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Mathematical Modeling of Characteristics of Leachate Treated with Scrap Tire Shreds as Leachate Collection Medium

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ABSTRACT

Laboratory studies were conducted to investigate scrap-tire-shreds as a potential alternative to conventional gravel in the drainage layer of leachate collection system at the base of landfill. Performance of various physico-chemical characteristics of leachate after passing it through combined bed of scrap-tire-shreds and gravel for different combinations of thickness of scrap-tire-shreds and gravel and for different variations of width of scrap-tire-shreds was studied. Best combination with the most suitable size and the percentage improvement in terms of reduction in various physico-chemical parameters of leachate samples was identified. Thus emphasized on using scrap-tire-shreds as potential alternative to conventional gravel in the drainage layer of leachate collection system for treating leachate and this would reduce the magnitude of the current tire disposal problem and convert one waste into a beneficial material. In this paper, equations through mathematical modeling have been developed using the experimental data. These equations can be used for calculation of effluent-influent ratio of physico-chemical characteristics of leachate, after passing the leachate through any combination of combined bed of scrap tire and gravel and also for any size of scrap tire shred. There is a very good agreement between the experiment and theory.

Keywords- Leachate, landfills, gravel, scrap-tire-shreds, leachate collection layer, mathematical modeling.

1. INTRODUCTION

Economically and environmentally feasible alternatives have been investigated for recycling of scrap tires. Attention has been given to the use of scrap tires for civil engineering applications such as highway embankments, retaining structures and lightweight fill material. A large number of used scrap tires are landfilled, stockpiled and illegally dumped. Two major problems associated with stockpiling whole tires are the potential for fire and mosquitoes. Eleazer et al. [1] reported that 14 emergency departments were required to extinguish a fire in a 50,000 tire stockpile on April 7, 1990 in Johnston County, North Carolina, USA. In addition to dense smoke, tire fires produce hydrocarbon liquids that can infiltrate the soil and result in contamination of ground and surface water resources. The present recycling techniques of the scrap tires may only consume a very small amount of the unwanted tires. The percentage of scrap tire recycled is not compatible with the growth of scrap tires. This has become a serious problem in many countries. In order to avoid the continual addition of scrap tires to these unsightly and unhealthy stockpiles, innovative methods of recycling and reuse of scrap tires need to be developed.

Various engineering properties must be known to assess the feasibility of using shredded scrap tires as drainage material in landfill cover systems. These properties include unit weight and specific gravity, hydraulic conductivity, compressibility and shear strength. Reddy and Marella [2] summarized the engineering properties of tire shreds based reported studies and evaluated the variation of these properties with the size of tire shreds. A wide range of values were reported for each property due to differences in the size and composition of tire shreds. Despite having a wide range of values, the properties of shredded scrap tires meet the specific requirements to serve as an effective drainage material in landfill cover systems. Tire shreds have also been used as an alternative to crushed stones (gravel) as drainage media in landfill leachate collection systems [3,4,5,6,7]. The recommended nominal tire shred size for use in leachate drainage layer is 50 mm with an acceptable range of 25-100mm [8]. Further, the granular medium used in the construction of leachate drainage layer must posses a hydraulic conductivity equal to or greater than 1x 10^{-2} cm/s and minimum thickness of 300 mm and of 500 mm at the location of perforated leachate collection pipes [9]. Tire shreds are, however, highly compressible and experience large vertical strains of approximately 25-50% upon vertical stress applications [8,10,11,12,13]. Observations made by Edil et al.[14], Reddy and Saichek [15] and Warith et al. [16] indicated that even at high compressive stresses, tire shreds posses a hydraulic conductivity of greater than 1 x 10^{-5}, a value generally recommended for the design of landfill leachate collection systems.

Several laboratory studies have been conducted to show the effectiveness of scrap tires in a leachate collection layer[17,18,16,15,14,7]. Chu and Shakoor [19] conducted field tests in Ohio. Their leachate analyses showed the concentration of trace elements from soil-tire mixtures was less than the maximum allowed contaminant levels specified in U.S. Environment Protection Agency regulations. These researchers concluded that soil-tire mixtures can be safely used as a light weight fill material and in situations where improvement in drainage characteristics is required. Mondal and Warith [20] reported scrap tire stockpiles are breeding grounds for pests, mosquitoes and west Nile viruses and, thereby, become a potential health risk. This experimental study was carried out in six stages to determine the suitability of shredded tire materials in a trickling filter system to treat landfill leachate. Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD) and NH_3-N removals were obtained in the range of 81 to 96%, 76 to 90% and 15 to 68%, respectively. In summary, the preponderance of the above mentioned literature strongly indicates that scrap tires can be safely used as a leachate collection layer for leachate treatment at landfill site with no substantial addition or only marginal addition of any pollutants that are of specific public health concern. The use of shredded scrap tires as protective drainage material has the potential for the utilization of large quantities of recycled scrap tires. Such use offers an economic advantage over conventional materials without compromising engineering performance in addition; this implementation utilizes the scrap tires as a valuable resource material and helps to alleviate the growing problems currently associated with the management and disposal of scrap tires.

2. EXPERIMENTAL WORK

Laboratory studies were conducted to investigate scrap-tire-shreds as a potential alternative to conventional gravel in the drainage layer of leachate collection system at the base of landfill. Gravel and scrap-tire-shreds in combination were used as leachate collection layer. Laboratory Test Cells consisting of different combinations of scrap-tire-shreds (size range length = 25 mm to 75 mm and width = 5 mm) and gravel (size range 10 mm to 20 mm) beds as leachate collection layer with total bed thickness of 500 mm were formed. A typical test cell is depicted in Fig. 1. Leachate sample after passing through combined beds of scrap-tire-shreds and gravel were tested for obtaining various physico-chemical parameters of leachate. The results so obtained are given in Tables 1 and 2. Detail of laboratory study is presented elsewhere [17]. In brief, as per the experimental observations, leachate sample after passing through combined beds of scrap-tire-shreds and gravel gave better results in comparison to Test Cell containing scrap-tire-shreds or gravel bed when used singly as indicated from the comparative performance study of Test Cells. The present study indicates that scrap-tire-shreds can be used as a potential alternative to conventional gravel in the drainage layer of leachate collection system thus by improving upon the reduction in the various leachate parameters of environmental concern. The percentage improvement in terms of reduction in various physico-chemical parameters of original leachate was as high as 68.8 % and 79.6 % reduction in case of BOD_5 and COD values respectively.

2.1 Analytical Considerations

The nature of variation of the effluent depends on the geometry of the arrangements. Considering the different arrangements, the variation is divided into the following categories.

2.1.1 Showing a Minimum

Fig. 2 (a-n) depicts a plot of effluent-influent ratio of physico-chemical characteristics versus the ratio of thicknesses of scrap tire layer to that of gravel layer d_s/d_g. A perusal of Fig. 2 (a-n) indicates that the effluent-influent ratio first dips down, attains a minimum and then monotonically saturates to a final value. A typical equation of this curve for physico-chemical characteristic C is proposed as

$$\frac{C_e}{C_i} = a - b\exp\left[\alpha\frac{d_s}{d_g} - \beta\left(\frac{d_s}{d_g}\right)^2\right] \quad (1)$$

where a, b, α and β are parameters to be determined from the experimental data. For this purpose the jth observed value $\left(C_{eo}/C_{io}\right)_j$ and the corresponding predicted by Eq. (1) is $\left(C_{ep}/C_{ip}\right)_j$ yields a proportionate error ε_j as

$$\varepsilon_j = \left(C_{ep}/C_{ip}\right)_j - \left(C_{eo}/C_{io}\right)_j \quad (2)$$

For determination of the parameters, an average of a criterion function f to be minimized is given by

$$E = \frac{1}{N}\sum_{j}^{N} f\left(\varepsilon_j\right) \quad (3)$$

where E = average criterion function; N = number of data. Several criteria functions for f have been proposed from time to time. The most common among them is a square function

$$f\left(\varepsilon_j\right) = \varepsilon_j^2 \quad (4)$$

The evaluation criteria given by Eq. (4), is popularly known as least square method introduced by Gauss in 1768. Another criterion function for $f(\varepsilon_j)$ is the absolute function given by

$$f\left(\varepsilon_j\right) = \left|\varepsilon_j\right| \qquad (5)$$

The absolute function is better than the square function of as it is less biased for large errors. Small random errors get eliminated by the minimization of *E*. Large random errors may be due to wrongly recorded observation in a data set. These errors play decisive role in estimates of parameters. Swamee and Ojha [21] gave the following criterion function, which reduces the effect of large errors:

$$f\left(\varepsilon_j\right) = \left(\varepsilon_j^{-2} + \varepsilon_c^{-2}\right)^{-0.5} \qquad (6)$$

where ε_c = proportionate cutoff error. Using the experimental data the parameters were evaluated by minimizing the sum of criterion function given by Eq. (6) with cutoff error 2%. *Example:* For phosphate the parameters obtained are: $a = 0.590$, $b = 0.090$, $\alpha = 2.83$ and $\beta = 2.12$. Thus, for Phosphate Eq. (1) reduces to

$$\frac{\mathrm{PO}^{2-}_{4e}}{\mathrm{PO}^{2-}_{4\,i}} = 0.590 - 0.090\exp\left[2.83\frac{d_s}{d_g} - 2.12\left(\frac{d_s}{d_g}\right)^2\right] \qquad (7)$$

The agreement between Eq. (7) and the data is depicted in Fig. 2(j). A perusal of Fig. 2 (a-n) indicates that Eq. (1) represents the data fairly accurately. The parameters of various attributes are given in Table 3.

For minimum of C_e/C_i, equating the differential coefficient of Eq. (1) by $(d_s/d_g)^*$ and simplifying, one gets,

$$\left(\frac{d_s}{d_g}\right)^* = \frac{\alpha}{2\beta} \qquad (8)$$

Where * stands for minimum. Combining Eqs. (1) and (8), the minimum, $(C_e/C_i)^*$ is found to be

$$\left(\frac{C_e}{C_i}\right)^* = a - b\exp\left(\frac{\alpha^2}{4\beta}\right) \qquad (9)$$

Table 3 also gives values of $(d_s/d_g)^*$ and $(C_e/C_i)^*$. A perusal of Table 3 shows that for all attributes $(d_s/d_g)^*$ is fairly constant; and it may be taken as 0.667.

2.1.2 Uniformly Increasing

Fig. 3 (a-n) depicts a plot of effluent-influent ratio of physico-chemical characteristics versus the ratio of width of scrap tire to the of gravel layer w/d_g. It can be seen from Fig. 3 (a-n) that the effluent-influent ratio monotonically increases with the increase in w/d_g. A typical equation of this variation is

$$\frac{C_e}{C_i} = k\left(\frac{w}{d_g}\right)^m \qquad (10)$$

where k and m are parameters that are determined by plotting the experimental data on a double log graph paper. In such a case m is the slope of straight line represented by the data; and k is the value of C_e/C_i at $w/d_g = 1$. *Example:* For phosphate $k = 1.2$; and $m = 0.14$. Putting these values in Eq. (10), one gets

$$\frac{\mathrm{PO}^{2-}_{4e}}{\mathrm{PO}^{2-}_{4\,i}} = 1.208\left(\frac{w}{d_g}\right)^{0.302} \qquad (11)$$

The parameters k and m for various attributes are listed in Table 4. A perusal of Eq. (11) and Fig. 3(j) indicates that there is quite good agreement between experiment and the theory.

3. CONCLUSIONS

Equation has been developed for calculating the value of various physico-chemical characteristics of leachate after passing it through combined bed of scrap tire and gravel for different combinations of thickness of scrap tire and gravel. Another equation has also been developed for calculation of effluent-influent ratio of physico-chemical characteristics for different variations of width of scrap tire shreds. The comparison between the experimental and the theoretical values show that there is a good agreement between experiment and theory.

NOTATION

The following symbols are used in this paper:

a = parameter (nondimensional);
b = parameter (nondimensional);
C = physico-chemical characteristics;
d_s = thickness of scrap tire layer (mm);
d_g = thickness of gravel layer (mm);
E = average error (nondimensional);
f = criterion function (nondimensional);
k = parameter;
m = parameter;
N = number of data;
w = width of scrap tire shreds;
α = parameter (nondimensional);
β = parameter (nondimensional);
ε = proportionate error;
ε_c = proportionate cutoff error;

SUPERSCRIPT

* = optimum;

SUBSCRIPT

e = effluent;
i = influent;
j = index;
o = observed; and
p = predicted.

REFERENCES

[1] W.E. Eleazer, M.A. Barlaz and D.J.Whittle, Resource recovery alternatives for waste tires in North Carolina, *Civil Engineering Department, North Carolina State University, Raleigh*, 1992.

[2] K.R.Reddy and A. Marella, Properties of different size scrap tire shreds: implications on using as drainage material in landfill cover systems, *Proceedings of the 17th International Conference on Solid Waste Technology and Management, Philadelphia, PA, USA*., 2001.

[3] D.N. Humphrey, Civil engineering applications of tire shreds, *Proceedings of the Tire Industry Conference, Clemson University*, 1999, 1-16.

[4] California Integrated Waste Management Board, Tire shreds as leachate drainage material at municipal solid waste landfill, *Guidance Manual*, 1998.

[5] R.Donovan, J. Dempsey and S. Owen, Scrap tire utilization in landfill applications, *Proceedings of Solid Waste Association of North America, Wastecon GR-G 0034*, 1996, 353-383.

[6] D.P. Duffy, Using tire chips as a leachate drai-nage layer, *Waste Age*, 26, 1995, 113-122.

[7] D.N. Humphrey and W.P. Manion, Properties of tire chips for lightweight fill, grouting, soil improvement and geosynthetics, *Proceedings of the Conference Sponsored by the Geotechnical Engineering Division of the American Society of Civil Engineers 2, New Orleans*, 1992, 1344-1355.

[8] Mississipi Department of Environmental Quality, Beneficial use of waste tire material guidance for using tire chips as leachate drainage layers at municipal solid waste landfills, *Mississipi Department of Environmental Quality, Solid Waste Management Branch*, 2002, 1-3.

[9] Ministry of Environment (MOE), Landfill standards- A guideline on the regulatory and approval requirements for new or expanding landfilling sites, *Ontario Ministry of the Environment*, 1998, 1-127.

[10] Geosyntec Consultants, Guidance manual - Tire shreds as leachate drainage material at municipal solid waste landfill, *Prepared for California Integrated Waste Management Board*, 1998.

[11] W.L.Nickels and D.N. Humphrey, The effect of tire chips as subgrade fill on paved roads, *Maine Department of Transportation, Maine*, 1997.

[12] D.N.Humphery, T.C. Sandford, M.M. Cribbs and W.P. Manion, Shear strength and compressibility of tire chips for use as retaining wall backfill, *Transportation Research Record 1422, Transportation Research Board, Washington, D.C.*,1993.

[13] W. P. Manion and D.N. Humphery, Use of tire chips as lightweight and conventional embankment fill, *Technical Paper 91-1, Technical Services Division, Maine Department of Transportation, Maine*, 1992.

[14] T.B.Edil, P.J.Fox and S.W. Ahl, Hydraulic conductivity and compressibility of waste tire chips, *Proceedings of 15th Annual Madison Waste Conf., Madison, Wis.*, 1992, 49-61.

[15] K.R.Reddy and R.E. Saichek, Characterization and performance assessment of shredded scrap tires as leachate drainage material in landfills, *Proceedings of the 14th International conference on solid waste technology and management, Philadelphia, PA*, 1998.

[16] M.A. Warith, E. Evgin and P.A.S. Benson, Suitability of shredded tires for use in landfill leachate collection systems, *Waste Management*, 24, 2004, 967-978.

[17] G. Bhalla, A. Kumar and A. Bansal, Performance of scrap tire shreds as a potential leachate collection medium, *J.Geotech. and Geological Eng., Springer*, 28(5), 2010, 661-669.

[18] R.K. Rowe and R. McIaac, Clogging of tire shreds and gravel permeated with landfill leachate, *J. Geotech. Geoenviron. Eng.*, 131(6), 2005, 682-693.

[19] C. Chu and A. Shakoor, Use of shredded scrap tires in soil, Eng. Geol. Environ., *22nd Proceedings of the International Symposium*, 2, 1997, 1687.

[20] B. Mondal and M.A. Warith, Use of shredded tire crumbs as packing media in trickling filter systems for landfill leachate treatment, *Civil Engineering Department, Ryerson University, Toronto, Canada, Environmental Technology*, 29 (8), 2008, 827- 836.

[21] P.K. Swamee and C.S.P. Ojha, Pump test analysis of confined aquifer, *J. Irrig. and Drain. Eng., ASCE*, 116 (1), 1990, 99-106.

Table 1 Observation of Test Cells 1 to 7

Attributes	influent	effluent	d_s (mm)	d_g (mm)	Attributes	influent	effluent	d_s (mm)	d_g (mm)
pH	10.3	9.6	0	500	Chloride (mg/l)	853	432	0	500
	10.3	9.5	100	400		853	396	100	400
	10.3	9.3	200	300		853	308	200	300
	10.3	9.4	250	250		853	326	250	250
	10.3	9.5	300	200		853	335	300	200
	10.3	9.7	400	100		853	448	400	100
	10.3	9.8	500	0		853	523	500	0
Total Solids (TS) (mg/l)	8600	3085	0	500	Ammonical Nitrogen (mg/l)	83	40	0	500
	8600	2543	100	400		83	38	100	400
	8600	2046	200	300		83	23	200	300
	8600	2285	250	250		83	25	250	250
	8600	2586	300	200		83	30	300	200
	8600	3150	400	100		83	49	400	100
	8600	3205	500	0		83	53	500	0
Total Dissolved Solids (TDS) (mg/l)	6800	1796	0	500	Phosphate (mg/l)	78	39	0	500
	6800	1575	100	400		78	32	100	400
	6800	1332	200	300		78	28	200	300
	6800	1430	250	250		78	30	250	250
	6800	1658	300	200		78	36	300	200
	6800	1808	400	100		78	43	400	100
	6800	2180	500	0		78	46	500	0
Hardness (mg/l)	638	493	0	500	Iron (mg/l)	6.6	3	0	500
	638	405	100	400		6.6	2.6	100	400
	638	342	200	300		6.6	1.3	200	300
	638	395	250	250		6.6	1.5	250	250
	638	488	300	200		6.6	1.9	300	200
	638	530	400	100		6.6	2.8	400	100
	638	542	500	0		6.6	3.6	500	0
Turbidity (NTU)	30	17	0	500	Lead (mg/l)	0.9	0.4	0	500
	30	15	100	400		0.9	0.3	100	400
	30	12	200	300		0.9	0.1	200	300
	30	13	250	250		0.9	0.2	250	250
	30	13	300	200		0.9	0.2	300	200
	30	19	400	100		0.9	0.4	400	100
	30	20	500	0		0.9	0.5	500	0
BOD (mg/l)	809	325	0	500	Chromium (mg/l)	1.5	1.2	0	500
	809	306	100	400		1.5	1	100	400
	809	253	200	300		1.5	0.4	200	300
	809	269	250	250		1.5	0.5	250	250
	809	285	300	200		1.5	0.6	300	200
	809	329	400	100		1.5	0.9	400	100
	809	363	500	0		1.5	1.3	500	0
COD (mg/l)	1690	595	0	500	Cadmium (mg/l)	3.2	1.4	0	500
	1690	584	100	400		3.2	1.3	100	400
	1690	345	200	300		3.2	1.1	200	300
	1690	386	250	250		3.2	1.2	250	250
	1690	398	300	200		3.2	1.2	300	200
	1690	589	400	100		3.2	1.4	400	100
	1690	650	500	0		3.2	1.6	500	0

Table 2 Observations of Test Cells 3, 8 to 10

Attributes	influent	effluent	*w* (mm)	d_g (mm)	Attributes	influent	effluent	*w* (mm)	d_g (mm)
pH	10.3	9.3	5	300	Chloride (mg/l)	853	308	5	300
	10.3	9.5	10	300		853	312	10	300
	10.3	9.4	15	300		853	346	15	300
	10.3	9.6	20	300		853	358	20	300
TS (mg/l)	8600	2046	5	300	Ammonical Nitrogen (mg/l)	83	23	5	300
	8600	2185	10	300		83	30	10	300
	8600	2343	15	300		83	35	15	300
	8600	2486	20	300		83	38	20	300
TDS (mg/l)	6800	1332	5	300	Phosphate (mg/l)	78	28	5	300
	6800	1486	10	300		78	32	10	300
	6800	1492	15	300		78	39	15	300
	6800	1503	20	300		78	42	20	300
Hardness (mg/l)	638	342	5	300	Iron (mg/l)	6.6	1.3	5	300
	638	358	10	300		6.6	1.5	10	300
	638	365	15	300		6.6	1.8	15	300
	638	382	20	300		6.6	1.9	20	300
Turbidity (NTU)	30	12	5	300	Lead (mg/l)	0.9	0.1	5	300
	30	15	10	300		0.9	0.2	10	300
	30	17	15	300		0.9	0.2	15	300
	30	18	20	300		0.9	3	20	300
BOD (mg/l)	809	253	5	300	Chromium (mg/l)	1.5	0.4	5	300
	809	255	10	300		1.5	0.5	10	300
	809	267	15	300		1.5	0.4	15	300
	809	282	20	300		1.5	0.5	20	300
COD (mg/l)	1690	345	5	300	Cadmium (mg/l)	3.2	1.1	5	300
	1690	365	10	300		3.2	1.2	10	300
	1690	368	15	300		3.2	1.2	15	300
	1690	375	20	300		3.2	1.3	20	300

Table 3 Parameters of various attributes

Attributes	*a*	*b*	α	β	$(d_s/d_g)^*$	$(C_e/C_i)^*$
pH	0.942	0.010	4.16	3.12	0.667	0.903
TS (mg/l)	0.373	0.014	6.80	5.10	0.667	0.238
TDS (mg/l)	0.320	0.056	2.38	1.78	0.668	0.196
Hardness (mg/l)	0.850	0.077	4.22	3.16	0.668	0.535
Turbidity (NTU)	0.667	0.100	2.94	2.21	0.665	0.401
BOD (mg/l)	0.449	0.047	3.19	2.39	0.667	0.313
COD (mg/l)	0.385	0.033	5.14	3.85	0.668	0.202
Chloride (mg/l)	0.613	0.107	2.58	1.93	0.668	0.360
Ammonical Nitrogen (mg/l)	0.639	0.157	2.51	1.88	0.668	0.276
Phosphate (mg/l)	0.590	0.090	2.83	2.12	0.668	0.359
Iron (mg/l)	0.546	0.091	4.03	3.02	0.668	0.197
Lead (mg/l)	0.556	0.111	4.16	3.12	0.667	0.112
Chromium (mg/l)	0.867	0.067	6.59	4.94	0.667	0.264
Cadmium (mg/l)	0.500	0.062	2.75	2.06	0.668	0.345

Table 4 Parameters of various attributes

Attributes	*k*	*m*
pH	0.975	0.018
TS (mg/l)	0.414	0.138
TDS (mg/l)	0.285	0.088
Hardness(mg/l)	0.724	0.074
Turbidity (NTU)	1.366	0.298
BOD(mg/l)	0.416	0.074
COD (mg/l)	0.260	0.058
Chloride (mg/l)	0.563	0.114
Ammonical Nitrogen (mg/l)	1.252	0.367
Phosphate (mg/l)	1.208	0.302
Iron (mg/l)	0.624	0.285
Lead (mg/l)	2.294	0.729
Chromium (mg/l)	0.416	0.101
Cadmium (mg/l)	0.534	0.108

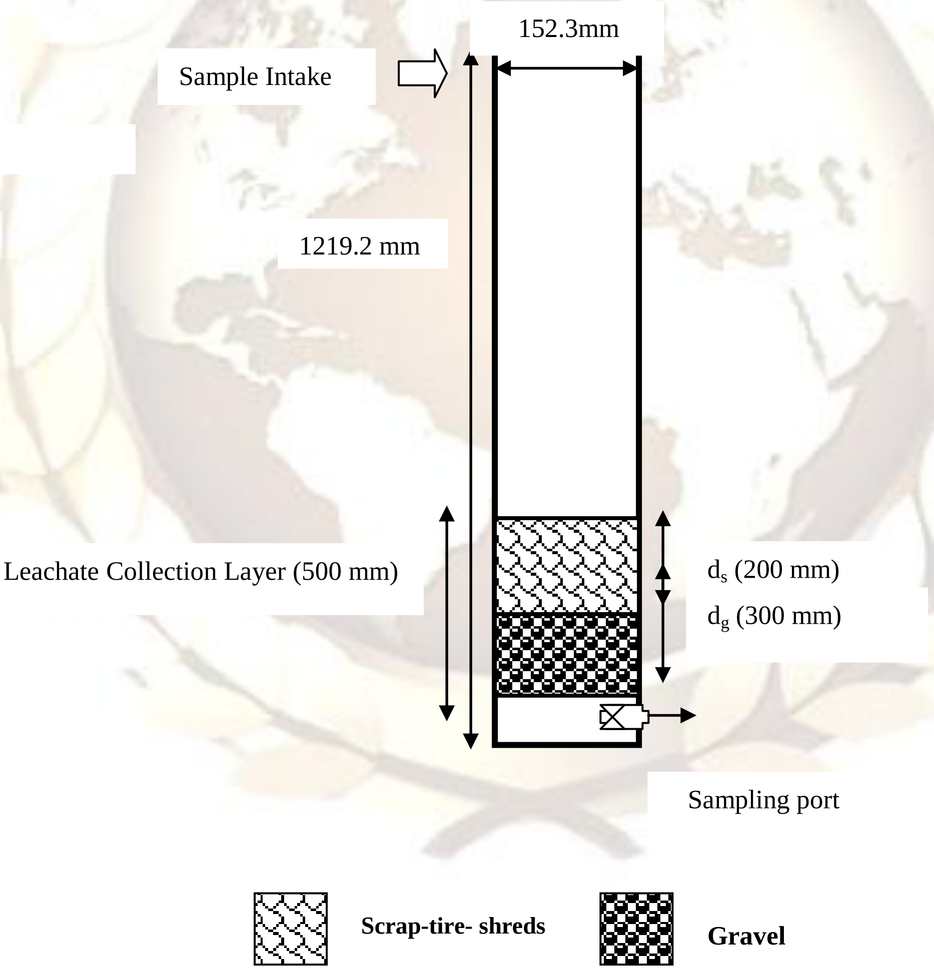

Fig. 1 A laboratory Test Cell showing leachate collection layer

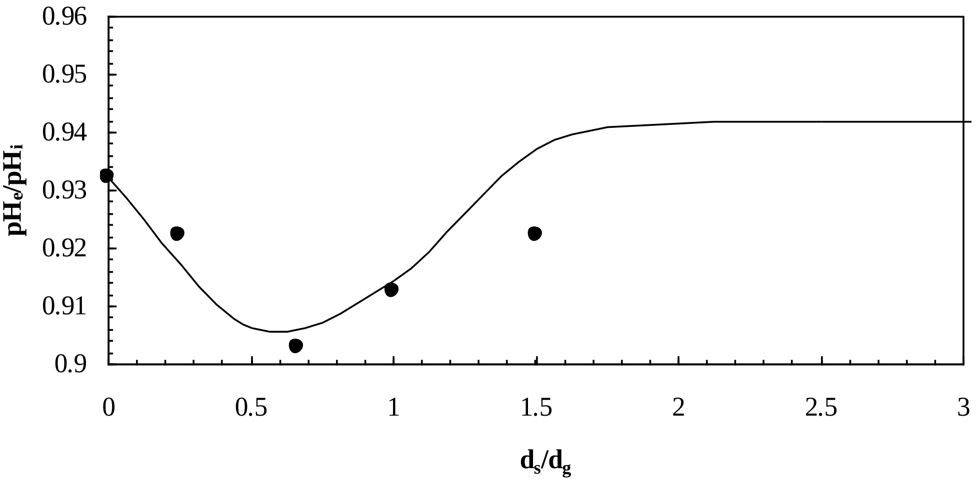

Fig. 2(a) Plot of effluent-influent ratio of pH versus d_s/d_g

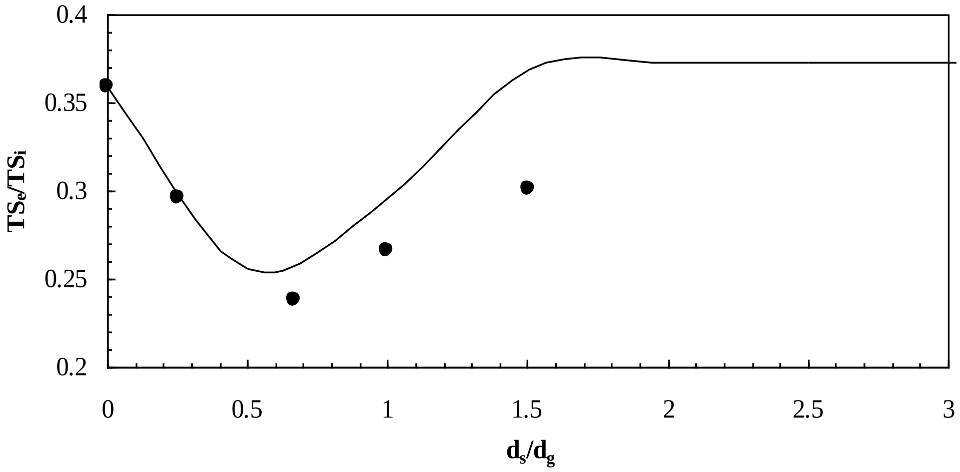

Fig. 2 (b) Plot of effluent-influent ratio of TS versus d_s/d_g

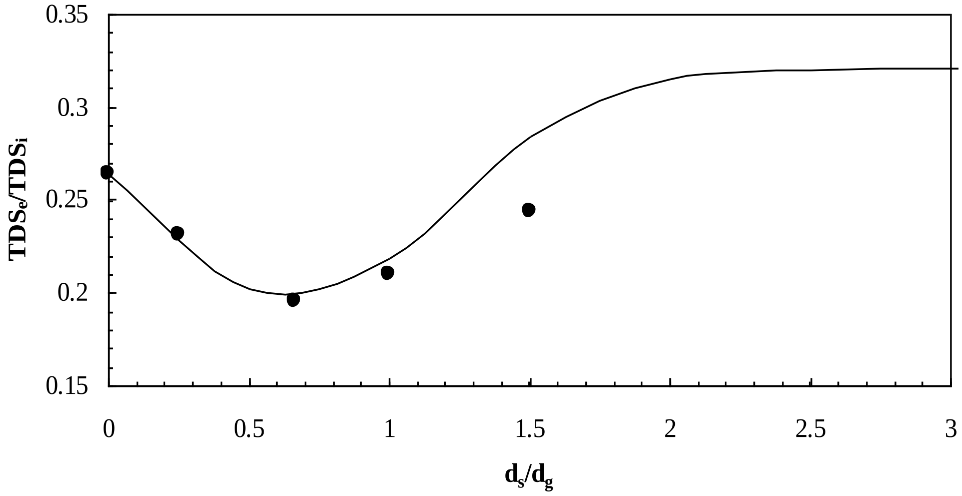

Fig. 2 (c) Plot of effluent-influent ratio of TDS versus d_s/d_g

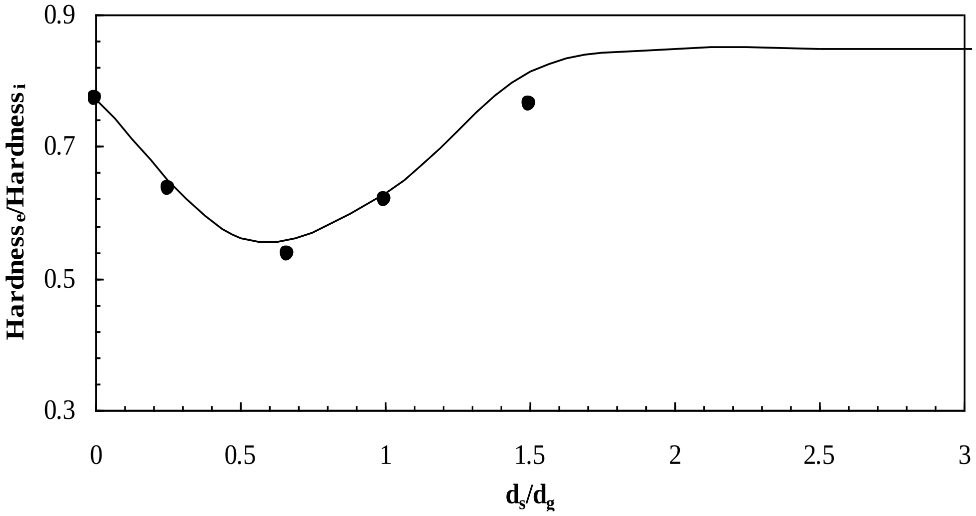

Fig. 2 (d) Plot of effluent-influent ratio of Hardness versus d_s/d_g

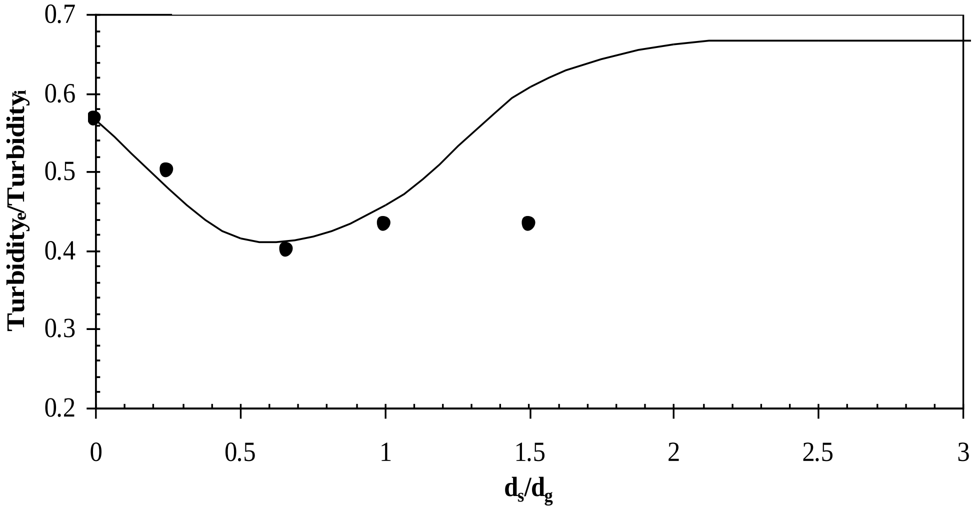

Fig. 2 (e) Plot of effluent-influent ratio of Turbidity versus d_s/d_g

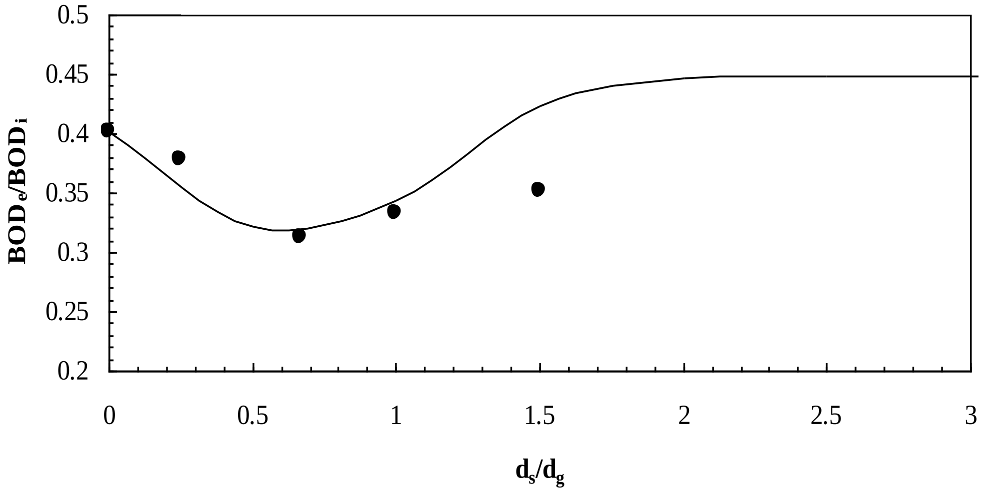

Fig. 2 (f) Plot of effluent-influent ratio of BOD versus d_s/d_g

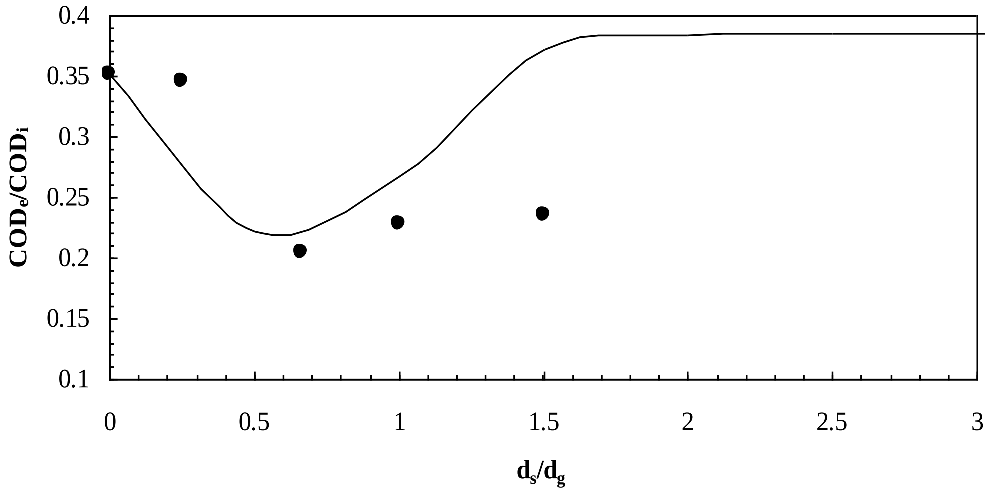

Fig. 2 (g) Plot of effluent-influent ratio of COD versus d_s/d_g

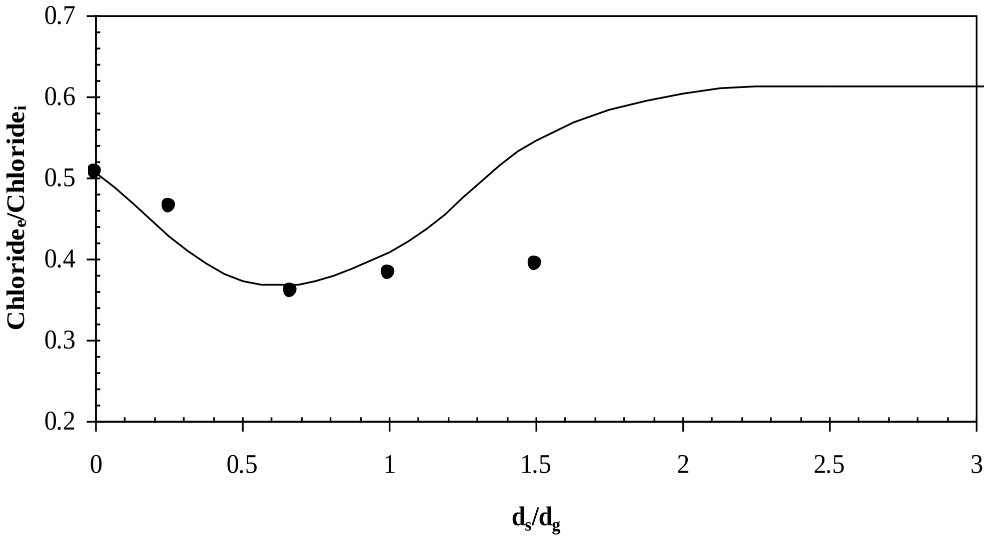

Fig. 2 (h) Plot of effluent-influent ratio of Chloride versus d_s/d_g

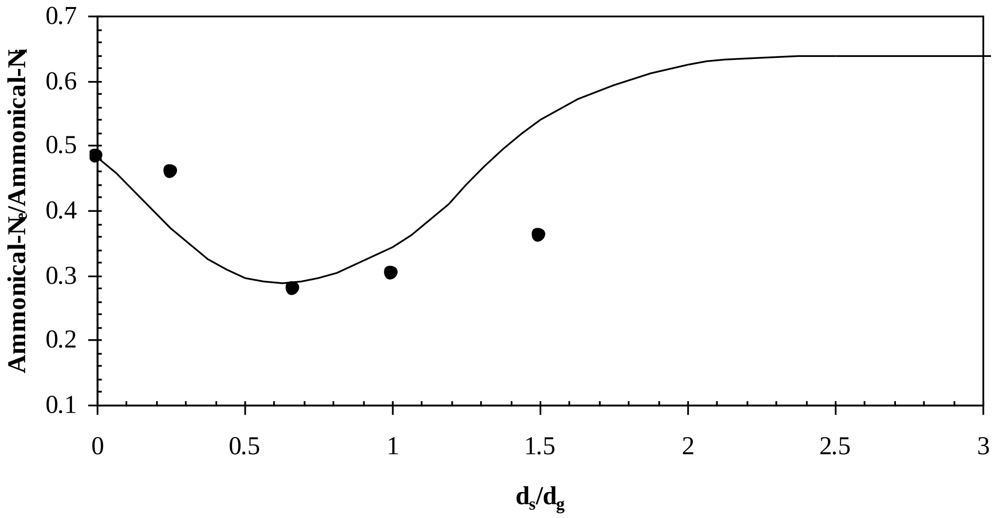

Fig. 2 (i) Plot of effluent-influent ratio of Ammonical-Nitrogen versus d_s/d_g

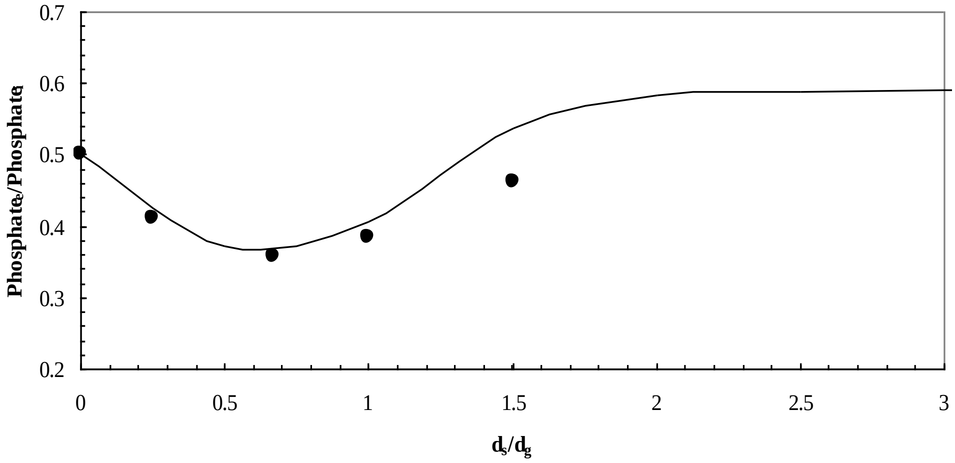

Fig. 2 (j) Plot of effluent-influent ratio of Phosphate versus d_s/d_g

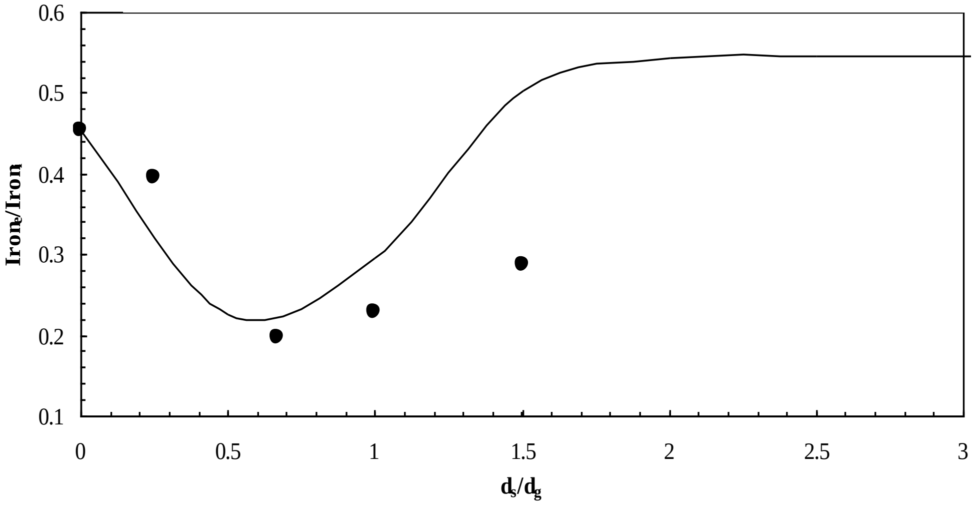

Fig. 2 (k) Plot of effluent-influent ratio of Iron versus d_s/d_g

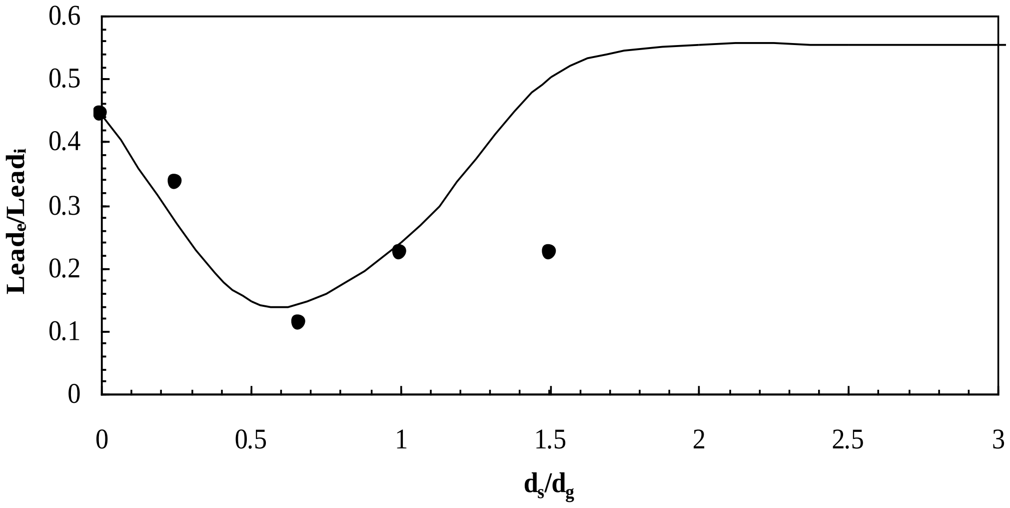

Fig. 2 (l) Plot of effluent-influent ratio of Lead versus d_s/d_g

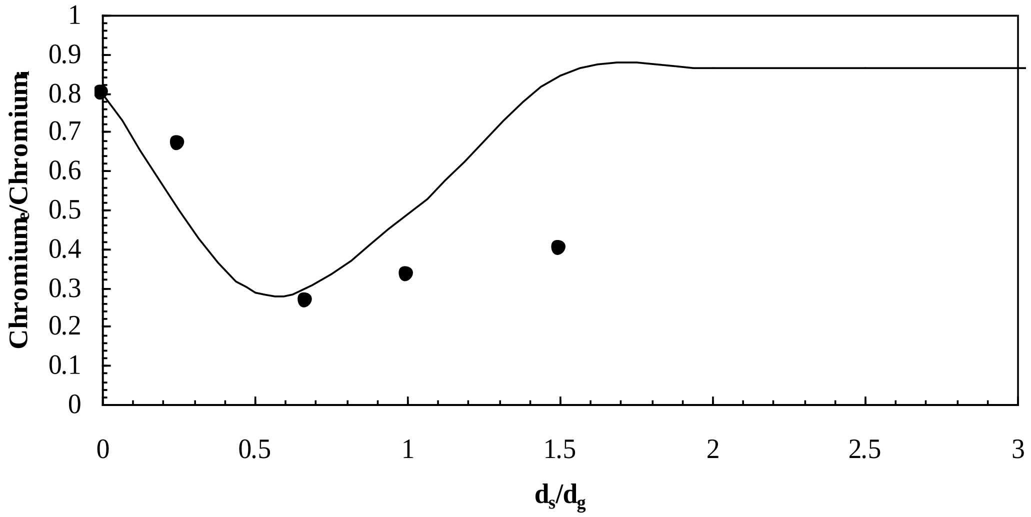

Fig. 2 (m) Plot of effluent-influent ratio of Chromium versus d_s/d_g

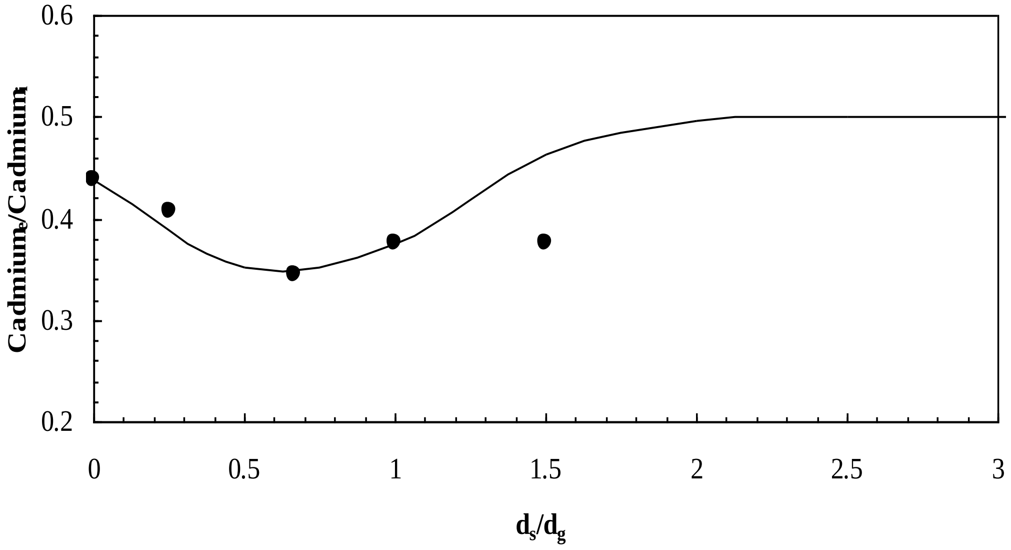

Fig. 2 (n) Plot of effluent-influent ratio of Cadmium versus d_s/d_g

Fig. 2 (a-n) Graphical representations of effluent-influent ratio of various parameters versus d_s/d_g

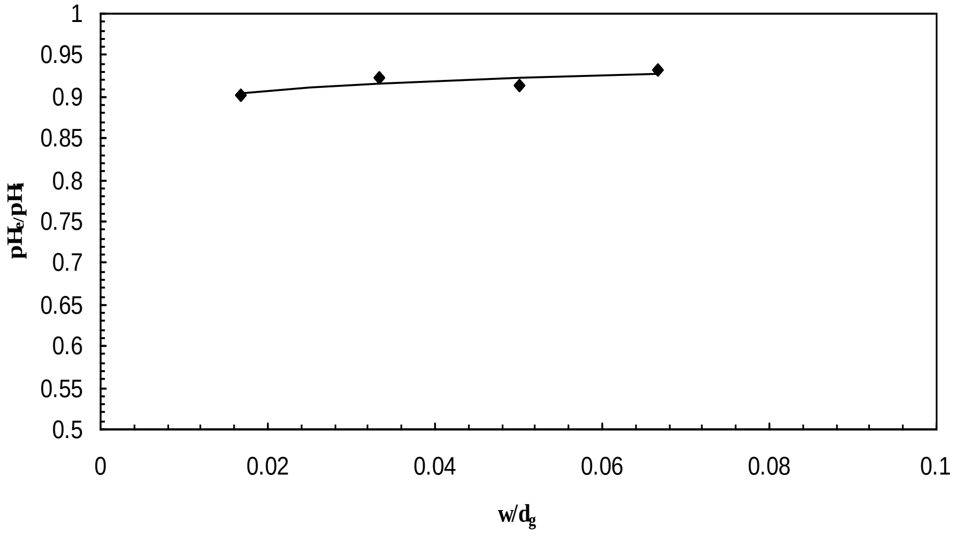

Fig. 3(a) Plot of effluent-influent ratio of pH versus w/d_g

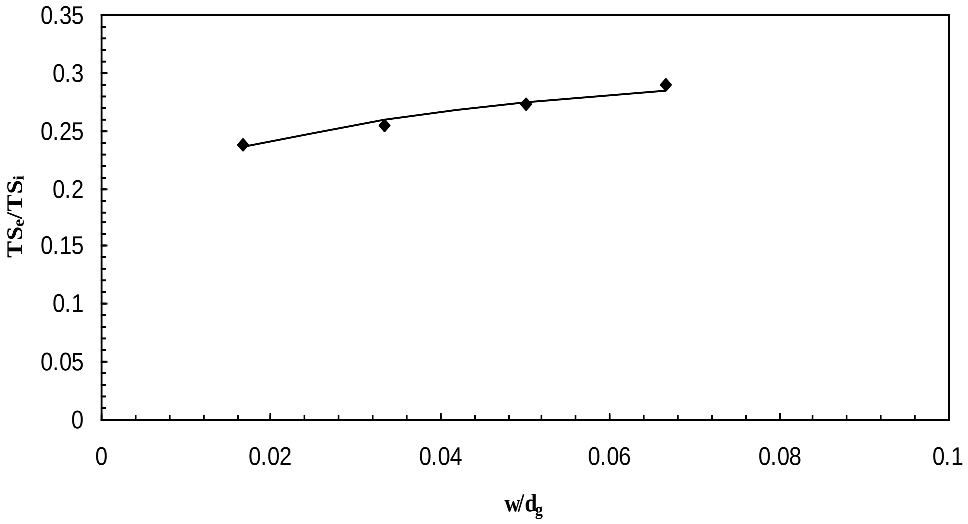

Fig. 3(b) Plot of effluent-influent ratio of TS versus w/d_g

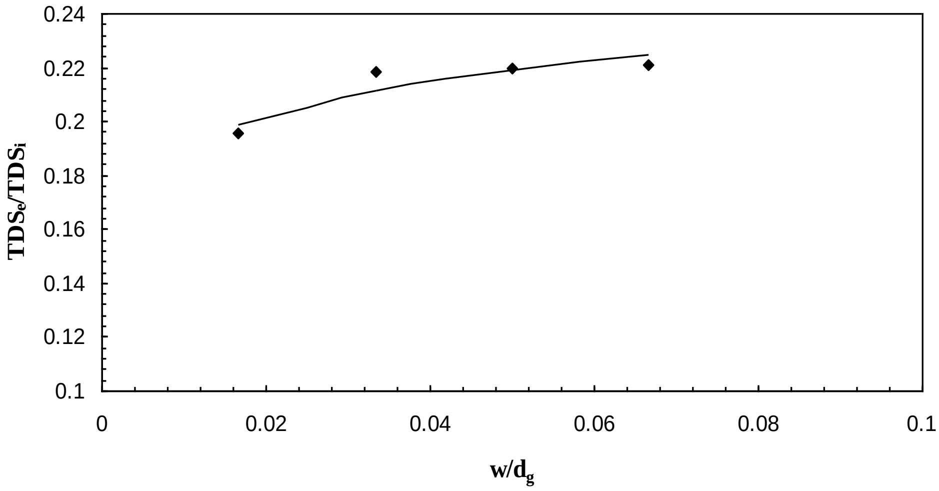

Fig. 3(c) Plot of effluent-influent ratio of TDS versus w/d_g

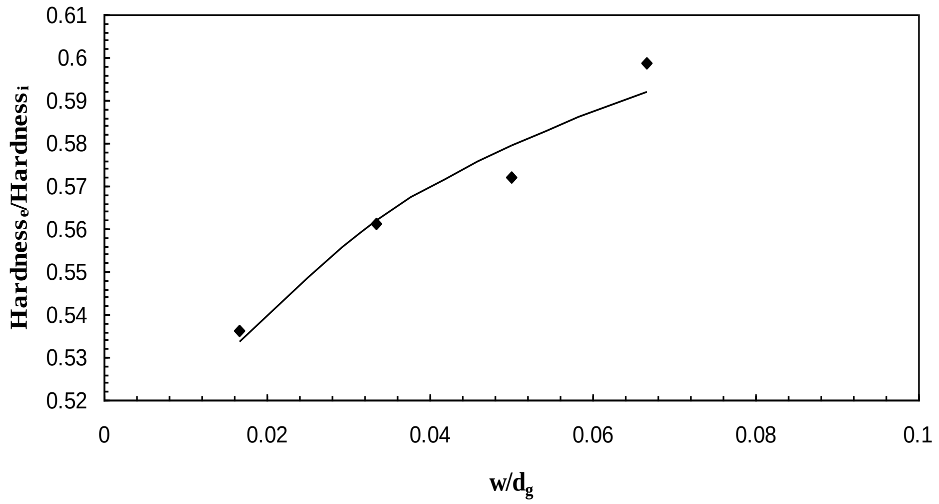

Fig. 3(d) Plot of effluent-influent ratio of Hardness versus w/d$_g$

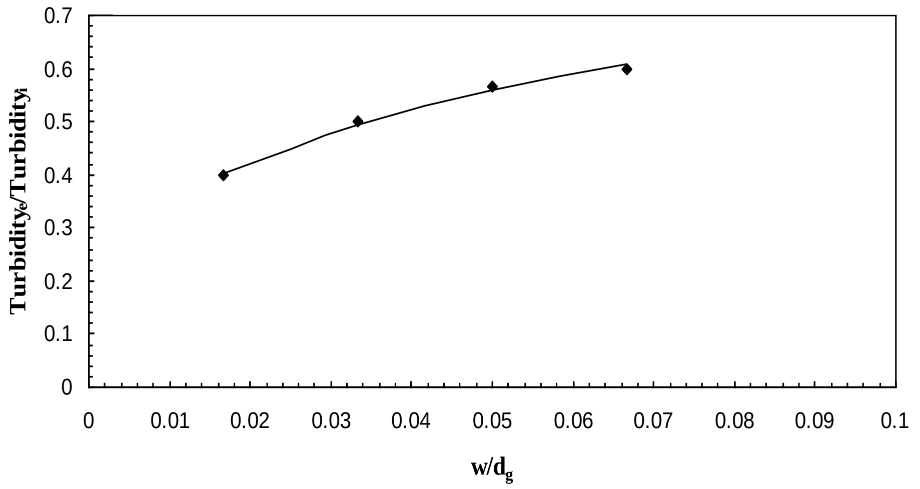

Fig. 3(e) Plot of effluent-influent ratio of Turbidity versus w/d$_g$

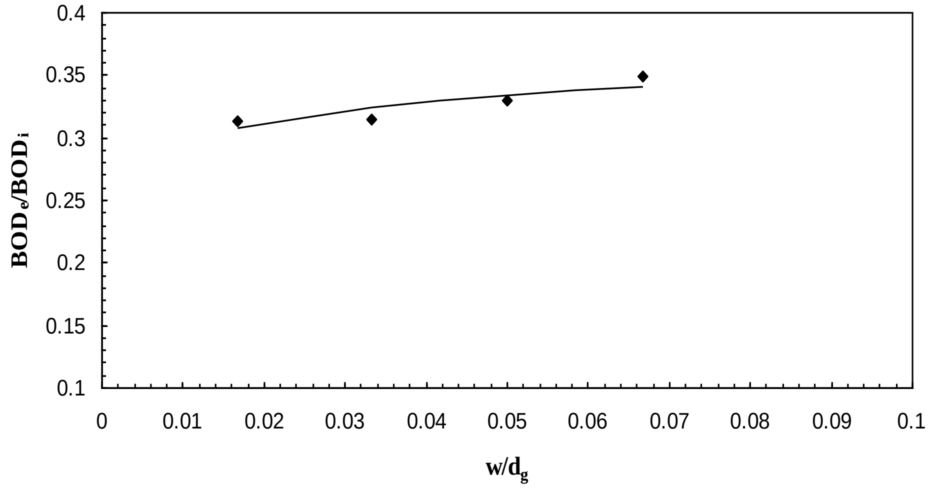

Fig. 3(f) Plot of effluent-influent ratio of BOD versus w/d$_g$

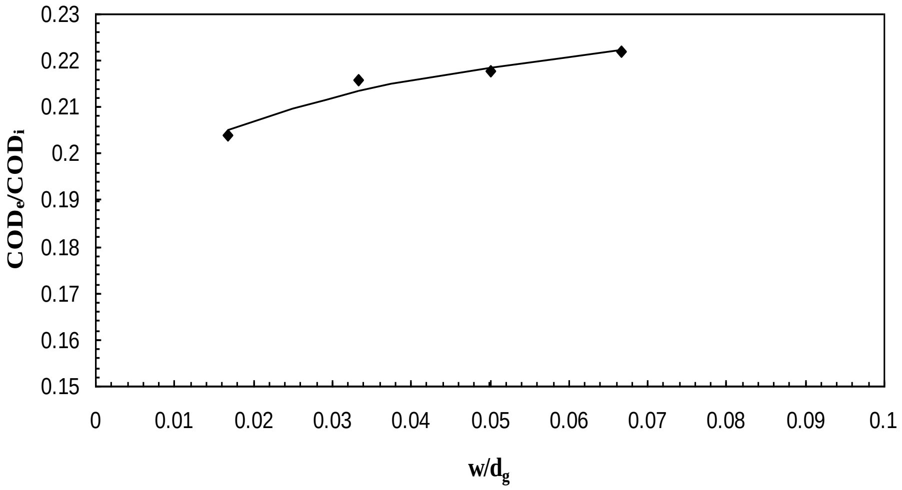

Fig. 3(g) Plot of effluent-influent ratio of COD versus w/d_g

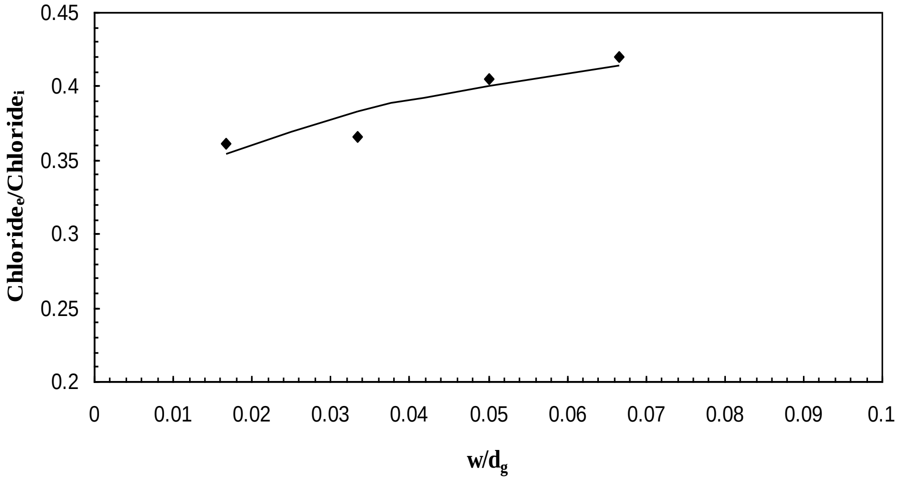

Fig. 3(h) Plot of effluent-influent ratio of Chloride versus w/d_g

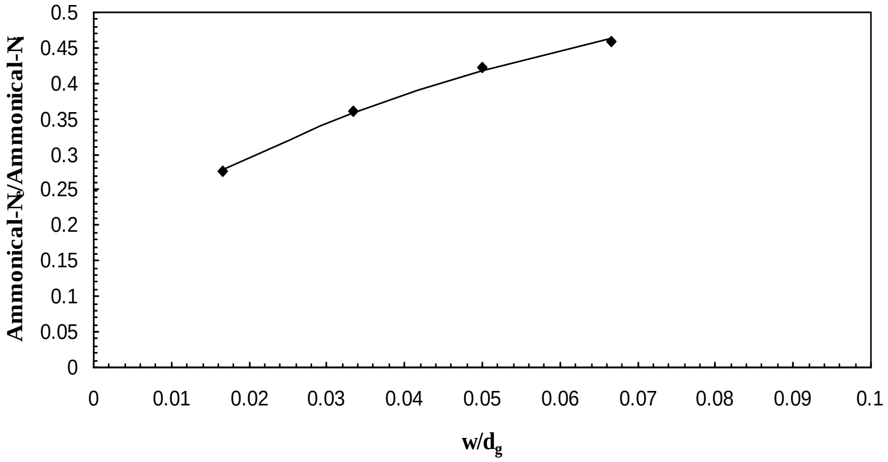

Fig. 3(i) Plot of effluent-influent ratio of Ammonical-Nitrogen versus w/d_g

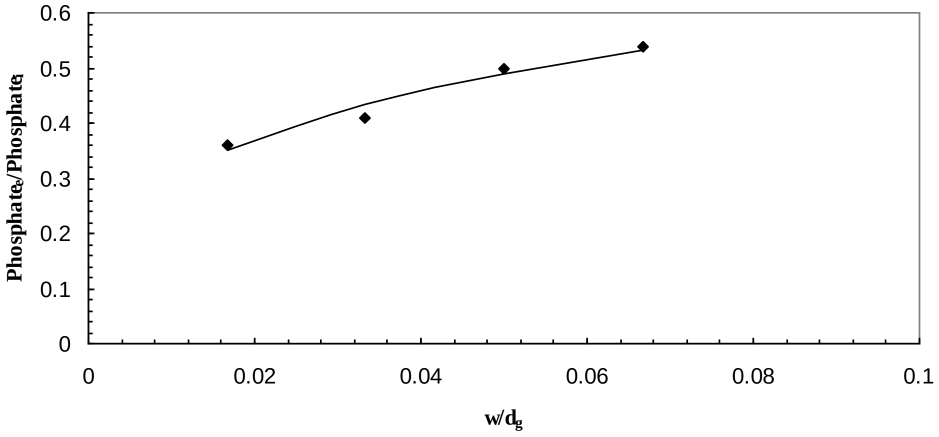

Fig. 3 (j) Plot of effluent-influent ratio of Phosphate versus w/d_g

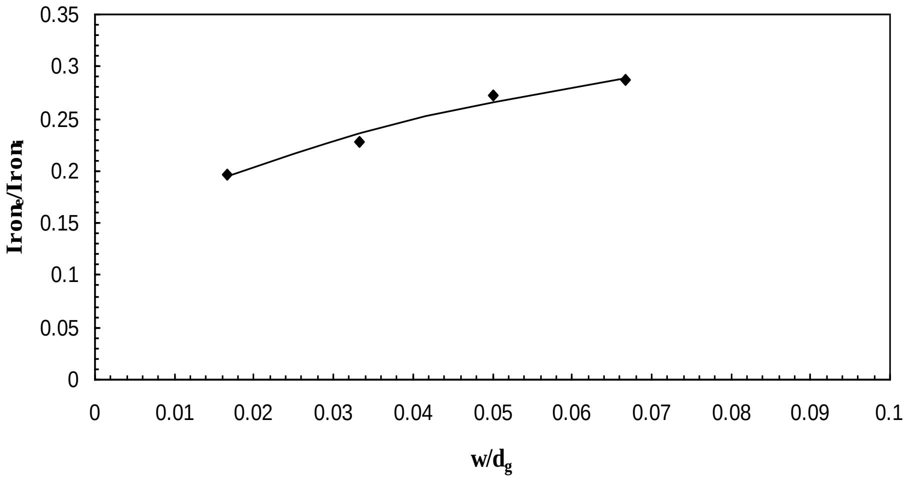

Fig. 3(k) Plot of effluent-influent ratio of Iron versus w/d_g

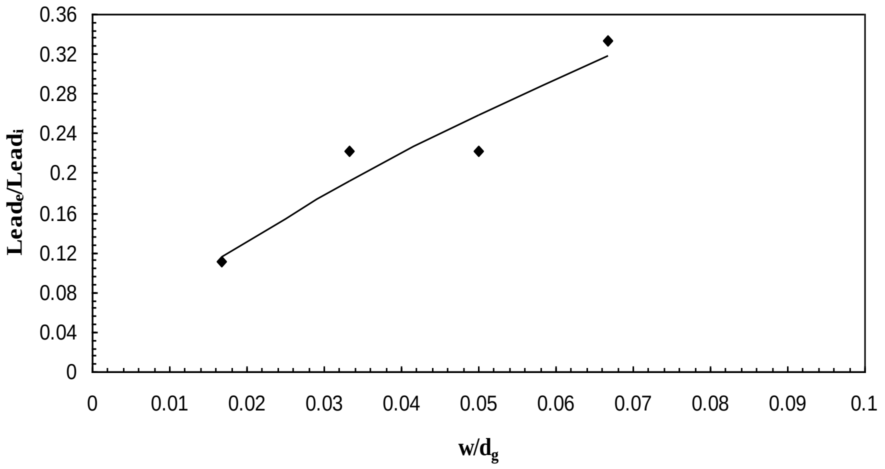

Fig. 3 (l) Plot of effluent-influent ratio of Lead versus w/d_g

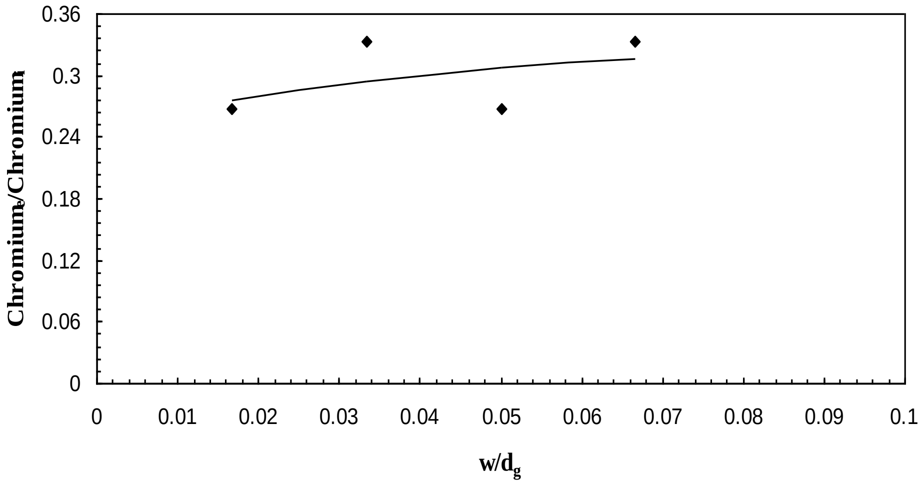

Fig. 3(m) Plot of effluent-influent ratio of Chromium versus w/d$_g$

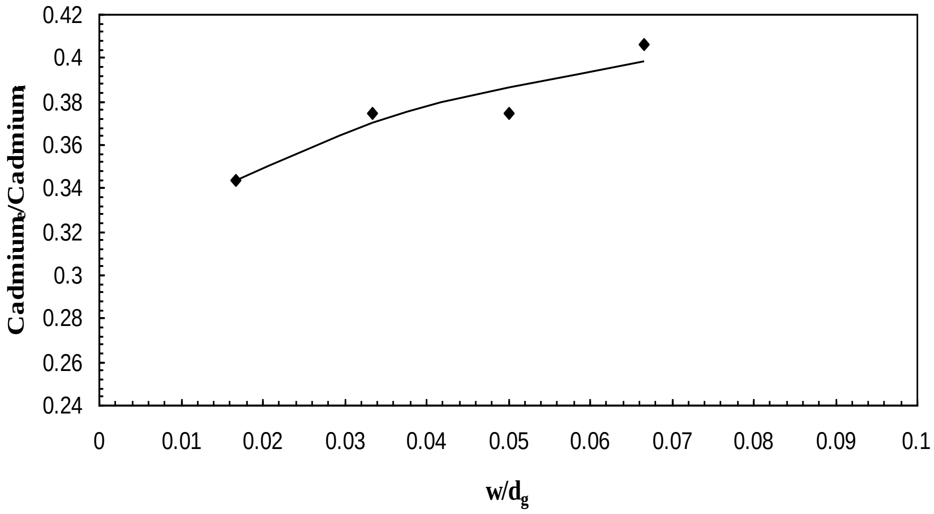

Fig. 3(n) Plot of effluent-influent ratio of Cadmium versus w/d$_g$

Fig. 3 (a-n) Graphical representations of effluent-influent ratio of various parameters versus w/d$_g$