 ppm(9.66%), 1.20 ppm(12.51%), 1.49 ppm(15.56%), 1.76 ppm(18.45%), 2.06 ppm(21.55%), 2.35 ppm(24.55%), 2.19 ppm(22.84%) and 1.87 ppm(19.50%) respectively. The results are shown in Figure 7.

The results show that the dissolved iron oxidation was highest (34.66%) at the lower discharge of 0.06 lps at angle of inclination 45° whereas lowest was 3.04% at 5° angle for discharge 0.1lps. Similarly the dissolved iron oxidation rate decreases at 50° and 60° angle for all discharge condition than at 45°.

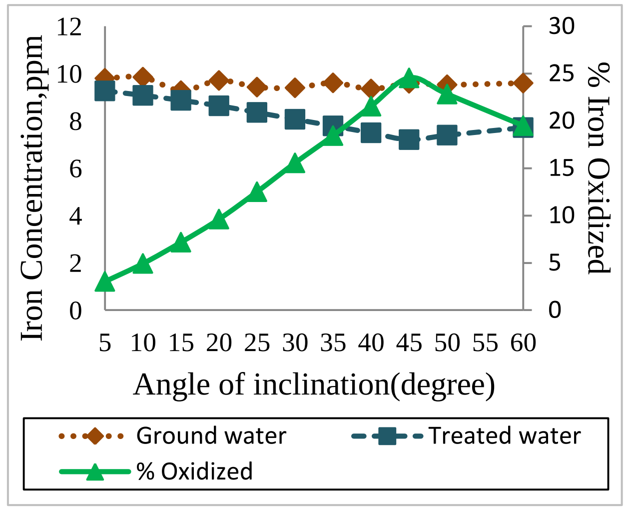

Figure 7: Profile of Iron Concentration in Ground water, Treated water and Percentage of Iron Oxidation for Discharge 0.1 lps

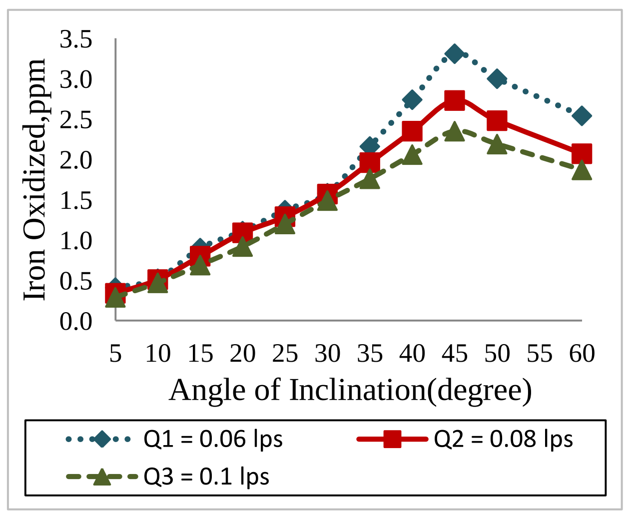

Figure 8: Iron Oxidation at Different Angle of Inclination

Figure 8 shows that oxidation rate increases slightly till 30° and from 30° to 45° dissolved iron oxidation rate increases abruptly. Again after 45° oxidation rate decreases abruptly and at 0.06 lps, oxidation rate from 30° to 45° seems quite good compared to discharge 0.08 lps and 0.1 lps and best angle is achieved where a balance between contact time and contact area is achieved.

5.3 Time of Contact in Inclined Aerator

The influent ground water was allowed to flow down the surface of inclined aerator. The time of contact was calculated theoretically and also observed in the field as well. The values of contact time calculated theoretically and observed in the field are presented in Table 4.1 up to angle 60°. The time of contact in the field was measured using stop watch from the time it starts to flow till it travels the full length of aerator. The difference in theoretical and observed contact time was due to additional height of fall and to some extent it may be due to Manning's roughness coefficient because exact value of coefficient was not known. So, the value was taken of that of corrugated metal which is 0.022 as well as there may be other constraints too. The theoretical contact time is denoted by (t_{th}) and observed contact time is denoted by (t_{obs}) in Table 2.

Table 2: Theoretical and observed time of contact for different discharge

S.N	Angle (θ)	Q=0.06 lps		Q=0.08 lps		Q = 0.1 lps	
		t_{th}(sec)	t_{obs} (sec)	t_{th} (sec)	t_{obs} (sec)	t_{th} (sec)	t_{obs} (sec)
1	5°	1.158	1.32	1.058	1.29	0.989	1.15
2	10°	0.931	1.11	0.849	1.09	0.792	0.93
3	15°	0.817	0.98	0.744	0.93	0.693	0.82
4	20°	0.758	0.93	0.690	0.89	0.643	0.76
5	25°	0.698	0.87	0.634	0.84	0.590	0.70
6	30°	0.655	0.82	0.593	0.79	0.551	0.66
7	35°	0.624	0.75	0.564	0.72	0.524	0.62
8	40°	0.593	0.68	0.536	0.61	0.496	0.56
9	45°	0.551	0.59	0.495	0.55	0.457	0.48
10	50°	0.538	0.54	0.482	0.48	0.445	0.45
11	60°	0.525	0.52	0.455	0.46	0.428	0.43

5.4 Relation of Observed Time of Contact, Iron Oxidized and Angle of Inclination in Inclined Aerator

Firstly, the observed contact time was noted during the study period and was found to be greater than theoretical contact time. Then the sample for influent ground water and effluent ground water are taken to know the percentage of dissolved iron oxidation at different angle of inclination.

For discharge 0.06 lps, observed contact time for 5 ° angle was 1.32 second and for 60° was 0.52 second. And the dissolved iron oxidation rates are 4.25 % and 26.52 % respectively for 5° and 60° angle. That means with increase in inclination dissolved iron oxidation rate increases though contact time decreases. The results are shown in Figure 9.

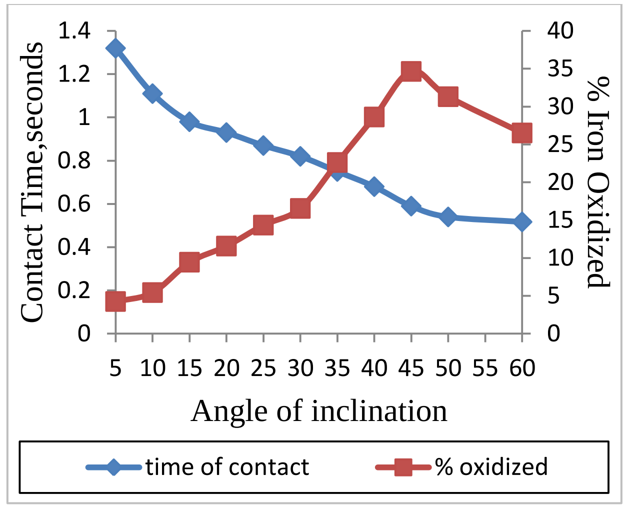

Figure 9. Iron oxidation with respect to contact time for discharge 0.06 lps

For discharge 0.08 lps, the contact time for 5° angle was 1.29 second and for 60° was 0.46 seconds. And the dissolved iron oxidation rates are 3.54 % and 21.53% respectively for 5° and 60° angle of inclination. The results are presented in Figure 10.

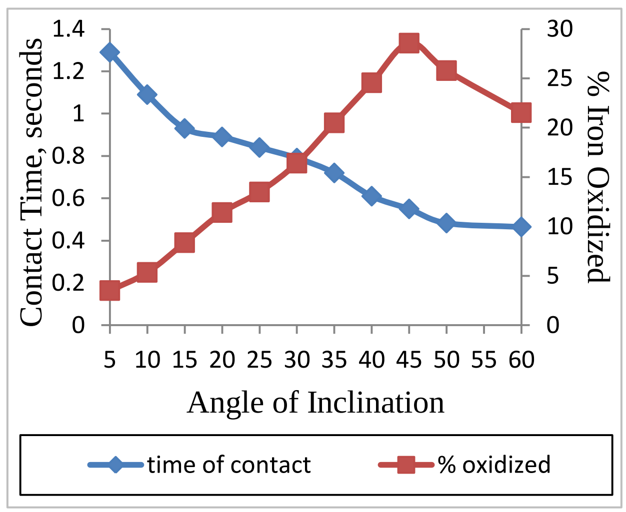

Figure 10: Iron oxidation with respect to contact time for discharge 0.08 lps

Similarly, for discharge 0.1 lps, the contact time for 5° angle was 1.15 second and for 60° was 0.43 seconds. And the iron oxidation rates are 3.04 % and 19.5% respectively for 5° and 60° angle of inclination. The results are presented in Figure 11.

Thus, concluded that the optimum angle of inclination for discharge 0.06 lps was found to be nearly 35°. Similarly, for discharge 0.08 lps the optimum angle was nearly 31° and for discharge 0.1 lps, the optimum angle was found to be around 28°.

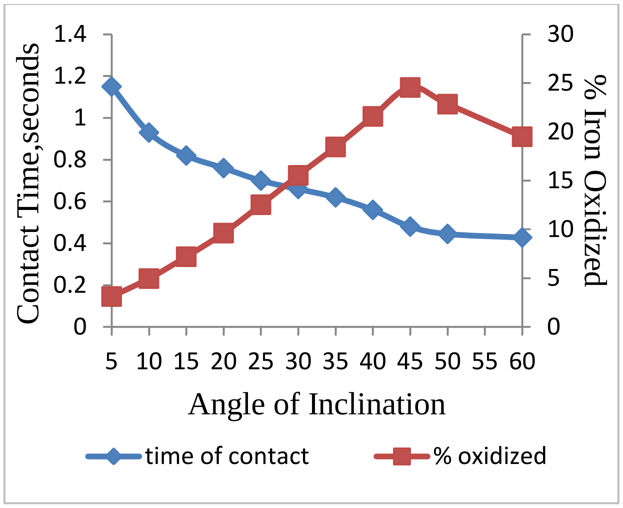

Figure 11: Iron oxidation with respect to contact time for discharge 0.1 lps

The results shows that lower discharge is effective in dissolved iron oxidation because at lower discharge time of contact is more compared to higher discharge, so that air and water can get maximum exposure to get dissolved oxygen. And also angle from 30° upto 45° was observed to be effective in dissolved iron oxidation rate for discharge 0.06 lps and 0.08 lps. And for discharge 0.1 lps the optimum angle observed was below 30° but below 30° the oxidation rate results not that good compared to above 30°.

Also the experiment shows that dissolved iron oxidation rate will not go on increasing with increase in angle of inclination. During the study, when the ground water was allowed to flow at angle above 45°, the rate of oxidation decreases as velocity is faster and contact time is lesser, thus exposure time required for ground water to entrap oxygen is not sufficient. The dissolved iron oxidation rate again decreases below 30° and at lower angle velocity being too less, aeration occurs is almost as surface aeration only. Though time of contact is more at 5° but the experiment shows that contact time is not only the governing factor for aeration. It is also governed by contact area that water comes in contact with.

There is one optimum point where dissolved iron oxidation rate reaches maximum and beyond that point it again declines. And the optimum angle exists where a balance between contact time and contact area is achieved.

6. Conclusions

On the basis of observation and analysis carried out during the study, the following conclusions have been drawn.

1. The average dissolved iron oxidation were found to be 4.25%, 5.43 %, 9.45%, 11.57%, 14.35%, 16.57%, 22.58%, 28.66% and 34.66% for discharge 0.06lps. Similarly, dissolved iron oxidation rate for discharge 0.08 lps were 3.54%, 5.35%, 8.37%, 11.42%, 13.54%, 16.44%, 20.51%, 24.55% and 28.58% respectively. Also iron oxidation rate for discharge 0.1 lps were 3.04%, 4.92%, 7.16%, 9.66%, 12.51%, 15.56%, 18.45%, 21.55% and 24.55% respectively for angle 5° to 45°. Whereas for angle 50°, the average dissolved iron oxidation for same discharge conditions are 31.31%, 25.79% and 22.84% and for angle 60°, it was 26.52%, 21.53% and 19.50% respectively.
2. Thus increment in dissolved iron oxidation for discharge 0.06 lps was by 41% with respect to 0.1 lps and again increment for discharge 0.08 lps was by 16% with respect to0.1 lps for angle 45°.
3. There was slightly increment in rate of dissolved iron oxidation below 30°.The oxidation rate abruptly increases from 30° to 45° and again it declines. That means the effective angle lies between 30° to 45°.
4. The optimum angle of inclination for discharge 0.06 lps was found to be nearly 35°, for discharge 0.08 lps the optimum angle was nearly 31° and for discharge 0.1 lps, the optimum angle was found to be around 28°.
5. Only by sedimentation followed by aeration, iron content cannot be reduced to permissible value. But, definitely cost required for chemicals can be reduced.

Acknowledgement

The authors are grateful to the MSc in Sustainable Water Sanitation Health and Development, Norwegian NOMA program, Pulchowk Campus, IOE, TU, Nepal for providing the part of the financial support necessary for this study.

References

Agrawal.B.2000.Comparative study of aeration. Thesis No. 054/EE/05

Arnold E. Greenberg, et al. 1992, Standard Method for Examination of Water and Waste Water, 18th edition. Draft Guidelines for Drinking water Quality Management for New-Zealand, October 2005, pp. 3-66.

Gharana.S.2009. Determination of gas transfer coefficient for tray aerators. Thesis No. 063/MSE/r/308/148.

Ghosh, M.M,O' Connor, J.T. and Engelbrecht,R.S.,1966, Journal, Precipitation of iron in aerated ground waters, Sanitary Engineering Division, American Society of Civil Engineers,pp.92,199.

Howard S. Peavy, Dolnald R. Rowe, George Tchobanoglous, 1985, Environmental Engineering, McGraw-Hill Book Company, Singapore, pp.66, 70.

Jha.Bidur, 2009, Iron removal by aeration with geo-textile. Thesis No.063/MSE/r/303/147.

JICA, 1990, Final Report, Groundwater Management Project in the Kathmandu Valley, pp. 83-85.

Modi, P. N., 2006, Water Supply Engineering, Standard Book House, Delhi, pp. 587.

NWSC, 2010, Draft on Drinking Water Quality Standards, Kathmandu ,Nepal.

Shanmugam. G, Jawahar.G.S., S.Ravindran,2004. Review on the uses of appropriate techniques for arid environment. International conference of Water Resource and Arid Environment, pp 2.