EnvironmentAsia
The international journal published by the Thai Society of Higher Education Institutes on Environment

Available online at www.tshe.org/EA
EnvironmentAsia 7(2) (2014) 117-123

Suitable Types and Constituent Ratios for Clay-Pot Water Filters to Improve the Physical and Bacteriological Quality of Drinking Water

Watcharaporn Wongsakoonkan [a], Tawach Prechthai [a] and Kraichat Tantrakarnapa [b]

[a] *Faculty of Public Health, Mahidol University, Bangkok, Thailand*
[b] *Faculty of Tropical Medicine, Mahidol University, Bangkok, Thailand*

Abstract

This study aimed to investigate suitable types and ratios of materials for making clay-pots, and their performance to improve the physical and bacteriological quality of drinking water. Synthetic water was prepared and used to select suitable types and ratios for clay-pot water filters. The clay-pots were prepared by combining clay with sand, coconut-shell charcoal, and rice-husk charcoal, at various ratios. The results indicated that all types and ratios could remove 100% of coliform bacteria and *Escherichia coli*, and were thus suitable for treating drinking water. However, for practical use, the system should have real-world application. Therefore, filtration rate/inner surface area/time was used as a criterion to determine suitable types and ratios. Different types of clay-plot water filter yielded significantly different filtration rates ($p<0.01$). Clay with coconut-shell charcoal generated the maximum filtration rate of 0.44 ± 0.11 mL/cm^2/hr. Different ratios of clay-pot water filter did not yield significantly different filtration rates ($p>0.01$). A ratio with a maximal filtration rate of 60:40(0.38 ± 0.28 mL/cm^2/hr) was found to be suitable. The quality of filtered water was acceptable in terms of turbidity, coliform bacteria level, and *Escherichia coli*, according to WHO drinking-water quality guidelines.

Keywords: clay-pot water filter; physical quality; bacteriological quality; drinking water; Escherichia coli; coliform bacteria

1. Introduction

Thailand is about 513,115 square km in area. The terrain consists mostly of plains, which experience rainfall throughout the year; the average annual rainfall for the whole country is >1,500 millimeters (The Royal Institute, 2002). During the years 1988-2011, 208 floods were recorded for the country, while some areas flooded more than once per year. The consequences of flooding were property damage, environmental deterioration, and impacts on public health. The health impacts of flooding e.g., injuries, fecal-oral diseases, and outbreaks of gastroenteritis, were monitored (Ahern *et al.,* 2005). The types of assistance needed by flood victims were ascertained, especially essential items for daily living (clothes, medicine, food, and drinking water) (Lertlum, 2003). The most urgent need was potable drinking water to ensure survival (Aitken, 2009); humans require 2-3 liters of drinking water per day (WHO, 2004). During floods, safe drinking water is usually scarce and the normal water supply often damaged and contaminated (Fernando *et al.,* 2009). Contamination may occur during the flood, such as pathogens harmful to human health in untreated drinking water being consumed (Ten, 2010). River sediments can accumulate coliform bacteria, which can be distributed during a flood, or when water resources are otherwise disturbed (Muirhead,2004). It is relatively safe to consume free coliform bacteria in water; they are usually not very harmful, but can cause short-term effects, e.g., diarrhea, cramps, nausea, headache, and other non-severe symptoms (Lukasik, 1999). *Escherichia coli* is the most frequently found coliform bacterium, because these bacteria are found in the intestinal tracts of humans and other warm-blooded animals (USEPA, 1986). Bacteriological quality was the most important factor in assessing the relationship between the safety of drinking water and diseases transferred by water. If coliform bacteria are found in water, they may cause diseases, so-called waterborne diseases (Macler and Merkel, 2000). During floods, victims need safe drinking water (Groendijk, 2009). A clay water filter has many advantages of being lightweight, portable, low-cost, requires no chemicals, and is simple to use; it can be produced locally, using naturally available clay and other materials. The pore size and surface charge of a clay-pot water filter determine its ability to remove particles and pathogens from water (Bielefeldt *et al.,* 2010). For the above reasons, researchers need to find suitable type and ratio of clay-pot water filter to improve the physical and bacteriological quality of water for drinking that is derived from surface water to obtain safe and clean drinking water for consumption.

Table 1. Material mixtures and ratios

Type	Materials	Percentage			
	Two materials				
1	Clay: Sand	60: 40	70:30	80:20	90:10
2	Clay: Coconut-shell charcoal	60: 40	70:30	80:20	90:10
3	Clay: Rice-husk charcoal	60: 40	70:30	80:20	90:10
	Three materials				
4	Clay: Sand: Coconut shell: charcoal	60: 20: 20	70:15:15	80:10:10	90:5:5
5	Clay: Sand: Rice-husk charcoal	60: 20: 20	70:15:15	80:10:10	90:5:5
6	Clay: Coconut-shell charcoal: Rice-husk charcoal	60: 20: 20	70:15:15	80:10:10	90:5:5
7	Clay	100			

2. Materials and Methods

This was a laboratory-scale experimental research study. All seven types and all nine percentages of clay-pot water filter were prepared and used for the experiments on the physical and bacteriological quality of treated drinking water. The performance of the clay-pot water filter was determined by physical and bacteriological quality, and filtration rate. The methods used to determine these characteristics followed the standard methods for water and wastewater examination (Amercan Public Health Association, 2005). Differences in turbidity, coliform bacteria, *Escherichia coli,* and filtration rate, were analyzed by one-way ANOVA. Significance was set at 1%. All the experiments were carried out in quintuplicate.

2.1. Clay-pot water filter preparation

Total number of examined clay-pots was consisted by 6 combinations of materials and 4 ratios of composition plus one original material (100%clay) as shown in Table 1.

2.2. Mold of clay-pot water filter

Each type and ratio of clay-pot water filter was sintered at 600^{o}C for 5 hours (biscuit firing). After sintering, the clay-pot water filter was dried at room temperature for 3 days before conducting the filtration process. At the beginning of the study, the clay-pot water filters were cleaned with tap water and sterilized in a hot-air oven at 180^{o}C for 2 hours. The clay-pot water filter was used with a receptacle container as illustrated in the schematic diagram (Fig. 1).

2.3. Synthetic water preparation

Synthetic water was prepared by mixing coliform bacteria with distilled water sterilized at 121^{o}C for 15 minutes. To this was added a colony of *Enterobacter* spp., *Klebsiella* spp., and *Escherichia coli,* with the use

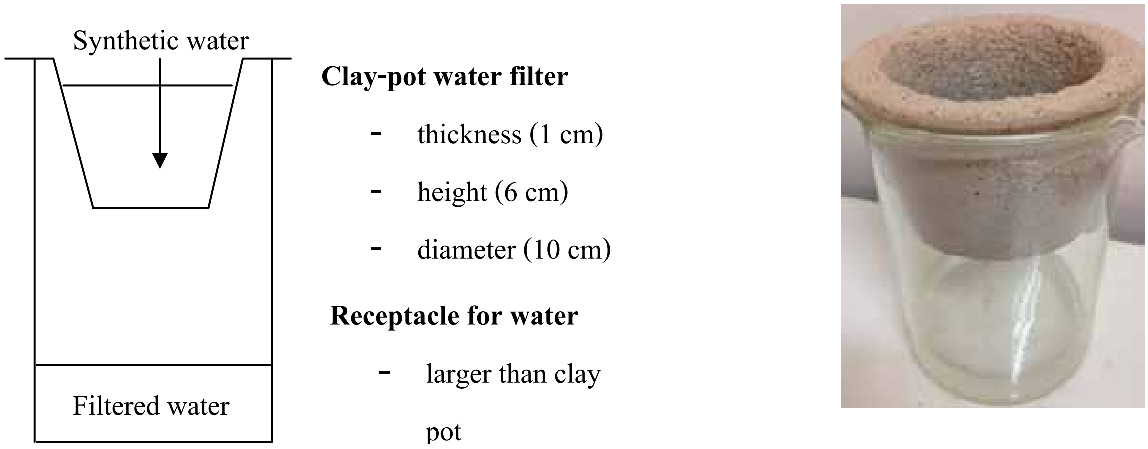

Figure 1. Design of clay-pot water filter

of a loop. Finally, sterilized soil was added. Turbidity, coliform bacteria, and *Escherichia coli* levels were controlled at 55-60 NTU, 2.4 x 10^7 MPN/100mL, and 2.4 x 10^4 MPN/100 mL, respectively. The synthetic water was poured into the clya0pot water filter and percolated through the filter element into the receptacle below. Water in the receptacle was analyzed for all parameters; turbidity, coliform bacteria, *Escherichia coli* and filtration rate/ inner surface/ hour.

3. Results and discussion

In this study, main research focused on selecting suitable types and ratios of clay-pot water filter, to improve the quality of surface water and to get safe and clean water for consumption. The results were shown in Table 2.

In order to determine the suitable materials and proper percentage of mixing materials, One-way ANOVA analysis at *0.01* significance level was performed the different concerned parameters namely; turbidity, pH and filtration rate. The results indicated that the different types of clay-pot water filter yield different degrees of turbidity ($p > 0.01$) except the mixing of clay and rice husk charcoal (p value = *0.005*) as shown in Table 3. However the pH of treated waster were significant different (p value < *0.001*) except the clay:sand (p value = *0.106*), and clay:coconut-shell-charcoal(p value = *0.026*), In case of filtration rate, all are significant different (p value < *0.001*). Turbidity in the other types was also acceptable; all are less than 5 NTU according to the WHO standard (WHO, 2004). Six types of clay-pots could remove 100% of coliform bacteria and *Escherichia coli.* In the case of pure clay, the physical and bacteriological quality could not be measured due to the inadequate volume of water. However, this result was similar to the research study by Murphy *et al.* (2009), who tried to decrease microorganism contamination in water using a clay-pot water filter composed of crushed bricks, rice husk, and laterite. In addition, when it was promoted for use in rural areas of Cambodia, diarrheal diseases were reduced by 50%. The ceramic water filter effectively removed up to 99.99% of total coliform in water samples (Van, 2006). In addition, the *E. coli* and bacteriophage MS2 in drinking water were removed by ceramic water filtration in the study by Brown (2007). All types and ratios could remove turbidity, coliform bacteria, and *Escherichia coli* to acceptable WHO standards. Thus, all the types and ratios could be used for water treatment. However, for use in a real-world situation, its filtration rate should also be considered.

The inner surface area was calculated from sum of side and bottom surface areas. The inner surface area was 201.06 sq cm. Clay: coconut-shell charcoal type with percentage of 60:40 provided the highest filtration rate; 127.0 mL/hr. This was consistent with the study by Murphy *et al.* (2009), who suggested a clay-pot water filter made of crushed, sun-dried clay bricks, local rice-husk waste, and laterite, could remove coliform bacteria. The burnt rice husk allowed for increased porosity, and with a large portion of coconut-shell charcoal, resulted in a highly porous clay-pot water filter, with a satisfactory filtration rate.

In order to use for the real situation, the filtration rate was also studied to determine the limitation. The mixing percentage of material 60:40 was used for study the variation. At the filtration was started, the filtration rate of water was gradually increased from 0.54 mL/hr. and reached 240 mL/hr. After that, it was gradually decreased to the increase of water volume. Howeve, it could be observed that the filtration rate of water trends to fluctuate when the experiment was started in each day such as at 13, 25, 37, 49, 61, 73, 85, 97, 109, 121 and 133 h since it was daily paused for every 12 hour. Fig. 2 shows the trendency of filtration rate of water by clay pot at 60:40 of clay and coconut shell charcoal. According to the experiment, the volume of water that poured into the clay pot filter was 300 mL at first hour. In addition, the surface water was refilled into the clay pot again until it is fully. Therefore, the approximate 12 times per day of filtration could be done. After twelve hour, then clay pot was covered with aluminum foil to protect contaminant of water. The filtration rate of water depends on the turbidity of influent water. Murphy *et al.* (2009) showed that when influent water has higher turbidity, the filtration rate was lower. At this point, however, the filtration rates were gradually decreased again. At second day of experiment, the turbidity of surface water decreased to 44.45 - 48.54 NTU. Similar to the previous experiment, the filtration rate of water seem to be lower at the first hour of experiment compared to that at the last experiment on previous day. Also, the higher filtration rate was observed in the next hour. Similar to the previous day, the filtration rate trends to decrease to the number of experiment or volume of water.

The observed higher filtration rate at the fourth hour of experiment compared to the starting point may be due to there is higher water addorption in dry clay pot. Raimondo *et al.* (2009) showed that the filtration rates of water collected first to third hour are generally lower than that sample collected at fourth hour. The new dry clay used to filter water can absorb influent water inside. That causes the lower water volume is generally found in the effluent. After the water is saturated at fouth hour, therefore, there is no water absorbed. This experiment is consistent with the research of Van (2006). They showed the increase of filtration rates at the fouth hour

Table 2. Average± SD values of turbidity, coliform bacteria, *Escherichia coli,* and filtration rate after filtration via clay-pot water filter

Types	Percentage	Turbidity (NTU)	pH	Coliform bacteria (MPN/100 mL)	Filtration rate (mL/h)
Initial water quality		55-60	2.4 x 107	2.4 x 104	-
Clay: sand	60: 40	1.03 ± 0.23	7.03 ± 0.08	< 2.2	14.8 ± 1.64
	70: 30	0.82 ± 0.28	7.00 ± 0.07	< 2.2	11.6 ± 1.82
	80: 20	0.64 ± 0.41	6.97 ± 0.05	< 2.2	9.80 ± 1.64
	90: 10	0.60 ± 0.55	6.93 ± 0.04	< 2.2	6.60 ± 1.82
Clay: coconut shell charcoal	60: 40	0.72 ± 0.32	8.45 ± 0.05	< 2.2	127.0± 1.22
	70: 30	0.70 ± 0.24	8.41 ± 0.05	< 2.2	112.4± 3.36
	80: 20	0.66 ± 0.23	8.40 ± 0.02	< 2.2	96.0 ± 3.16
	90: 10	0.35 ± 0.25	8.36 ± 0.02	< 2.2	82.8 ± 1.79
Clay: rice husk charcoal	60: 40	0.88 ± 0.22	8.78 ± 0.02	< 2.2	99.2 ± 3.90
	70:30	0.79 ± 0.15	8.72 ± 0.02	< 2.2	67.0 ± 2.92
	80: 20	0.74 ± 0.15	8.68 ± 0.03	< 2.2	59.4 ± 3.44
	90:10	0.42 ± 0.15	8.61 ± 0.01	< 2.2	51.6 ± 2.41
Clay: sand: coconut shell charcoal	60: 20: 20	1.03 ± 0.30	8.03 ± 0.05	< 2.2	59.4 ± 2.88
	70: 15: 15	1.02 ± 0.18	7.92 ± 0.04	< 2.2	45.8 ± 2.59
	80: 10: 10	1.00 ± 0.31	7.83 ± 0.03	< 2.2	39.4 ± 3.44
	90: 5: 5	0.99 ± 0.31	7.73 ± 0.06	< 2.2	33.8 ± 3.03
Clay: sand: rice husk charcoal	60: 20: 20	1.51 ± 0.38	8.11 ± 0.03	< 2.2	46.2 ± 3.11
	70: 15: 15	1.27 ± 0.27	7.99 ± 0.04	< 2.2	36.0 ± 3.87
	80: 10: 10	1.25 ± 0.32	7.70 ± 0.04	< 2.2	30.6 ± 3.87
	90: 5: 5	1.00 ± 0.26	7.67 ± 0.04	< 2.2	27.2 ± 2.68
Clay: coconut shell charcoal: rice husk charcoal	60: 20: 20	1.22 ± 0.26	9.04 ± 0.04	< 2.2	89.8 ± 3.61
	70: 15: 15	1.10 ± 0.50	8.95 ± 0.03	< 2.2	93.0 ± 3.52
	80: 10: 10	1.07 ± 0.29	8.87 ± 0.03	< 2.2	74.4 ± 3.06
	90: 5: 5	0.90 ± 0.40	8.82 ± 0.02	< 2.2	62.6 ± 1.82
Clay	100: 0: 0	-	-	-	1.80 ± 0.84

The symbol-means not detectable, since the filtered water volume was very small

of filtration. Ceramic pot filter was gradually absorbed water in the fifth hour of filtration. When ceramic pot filter was saturated, almost influent water could be released in the fourth hour (Fig. 2). Accumulation of sediment leads to reduction of filtered water volume. Inner surface of clay pot water filter was accumulated with sediment. Van (2006) found that filter clogging is normally resulting from colloidal particles. Direct effects may be identified from the decrease of flow rate and frequent scrubbing. The maintenance procedure is generally scrubbing the filter when clogging was observed. Frequent scrubbing, however, may cause recontamination of water and breakage of filter. As show previously, the relatively high porosity and low

Table 3. Analysis of variance (ANOVA) of water quality in difference types and percentage

Types	Percentage	Parameter	*p-value*	*F-value*
Clay: sand	60: 40	Turbidity	0.312	1.290
	70: 30	pH	0.106	2.396
	80: 20	Filtration rate	<0.001	19.578
	90: 10			
Clay: coconut shell charcoal	60: 40	Turbidity	0.102	2.440
	70: 30	pH	0.026	4.041
	80: 20	Filtration rate	<0.001	285.074
	90: 10			
Clay: rice husk	60: 40	Turbidity	0.005	6.191
charcoal	70:30	pH	<0.001	51.029
	80: 20	Filtration rate	<0.001	211.558
	90:10			
Clay: sand: coconut	60: 20: 20	Turbidity	0.993	0.029
shell charcoal	70: 15: 15	pH	<0.001	39.206
	80: 10: 10	Filtration rate	<0.001	67.437
	90: 5: 5			
Clay: sand: rice husk	60: 20: 20	Turbidity	0.118	2.287
charcoal	70: 15: 15	pH	<0.001	159.985
	80: 10: 10	Filtration rate	<0.001	32.645
	90: 5: 5			
Clay: coconut shell	60: 20: 20	Turbidity	0.774	0.372
charcoal: rice husk	70: 15: 15	pH	<0.001	46.325
charcoal	80: 10: 10	Filtration rate	<0.001	107.955
	90: 5: 5			

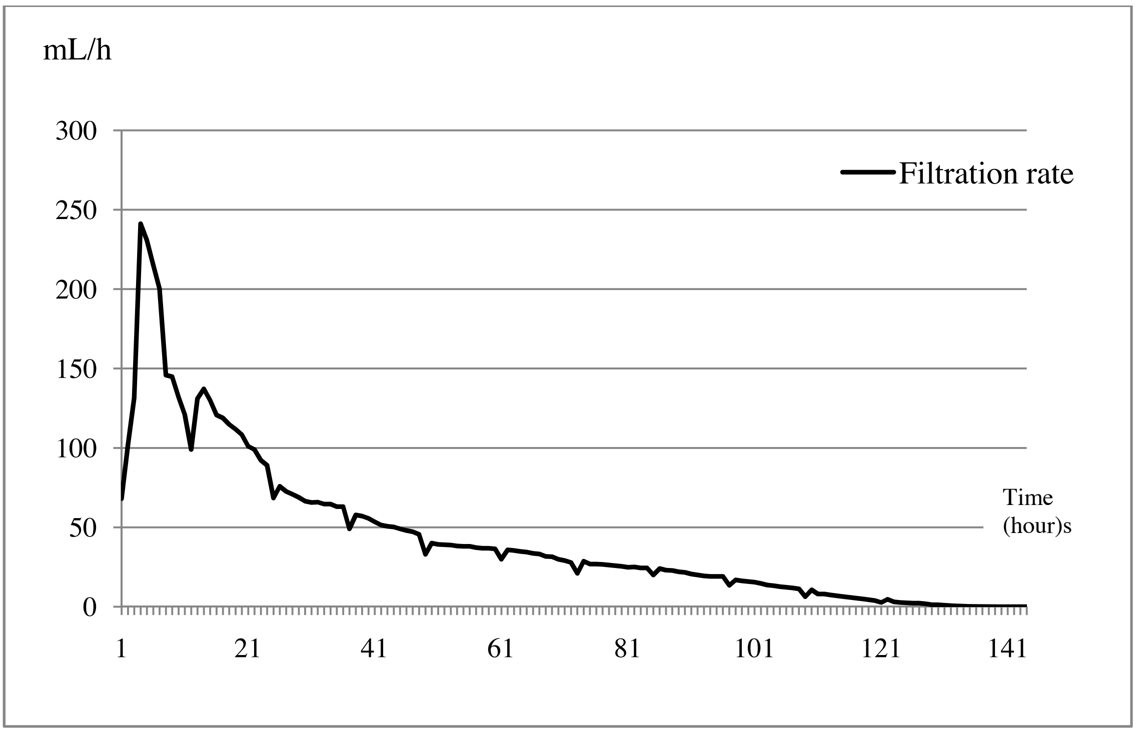

Figure 2. Filtration rate of filtered water over time (hour)

strength may enhance clay pot breaking and clogging from scrubbing. Clay pot filter can remove coliform bacteria in surface water. This study showed that after pouring 6.28 liter of water filtration found coliform bacteria less than 2.2 MPN/100 mL which meet to the acceptable level of WHO drinking water standard (2004). Sui and Huang (2003) showed the potential of gradient ceramic membrane to remove 100% of pathogenetic bacteria such as; *E.coli,* Salmonelle, microzyme, staphylotoxin, *Psuedomonas aeruginosa*, mold, rust, worm and suspension particles in water. The removal efficiency for pathogenic bacteria by filtration through clay pot filter at 60:40 ratios of clay: coconut shell charcoal varied between 98% and 99.9%. It can be suggested clay pot filter at 60:40 ratio of clay: coconut shell charcoal can be used as filter for drinking water treatment. However, the filtration period and treated volume were limited since it can be used only in the short period. To solve the constrain mentioned above the size expanding can be alternative approach to obtain more volume of treated water. The another issue to be concerned is the turbidity level, therefore the correlation between turdibity and filtration rate should be taken into account for further study.

4. Conclusion

The results showed that different types of clay-pot water filter created drinking water of significantly different physical quality ($p<0.01$). Different ratios of clay-pot water filter yielded significantly different turbidity levels ($p<0.01$). Six types and eight ratios could remove 100% of coliform bacteria and *Escherichia coli.* Of the different types and ratios of clay-pot water filter, the best r for practical use could not be determined on physical and bacteriological quality factors alone. Therefore, filtration rate/inner surface area/time was added as a variable to aid selection. Different types of clay-pot water filter yielded significantly different filtration rates ($p<0.01$). The maximum filtration rate was 0.44 ± 0.11 ml/cm2/h in the ratio 60:40 of clay: coconut-shell charcoal. When the filtered water was compared with the drinking-water standard by WHO, the types and ratios of clay-pot water filter were within the acceptable range for turbidity, coliform bacteria, and *Escherichia coli.*

References

Ahern M, Kovats RS, Wilkinson P, Few R, Matthies F. Global health impacts of floods: epidemiologic evidence. Epidemiologic Reviews 2005; 27(1): 36-46.

Aitken P, Leggat P, Robertson A, Harley H, Speare R, Leclercq M. Health and safety aspects of deployment of Australian disaster medical assistance team members: results of a national survey. Travel Medicine and Infectious Disease 2009; 7(5): 284-90.

American Public Health Association (APHA). Standard methods for the examination of water and wastewater. 21st ed. American Public Health Association, Washington DC, USA. 2005.

Bielefeldt AR, Kowalski K, Schilling C, Schreier S, Kohler A, Summers RS. Removal of virus to protozoan sized particles in point-of-use ceramic water filters. Water Research 2010; 44(5): 1482-88.

Brown J.M. Effectiveness of ceramic filtration for drinking water treatment in Cambodia. Ph.D. Dissertation. University of North Carolina at Chapel Hill, 2007.

Fernando WBG, Gunapala AH, Jayantha WA. Water supply and sanitation needs in a disaster: lessons learned through the tsunami disaster in Sri Lanka. Desalination 2009; 248(1-3): 14-21.

Groendijk L, de Vries HE. Development of a mobile water maker, a sustainable way to produce safe drinking water in developing countries. Desalination 2009; 248 (1-3): 106-13.

Lertlum A. Needs of flood victims and management in flood problem solving. Master of Science Thesis in Public Health. Khon Kaen University, Thailand, 2003.

Lukasik J, Cheng YF, Lu F, Tamplin M, Farrah SR. Removal of microorganisms from water by columns containing sand coated with ferric and aluminum hydroxides. Water Research 1999; 33(3): 769-77.

Macler AB, Merkel CJ. Current knowledge on groundwater microbial pathogens and their control. Hydrogeology Journal 2000; 8(1): 29-40.

Muirhead RW, Davies-Colley RJ, Donnison AM, Nagels JW. Faecal bacteria yields in artificial flood events: quantifying in-stream stores. Water Research 2004; 38(5): 1215-24.

Murphy HM, Sampson M, McBean E, Farahbakhsh K. Influence of household practices on the performance of clay pot water filters in rural Cambodia. Desalination 2009; 248(1-3): 562-69.

Raimondo M, Dondi M, Gardini D, Guarini G, Mazzanti F. Predicting the initial rate of water absorption in clay bricks. Construction and Building Materials 2009; 23 (7): 2623-30.

Sui X, Huang X. The characterization and water purification behavior of gradient ceramic membranes. Separation and Purification Technology 2003; 32(1-3): 73-79.

Ten Veldhuis JAE, Clemens FHLR, Sterk G, Berends BR. Microbial risks associated with exposure to pathogens in contaminated urban flood water. Water Research 2010; 44(9): 2910-18.

The Royal Institute. Gazetteer. The Royal Institute, Bangkok, Thailand. 2002.

U.S. Environmental Protection Agency (USEPA).Ambient water quality criteria for bacteria. U.S. EPA, Washington DC, USA. 1986.

Van HD. Ceramic silver impregnated pot filters for household drinking water treatment in developing countries. Master of Science Thesis in Civil Engineering. Delft University of Technology, Netherlands, 2006.

World Health Organization. Guidelines for drinking-water quality. 3rd ed. Geneva: World Health Organization,2004.

Received 5 February 2014
Accepted 30 April 2014

Correspondence to
Associate Professor Dr.Kraichat Tantrakarnapa
Faculty of Tropical Medicine,
Mahidol University,
420/6 Rajvithi Road,
Bangkok 10400,
Thailand
E-mail: kraichat.tan@mahidol.ac.th