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An empirical model for sedimentation of suspended solids under influence of magnetic field

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Abstract

The magnetic treatment of wastewater is an alternative simple approach by which the wastewater that need to be treated flow through a magnetic field, and consequently some of its physicochemical properties such as suspended particles changes. The primary propose of wastewater treatment is to remove the suspended and soluble organic constituents measured as chemical oxygen demand (COD) and biochemical oxygen demand (BOD) in the incoming liquid streams. The essence of flocculation process is the aggregation of suspended coagulated particles to form larger flocs amenable to separation from the suspending medium by some subsequent physical process, generally sedimentation. Using performance data from the application of magnetic field of 0.55 Tesla in circulation flowing system, empirical mathematical models were developed in this paper relating suspended solids (SS) removal efficiency to operating flow rate and retention time. The obtained experimental results showed that percent of SS removal increased with increasing magnetic exposure time at lower flow rates. The model coefficients were derived from the combined analysis of well correlated sets of data, thus giving a good indication for their possible general applicability. The analysis of experimental data also gave a relationship between SS and chemical oxygen demand (COD) removal efficiencies.

Keyword: magnetic treatment; wastewater; sedimentation; suspended particles; empirical model.

1.0 Introduction

Sedimentation is an operation in which particles or aggregates are separated from the liquid due to gravity, being probably the most important large-scale method used in wastewater treatment plant and industry. Important efforts have been made recently in order to clarify the fundamentals of the process and the performance expressions with the different variables and parameters [1]. The sedimentation process presents, as a characterizing feature, the contaminant formation of distinct zones such as of that of clarified liquid, that of free settling and that of compression, which are separated by mobile interfaces which vary as a faction of experiment time. Apparently simple, this process is based on the gravitational separation of a solid-liquid mixture; the sedimentation may be represented by continuity and momentum balance equations.

Although plain sedimentation is the oldest and one of the most widely used unit processes in sewage treatment, no satisfactory mathematical models have been developed as yet, mainly due to the complexity of the phenomena involved. Sewage contains flocculent particles, which do not have constant settling characteristics. Flocculation and settling are influenced

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by many factors such as the detailed velocity field, SS concentrations, particle size and density, and the density and viscosity of the fluid. The chemical characteristics of the particles and the fluid also affect flocculation. Random environmental factors (heat flux such as influence of magnetic field and wind action) and inlet condition often because dramatic changes to the density and velocity field, which in turn can cause major variations in SS removal. Short circuiting and circulating flow are typical examples of such changes.

In the absence of a more valid practical approach, the empirical models, sometimes called “regression models” can be helpful to the design sedimentation tanks, either directly or after calibration with pilot plant performance data. The higher removal efficiency of SS concentrations results in higher collision rates between particles under influence of magnetic field and consequently in better flocculation. However, the influence of operating flow rates in magnetic treatment, when studied on the basis hourly performance data, is often overshadowed by the random effect of the previously mentioned factors. Only when the study is carried out with averaged data over adequately long periods, several weeks at least, the random variations are smoothed out and the dependence of the SS removal efficiency, RE_S on operating flow rates (Q) in magnetic treatment becomes clear.

2.0 Experimental Setup and Methods

The samples were used for the magnetic treatment experiments at room temperature. The parameters chosen in the experiments were flow rate, pH and retention time; their ranges are given in table 1.

Table 1: Experimental parameters

Parameters	Range
Flow rate (mL/s)	0.92, 1.84, 3.68, 5.52
Retention time (minutes)	0, 5, 10, 20, 30, 40, 60, 80, 120, 150, 180, 210

The experimental set up employed magnetic field that is orientated orthogonal to the direction of flow (treated sample). The permanent magnets with 0.55 Tesla of magnetic field strengths were used in this experiment, namely type of NdFeBo (Neodymium-Ferrite-Boron). All magnets are cubic-shape rare earth permanent magnet size (50mm x 50mm x 20mm).

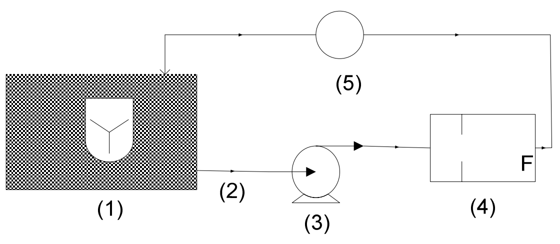

Figure 1 Experimental setup for magnetization of sample: (1) open tank with mixing (plastic, working volume 2.0 m^3), (2) circulation tube (1 cm internal diameter), (3) Circulation pump, (4) Flow rate meter, (5) external magnetic device.

The laboratory experimental equipment was shown in figure 1. The test rig with a 2 m^3 reservoir supplying a broth circulation system was constructed (1 cm internal diameter polyvinylchloride tubing).Sample flows through out the system is provided by means of a pump controlled and can be adjusted from zero to maximum of 100 mL/s. The fields were provided by permanent magnets to produce a magnet field orthogonal to the fluid flow. The sample was circulated with a constant flow rate where sample were flowing in the magnetic fields conducted under controlled laboratory conditions.

Sewage samples were collected between January and December 2003. Samples were collected in plastic container, transported to the laboratory and stored at 4°C. It was analysed for suspended solids according to Standard Methods for Examination of Water and Wastewater [2]. Samples were removed from the refrigerator and were placed for about 2 hours at about 22°C for the conditioning at room temperature. Samples were withdrawn using plastic syringe from the point located at supernatant of sedimentation column after magnetic treatment for the determination of suspended solids.

Sedimentation tanks are used in wastewater treatment for the removal of suspended solids (SS) by gravitational settling. Since the SS are largely organic in nature, this removal results in significant decrease of the sewage organic load, usually expressed in terms of biochemical oxygen demand (BOD) or chemical oxgygen deman (COD).The Removal efficiency of suspended solids was obtained using the following formula:

$$RE_S = [(Ci-Cf)/Ci] * 100 \qquad (1)$$

where Ci and Cf are the initial and final concentration of sample, respectively. Similar definitions are applied for the BOD and COD removal efficiencies RE_B and RE_C, respectively. And removal efficiency was fitting to the following formula:

$$RE = a\,(1- e^{-bT}) \qquad (2)$$

The curve fitting parameters a and b (Eq.(2)) used to describe the relationships between SS removal efficiencies and retention times.

3.0 Model Development

The SS removal efficiencies (RE_S) for the application of 0.55 T were determined at four different flow rate, at 2 hours exposure time, without adjustment of pH and retention time ranging from 5 to 210 min. The removal efficiencies as a function of retention time, at various flow rates are illustrated in Fig.2.

The effect of flow rate on the removal efficiency of particles is experimentally shown in Figure 3, where magnetic treatment experiments were conducted by varying the flow rate between 0.92 mL/s to 5.52 mL/s. The effect of flow rate on the removal efficiencies of particles followed the equation 2.

The comparison constant value *a* and *b* in the application of magnetic field 0.55 Tesla with varying flow rate between 0.92 mL/s to 5.52 mL/s shown in Table 2. The analysis results shown that constant value *a* and *b* decreased as the increasing operating flow rate in magnetic treatment. It is indicated that the ability to remove particles effective in lower operating flow rate than higher operating flow rate in magnetic treatment. As an example constant value *a* and *b* at 0.92 mL/s operating flow rate of magnetic treatment are 43.96 and 0.0002 compare to constant value a and b at 5.52 mL/s are 26.08 and 0.012. The plot constant value *a* and *b* (as *y* coordinate) to the flow rate (as *x* coordinate) as a linear trend followed the mathematic equation y = m x + c where m is a gradient and c is a constant. Parameters a and b could be related to prevailing flow rates being eqs (3) and (4) for parameters *a* and *b*

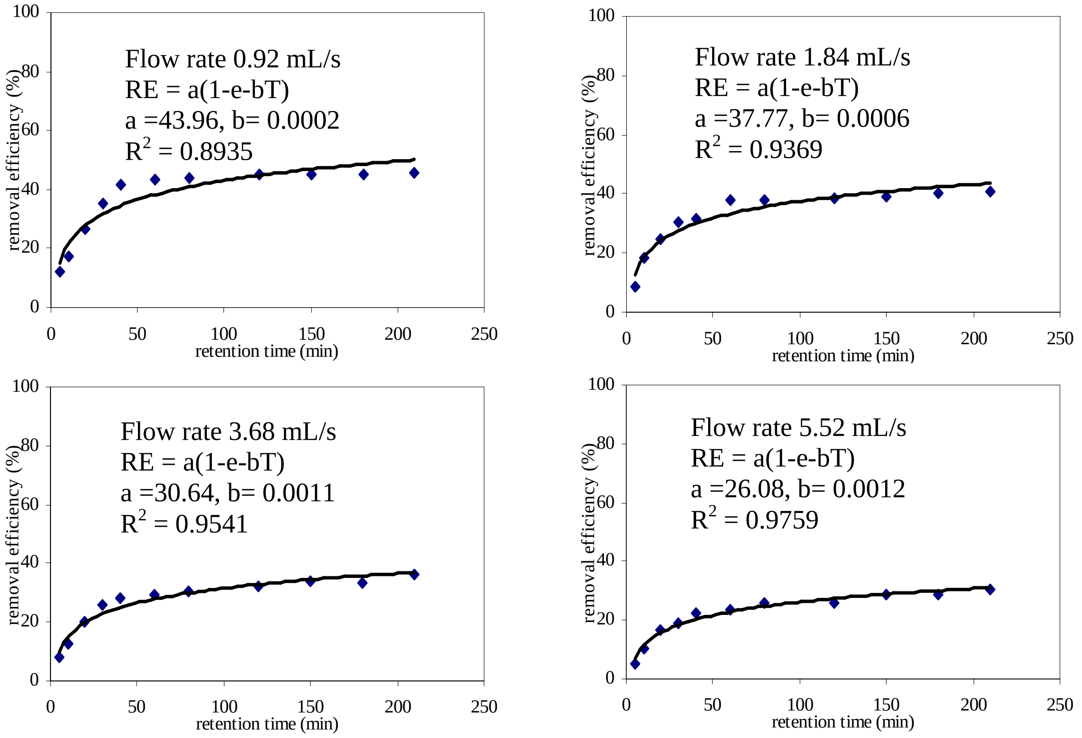

Figure 2 The comparison removal efficiencies of suspended solids by circulation flowing method using magnetic field of 0.55 Tesla at 2 hours treatment period without pH adjustment.

Table 2: Value parameters a and b (Eq (2)) for various flow rates

Flow rate (mL/s)	A	b
0.92	43.96	0.0002
1.84	37.77	0.0006
3.68	30.64	0.0011
5.52	26.08	0.0012

$$a = [-10.086 \ln(Q)] + 43.587 \qquad (3)$$

$$b = [0.0006 \ln(Q)] + 0.0002 \qquad (4)$$

Substitution of Equation (3) and (4) into Equation (2), provided an empirical model (Eq. (5)) that described the removal efficiency of SS as a function of flow rates and retention time.

$$RE = ([-10.086 \ln(Q)] + 43.587)\,(1 - e^{-T([0.0006 \ln(Q)] + 0.0002)}) \qquad (5)$$

This empirical had fitted to the entire data set of the magnetic treatment performance as function of flow rates (mL/s) and retention time (minutes). It should be noted this empirical model is based on the experimental results and conditions prevailing in this study. Despite this limitation, the model does provide a useful performance estimation of similar systems.

The comparison constant value *a* and *b*, constant values based on exposing to magnetic field, shown removal efficiencies increased as decreasing flow rate. The phenomenon exposing sample to magnetic field in the circulation flowing method caused the condition that particles exposed to the magnetic field repeatedly. This method caused strong effect trough the sample where particles exposed to magnetic field in longer exposure time period at lower flow rate. The reason is that the magnetization effect starts to wear off as the particles' magnetic memory depleted [3]. Treatment period that is applied in the treatment process reflects to the exposure time and quantity of magnetic fields that are absorbed by the particles. Longer treatment period at lower flow rate means more magnetic field quantity given to the particles thus increasing the magnetic memory and magnetization effect on the sample. Baker and Judd [4], Ifill *et al*. [5] and Fan and Cho [6] support this result of experimentation. The results show that increase exposure time to magnetic field in circulation flowing method may increase frequency of turbulation between particles in sample which cause aggregation. The aggregation may enhance the sedimentation of particles.

The phenomenon indicates that, hydrodynamic factor in circulation flowing method influence particle aggregation. Increased flow rate results in increased drag force; therefore particles are not easily aggregated or accumulated under high flow velocities. Exposing sample to magnetic field in the circulation flowing method caused the condition that particles exposed to the magnetic field repeatedly, means more particles expose to magnetic field thus increase the magnetization effect and start to wear the particle's magnetic memory. Removal efficiency of particle in magnetic treatment is strongly affected by treatment period where particles expose to magnetic field at lower flow rate; longer particles exposed to magnetic field thus increase the magnetization effect. Magnetization may enhance the collision rate among colloidal particles. Particles are then attracted and agglomerated into bigger aggregates to accelerate the settling of aggregated particles.

The experimental work in determination the effect of operating flow rate in magnetic field can be concluded that flow rate influence removing particles in sample. The results reveal that the removal efficiency of particles decreases as the flow rate is increased. Increased flow rate results increased drag force; therefore particles are not easily aggregated or accumulated under high flow velocities. Circulation flowing method in magnetic application supported by *magnetohydrodynamic* theory, when samples flows perpendicular to the impose magnetic field, a potential gradient is created, causing electric currents to flow that helps the charged particles to vibrate and collide excursively. As a result particles can move closer as the electrostatic repulsive forces have less effect on them. Thus more particles are flocculated and precipitated together. This effect is best explained as a *magnetohydrodynamic* effect [7, 8, 9].

The average RE_S and RE_C data show a good linear relationship. Regression analysis produced the following relationship:

$$RE_C = 0.7547\ RE_S - 17.92 \qquad (6)$$

with r = 0.9683 significant at a probability level higher than 99%.

4.0 Conclusions

Analysis of the performance data from lab scale magnetic treatment has shown that a simple empirical performance relationship in the form: $RE = a\,(1- e^{-bT})$ can satisfactory describe the average SS removal in the terms of operating flow rates in magnetic treatment. The coefficients a and b were found to be flow rate-dependent according to $a = [-10.086 \ln(Q)] + 43.587$ and $b = [0.0006 \ln(Q)] + 0.0002$, valid for operating flow rate 0.92 – 5.52 mL/s.

References

[1] Perez, M., Font, R., Pastor, C.1998.A Mathematical model to simulate bacth sedimentation with compression behavior.*J of Computers Chem.Eng*. **22**(11):1531-1541.

[2] APHA, AWWA and WPCF.2000.*Standard methods for examination of water and wastewater*. 21th Edition. Washington DC: American Public Health Association.

[3] Colic, M., and Morse, D. 1999. The elusive Mechanism of the Magnetic 'Memory' of Water. *J of Colloid and Surfaces A*. 154:67-174.

[4] Baker, J.S. and Judd, S.J.1996. Magnetic amelioration of scale formation. *J of Water Research*. **30** (2):47-260.

[5] Ilfill, A.S., Baker, J.S., Judd, S.J.1996.Magnetically-enhanced chemical disinfection.*J of Transaction of Institution of Chemical Engineers (part B)*, **74**(2):120-124.

[6] Fan, C and Cho, Y.I.1997.A new electronic anti-fouling technology to control precipitation fouling.*National heat transfer conference*.12:183-188.

[7] Busch, K.W., and Busch, M.A.1997. Laboratory studies on Magnetic Water Treatment and Their Relationship to a possible mechanism for Scale Reduction. *J of Desalination*.109:1-148.

[8] Goldsworthy, A., Whitney, H. and Morris, E.1999.Biological effects of physically conditioned water.*Journal of Water Resource*.33(7):1618-1626.

[9] Johan S., Fadil O., and Zularisam A.W.2004.Effect of magnetic fields on suspended particles in sewage. *Malaysian Journal of Science*.(23):141 – 148.