Influence of magnetic treatment on the improvement of landfill leachate treatment

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Abstract: Magnetic treatment is an alternative simple approach by which landfill leachate treatment could be improved. The purpose of landfill leachate treatment is to remove the Suspended Solids, Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD). Based on experiment by using circulation flowing system with a magnetic strength of 0.55 T, it was shown that the leachate quality could be improved. The results showed that the removal percentages of above 60% for SS, COD and BOD. This study concluded that magnetic technology has the potential to be used for improving the removal of SS and organic concentration from landfill leachate.

Keywords: magnetic treatment; landfill leachate; sedimentation.

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1 Introduction

Landfilling is a widely used method for the disposal of wastes from households and industries, and accepted and used in the several countries. This method generally offers lower cost of operation and maintenance when compared with others. One of the main problems with landfill management is to find efficient treatments for large quantities of leachate. Migration of leachate from landfill could be a potential source of surface and groundwater contaminants (Tchobanoglous et al., 1993). Landfill leachate is a very dark coloured liquid formed primarily by the percolation of precipitation through open landfill or through the cap of completed site. Landfill leachate contains high amounts of organic compounds, ammonia and heavy metals. Decomposition of organic waste containing solid waste may cause the water to be yellow, brown or black. Combinations of physical, chemical and biological treatments are usually used to improve the treatment efficiency of landfill leachate (Kargi and Pamukoglu, 2004). For example, coagulation followed by flocculation process is an effective way for removing high concentration of organic pollutants (Wang et al., 2002). There are many methods for leachate treatment, but those methods are employing large quantities of chemicals and energy. Instead, the focus is on eco-technological treatment methods since landfill leachate operators seek alternatives that can be applied and managed at a low cost, and can be efficient enough to comply the landfill operational requirements under the Environmental Quality Act of Malaysia.

Sedimentation is an operation in which particles or aggregates are separated from the liquid by utilising the force of gravity. It is probably the most important large-scale method used in landfill leachate treatment plant and industry. Important efforts have been made recently to clarify the fundamentals of the process and the performance expressions with the different variables and parameters (Perez et al., 1998). A characterising feature of the sedimentation process is the formation of contaminant in distinct zones, such as the clarified liquid zone, the free settling zone and the compression zone, in which all zones are separated by mobile interfaces, which vary as a fraction of experiment time. This simple process is based on the gravitational separation of a solid–liquid mixture, therefore, 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 yet to be developed, mainly owing to the complexity of the mechanism involved. Sewage contains flocculent particles, which do not have constant and uniform settling characteristics. Flocculation and settling are influenced by many factors such as the detailed velocity field, SS concentrations, particle size and density, and the density and viscosity of the fluid. Furthermore, the chemical characteristics of flocculent particles and the fluid body also affect the flocculation process. Random environmental factors (heat flux such as influence of magnetic field and wind action) and inlet condition often induce dramatic changes to the density and velocity field, which in turn reflect major variations in SS removal (Sohaili, 2003). Short-circuiting and circulating flow are typical examples of such changes.

This paper describes research on the influence of a number of variables on the flocculation process in magnetic treatment of landfill leachate. These variables can be divided into two categories: chemical variable, such as the pH of the sample, and physical variable such as magnetic field strength and operating flow rate in magnetic treatment. Experiments on the pH of the sample sedimentation process in magnetic treatment will be studied. The effects of the increasing removal efficiency of suspended particles, COD and BOD by circulation flowing method in magnetic treatment will be discussed. All of these experiments were performed in a batch system.

This study focused on the leachate generated from Pasir Gudang Landfill Site, Johor Bahru, State of Johore, Malaysia. This site is subjected to highly suspended solids and turbid leachate, ranging from 500 mg/L to 800 mg/L owing to the presence of high organic matters that associated with suspended solids. The characteristic of the leachate sample employed in this study is shown in Table 1. The objective of this research was to investigate the influence of magnet for suspended solids, COD and BOD removals from landfill leachate using different operating treatment conditions, exposure time, flow rate and pH.

Table 1 Characteristic of leachate sample from Pasir Gudang landfill

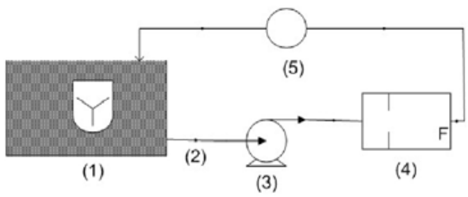
Parameters	*Raw leachate concentration range*	*Pre-treated leachate concentration range*	*Standard B of malaysian effluent regulation*
TSS	249–589	182–346	100
Turbidity	418–1065	24–80	–
pH	8.45–8.8	8.1–8.48	6.0–9.0
BOD_5	201.5–356.5	175–300	50
COD	3100–4150	314–458	100
NH_4-N	93–175	5.8–18.9	–

2 Experimental set-up and methods

The experimental set-up employed magnetic field that is orientated orthogonal to the direction of flow (treated sample). Two permanent magnets with different strengths were used in this experiment, namely of NdFeB and AlNiCo. All magnets are cubic-shape rare earth permanent magnet of size 50 mm × 50 mm × 20 mm.

The set-up of the laboratory experimental equipment is shown in Figure 1. The test rig consists of two identical flow loops, each with a 2-m^3 reservoir supplying a broth circulation system was constructed (1 cm internal diameter polyvinylchloride tubing). Sample flows throughout the system was provided by means of a pump with a control device that can be adjusted from 0 to maximum of 100 mL/s. The magnetic field was provided by a permanent magnet to produce a magnet field orthogonal to the fluid flow. The sample was circulated with a constant flow rate where samples were flowing in the magnetic fields conducted under controlled laboratory conditions.

Figure l Experimental set-up for magnetisation 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 and (5) external magnetic device



3 Methods of leachate analysis

Leachate samples were collected from an active detention pond with leachate age of more than five years at Pasir Gudang Landfill Site. Samples were collected, transported to the laboratory and stored at 4°C. Leachate was analysed for suspended solids, COD and BOD according to the Standard Methods (APHA, 2000). Leachate samples were removed from the refrigerator and were placed for about 2 h at about 22°C for conditioning at room temperature. Sulphuric acid and sodium hydroxide were used for pH adjustment.

4 Determination of sedimentation rate and removal efficiency

Johnson and Amistharajah (1983), Gamayunov (1983, 1994) and Wang et al. (1997) suggested that measuring turbidity is the best method to predict the phase of particles. The removal efficiency (*R*) of SS, COD and BOD can be derived according to equation (1).

$$R = \frac{(C_0 - C)}{C_0} \times 100 \qquad (1)$$

where C and C_0 are final and initial concentrations of SS, COD and BOD, respectively.

The settling of suspended particles is considered as first-order kinetic (Schnoor and Zehnder, 1996). According to Sohaili (2003), the change of SS during sedimentation can be described by a first-order kinetic model, as in equation (2).

$$\frac{C}{C_0} = e^{-bT} \tag{2}$$

where b and T are kinetic constant and retention time, respectively.

Analysis of percentage removal efficiencies, R, towards the retention time (T) mathematically in a simple empirical form can be shown as in equation (3). Negative sign explains the reduction of removal efficiency (R).

$$\frac{\mathrm{d}R}{\mathrm{d}T} = -a(R)^n \tag{3}$$

Since the analysis of removal efficiency follows first-order kinetic (Schnoor and Zehnder, 1996), equation (3) can be solved by integration as the following, and the result is shown in equation (4):

$$\int \mathrm{d}R = \frac{\mathrm{d}a}{\mathrm{d}t} \ \mathrm{d}T$$

$$\int_0^R \mathrm{d}R = a \int_0^T \mathrm{e}^{-bT}$$

$$R = a(1 - \mathrm{e}^{-bT}) \tag{4}$$

where b is removal constant value prevailing under magnetic exposure to particles (Sohaili et al., 2004).

5 Results and discussion

The experimental works showed similar trend of results for SS, COD and BOD removals as shown in Figures 2, 3 and 4, respectively. It was found as presented in the figures that the magnetic treatment is able to remove SS, COD and BOD in the range of 60–80%. The results also showed that percentages of SS, COD and BOD removals increased with the increment of magnetic exposure time as shown in Figure 5. Meanwhile, Figure 6 presents the increment of removal efficiencies with the decrement of flow rate. The change of pH had uncertain significant effects on the percentages of SS, COD and BOD removal. Figure 7 showed an example of pH effect on the removal percentage of SS. Since the removal results were of similar trend, the further discussion of the result was focused only on SS result.

Figure 2 Removal percentage of suspended solids by circulation flowing method using magnetic field of 0.55 T at 2 mL/s flow rate with varying exposure times of 1–6 h

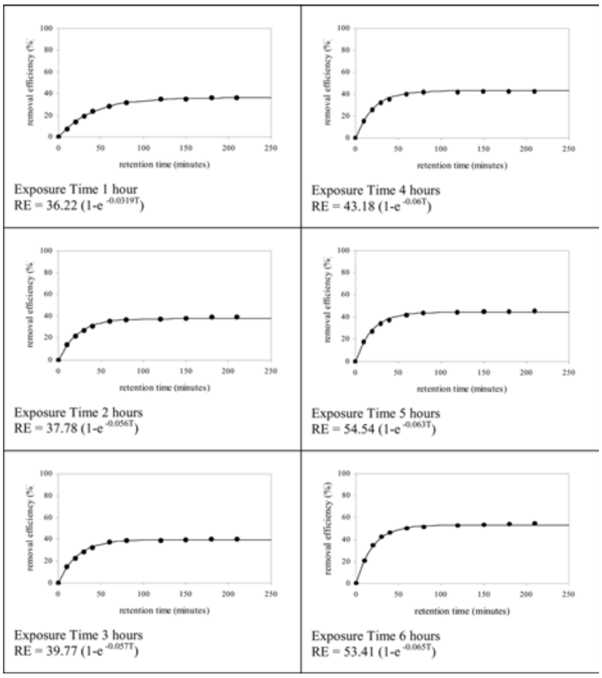


Figure 3 Removal percentage of BOD by circulation flowing method using magnetic field of 0.55 T at 2 mL/s flow rate with varying exposure times of 1–6 h

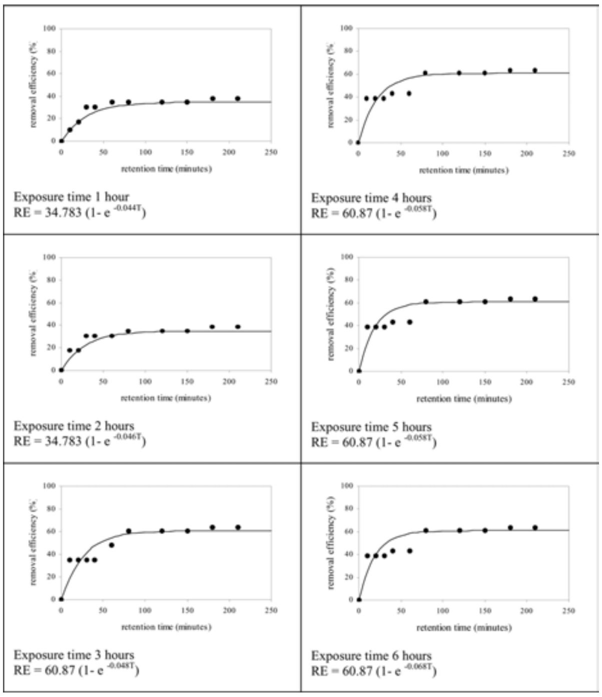


Figure 4 Removal percentage of COD by circulation flowing method using magnetic field of 0.55 T at 2 mL/s flow rate with varying exposure times of 1–6 h

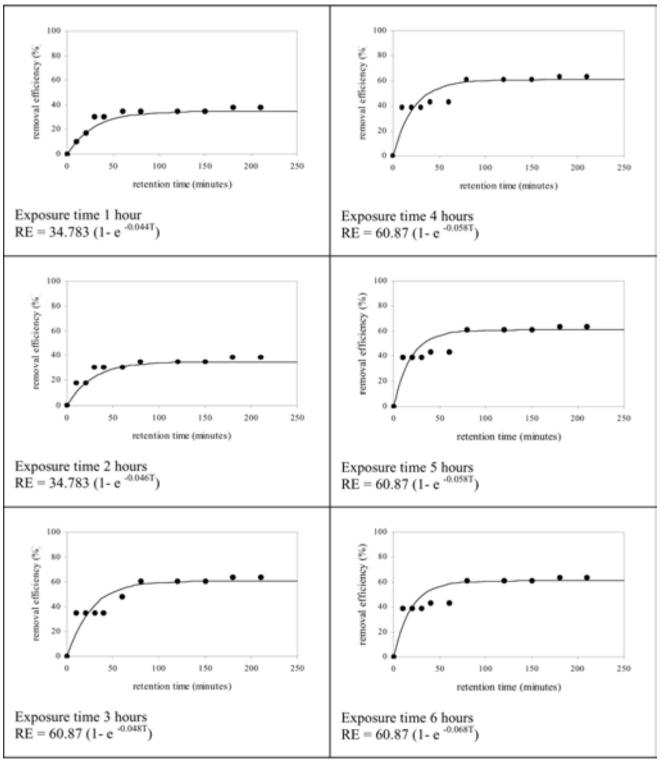


Figure 5 The effect of exposure time on the removal constant of suspended solids in magnetic force of 0.55 T at 2 mL/s flow rate

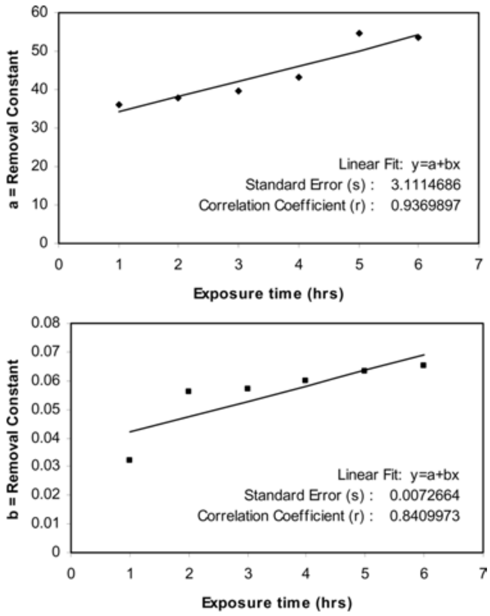


Figure 6 The effect of flow rate on the removal constant of suspended solids in magnetic force of 0.55 T at 6 h treatment period

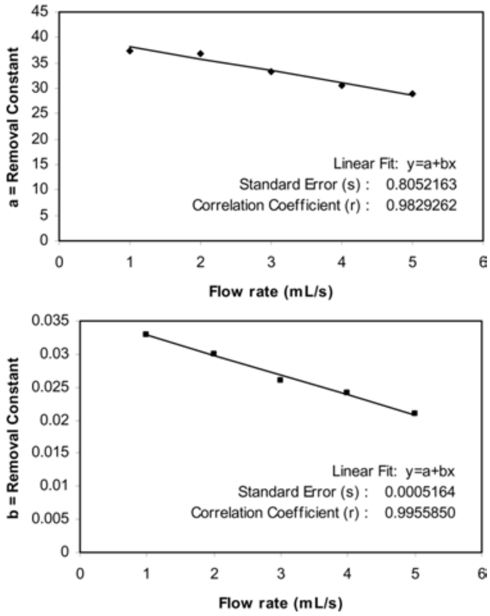
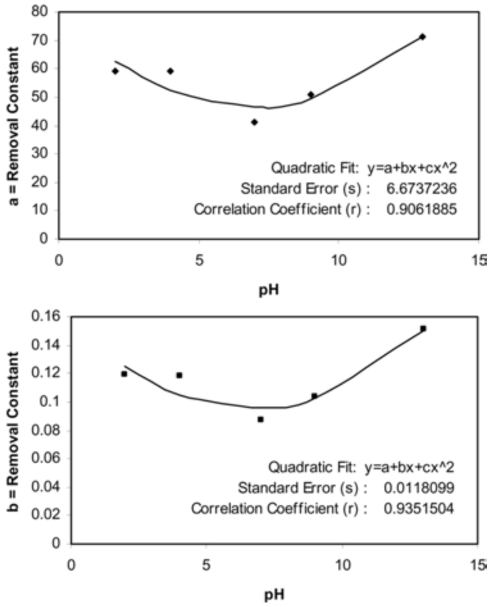
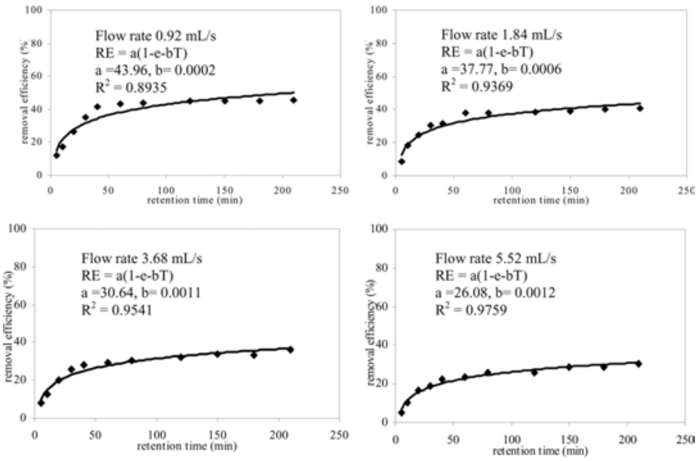


Figure 7 The effect of pH on the removal constant of suspended solids in magnetic force of 0.55 T at 6 h treatment period and flow rate of 2 mL/s



The SS removal efficiencies (RE_{SS}) for the application of 0.55 T were determined at four different flow rates, at 2 h exposure time, without adjustment of pH and retention time ranging from 5 min to 210 min. The removal efficiencies as a function of retention time, at various flow rates, are illustrated in Figure 8.

Figure 8 The comparison removal efficiencies of suspended solids by circulation flowing method using magnetic field of 0.55 T at 2 h treatment period, with verified flow rate and without pH adjustment



The curve fitting parameters *a* and *b* (equation (4)) used to describe the relationships between SS removal efficiencies and retention times, at different flow rates, are given in Table 2.

Table 2 Value parameters *a* and *b* (equation (4)) 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

The effect of flow rate on the removal efficiency of particles is experimentally shown in Figure 8, where magnetic treatment experiments were conducted by varying the flow rate between 0.92 mL/s and 5.52 mL/s. The effect of flow rate on the removal efficiencies of particles followed equation (4).

The comparison constant values *a* and *b* in the application of magnetic field 0.55 T with varying flow rates between 0.92 mL/s and 5.52 mL/s are shown in Table 2. The analysis results show that constant values *a* and *b* decreased as the operating flow rate in magnetic treatment increased gradually. It indicated that the ability to remove particles effectively is greater in lower operating flow rate than in higher operating flow rate using magnetic treatment. For example, constant values *a* and *b* at 0.92 mL/s operating flow rate of magnetic treatment were 43.96 and 0.0002, respectively, compared with constant values *a* and *b* at 5.52 mL/s, which were 26.08 and 0.012, respectively. The plotted constant values *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 the gradient and *c* is the constant. Parameters *a* and *b* could be related to prevailing flow rates being shown in equations (5)–(6) for parameters *a* and *b*.

$$a = [-10.086 \ln(Q)] + 43.587 \quad (5)$$

$$b = [0.0006 \ln(Q)] + 0.0002 \quad (6)$$

Substitution of equations (5)–(6) into equation (4) provided an empirical model (equation (7)) that described the removal efficiency of SS as a function of flow rates and retention time.

$$RE_{SS} = ([-10.086 \ln(Q)] + 43.587)\,(1-e^{-T([0.0006 \ln(Q)] + 0.0002)}) \quad (7)$$

where RE_{SS} is removal efficiency of SS.

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

The comparison between constant values *a* and *b* based on exposure to magnetic field showed that removal efficiencies increased with decreasing flow rate as presented in Figure 6. The phenomenon exposing sample to magnetic field in the circulation flowing method created a condition in which particles were exposed to the magnetic field repeatedly. This method generated strong positive effect throughout the sample where particles are exposed to magnetic field in longer exposure period at lower flow rate. The reason behind the application of repeated exposure is that the magnetisation effect started to wear off as the particles' magnetic memory is being depleted (Colic and Morse, 1999). Treatment period that is applied in the treatment process reflects 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 is given to the particles thus increasing the magnetic memory and magnetisation effect of the sample. Baker and Judd (1996), Ifill et al. (1996) and Fan and Cho (1997) support this result of experimentation. The results showed (Figure 5) that increased exposure time to magnetic field in circulation flowing method may increase frequency of turbulence between particles in sample causing aggregation. The aggregation may enhance the sedimentation of particles.

The phenomenon indicates that hydrodynamic factors 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. Removal efficiency of particles in magnetic treatment is strongly affected by treatment period in which particles are exposed to magnetic field at lower flow rate long enough to increase the magnetisation effect. Magnetisation may enhance the collision rate among colloidal particles. Particles are then attracted and agglomerated into bigger aggregates thus settling of aggregated particles can be accelerated.

The experimental work in determining the effect of operating flow rate in magnetic field can be concluded that flow rate influences the removal of particles in sample. The results reveal that the removal efficiency of particles decreased as the flow rate is increased. Increased flow rate will increase the level of drag force; therefore, particles will not be easily aggregated or accumulated under high flow velocities. Circulation flowing method in magnetic application is supported by *magnetohydrodynamic* theory. When samples flow perpendicularly to the imposed magnetic field, a potential gradient is created, causing electric currents to flow, which in turn assists 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. Therefore, more particles are flocculated and precipitated together. This effect is best explained as a *magnetohydrodynamic* effect (Busch and Busch, 1997; Goldsworthy et al., 1999; Sohaili et al., 2004).

With the same methods as for SS removal, the COD removal efficiency was determined. It was found that the data of average SS removal efficiency (RE_{SS}) and COD removal efficiency (RE_{COD}) showed a good linear relationship. Regression analysis produced the following relationship as in equation (8).

$$RE_{\mathrm{COD}} = 0.7547\ RE_{SS} - 17.92 \tag{8}$$

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

6 Conclusions

It could be concluded that magnetic technology has the potential to be used for improving the removal of suspended solids and organic concentration from landfill leachate besides operating condition could influence the removal efficiency. It showed that the lower operating flow rate, longer exposure time to the magnet and the pH of the leachate sample could result in optimum condition for the efficiency of suspended solid and organic removals. Operating flow rate and pH in magnetic treatment play an important role on particle interactions and sedimentation process. Therefore, further study should be carried out for investigating magnetic treatment potential as an alternative method in improving the suspended solids and organics removal from landfill leachate.

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References

APHA, AWWA and WPCF (2000) *Standard Methods for the Examination of Water and Wastewater*, 21st ed., American Public Health Association, Washington, DC.

Baker, J.S. and Judd, S.J. (1996) 'Magnetic amelioration of scale formation', *Water Research*, Vol. 30, No. 2, pp.247–260.

Busch, K.W. and Busch M.A. (1997) 'Laboratory studies on magnetic water treatment and their relationship to a possible mechanism for scale reduction', *Desalination*, Vol. 109, No. 2, pp.131–148.

Colic, M. and Morse, D. (1999) 'Elusive mechanism of the magnetic memory of water', *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, Vol. 154, Nos. 1–2, pp.167–174.

Fan, C and Cho, Y.I. (1997) *A New Electronic Anti-Fouling Technology to Control Precipitation Fouling*, National Heat Transfer Conference ASME, Vol. 12, pp.183–188.

Gamayunov, N.I. (1983) 'Coagulation of suspension after magnetic treatment', *Journal Applied Chemistry of the USSR (Kolloid Zhurnal)*, Vol. 56, No. 5, pp.975–982.

Gamayunov, N.I. (1994) 'Action of a static magnetic field on moving solutions and suspensions', *Colloid Journal of the USSR (Kolloid Zhurnal)*, Vol. 56, No. 2, pp.234–241.

Goldsworthy, A., Whitney, H. and Morris, E. (1999) 'Biological effects of physically conditioned water', *Journal of Water Resource*, Vol. 33, No. 7, pp.1618–1626.

Ifill, A.S., Baker, J.S. and Judd, S.J. (1996) 'Magnetically-enhanced chemical disinfection', *Transactions of the Institution of Chemical Engineers (Part B)*, Vol. 74, No. 2, pp.120–124.

Johnson, P.N. and Amistharajah, A. (1983), 'Ferric chloride and alum as single and dual coagulants', *Journal of the American Water Works Association*, May, pp.232–238.

Kargi, F. and Pamukoglu, M.Y. (2004) 'Adsorbent supplemented biological treatment of pre-treated landfill leachate by fed-batch operation', *Bioresource Technology*, Vol. 94, No. 3, pp.285–291.

Perez, M., Font, R. and Pastor, C. (1998) 'A mathematical model to simulate batch sedimentation with compression behavior', *J. of Computers Chem.Eng*., Vol. 22, No. 11, pp.1531–1541.

Schnoor, J.L. and Zehnder, A. (1996) *Environmental Modelling: Fate and Transport of Pollutions in Water*, Air and Soil, John Willey & Sons Inc., New York.

Sohaili, J. (2003) *Kesan Medan Magnet Terhadap Pengenapan Zarah Terampai dalam Kumbahan*, Universiti Teknologi Malaysia. PhD Thesis.

Sohaili, J., Othman, F. and Wahid, Z.A. (2004) 'Effect of magnetic fields on suspended particles in sewage', *Malaysian Journal of Science*, Vol. 23, pp.141–148.

Tchobanoglous, G., Theisen, H. and Vigil, S. (1993) *Integrated Solid Waste Management Engineering Principles and Management Issues*, McGraw-Hill Inc., New York.

Wang, Y., Babchin, A.J., Chernyi, L.T., Chow, R.S. and Sawatzky, R.P. (1997) 'Rapid onset of calcium carbonate crystallization under the influence of a magnetic field', *Water Research*, Vol. 31, No. 2, pp.346–350.

Wang, Z., Li, K., Fingas, M., Sigouin, L. and Menard, L. (2002) 'Characterization and source identification of hydrocarbons in water samples using multiple analytical techniques', *Journal of Chromatography A*, Vol. 971, Nos. 1–2, pp.173–184.