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REACHING THE UNREACHED: CHALLENGES FOR THE 21ST CENTURY

Electrolytic treatment of turbid water in package plant

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THE SURFACE WATER from rivers very often contains suspended clay, sand and lime particles, various organic dissolved solids and other materials, which manifest themselves as turbidity, dissolved solids and other chemical parameters. This water has to be treated properly to make it suitable for drinking and domestic use. The conventional treatment method consists of addition of metal salts (aluminium, iron etc.), destabilization of colloidal particles (which is called coagulation), followed by flocculation, sedimentation, filtration and disinfection. In this way the application of chemical reagents like alum, lime, soda ash etc, which are widely used in good quantity, become imperative for clarification. Finally a disinfectant like chlorine is used to make water portable.

This method of treatment has certain drawbacks like handling large quantities of chemicals, proper assessment of requirements, feeding of chemicals and production of large volume of sludge causing disposal problem and loss of water.

During recent decades research on electricity applied directly in water treatment has progressed well, making it an attractive method for coagulation or clarification of water, usually known as the electrocoagulation / electrochemical method. In this method direct current is passed through aluminium / iron plates suspended in water.

This system causes sacrificial electrode ions to move into an electrolyte. Undesirable contaminants are removed either by chemical reaction and precipitation or by causing colloidal materials to coalesce. They are then removed by electrolytic flotation, or sedimentation and filtration.

Disinfection is also accomplished by anodic oxidation. Donini at el (1988) pointed out that for electrocoagulation and aluminium salts treatment the mechanisms of coagulation were similar. The difference is mainly in the way aluminium ions are delivered. Compared to water treatment with aluminium sulphate or ferrichloride, electrochemical aluminium / ferrous iron generation has several distinct advantages. Aluminium is introduced without corresponding sulphate ions. Also there is no need for a alkalinity supply to give a reaction. By eliminating competing anions using a highly pure aluminium source, lower metal residuals are obtained and less sludge is produced (50-70 per cent). The adjustment of aluminium ion dose in the water can be done easily by manipulating the dial for control of current.

The following physio chemical reactions take place in the electrode cell:

- Anodic oxidation and cathodic reduction of impurities present in waters.
- Solution of metallic anodes, discharge and coagulation of colloidal particles.
- Electrophoresis, the passage of ions through semipermeable membranes.
- Flotation of solid particles by gas bubbles produced on electrodes.
- Precipitation of metallic ions on cathodes.
- Regeneration and concentration of acids and alkalis.
- Desalination of water.
- Other electrochemical and chemical processes.

The following electrode reactions occur in this process:

Anode: $A1^0 = A1^{3+} + 3e^-$ (1)

Cathode: $2H_20 + 2e^- = 20H + H_2$ (2)

The quantity of dissolved or deposited metal depends on the quantity of electricity passing through the water, and can be found by Faradays Law: m = KIt, where K is the electrochemical equivalent mg / c; I is the current, and t is the time of electrolysis.

Therefore

$m = 1/96500 \times A/V \times It$

where m = mass of dissolved metal

v = valency of aluminium (al +++ = 3).
A = atomic mass of aluminium (27).
I = current in amperes.
t = time in seconds.

Additionally, both the anode and the cathode will be dissolving chemically in water.

$AI^0 + 3H_2 = AL(OH)_3 + 1.5H_2 \ldots\ldots$ (3)

Pzhegorlinski et al (1987) determined the contribution of the individual reactions of equations (1) - (3). Each of these reactions was evaluated from the weight loss of the corresponding electrode and from the volume and composition of the collected hydrogen. Since both electrodes were chemically dissolving with time the current efficiency of aluminium dissolution was above 100% and was in the range of 165 per cent - 215 per cent. Higher than 100 per cent current efficiency of aluminium dissolution was also reported by others (Bozin and Mikhailov, 1990; Przhegorlinskil et al . . . 1987).

The nascent oxygen produced is a very powerful oxidizer and oxidixes metals present in water.

The nascant A1 reacts with the water to form insoluble hydroxides and the colloid destablilization process is therefore analogous to that obtained with traditional metal salts.

For complete treatment electrocoagulation is followed by the usual separation processes, i.e., sedimentation, flotation, filtration etc.

Design consideration for electrolytic cell

At the anode oxygen is evolved and at the cathode hydrogen gas is evolved in the form of gas bubbles nucleates. These grow at the electrode surface until they are large enough for buoyancy and shear forces to dislodge them. The bubbles are insulating spheres, which when accumulated between the electrodes contribute to the cell resistance which is given by KR = (1-f) / (1+f/2), Maxwell Equation, where KR = ratio of electrolyte conductivity with gas bubbles with respect to without bubbles, f = void fraction of the dispersion. To reduce the accumulation of gas bubbles in the cell gap, in practice the electrolyte flow was directed between the electrodes to sweep out the bubbles.

For shape and thickness of electrode the relation amongst maximum potential drop over the height and thickness of the electrode (anode) had to be considered. The relation can be expressed as:

V_{met}, max = $(iyL^2 / 2\delta t_a)$ iy = constant

Where

V_{met}, max = metal phase potential maximum drop along electrode.
y = direction normal to electrode surface cm
ta = thickness of planer anode.

This equation states that the maximum potential drop is proportional to the square of height (L) of electrode and inversely proportional to the thickness (td).

We had to use thicker and wider electrodes to minimise the potential drop.

From mass transfer characteristic simple design of the parallel planer electrode cell had been used. The reactant concentration was most important in our case. Narrow gaps enhanced the mass transfer characteristic and decreased ohmic loss. However, when a gas product is present, a decrease in gap results in an increase in electrolyte resistance. Therefore, the gap between the plates had to be determined considering all those factors. But from the practical consideration and field conditions this was kept at 20 mm. For design simplicity no mechanical agitation was provided. Edmondsmith (1972) has given the relation of mass transfer with current, voltage etc. from which the area of the electrodes could be arrived. With an increase of current density, water purified more quickly and completely.

Laboratory pilot model study

The design considerations were checked and evaluated in the laboratory, where an electrolytic cell consisting of 11 aluminium plates of 4" x 8" size, each in a rubber lined rectangular vessel with baffles, had been set up. The D.C. power was drawn from a rectifier through an hour run meter, for monitoring important parameters. A Jackson flame turbidity meter for turbidity, a Nephelometer for clear water turbidity, a stirrer, a pH meter, conductivity meter, alkalinity apparatus were used. The river water of various turbidities was treated in the electrolytic cell and for comparison the turbidity of decanted supernatant of electocoagulated water was measured. It was seen that pH, alkalinity and conductivity did not change after electrolytic treatment. The power consumption on average for the treatment of water varied from 0.08kwh to 0.18kwh per M3/hr. water and for quick settling of flocs rapid stirring of water for 1 minute after coagulation was necessary. It has been noticed, as expected, that the conductivity of water fell from 0.03 mho to 0.02 mho when gas bubbles saturated the water.

The electrocoagulation was found to be most effective at pH 6.5 to 7.5, and poor at high pH (>9) as well as at low pH (<5).

Description of the package plant with electrolytic cell

The package water treatment plant consisted of an electrolytic cell containing sixteen 0.8 x 0.3m size aluminium plates in parallel. The cell was rubber lined MS body. The cell was placed at the top of down-flow solid media flocculator. The flocculator was connected with the upflow tube settler chamber. The launders at the top of tube settler collected clarified water and passed it to the dual-media filter consisting of 40 cm Anthracite coal bed laid over 30 cm sand, supported over 4 layers of pea gravels of different sizes. The underdrainage system consists of manifold and laterals. The solid media flocculator had 4 layers of gravel over iron gratings at the bottom. The size and layer thickness of gravels were so chosen as to produce a tapered velocity gradient (- value 70 Sec-1 to 20 sec-1) in the direction of flow for efficient floc formation. The over all size of the plant was 1.5 x 1.2 x 2.1 m (ht) and movable D.C. was generated by a portable diesel engine driven generating set.

The plant was placed by the side of the existing 2.5 mgd capacity conventional rapid sand gravity filter of Karimganj town consisting of flash mixer, clariflocculator, rapid sand filter with lime alum and chlorine dosing arrangement. Both the plants treated the same river water. The purpose was to compare the efficacy of the package plant based of electrolytic treatment vis a vis a conventional plant. While the conventional plant ran as usual, the package plant was operated @ 1600 gallons/hour at varying turbidity load from 400-900 J.T.U. It ran for 4-6 hours/day for 25-30 days and produced sparkling clean disinfected water totally comparable with that of the conventional plant.

The package plant consisting of electrocoagulator, with depassivation circuit, coupled with a solid media flocculator capable of producing tapered gradient (patent no. 171060 Kar Sudip 1990) upflow tubesettler and downflow multimedia filter gave very good quality of water turbidity within 2 J.T.U. The chlorine produced by conversion of naturally present chloride (30mg / litre) was enough to disinfect the water. Also anodic oxidation killed the bacteria. Later on a laboratory model had proved the disinfection of water completely.

The operating cost of electrocoagulation

The operating cost of electrocoagulation mainly consists of the cost of power and cost of materials i.e. consumption cost of aluminium electrodes.

For cost calculation the average applied electric voltage on the cell VAF (Voltmeter reading across the electrocoagulation cell) and current, I, measured from time to time minutes, which was 1.73 KWh for 7200 l.per hour discharge.

Assuming an energy price of Rs 1.50 / Kwh, the consumption of pure aluminium is 8mg / litre. and consumable aluminium electrode material cost is Rs 100 / - per kg, the operating cost can be calculated as

Operating cost in rupees per hr = 1.5 x E x 1hr + Cost of Aluminium consumption

= 1.5 X 1.73 X 1+0.6 = 3.195

Therefore, the cost per 1000 litres of water = Rs 0.44 only.

The cost of chemical treatment of the same water as per chemical consumption of conventional plant — alum 100 mg / litre and lime 50 mg / litre is as follows:

Requirement of alum for 1000 litres is 100 grams. and that of lime is 50 gmams. If the cost of alum is Rs 6 / = and lime is 10 / = per kg is .6 / = 10 / = respectively, the total chemical cost for 100 mg / litre water

= cost 100 grams of alum + cost 50 grams of lime = Re. 0.06 + 0.5 = Re. 1.1

It will be seen that for small water treatment plants the electrocoagulation should be cheaper.

Conclusion

The effectiveness of electrocoagulation in the treatment of turbid water has been effectively demonstrated. The movable package water treatment plant incorporating electrocoagulation can be used under various situation. Solar energy may be utilized in small plants for small community water supply scheme. With the addition of sodium chloride the efficiency of the plant can be increased and not only clarified water but disinfected water can be obtained without addition of further disinfectant. The electrocoagulation technique is cheaper for small capacity plant. By using scrap aluminium plates we may further lower the cost. However, that extent of saving can be conclusively quantified only after careful monitoring over a long period of time.

References

Donini J.C. et. al. “The operating cost of electrocoagulation”, The Canadian Journal of Chemical Engg, Vol-72 Dec 1994 pp.1007-1012.

Brewster MD. et al, “Use of electrochemical iron generation for removing heavy metals from contaminated ground water” J. Environmental Progress, Vol-13.No.2 May 1994 pp 143-148.

Musequre P. “Electrotechnics in drinking and waste water” Electricite de France SS-8-1-6. Yorkshire Water Authority Library.

Cenkin V.E. “Electrochemical treatment of industrial waste water” Effluent and Water Treatment Journal, July 1985, pp 243-247.

Savinel R.F. “Some aspects of electrochemical reactor design” Tutorial Lectures, In Electrochemical Engg. And Tech-11 AICHE Symposium Design pp-16, 18.

Paul, A.B. “Experiment and aplication of portable package water treatment plant in Assam” Technical papers, 4th ASCEN conference of International water supply ASSO. Nov’88 pp-ABP-1-9.

Nikolodge, G et al, “Water treatment for public and industrial supply”, pp-70-72 Mir Pub. Moscow1089.

Przhegorlinskii. V.I. et al “Dissolution of aluminium electrodes in the electrocoagulation treatment of water” Khymiya i Tech. Vody 9 (2), 81-182 (1987).