Sci., Tech. and Dev., **31 (3): 271-279, 2012**

LOW-COST ENGINEERING TECHNIQUES IN SUSTAINABLE OPERATION OF A RURAL CLEAN WATER PLANT IN THAILAND

PETCH PENGCHAI*, KANOKWAN KEAWKHUN AND NUCHIDA SUWAPAET

Environmental Engineering Laboratory, Faculty of Engineering, Mahasarakham University, Khamriang, Kantarawichai, Mahasarakham province, 44150, Thailand.

Abstract

Problems of water supply in many rural regions of Thailand result from the lack of awareness and financial limitations. Payanghang Clean Water Plant is an example of the rural water plant that has been suffering from the poor operation since 2003. The objective of this study was to modify the operation processes of this water plant to achieve cleaner water and better financial condition. Low-cost engineering techniques, such as the use of floating switches in filtration ponds, the use of water drip system for alum dosing and the addition of *Tamarindus indica* Linn seed solution was applied. As a result, 76% of turbidity removal efficiency was derived. Although, the difference was not statistically significant at 95% confidence level, higher removal efficiency in comparison with the one before modification (65%) suggested better operation. In the view of financial aspect, 107 dollars (1 baht = 0.0326 U.S. dollar) benefit was obtained from 7 month-operation period.

Keywords: Water supply, Rural, Thailand, Natural coagulan, Problem base learning.

Introduction

Clean water is included in 4 human basic needs for living, food, clothes, house and medicine. It is always inopportune to live in rural area where the basic utilities are inadequate. Thus, it is preferred that a stand-alone water utility system should be provided by the government. Since the governmental support to the rural water supply has traditionally focused on designing and constructing new systems based on prescribed needs only, the system sustainability is never brought to the table. Thus, the system is left to operations of the rural community itself. This traditional service consequently causes water quality problems due to the lack of knowledge and skill in water supply management and the financial limitation of the rural community. Payanghang is a rural village located at Mahasarakham province, northeastern region of Thailand. Payanghang Clean Water Plant is approximately 2 km far from the water resource, Shee River. Water is sent from Shee River to the clean water plant via an electric pump. In the plant, there are 2 coagulation-flocculation ponds, 2 settling ponds, 3 filtration ponds and 1 underground clean water tank. The plant is managed by 2 elected men on a volunteer basis. The raw water pump is turned on and off manually by a hired employee. Payanghang Clean Water Plant has been working since 2002 and run by the villagers. The plant has been facing financial problems since the first year of the operation. Operational expenses of the water plant include electricity cost, cost of chemicals and a salary for the hired employee whilst the income is collected from villagers as the water cleaning cost. Since a deficit usually occurs, chemicals such as coagulation agent (alum) and chlorine solution have not been added to the process since 2003. An injection pump for alum addition was also decadent. This caused overload of turbidity in the filtration ponds which produced a clog in the filter media. Payanghang representatives solved this problem by removing the filter media from the ponds and continued the operation with non-functional coagulation and filtration processes since then. Consequently, the produced water from this water plant has high

***Author for correspondence E-mail: petchpengchai@zoho.com**

turbidity, especially in the rainy season. The villagers have been using this turbid water for 8 years without any intention to solve the problem. In order to grant community awareness in solving financial deficit and turbidity problems, interdisciplinary cooperation of low-cost engineering techniques and educational enhancement procedure were applied.

For low-cost engineering techniques, installations of low-cost innovations as well as an application of natural coagulants made from plant seeds were made. The increase of turbidity removal and the small addition of coagulant cost were expected by the application of natural coagulants. *Moringa oleifera Lam* is the most widely cultivated species of *Moringaceae* family in the sub-Himalayan tracts of India, Pakistan, Bangladesh and Afghanistan (Anwar and Bhanger, 2003). Earlier studies recommended *Moringa oleifera Lam* seed extract as coagulant for water treatment in developing countries so as to reduce the exorbitant cost of water treatment (Jahn, 1986; Jahn, 1988; Sutherland and Aye, 1989; McConnachie, 1993; Nyein et al., 1997; Mandloi et al., 2004; Pritchard et al., 2009; Lea, 2010). Numerous laboratory studies have reported that *Moringa oleifera Lam* seed extract could be used as the primary coagulant instead of the conventional coagulant, alum (Ndabigengesere and Narasiah, 1998). However, in cases of low turbidity, *Moringa oleifera Lam* seed extract has to be applied in conjunction with the addition of alum. In Nigeria, Dalen et al. (2009) have found that the mixture of alum and *Moringa oleifera Lam* seed powder in the ratio of 40:60 could be efficiently applied to natural raw water for turbidity removal. In Ghana, Amagloh and Benang (2009) reported that 12g/L of *Moringa oleifera Lam* seed powder combined with 10 or 12g/L of alum injection could remove turbidity in pond water down to the acceptable level, 5 NTU (World Health Organization : WHO, 2006). For Thailand, rural areas in which the water resources often have turbidity of lower than 100 NTU, the advantage of using *Moringa oleifera Lam* seed instead of alum has not been well-proved, as far as the knowledge of the author is concerned. *Tamarindus indica* Linn seed could also be used as the natural coagulant in water purification process (Mishra and Bajpai, 2006 and Yin, 2010). Bulusu et al. (1968) had applied *Tamarindus indica* Linn seed powder as an additional coagulant to raw water collected from Kanhan River, India. Turbidity of the influent had been reduced from 5000-7000 NTU to 30 NTU by the addition of 6 mg/L *Tamarindus indica* Linn seed powder coupled with 160mg/L of alum in the coagulation process. In comparison with the conventional case which needs 360 mg/L of alum, the application of *Tamarindus indica* Linn seed powder can reduce the necessary amount of alum up to 55.6%. However, for the influent of low turbidity, such as 50 NTU, the addition of *Tamarindus indica* Linn seed powder and alum at the level which is lower than the alum optimal dose have not yet been proved possible to reduce turbidity into the acceptable level. *Vigna radiata* (L.) R. Wilczek powder, namely mung bean flour is widely known as the raw material for Thai dessert as well as one of the major pulse crops of Pakistan (Asim et al., 2006). Although no proof has been done on its coagulation ability, the viscosity of water after its dissolution has given a hint of its use as a coagulant.

This research aimed to apply the low-cost engineering techniques including the use of floating switches in filtration ponds, the use of water drip system for alum dosing, and the addition of plant seed solution in the coagulation process to Payanghang Clean Water Plant operation. An accomplishment to sustainable operation was expected to show as better water quality and financial improvement.

Material and Methods

Laboratory experiment

Preparation of plant seed powder and alum stock solutions

Moringa oleifera Lam seed powder was prepared by using manual mortar to crush dried *Moringa oleifera Lam* seeds. *Tamarindus indica* Linn seed powder was made by crushing roasted *Tamarindus indica* Linn seeds by manual mortar to remove the brown shells. They were then grinded into powder by an electric grinder. Mung been powder was bought from a market in Mahasarakham Province. Each type of seed powder was size-classified by a 1×1mm screen and dissolved in distilled water in 500mL-volumetric flasks to remove the coarse particle before making 5g/L *Moringa oleifera Lam* seed powder stock solution, 1g/L *Tamarindus indica*

Linn seed powder stock solution and 5g/L *Vigna radiata* (L.) R. Wilczek powder stock solution. The alum stock solution of 5g/L was prepared by dissolving aluminum sulfate in distilled water in 500mL-volumetric flasks.

Jar test experiment

Jar test experiments were performed to determine the optimum dose of alum and the optimum doses of plant seed powders which are needed in order to get the acceptable turbidity value. Water samples used in the experiments were collected from Shee River during March and August, 2010. Firstly, raw water was set into six 1-litre beakers. In case of single-type coagulant jar test, prepared alum stock solution or plant seed powders stock solution was added into the beakers. The concentrations of the solutions ranged 0-120mg/L for alum and 0-40mg/L for plant seed powder. After adding the solutions, each sample was mixed by 100rpm-stirrer for 1 minute. In case of 2 type-coagulants jar test, the fist-type coagulant was added to beakers and mixed at 100rpm for 1minute before adding the second-type coagulant and then mixing was continued at 100rpm for 1 minute. Secondly, the mixing condition was changed to 40rpm for 20 minutes and then the stirrers were stopped. All water samples were set at rest for 20 minutes to allow particle settling. Clear supernatant was then taken from each beaker and analysed for turbidity and other compositions whose detail is described in the next section. The lowest dose of coagulants which could reduce the water turbidity down to the acceptable level was defined as the optimum dose.

Water Composition Analysis

Turbidity of the water samples was measured using turbidity meter (Model 2020, Code 1799-EX2, LaMotte, USA). Hardness and pH values were tested using a titration test kit (V-unique, Better Syndicate, Thailand) and pH meter (SG8-ELK, Mettler Toledo, USA), respectively. Concentration of Biological Oxygen Demand (BOD) was measured following the 5-Day BOD Test described in Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Chemical Oxygen Demand (COD), Suspended Solid (SS), Total Dissolved Solid (TDS), total coliform bacteria, and fecal coliform bacteria concentrations were also measured according to the methods defined in Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

The improvement plan at Payanghang Clean Water Plant

The main processes of Payanghang Clean Water Plant were reformed, additional equipments were installed and the alternative procedure was introduced. The filtration process was reformed by reinstalling filter media to the filtration ponds. Floating switches (Figure 1) were installed to the filtration ponds to monitor the water level in order to control the water pump at Shee River. According to this method, contact time of water in the filtration ponds was expected to increase which should result in the increase of turbidity removal. With the floating switch, the water pump could work automatically. Thus the electricity cost of this water plant should become lower. In the coagulation-flocculation process, alum was donated to the water-plant as a coagulant. The reformation of coagulant injection process was done by the performance of water dripping technique. The water dripping technique was selected because of its non-electrical operation. Alum solutions from 2 small tanks were dosed to 2 coagulation-flocculation ponds by mean of water drip (Figure 2). CaO solution was also added to 2 sedimentation ponds by the same mean in order to reduce the acidity in the effluent of the sedimentation ponds. Doses of alum and CaO were decided on a case-by-case basis by the 2 villager representatives. Apart from these considerations, the most practical method of plant seed powder application with laboratory support was applied to Payanghang Clean Water Plant. Water samples, including water from Shee River and effluents from sedimentation ponds and filtration ponds, were analysed for the compositions. Possibility of plant seed powder application in the process and the financial profit of the plant from this application are discussed in this study.

Fig. 1. Floating switches installed in the filtration ponds of Payanghang clean water plant

Fig. 2. Water drip for chemical addition at Payanghang clean water plant

Results and Discussion

Water quality of Shee River

The quality indexes of water samples from Shee River are summarised in Table 1. Total coliform bacteria and fecal coliform bacteria were not detected in any samples. Turbidity, SS, pH, TDS, COD, BOD and hardness values are in range 14-190NTU, 12-38mgSS/L, 6-7, 186-538 mgTDS/L, 54-72 mgCOD/L, 1-2 mgBOD/L, and 3-4 mg CaCO3/L, respectively. Excluding high turbidity in raining season (August 20, 2010), all water quality indices suggested Shee River as a water resource for clean water production.

Table 1. Water quality of Shee river measured in year 2010.

Sample	pH	Turbidity (NTU)		BOD (mg/L)	COD (mg/L)	SS (mg/L)	TDS (mg/L)	Hardness (mg $CaCO_3$/L)
		Average	Standard deviation					
Mar. 12	7.28	17.8	-[a]	-[b]	16	38	538	3
May 1	7.5	15.2	0.33	1.78	32	12	271	4
Apr. 19	7.51	14.1	0.54	1.88	-[c]	22	232	3
July 9	7.84	25	0	2.07	67.2	25	215	3
Aug. 20	6.56	190	0	1.92	96	-[c]	186	4
PCD standard[d]		-	-	2.0	-	-	-	-
PWA standard[e]		5	-	-	-	-	600	300

[a] : the measurement was done once, [b] : no measurement, [c] : the measurement was failed, [d] : the standard of river water used for public water supply (class 3) defined by Thailand Pollution Control Department (PCD), [e] : the standard of tap water quality defined by Thailand Provincial Waterworks Authority (PWA)

Turbidity removal using alum and plant seed powders

From the results of jar test experiment, relationship between supernatant turbidity and doses of plant seed powders are shown in Figure 3. The highest turbidity removal was found at the addition of 2mg/L *Tamarindus indica* Linn seed powder and 2.5mg/L *Moringa Oleifera* seed powder. In case of mung bean powder, the removal ability of each dose was similar. Thus, 1mg/L was chosen as the reasonable dose for the process. However, none of the plant seed solutions can reduce turbidity to the acceptable level (no greater than 5 NTU). Therefore, the addition of the plant seed powders in conjunction with alum (two-type coagulant jar test) was then tested.

The results of two-type coagulant jar test experiment were expressed coupled with the results of alum jar test in Table 2. According to the result of experiment 1, adding alum before adding *Tamarindus indica* Linn seed powder could reduce more turbidity than the other way around did. Results of experiment 2 and 3 indicate that the addition of *Moringa oleifera Lam* seed powder or *Vigna radiata* (L.) R. Wilczek powder should be done before dosing the alum.

The shaded cells in Table 2 indicate the experimental conditions that could produce clean water with turbidity of less than 5NTU. They also showed that the usage of seed powders could reduce amount of alum dosage comparing to the optimum dose of alum at 100mg/L in the

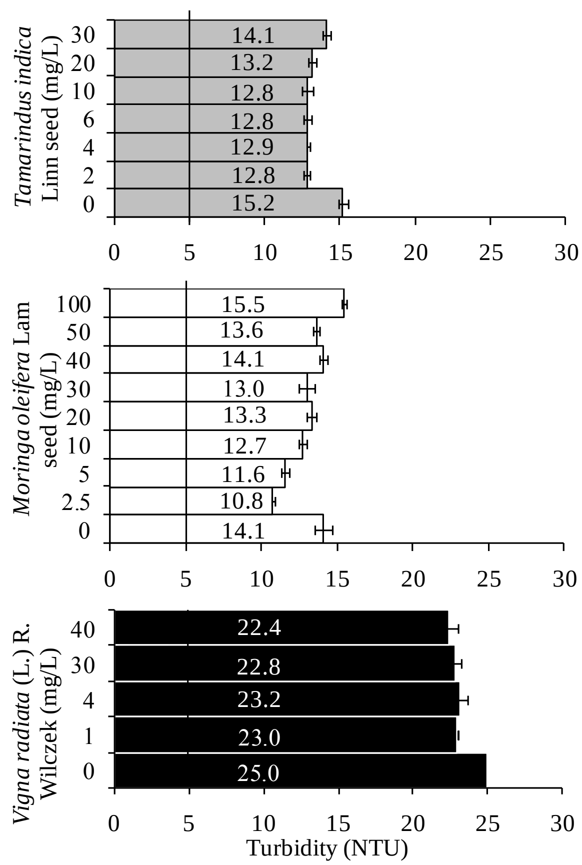

Fig. 3. Jar test experiments using plant seed powder as a single coagulant. Standard deviation error bars are expressed at the edge of the average bars (n=5)

conventional single-coagulant jar test. The water quality in those conditions was analysed in a laboratory with the following results: SS, pH, TDS, COD, BOD and hardness ranged 2-35mg SS/L, 6-7, 162-254mgTDS/L, 54-72mgCOD/L, 1.3-1.8mgBOD/L, and 3-4mg$CaCO_3$/L, respectively. Total coliform bacteria and fecal coliform bacteria were not detected in any samples. The water quality did not exceed the standards of Thailand Provincial Waterworks Authority (PWA) and Thailand Pollution Control Department (PCD).

Table 2. Results of two-type coagulant jar test experiment.

No.	Firstly added coagulant	Secondly added coagulant	Turbidity (NTU) Average (n=5)	Turbidity (NTU) Standard deviation
1	None	None	15.2	0.33
	Alum 50mg/L	None	3.8	0.55
	Tamarindus indica Linn seed powder 2mg/L	Alum 2mg/L	11.3	0.21
	Alum 2mg/L	*Tamarindus indica* Linn seed powder 2 mg/L	11.2	0.07
	Tamarindus indica Linn seed powder 2 mg/L	Alum 4mg/L	10.6	0.21
	Alum 4mg/L	*Tamarindus indica* Linn seed powder 2mg/L	9.7	0.31
2	None	None	16.7	0.28
	Alum 50mg/L (optimal dose)	None	3.5	0.30
	Alum 20mg/L	*Tamarindus indica* Linn seed powder 2mg/L	6.4	0.27
	Alum 25mg/L	*Tamarindus indica* Linn seed powder 2mg/L	6.0	0.08
	Alum 30mg/L (60% of optimal dose)	*Tamarindus indica* Linn seed powder 2mg/L	4.8	0.09
	Alum 30mg/L	*Moringa oleifera Lam* seed powder 2.5mg/L	4.8	0.15
	Moringa oleifera Lam seed powder 2.5 mg/L	Alum 30 mg/L	2.5	0.12
	Moringa oleifera Lam seed powder 2.5 mg/L	Alum 25 mg/L (50% of optimal dose)	3.6	0.38
3	None	None	25.0	0.00
	Alum 100 mg/L (optimal dose)	None	3.5	0.17
	Alum 70 mg/L	*Vigna radiata* (L.) R. Wilczek powder 1 mg/L	6.0	0.05
	Vigna radiata (L.) R. Wilczek powder 1 mg/L	Alum 70 mg/L (70% of optimal dose)	5.6	0.21

Results of Payanghang Clean Water Plant after improvement

The water quality was obviously improved by using the low cost engineering techniques, especially by the process of adding seed powder. From a financial aspect, choosing the right plant seed powder was a challenge. Although the usage of *Moringa oleifera Lam* seed powder can decrease the largest amount of alum dose, its market price was 1000 baht/kg. It was the highest price in comparison with *Tamarindus indica* Linn seed powder (30-50 baht/kg), and *Vigna radiata* (L.) R. Wilczek powder (50-60baht/kg). Since the financial situation of the plant was concerned, *Tamarindus indica* Linn seed powder was selected for the real application. Two new tanks filled with *Tamarindus indica* Linn seed powder solution were placed near the tanks of alum solution. The solution of *Tamarindus indica* Linn seed powder was added to the coagulation-flocculation ponds by means of water drip in the concentration of 2mg/L. Turbidity of the effluent from each process is shown in Table 3. Before the application of *Tamarindus indica* Linn seed powder solution, the turbidity in produced water ranged from 9 to 24NTU, which exceeded the acceptable value. After the addition of *Tamarindus indica* Linn seed powder solution, the turbidity in produced water ranged from 9 to 17 NTU. Since the low turbidity (below 100NTU) of raw water was focused, average removal efficiencies were calculated excluding the data on August 5, 2010 and August 6, 2010. Although, the turbidity value of produced water of both cases still exceeded the standard value, average removal efficiency of the process after *Tamarindus indica* Linn seed powder application (76%) was higher than the case before the application (65%). However, the difference between average removal efficiencies of the 2 cases was not statistically significant at 95% confidence level (sample pair t-test, t= -1.098, sig (2-tailed) = 0.387). The removal ability limitation of *Tamarindus indica* Linn seed powder and the inconsistency of alum and seed powder dosing were considered as the main causes for unsatisfied turbidity results. A possible alternative recommended by authors, suggesting that if Payanghang villagers can plant *Moringa oleifera Lam* in their own farm, the clean water plant will have enough amounts of *Moringa oleifera Lam* seeds to be used as an aid coagulant for better results and less cost. However, daily amount of optimal alum dose should be identified in order to get better water quality from the process. According to Table 4, the deficit was less in overall. With the alum donation from authors, the benefit of 107 U.S. dollars was obtained from 7 month-operation. Electricity cost reduction plan is suggested in order to make the clean water plant become more financially sustainable.

Table 3. Results of the real application of *Tamarindus indica* Linn seed powder in Payanghang clean water plant.

Sample	Average turbidity (NTU) before the application				Average turbidity (NTU) after the application			
	Sep. 25, 2009	Oct. 14, 2009	July 2, 2010	Aug. 5, 2010	Aug. 6, 2010	Aug. 31, 2010	Sep. 6, 2010	Sep. 28, 2010
Shee River water	66.0	49.0	15.8	160.0	120.0	65.0	57.0	33.6
Sedimentation ponds effluent	64.0	20.0	12.4	28.2	22.4	50.0	12.0	11.0
Filtration ponds effluent (produced water)	22.0	6.6	9.2	23.6	13.0	17.0	9.7	9.5
Removal efficiency (%)	67	87	42	85	89	74	83	72
Average removal efficiency (%)	70				79			
	65 (excluding Aug. 5 data)				76 (excluding Aug. 6 data)			

Table 4. Financial account of Payanghang clean water plant after the improvement

Month	Revenue (baht)	Cost (Baht)			Benefit (baht)
		Electric	Material and equipment	Salary	
Jan.	3,754	1,577	155	800	1,222
Feb.	4,923	2,304	0	800	1,819
Mar.	2,463	3,911	0	800	-2,248
Apr.	4,581	2,279	200	800	1,302
May.	3,892	3,035	780	800	-723
Jun.	5,266	2,834	0	800	1,632
July.	3,719	2,638	0	800	281

There is a need to reduce electricity costs for the villagers so they can buy alum by themselves. For this, authors recommend saving a small amount of money spent on lotteries. Generally, Thai people, especially rural villagers, have certain habit in spending their money on lotteries. If the villagers can save their 20 baht from buying the lotteries and donate to the water plant every month, approximately 5,040 baht per month will be collected. In this case, external financial support would become unnecessary. Therefore, the clean water plant could be completely operated by the villagers themselves. Thus, the next challenge sustainable operation of Payanghang Clean Water Plant should be done on the lottery issue.

Conclusion

Produced water from Payanghang clean water plant was improved by the application of low cost engineering techniques. The use of floating switches in filtration ponds, the use of water drip system for alum dosing and the addition of *Tamarindus indica* Linn seed solution were applied to the plant processes. Although, the difference in turbidity values was not statistically significant at 95% confidence level, the average removal efficiency when *Tamarindus indica* Linn seed powder was applied was higher (76%) than the value (65%) derived without seed powder application. In addition, daily amount of optimal alum dose should be identified in order to get better water quality from the process. Thus, field technique for that matter should be developed. With the alum donation, 107 dollars benefit was obtained from 7 month-operation. More effort in electricity cost reduction is needed for the villagers in order to buy the alum by themselves. For that financial issue, authors recommend saving a small amount of money spent on lotteries by the villagers in order to raise more money for the plant.

Acknowledgement

We would like to acknowledge Faculty of Engineering, Mahasarakham University, Thailand, for financial contribution and support for laboratory equipments. We also appreciate Rattana Homwichian for the cooperation in water collection and Jatuporn and Supan Pengchai for their cooperation in buying the water tank and grinding the plant seeds.

References

Amagloh, F.K. and Benang, A. 2009. Effectiveness of Moringa oleifera seed as coagulant for water purification. *African Journal of Agricultural Research*, 4 (1):119-123.

American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF). 2005. *Standard Methods for the Examination of Water and Wastewater, 21st Edition*. American Public Health Association, New York, U.S.A.

Anwar, F. and M.I. Bhanger. 2003. Analytical Characterization of Moringa oleifera Seed Oil Grown in Temperate Regions of Pakistan. *Journal of Agricultural and Food Chemistry*, 51 (22):6558–6563.

Asim, M., M. Aslam, N.I. Hashmiand, N.S. Kisana. 2006. Mungbean (Vigna radiata) in wheat based cropping system: An option for resource conservation under rainfed ecosystem. *Pakistan Journal of Botany*, 38(4): 1197-1204.

Bulusu, K.R., V.P. Thergaonkar, D.N. Kulkarniand B.N. Pathak. 1968. Natural polyelectrolytes as coagulant aid. *Indian Journal of Environmental Health*, 10:239–264.

Dalen, M.B., J.S. Pam, A. Izang, and R. Ekele. 2009. Synergy Between Moringa oleifera Seed Powder and Alum in The Purification of Domestic Water. *Science World Journal*, 4(4):6-11.

Jahn, S.A.A. 1986. Proper use of African coagulant for rural water supply: Research in the Sudan and a guide for new projects. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ), *Manual 191*, Eschborn.

Jahn, S.A.A. 1988. Using Moringa oleifera seeds as coagulant in developing countries. *Journal of the American Water Works Association*, 6:43-50.

Lea, M. 2010. Bioremediation of Turbid Surface Water Using Seed Extract from Moringa oleifera Lam. (Drumstick) Tree. Current Protocols in Microbiology. http://onlinelibrary.wiley.com/doi/10.1002/9780471729259.mc01g02s16/full [May 30, 2012].

Mandloi, M., S. Chaudhari and G.K. Folkard. 2004. Evaluation of natural coagulants for direct filtration. *Environmental Technology* 25(4): 481-489.

Mangale, S.M., S.G. Chonde and P.D. Raut. 2012. Use of Moringa Oleifera (Drumstick) seed as Natural Absorbent and an Antimicrobial agent for Ground water Treatment. *Research Journal of Recent Sciences*, 1(3):31-40.

McConnachie, G.L. 1993. Water treatment for developing countries using baffled-channel hydraulic flocculation. Proceedings of the Institution of Civil Engineers, *Water Maritime & Energy*, 101(1):55-61.

Mishra, A. and M. Bajpai. 2006. The flocculation performance of Tamarindus mucilage in relation to removal of vat and direct dyes. *Bioresource Technology*, 97(8):1055–1059.

Ndabigengesere, A. and S.K. Narasiah. 1998. Quality of water treated by coagulation using. Moringa oleifera seeds. *Water Research*, 32(3):781-791

Nyein, M.M. and T. Aye. 1997. The use of Moringa oleifera (dan-da-lun) seed for the sedimentation and decontamination of household water. Part II: community-based study. *Myanmar Health Sciences Research Journal*, 9(3):163–166.

Pritchard, M., T. Mkandawire, A. Edmondson, J.G. O'Neill and G. Kululanga. 2009. Potential of using plant extracts for purification of shallow well water in Malawi. *Physics and Chemistry of the Earth*, 34:799–805.

Pollution Control Department (PCD). 1994. Surface Water Quality Standards. http://www.pcd.go.th/info_serv/en_reg_std_water05.html [September 14, 2012].

Provincial Waterworks Authority (PWA). 2007. Tap Water Quality Standard. http://www.pwa.co.th/service/download/pwastandard50-1.pdf [September 14, 2012].

Sutherland, J.P., G.K. Folkard, and W.D. Grant, 1989. Seeds of Moringa species as naturally occurring flocculants for water treatment. *Science, Technology and Development*, 7(3):191–197.

WHO. 2006. *Guidelines for Drinking Water Quality, Third Edition*. Incorporating First Addendum, Vol. 1. Recommendations. World Health Organization, Geneva, Switzerland.

Yin, C.Y. 2010. Emerging usage of plant-based coagulants for water and wastewater treatment. *Process Biochemistry*, 45(9):1437–1444.