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Effects of Co-current and Cross Flows on Circular Enhanced Gravity Plate Separator Efficiencies

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Abstract

This study compares the effects of flow on oil and suspended solids removal efficiencies in circular enhanced gravity plate separator equipped with coalescence medium. Coalescence medium acts to capture rising oil droplets and settling solid particles and assist in the coalescence of oil and coagulation of solid. The circular separator uses an upflow center-feed perforated-pipe distributor as the inlet. The co-current flow is achieved using 4 increasing sizes of frustum, whereas cross flow uses inclined coalescence plates running along the radius of the separator. The different arrangement gave the cross flow separator a higher coalescence plan area per operational volume, minimal and constant travelling distance for the oil droplets and particles, lower retention time, and higher operational flowrate. The cross flow separator exhibited 6.04% and 13.16% higher oil and total suspended solids removal efficiencies as compared to co-current flow.

Keywords: Circular enhanced gravity plate separator, Coalescence medium, Co-current flow, Cross flow, Oil droplets and solid particles removal

1. Introduction

Regulatory requirement for oil and suspended solids content allowable in sewage and industrial effluent discharge are ≤10 mg/L and ≤100 mg/L, respectively, for most countries, such as the United State, Canada, Colombia, Malaysia, and some European countries [1]. Effluent from oil and gas industry or shipping activities contains high amount of oil [2]. Wastewater high with suspended solids particles due to erosion are introduced into the environment from land clearing and earthworks activities [3].

Most separators used to treat oil or solids are rectangular separator [4]. Some of these separators currently in use include 1) the American Petroleum Institute separators, 2) coalescing plate separators, 3) coalescing tube separators, and 4) packing type separators [5]. Rectangular separator has a constant horizontal velocity, v_h throughout. In rectangular separator, co-current flow is favorable for solid particles removal whereas cross flow is preferable for oil separation [6].

A circular separator takes advantage of the continual decrease in horizontal velocity, v_h as surface area increases along the radius. The decrease in horizontal velocity, v_h enhances separation. The circular separator is more compact as compare to rectangular separator [7]. The aim of this study is to determine which flow pattern along coalescence medium is preferable for oil and solid separation in a circular separator.

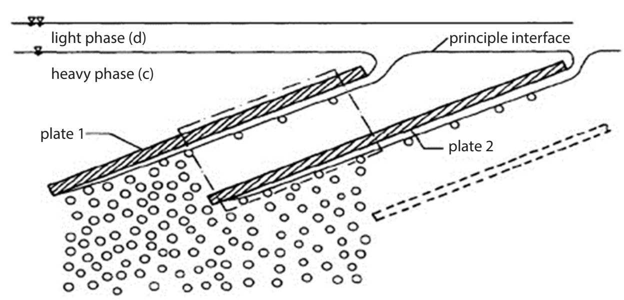

Fig. 1. Physics of processes in a plate settler [9].

Coalescence mediums in the form of parallel plates are applied in enhanced gravity separators to increase the separation efficiency by making the settling distance smaller and the interfacial area for the coalescence larger. In these separators, the oil droplets rise to the upper plate and form a trickling film which flows along the plate following the hydrostatic pressure gradient to the principal interface as shown in Fig. 1 [8-10]. Droplets of oil then coalesce on the trickling film [9].

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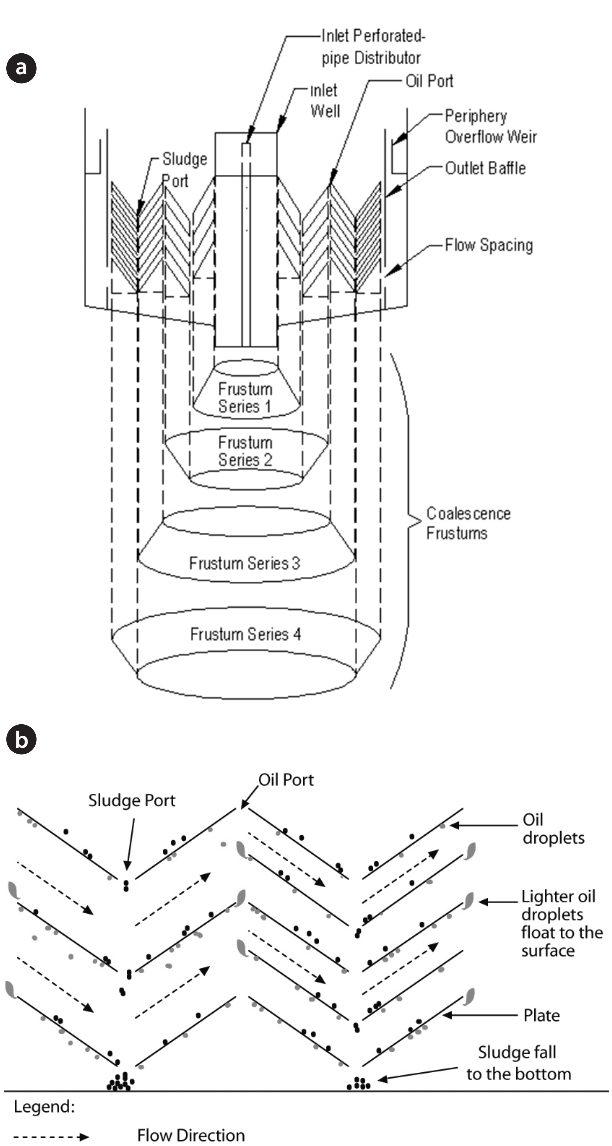

Fig. 2. Co-current flow (a) plate arrangement and (b) oil-water-solid separation mechanism.

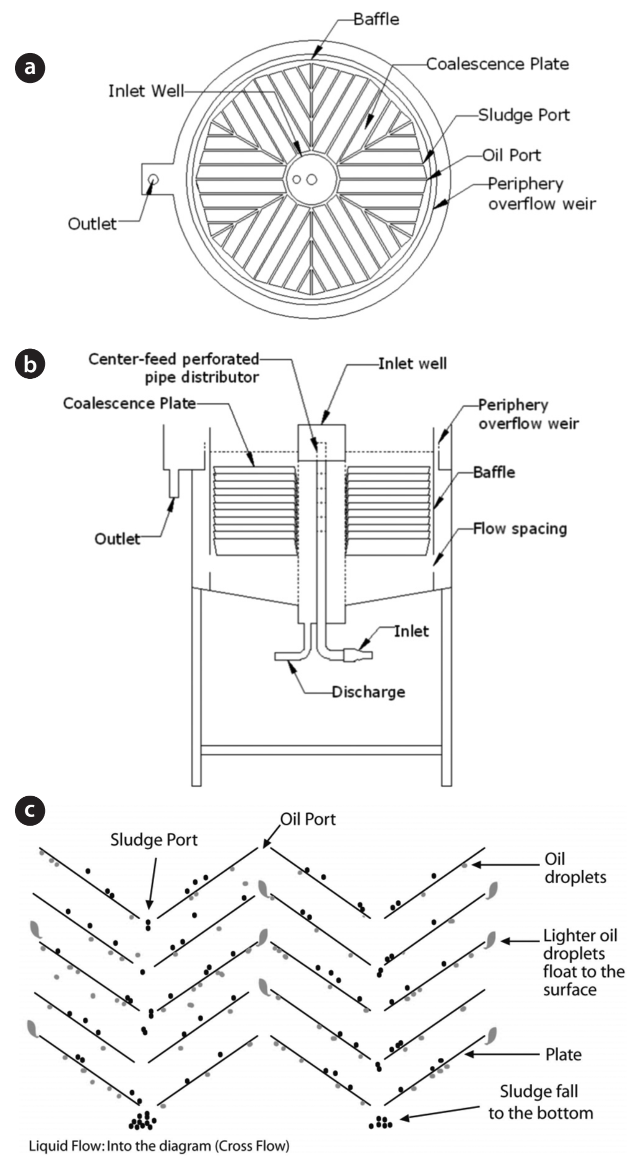

Fig. 3. Cross flow (a) plate arrangement (top view), (b) plate arrangement (cross sectional view), and (c) oil-water-solid separation mechanism.

Circular oil-water-solid separator with coalescing plates are suitable for applications on small-scale wastewater flow for workshop, oil terminal, land clearing and earthwork surface runoff, residential at rural or low population density areas where the transportation of wastewater to a central treatment system is costly [11]. This separator is also suitable for wastewater treatment where availability of large area is a constraint, such as on oil and gas platforms and shipping activities.

2. Materials and Methods

Co-current and cross flow were achieved in circular separator by utilizing an upflow center-feed perforated-pipe distributor as the inlet [12] directing flow to different arrangement of inclined coalescence plates. Fig. 2(a) illustrates how inclined plates were arranged to achieved co-current flow. The arrangement consists of four series of inclined frustums. Each series consists of several successive layers of frustums. The frustums were inclined at an angle of 55° (up-right) [13] and 125° (inverted) that subsequently form a multiple-angle arrangement. All frustums had an inclined length of 10.0 cm. The amount of frustums increases with each subsequent series, and the interval between frustum decreases with each subsequent series [7]. Fig. 2(b) shows the mechanism of oil-water-solid separation for co-current flow.

Fig. 3(a) and (b) illustrates the arrangement of plates to achieve cross flow. The arrangement consists of 6 set of coalescing plates, each covering 60° of the circular separation tank. Each coalescing plates set consists of several parallel successive layer of plates inclined at angle θ, 55° and 125° to form the dual angle coalescing plates arrangement. The intervals between inclined plates are constant, and the intervals between stacks of inclined plates form the oil and sludge port [11]. Fig. 3(c) shows the mechanism of oil-water-solid separation for cross flow.

2.1. Oil-Water-Solid Separation Mechanism

Coalescence plates promote laminar flow and facilitate the coalescence of oil droplets and the coagulation of solid particles. Plates are kept at a minimal spacing to reduce the vertical distance that the oil droplets and solids particles need to travel before encountering a plate. Droplets and particles captured on the plates would increase in size. When they are large enough the buoyancy forces will overcome the attractive forces holding the droplets and particles to the plate [14]. Then the large droplets rose to the surface to be skimmed out and the coagulated particles settled to the bottom.

In rectangular separator the plates extend from one side of the separator all the way to the opposite side of the separator; all captured oil/solids must progress along the entire length of the plate before exiting to the surface at the opposite side of the separator [15]. In a large separator, this could measure 2.5 m in length, or more. This means that the amount of oil running along the undersides of plates increases as it moves upward along the sloped surface of the plates.

In circular separator, oil/sludge ports are placed at intervals along the radius (co-current) or vertically aligned along the radius (cross flow) for the quick release of oil droplets and solid particles from the plates to rise to the surface or fall to the bottom of the tank. These are illustrated in Figs. 2(b) and 3(c).

2.2. Different between Co-current and Cross Flow Circular Separator

Both the separators were designed with 86 L of operational volume [16]. The coalescence plate arrangements for cross flow separator gave a higher coalescing plan area per operational volume of 0.0436 m²/L as compared to co-current flow with 0.0241 m²/L [17]. Higher coalescing plan area provides more surface area for oil droplets to coalesce and solids particles to coagulate, hence theoretically enable higher removal capacities of oil droplets and solid particles. Due to this, separator with cross flow can operate at higher operational flowrates which allow more waste water to be treated.

2.3. Experimental Procedure

Influent oil water mixtures were prepared from used palm olein oil with mass density (ρ_o) of 917 kg/m³. Different influent oil concentrations, C_{io} were prepared (50, 75, 100, 150, 200, and 250 mg/L). Oil concentrations in water were measured using an oil-in-water analyzer which is a non-dispersive infrared absorption method. The measurement error for this instrument is ±0.2 mg/L (oil content analyser OCMA-310; Horiba, Tokyo, Japan).

Influent suspended solids water mixtures were prepared from sieved silt and clay particles that passed through 0.063 mm sieve (with specific gravity of 2.72) [18]. Seven different influent suspended solids concentrations, C_{iss}, were prepared: 100, 150, 200, 250, 300, 350, and 400 mg/L. Total suspended solids (TSS) were measured by a spectrophotometer (DR/2400; HACH, Loveland, CO, USA) using the photometric method at 810 nm. The instrument wavelength accuracy is ±1 nm and calibrated automatically via internal filter.

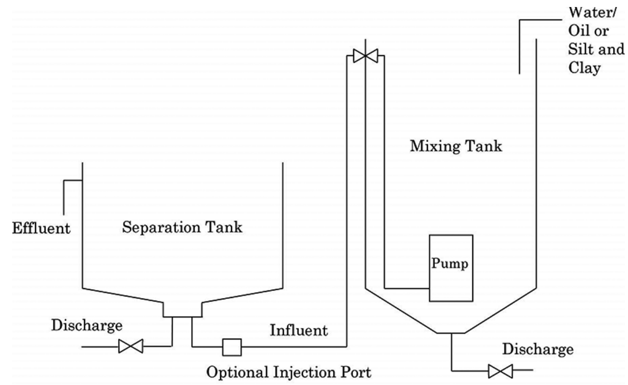

Fig. 4. Schematic diagram of experimental setup.

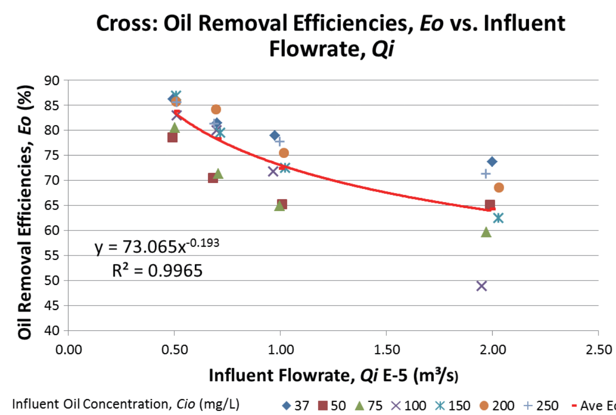

Fig. 5. Average oil removal efficiencies, E_o of various C_{io} at different Q_i for cross flow separator.

The prepared influent mixtures were tested at four different influent flowrates (Q_i; 0.5 × 10^{-5}, 0.7 × 10^{-5}, 1.0 × 10^{-5}, and 2.0 × 10^{-5} m³/s). Fig. 4 indicates the schematic diagram of the experimental setup.

3. Results and Discussions

3.1. Oil Removal

Fig. 5 illustrates the average oil removal efficiencies, E_o of various C_{io} at different Q_i of the cross flow separator. The average E_o of various C_{io} increases with decreases in Q_i. The average E_o at Q_i of 0.5 × 10^{-5}, 0.7 × 10^{-5}, 1.0 × 10^{-5}, and 2.0 × 10^{-5} m³/s were 83.8%, 78.4%, 72.4%, and 64.3%, respectively. The R^2 correlation of Q_i relation with average E_o was 0.9965. The equation $E_o = 73.065\ (Q_i \times 10^{-5})^{-0.193}$ can be used to determine the average oil removal efficiency of cross flow at given Q_i.

Fig. 6 compares the oil removal efficiencies of co-current flow and cross flow for circular separator at C_{io} of 100 mg/L [11]. It indicates that oil removal for cross flow is approximately 13.16% higher compared to co-current flow.

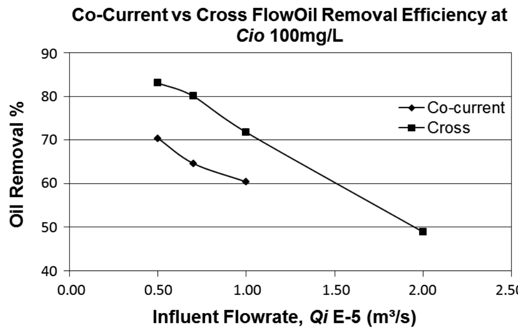

Fig. 6. Oil removal efficiencies at influent oil concentration of 100 mg/L and various flowrate for co-current and cross flow.

3.2. Suspended Solids Removal

Fig. 7 shows the relationship of average TSS removal efficiencies, E_{ss} of various C_{iss} at different Q_i for the co-current flow and cross flow separators. Similar to oil removal trend, it was also observed that average E_{ss} of various C_{iss} increases when Q_i decreases. For cross flow separator the average E_{ss} at Q_i of 0.5 × 10^{-5}, 0.7 × 10^{-5}, 1.0 × 10^{-5}, and 2.0 × 10^{-5} m^3/s were 67.1%, 62.6%, 56.7%, and 46.9%, respectively. The R^2 correlation of Q_i relation with average E_{ss} was 0.9973. The equation $E_{ss} = 56.472\ (Q_i \times 10^{-5})^{-0.262}$ can be used to determine the average TSS removal efficiency of the cross flow separator at given Q_i.

For co-current flow separator the average E_{ss} at Q_i of 0.5 × 10^{-5}, 0.7 × 10^{-5}, 1.0 × 10^{-5}, and 2.0 × 10^{-5} m^3/s were 60.70%, 54.91%, 50.06%, and 43.45%, respectively. The R^2 correlation of Q_i relation with average E_{ss} was 0.9916. The equation $E_{ss} = 50.799\ (Q_i \times 10^{-5})^{-0.238}$ represents the relationship between average TSS removal efficiency of the co-current flow separator with Q_i.

Comparatively, cross flow has an average 6.04% higher TSS removal rate as compared to co-current flow. It is approximately 12% higher at lower influent concentration of 100 and 150 mg/L.

3.3. Discussion

Circular plate separator with cross flow exhibits 6.04% and 13.16% higher oil and TSS removal efficiencies as compared to co-current flow. Cross flow coalescence medium arrangement return a higher coalescing plan area per operational volume of 0.0436 m^2/L as compared to co-current flow with 0.0241 m^2/L. This gave cross flow more surface area for oil droplets to coalesce and solids particles to coagulate, and hence increases its removal capacity.

The arrangement of coalescence plates with relation to the flow direction gave cross flow a constant distance (denoted as x in Fig. 8) for oil droplets/solid particles to travel before it meet a coalescence plate. With a co-current flow arrangement the distance might varies from x to y depending on the size of the droplets/particles. Therefore, in cross flow arrangement, oil droplets/solid particles regardless of its size need only to travel the minimum x distance before it encounter a coalescence plate. These factors enhance separation and performance in the cross flow separator. With a cross flow arrangement a separator can be operated at higher flowrate and shorter retention time to achieve comparable results with a co-current flow separator.

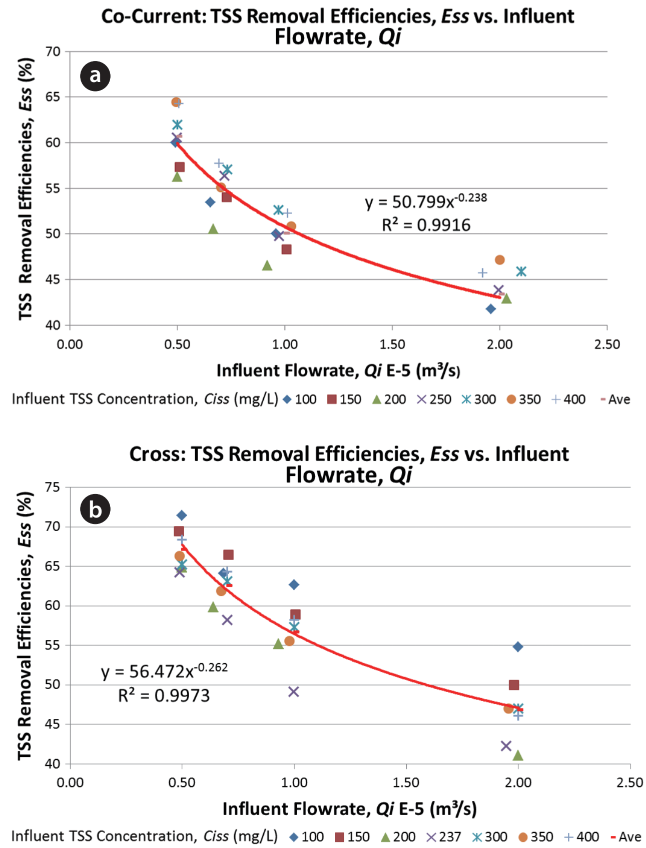

Fig. 7. Average total suspended solid removal efficiencies, E_{ss} of various C_{iss} at different Q_i for (a) co-current flow separator and (b) cross flow separator. TSS: total suspended solids.

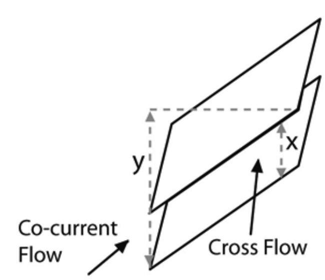

Fig. 8. Distance travel by oil droplets/solid particles before encountering a coalescence plate.

4. Conclusions

Circular enhanced gravity plate separator with cross flow exhibits 6.04% and 13.16% higher oil and TSS removal efficiencies as compared to co-current flow. Cross flow coalescence medium arrangement has a better removal performances due to its higher coalescing plan area per operational volume and minimum and constant droplets/particles travelling distance between coalescence plates.

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Nomenclature

θ	°	coalescence plate angle
ρ_o	kg/m³	used palm olein oil with mass density
C_{io}	mg/L	influent oil concentration
C_{iss}	mg/L	influent TSS concentration
E_o	%	oil removal efficiencies
E_{ss}	%	TSS removal efficiencies
Q_i	m³/s	influent flowrates
TSS	mg/L	total suspended solids
v_h	m/s	horizontal velocity

References

1. Mohr KS. An overview of US and international regulations regarding hydrocarbons in water effluents. Proceedings of the Water Environment Federation and Purdue University Industrial Wastes Technical Conference; 2000 May 21-24; St. Louis, MO. p. 158-166.
2. LaRusic A, Mohr KS. Design and installation of a hydrocarbon removal separator for industrial storm runoff. Proceedings of the British Columbia Water and Waste Association Annual Conference; 1998 Apr; Whistler, BC.
3. Malaysia Department of Environment. Malaysia environmental quality report 2011. Kuala Lumpur: Department of Environment; 2011.
4. Tchobanoglous G, Burton FL, Stensel HD. Wastewater engineering: treatment and reuse. 4th ed. New York: McGraw-Hill; 2004.
5. Mohr KS. Stormwater treatment for contaminant removal. In: Public works and the human environment: proceedings of the International Symposium of the American Public Works Association; 1995 Apr 19-21; Seattle, WA.
6. Schlegel S, Stein A. Design measures to increase the efficiency of secondary sedimentation tanks. *Water Sci. Technol.* 2000;41:209-215.
7. Ngu LH. Development and performance test of a separation system for removal of physically emulsified and free oils from wastewater [dissertation]. Kota Samarahan: Universiti Malaysia Sarawak; 2004.
8. Meon W, Rommel W, Blass E. Plate separators for dispersed liquid–liquid systems: hydrodynamic coalescence model. *Chem. Eng. Sci.* 1993;48:159-168.
9. Rommel W, Blass E, Meon W. Plate separators for dispersed liquid–liquid systems: multiphase flow, droplet coalescence, separation performance and design. *Chem. Eng. Sci.* 1992;47:555-564.
10. Rommel W, Blass E, Meon W. Plate separators for dispersed liquid–liquid systems: the role of partial coalescence. *Chem. Eng. Sci.* 1993;48:1735-1743.
11. Ngu LH. Development and optimization of a circular phase separator with dual angle coalescence plates for removal of suspended solids, free and physically emulsified oils [dissertation]. Kota Samarahan: Universiti Malaysia Sarawak; 2008.
12. Ngu LH, Law PL, Wong KK. A study on flow characteristics of a vertical perforated-pipe distributor in a circular separator. *J. Civil Eng. (IEB)* 2004;32:121-132.
13. Demir A. Determination of settling efficiency and optimum plate angle for plated settling tanks. *Water Res.* 1995;29:611-616.
14. Law PL, Ngu LH, Wong KK, Yusof AA. Development and performance tests of a separator for removal of physically emulsified and free oils from wastewaters. *J. Inst. Eng. Malaysia* 2006;67:10-19.
15. Deininger A, Gunthert FW, Wilderer PA. The influence of currents on circular secondary clarifier performance and design. *Water Sci. Technol.* 1996;34:405-412.
16. Ngu LH, Law PL, Wong KK, Yusof AA. Oil droplets and solid particles removal using circular separator with inclined coalescence mediums: comparison between co-current and counter-current flow. *Water Sci. Technol.* 2010;65:1129-1135.
17. Ngu LH, Wong KK, Law PL. Optimization of circular plate separators with cross flow for removal of oil droplets and solid particles. *Water Environ. Res.* 2012;84:299-304.
18. Ghani AA, Zakaria NA, Kassim M, Nasir BA. Sediment size characteristics of urban drains in Malaysian cities. *Urban Water* 2000;2:335-341.