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Efficiencies of Horizontal and Vertical Baffle Mixers

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Abstract

Efficiencies of sedimentation tanks with horizontal and vertical baffle mixers were studied, compared, and also to determine the optima values of factors of clarification in the sedimentation tanks. These are the discharge, basin baffle spacing and dosing factors, thereby comprises three factors at five levels for a 5k factorial design model. 2.0 mg/l of clay solution was introduced into the basin at discharge rates of 48.75 ml/s, 55.07 ml/s, 60.34 ml/s, 62.45 ml/s and 63.27 ml/s respectively. Alum solution was introduced as coagulant at the inlet of the basin, samples were collected both from the basin and the outlet and concentrations of flocs were measured. Plots of variation of total outlet and average outlet floc with dosing rates for horizontal and vertical mixers show that vertical mixers are better only at discharge of 48.75 ml/s, but horizontal mixers are better at 55.05 ml/s, 60.34 ml/s, 62.45 ml/s and 63.27 ml/s. Variation of grand total floc with dosing rates is also in favour of horizontal mixers. Plots of outlet floc against dosing rates at 48.75 ml/s discharge show that horizontal mixer spaced at 100 mm is better with maximum sediment/floc of 333×10^{-4} g at a dosing rate of 0.55 ml/s, at 55.07 ml/s discharge vertical mixer is better with 250 mm spacing giving maximum sediment of 985×10^{-4} g at a dosing rate of 0.95 ml/s. For 60.34 ml/s discharge, horizontal mixer is better at 250 mm spacing with maximum sediment of 307×10^{-4} g at 0.75 ml/s dosing rate. In the case of 62.45 ml/s discharge, horizontal mixer at a spacing of 300 mm is better with a maximum deposit of 335×10^{-4} g at a dosing rate of 0.95 ml/s, and for discharge of 63.27 ml/s, horizontal mixer is better at 150 mm spacing having a maximum sediment of 715×10^{-4} g for a dosing rate of 0.35 ml/s. Response surface methodology (RSM) presented by Montgomery, 2008 was further used for the analysis of data in this study for more reliable inference because it optimized the responses of these three variables. It was observed that for the vertically placed baffles, the stationary points of response surface for discharge rate, baffle spacing and dosing rate are 80.56762847 ml/s, 100.00000 mm and 0.04965779 ml/s, while for horizontally placed baffles, it was 70.636018 ml/s, 332.864704 mm and 1.402526 ml/s, however, these results indicate that horizontally placed baffle mixers are better than vertically placed baffle mixers.

Keywords:

Efficiencies;
Horizontal;
Vertical;
Baffle Mixers;
Comparison.

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1- Introduction

This study compared the efficiencies of horizontal and vertical baffle mixers in sedimentation basins. It also determined the optima values for the three variables considered in this work, discharge rates, dosing rates and baffle spacing respectively. The objective of this work is to assist in making timely decision in the recommendation of a better configuration of baffle mixers in the treatment of wastewater. Baffles are needed to stop the swirl in a mixing tank. Almost all impellers rotate in the clockwise or counter- clockwise direction. Without baffles, the tangential velocities coming from any impeller(s) causes the entire fluid mass to spin. It may look good from the surface seeing that vortex all the way down to the impeller, but this is more like a centrifuge than a mixer. In order to achieve the objective of removing fine discrete particles in sedimentation tanks, baffles are used to enhance flocculation. Solids removal is

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probably the main aim of water purification in sedimentation tanks. The performance of these sedimentation tanks is directly affected by the filtration basin [1]. Sedimentation tanks are divided into two main categories, namely primary and secondary sedimentation tanks. Primary sedimentation tanks have low influent concentrations, their flow field is not much influenced by the concentration field and buoyancy effects can be negligible. Secondary sedimentation tanks on the other hand have higher influent concentrations [2]. In a study of secondary sedimentation basin design, with a 2-Dimensional Computational Fluid Dynamics (CFD) model, Settler CAD, used as a basic 3-Dimensional full-scale sedimentation basin, Metcalf and Eddy (2003) showed that although the baffle could significantly reduce the effluent suspended solids (ESS) concentrations while the sedimentation basin was under-loaded, it did not increase the flux rating (or capacity) of these basins [3]. Qualitatively, baffle positions have significant effect on the flow patterns, suspended solids concentration and solids removal efficiency [1]. Crosby (1984) used an additional baffle at mid-radius extending from the floor upwards to the mid depth, and observed a reduction of 38% in effluent concentration [4]. Placing of an intermediate baffle, installed close to the middle of the clarifier and extending from the floor upward to one-third depth, had no significant effect on the efficiency [5], but a change in the arrangement of inlet feed could allow a device to handle higher volumes by maintaining the flow conditions that improve sedimentation [6].

Reynolds and Froude numbers must be considered together in studies concerning flows in sedimentation tanks, and at high Reynolds number, the flow fields and baffle positions were not affected by the inlet Froude numbers [7]. Dynamic mixers are qualified as efficient vessels for mixing in processes accompanied by mass, momentum and heat transfer and chemical reaction. In recent researches, there has been an increasing interest in the development of alternative designs for improvements of key elements, such as geometry of baffles, mixer vessels, impellers, operational parameters of mixers and impellers, etc. [8]. Sedimentation tanks are important components of any water purification plant, and account for approximately a third of the infrastructure cost [9]. Their task is to remove suspended particles from the flow field, so their efficiency affects the performance of other parts of the plant [10]. Sedimentation tank (ST) usage can be classed into two main categories: (i) Waste-Water Treatment Plants (WWTPs) and (ii) Water Treatment Plants (WTPs). WWTPs include Primary Settling Tanks (PSTs) and Secondary Settling Tanks (SSTs). Primary settling tanks (PSTs) are designed to dissipate kinetic energy, reduce the overall flow velocity and to let solids settle [11]. Typically, secondary settling tanks (SSTs) are located after mixers in wastewater treatment plants (WWTPs) where flocculation and coagulation processes occur.

In terms of their internal functioning, ST can be divided into four areas: (i) inlet zone, (ii) settling zone, (iii) sludge zone, and (iv) outlet zone [12]. At the tank exit, the solids loading (SL, solids flux in the outflow [13] is the design parameter that defines the tank capacity. Sediment deposition and thus tank efficiency, is a function of energy dissipation in the tank, which is in turn related to maximal flow rates. Probably the least efficient ST is one in which a jet formed at the inlet is routed directly to the tank exit without appreciably lowering its inlet (i.e. maximum) velocity. This pattern would, additionally, induce circulations that would maintain sediments in suspension. These "dead" zones decrease the tanks effective volume, and decrease tank performance if they are accompanied by intense mixing and turbulence leading to sediment re-suspension (e.g., [14]). There are a number of comprehensive studies on baffled tanks that investigate their hydraulic efficiency [15, 16]. Bretscher et al. (1992) considered a rectangular clarifier and showed that an intermediate (where intermediate refers to location along the tank length) baffle on the base of the tank, transverse to the main flow direction, influences the flow field and can improve efficiency [17]. Krebs (1991) and Krebs et al. (1995) focused on the flow field and the potential energy of incoming flows. His analysis was based on a 2D hydrodynamics code validated by laboratory results. The model was applied to evaluate various inlet arrangements and bottom currents. To enhance sediment settlement on the tank bottom, he suggested placement of an inlet baffle [2, 18].

Numerical models of flow patterns, sediment mixing rate and turbulence characteristics in STs have been reported. Celik et al. (1985) and Adams and Rodi (1990) used the $k-\varepsilon$ turbulence closure model [19, 20]. Lyn et al. (1992) showed that the flow field depends on the particle density entering the tank and the entrance geometry [21].

Tamayol et al. (2008) examined the tank performance using the particle-tracking method. They observed a large circulation zone and concluded that a baffle placement that disturbed this zone resulted in improved tank performance [9]. Goula et al. (2008) indicated that the baffle height is important, as it can decrease the inlet recirculation zone and increase sedimentation [11]. Liu et al. (2009) used laser Doppler velocimetry to conduct flow-field measurements, accompanied by numerical simulation of the flow field to evaluate the effect of inlet height on sedimentation efficiency [22]. Effects of baffle height and position were not considered. The effect of baffle angles and positions were examined using a 2D model [23] applied to a small-scale, 2-m long laboratory setup [24-26]. Right-angled (to the tank base) baffles were most favorable for sedimentation. In addition, it was concluded that, to achieve high settling performance, the baffle should be somewhere close to the inlet. However, the effects of baffle height and optimal baffle configuration were not considered.

2- Materials and Method

2-1- Sources of Data

Primary data was the main source of data for this study, of course this is an experimental research so that a distorted model of scale ratio 1:8 to that of Razmi et al. (2013) [27] was constructed and used for the experiment. After the experiment, data was generated and was analyzed statistically using response surface methodology (RSM).

2-2- Parameters of Interest

The parameters of in this study are;

a. Optimum baffle spacing from the inlet (mm)

b. Optimum discharge rate (ml/s)

c. Optimum dosing rate (ml/s)

d. Flocs inlet concentrations (g)

e. Flocs outlet concentrations (g)

2-3- Samples and Sampling Techniques

A 1 : 8 scale distorted model sedimentation tank geometrically similar to the one used by Razmi et al. (2013) [27] in their research was used in conducting the experiment, with dimensions 1.00 m long, 0.30 m deep and 0.20 m wide. The materials for this study include alum solution, clay soil, distilled water and horizontal and vertical baffle mixers with baffles spaced at 100 mm, 150 mm, 200 mm, 250 mm and 300 mm respectively. The specific gravity of clay soil passing the No.300 BS sieve (i.e. 63 μm) was determined and used to prepare the turbid water for this study by dissolving 1000 g of the pre-treated soil in 0.50 m^3 of distilled water (i.e. 2.0 mg/l) after which a dispersing agent was added to prevent flocculation. Essentially, the pre-treatment was meant to remove organic matter content from the soil. The dissolved clay water was introduced into the clay solution tank by opening the control valve. The clay solution tank is a cylindrical tank of 0.85m diameter, 1.00 m depth, with volume capacity of 0.567 m^3. The content was allowed to settle for 15 minutes after which it was gently mixed for 10 minutes in order to obtain a homogeneous clay solution before discharge into the sedimentation tank with the baffles revolving at 2 revolutions per minute (rpm).

2-4- Experimental Setup and Procedure

The equipment is made up of the following components; constant head refilling tank of dimensions 0.40 m diameter and 0.6 m depth which contains clay solution of 2.0 mg/l concentration; the dossator; detachable sedimentation tanks of dimensions 1.0 m length, 0.30 m wide and 0.70 m depth of capacity 0.210 m^3, adapted for the fixing of both vertical and horizontal baffles, detachable baffles at 100, 150, 200, 250 and 300 mm spacing respectively, alum solution container and the pumping machine for supply of clay solution into the sedimentation tank. The experimental set up is shown in Figure 1. Clay solution was injected into the baffle tank when the dosing pump was set at zero, a 10ml sample of solution was collected and subjected to fine analysis using the pipette method. This a lengthy and painstaking process, described in detail in [28] to determine the quantity of floc/sediments in microns (μm) contained in the solution, which served as the control experiment.

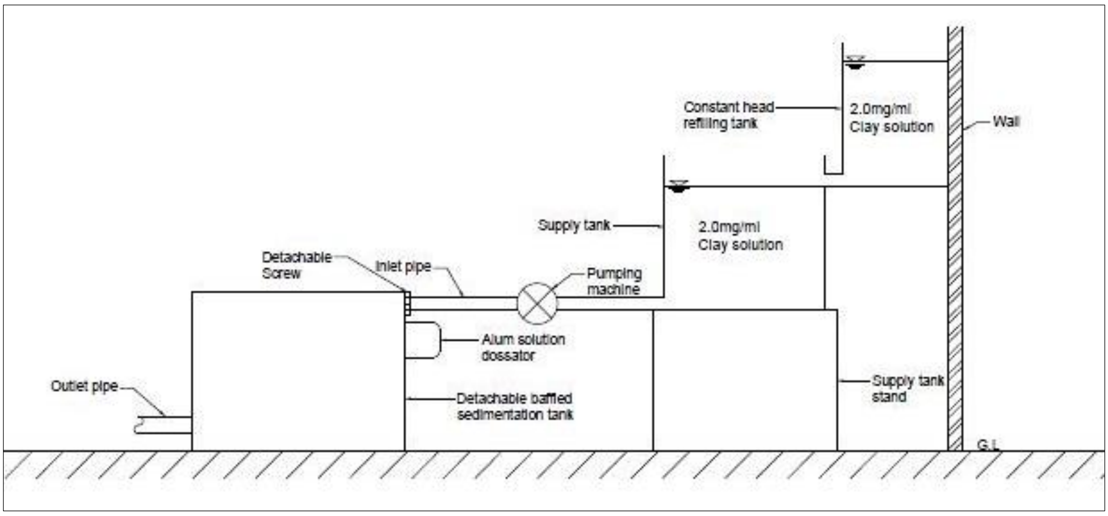

Figure 1. Schematic diagram for the efficiencies of horizontal and vertical baffle mixers.

2-5- Laboratory Analysis

In the control experiment, 0.105 m^3 containing 102 g weight (W_b) of the fine particles was made up to 500 ml with distilled water and placed in a constant temperature bath. When the suspension had reached the temperature of the bath it was taken out, shaken to disperse the particles and replaced in the bath. A stop watch was started immediately the suspension was replaced.

After 4 minutes a 10-ml sample of the suspension was taken by pipette from a depth of 100 mm and the weight of the solids in the sample found (W_D). A correction was made for the weight of the dispersing agent (sodium hexametaphosphate) in the suspension. To do this a separate solution of the dispersing agent was tested at the same time in the same manner. The whole procedure was repeated after 45 minutes and again after 7 hours. From Stoke's law the velocity of the particles is given by the expression;

$$v = KD^2 \quad (1)$$

Where K is a constant equal to;

$$(\gamma_s - \gamma_w)/18\mu_w \quad (2)$$

Where γ_s and γ_w are the weights of the fine particles and water and μ_w is the dynamic viscosity of water. After time t_1 all the particles of a certain size D_1 will have settled from the surface to a depth of 100mm. any particles larger than size D_1 will have sunk below the 100 mm mark in the suspension. The velocity of particle size D_1 can therefore be calculated since they have moved a distance of 100 mm in known time t_1, i.e.

$$v = h/t_1 \quad (3)$$

$$KD_1^2 = h/t_1 \quad (4)$$

$$D_1^2 = h/Kt_1 \quad (5)$$

As h, t_1 and K are known, the maximum grain size D_1, at depth 100 mm after t_1 can be calculated. Since all smaller sizes than D_1 at this depth will be present in the same concentration as they were in the original suspension.

Percentage of particles less than size D_1 in original solution N;

$$N = [(w_{D_1}/10)/(w_b/500)] \times 100 \quad (6)$$

Where $w_{D_1}/10$ is weight of solids per ml at depth 100 mm after time t; $w_b/500$ is the weight of solids per ml in original suspension.

Clay solution was further injected into the sedimentation tank using a control valve and the dossator valve opened to supply alum solution into the sedimentation tank at the rate of 0.15, 0.35, 0.55, 0.75 and 0.95 ml/s at 60 seconds intervals, while the rate of discharge from the sedimentation tank was measured at 48.75, 55.07, 60.34, 62.45 and 63.27 ml/s respectively at 60 seconds intervals also. At each dose of alum, sample was collected from the tank to determine the concentration of the clay solution after injection into the sedimentation tank c_i. Another sample was also collected at the outlet to determine the concentration of the clay solution c_0 using the method and procedure described above. The rate of flow and efficiency of the system were determined from the relationships;

$$Q = v/t \quad (7)$$

Where Q = Rate of discharge (ml/s); v = Volume of sample collected from the outlet (ml); t = Time (s).

$$E = \left(\frac{c_0 - c_1}{c_0}\right) \times 100\% \quad (8)$$

Where E = Efficiency; c_0 = Concentration of the clay solution at the outlet; c_i = Concentration of the clay solution after injection into the sedimentation tank.

The data generated was analyzed using the response surface methodology (RSM) presented by Montgomery (2008) [29] and the software used was R Core Team (2017) Statistical software [30]. The model was used to compare the efficiencies of horizontal and vertical baffle mixers and determination of the optimum baffle spacing, discharge rates and dosing rates for both horizontal and vertical baffle mixers.

2-6- Statistical Analysis

Factorial experiments are employed in all fields of life such as agricultural science, biology, medicine and the physical sciences. Experiments are usually carried out by researchers either to discover something about a particular process or to compare the effects of several factors on responses. Factorial experiment is therefore a crossed factor design that usually involves several factors and it is such that every possible combination of the factor is included, observed or examined. Factorial experiments permit the analyses of a number of factors with the same precision (e.g., individual and joint effects) as if the entire experiment had been devoted to the study of only one factor.

Some notable factorial experiments are as follows;

2^k factorial experiments - This involves k factors each at two levels.

3^k factorial experiment - This involves k factors each at three levels. B^k factorial experiment - This involves k factors each at B levels. Factorial designs are widely used in experiments involving several factors where it is necessary to study the joint effect of the factors on a response. There are several special cases of the general factorial design are widely used in research work and also because they form basis of the designs of considerable practical value. The most important of these special cases is that of k factors, each at only two levels. These levels may be quantitative, such as two values of temperature, pressure, or time or they may be qualitative, such as two machines, two operators, the "high" and "low", levels of factor, or perhaps the presence and absence of a factor. Considering this case, we considered 3-factors at 5 levels each making a 5k factorial design. The discharge factors at (48.75, 55.07, 60.34, 62.45 and 63.27), the baffle spacing factors at [B1(100), B2(150), B3(200), B4(250) and B5(300)] and the dosing factors at (0.15, 0.35, 0.55, 0.75 and 0.95),

The general model is given:

$$y_{ijk} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{123} x_1 x_2 x_3 + \beta_{23} x_2 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \varepsilon_{ijk} \tag{9}$$

Response surface methodology (RSM) used in this work, is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize these responses. For example, suppose that an engineer wishes to find the levels of the three design factors such as discharge (x_1), dosing rates (x_2), and baffle spacing (x_3) as discussed in the above factorial experiment that maximize the response (y) of the process. The process response is a function of the levels of discharge, dosing rates and baffle spacing;

$$y = f(x_1, x_2, x_3) + \varepsilon \tag{10}$$

Where ε represents the noise or error observed in the response y. If we denote the expected responses by:

$$E(y) = f(x_1, x_2, x_3) = \eta \tag{11}$$

Then the surface represented by

$$\eta = f(x_1, x_2, x_3) \tag{12}$$

A response surface is fitted as an extension of linear model algorithm and works almost exactly like that. However, the model formula for response surface must make use of the first-order, two-way interaction, pure quadratic or second-order models where the first-order model in Equation 10 is given by:

$$y_{ijk} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon_{ijk} \tag{13}$$

3- Results and Discussion

The interpretation follows the same line as that of the horizontal. However, the horizontal stationary point seems to be better than that of the vertical. Plots of variation of total and average floc with dosing rates indicate that vertically spaced baffles are better at low discharges as can be seen in Figure 2 at 48.75 ml/s flow rate. The trend changed at flows of 55.07 ml/s, 60.34 ml/s, 62.45 ml/s and 63.27 ml/s in Figures 3-6 in which better performances were experienced from the horizontally spaced baffle tanks. Figure 7 is a plot of the variation of grand total weight of floc generated with dosing rates from the two systems, and this plot is an indication that horizontally spaced baffle tanks perform better than vertically spaced baffle tanks. Table 6 summarized the results in Tables 1 to 5, it shows that at discharge of 48.75ml/s, horizontal mixers are better with maximum sediment deposition of 333×10^{-4} g at baffle spacing of 100 mm and dosing rate of 0.55 ml/s, while the relationship between outlet floc and dosing rate at 55.07 ml/s discharge indicate that vertical mixers are better at 250 mm baffle spacing having a maximum sediment deposition of 985×10^{-4} g with a 0.95 ml/s dosing rate. For 60.34 ml/s discharge, the maximum sediment deposition was 307×10^{-4} g at 250 mm spacing and 0.75 ml/s dosing rate indicating that horizontal mixers are better. In 62.45 ml/s discharge, maximum sediment deposition was found to be 335×10^{-4} g at 300 mm spacing and 0.95 ml/s dosing rate showing that horizontal mixers are better. Considering the performance of the tank at 63.27ml/s, maximum sediment deposit was 715×10^{-4} g for a dosing rate of 0.35 ml/s when the baffle spacing 150 mm in which the result show that horizontal mixers are better. Response surface methodology (RSM) presented by Montgomery (2008) [29] was further used for the analysis of data in this study for more reliable inference because it optimized the responses of these three variables. After the analysis, it was observed that for the vertically placed baffles, the stationary points of response surface for discharge rate, baffle spacing and dosing rate are 80.56762847 ml/s, -119.8510359 mm and 0.04965779 ml/s, the negative value of -119.8510359 mm baffle spacing is indicative that the lowest value of 100 mm should be recommended, while for horizontally placed baffles, it was 70.636018 ml/s, 332.864704 mm and 1.402526 ml/s, however, these results indicate that horizontally placed baffle mixers are better than vertically placed baffle mixers. To the best of our knowledge and the literature available to us, no work has compared the efficiencies of horizontal and vertical baffles in sedimentation tank. The only work where we can make slight comparison was the work of Razmi et al. (2013) [27], where a baffle half way along its length decreases performance, while a baffle closer to its inlet, s/L = 0.15 (i.e. 1.2 m from inlet for 8.0 m long tank) and with height 25 - 30% of water depth improves efficiency. It is worthy to note that 1.2 m distance from inlet in the study by Razmi et al. (2013) [27] is equivalent to 150 mm in our work in terms of baffle spacing from the inlet. This is evident in Table 6 where the distances of baffle from the inlet 100 mm, 200 mm and 150 mm for discharge rates of 48.75 ml/s, 60.34 ml/s and 63.27 ml/s respectively gave an average value of 150 mm baffle distance from the inlet.

Table 1. **Variation of dosing rate with inlet and outlet flocs. at discharge of 48.75 ml/s.**

Q = 48.75ml/s											
Dosing rate (ml/s)	**Vertical baffles**						**Horizontal baffles**				
	0.00 (control)	0.15	0.35	0.55	0.75	0.95	0.00 (control)	0.15	0.35	0.55	0.75	0.95
Floc. c_i $(g) \times 10^{-4}$	164.0	68.1	50.0	33.8	15.0	8.0	122	67.9	49.9	33.9	14.9	9.0
Baffle spacing (mm)	Floc. for vertical baffles c_0 $(g) \times 10^{-4}$						Floc. for horizontal baffles c_0 $(g) \times 10^{-4}$					
100	164	160	155	158	163	168	122	184	204	333	200	208
150	56	122	158	174	188	195	56	128	167	174	205	208
200	45	83	120	124	104	192	45	124	126	125	154	200
250	52	127	106	113	113	130	52	98	136	123	102	100
300	56	78	86	101	92	99	56	88	106	110	112	109
Total	373	570	625	670	660	784	331	622	739	865	681	825
Average	75	114	125	134	132	157	67	124	148	173	136	165

Table 2. **Variation of dosing rate with inlet and outlet flocs. at discharge of 55.07 ml/s.**

Q = 55.07 ml/s												
Dosing rate (ml/s)	**Vertical baffles**						**Horizontal baffles**					
	0.00 (control)	0.15	0.35	0.55	0.75	0.95	0.00 (control)	0.15	0.35	0.55	0.75	0.95
Floc. c_i $(g) \times 10^{-4}$	55.0	54.7	44.0	33.8	22.0	3.8	55	54.9	43.9	33.9	21.9	3.9
Baffle spacing (mm)	Floc. for vertical baffles c_0 $(g) \times 10^{-4}$						Floc. for horizontal baffles c_0 $(g) \times 10^{-4}$					
100	55	189	167	190	170	174	55	260	167	202	197	138
150	47	125	125	126	123	124	54	136	128	139	140	138
200	47	83	156	164	171	159	54	182	179	189	196	190
250	29	302	966	102	106	985	83	280	276	290	302	302
300	30	153	166	152	146	139	30	101	99	101	98	101
Total	469	852	1580	734	716	1580	276	959	849	921	933	869
Average	42	170	316	146	143	316	55	192	170	184	187	174

Table 3. **Variation of dosing rate with inlet and outlet flocs. at discharge of 60.34 ml/s.**

Q = 60.34 ml/s												
Dosing rate (ml/s)	**Vertical baffles**						**Horizontal baffles**					
	0.00 (control)	0.15	0.35	0.55	0.75	0.95	0.00 (control)	0.15	0.35	0.55	0.75	0.95
Floc. c_i $(g) \times 10^{-4}$	52.0	52.0	50.0	45.0	35.0	17.0	52.0	52.0	43.0	35.0	25.9	17.0
Baffle spacing (mm)	Floc. for vertical baffles c_0 $(g) \times 10^{-4}$						Floc. for horizontal baffles c_0 $(g) \times 10^{-4}$					
100	52	150	149	152	155	161	52	167	165	162	170	178
150	43	99	128	121	132	136	157	155	163	160	159	166
200	40	89	111	124	133	136	143	200	231	204	307	236

250	57	112	121	189	155	170	122	167	201	230	199	200
300	57	99	121	174	138	153	117	232	198	204	248	219
Total	249	549	630	760	713	756	591	921	958	960	1083	999
Average	50	110	126	152	143	151	118	184	192	192	217	199

Table 4. Variation of dosing rate with inlet and outlet flocs. at discharge of 62.45 ml/s.

Q = 62.45 ml/s												
Dosing rate (ml/s)	**Vertical baffles**						**Horizontal baffles**					
	0.00 (control)	0.15	0.35	0.55	0.75	0.95	0.00 (control)	0.15	0.35	0.55	0.75	0.95
Floc. $c_i\ (g) \times 10^{-4}$	45.0	46.0	37.0	30.0	19.0	10.4	45.0	45.0	38.0	29.0	19.1	10.3
Baffle spacing (mm)	Floc. for vertical baffles $c_0\ (g) \times 10^{-4}$						Floc. for horizontal baffles $c_0\ (g) \times 10^{-4}$					
100	45	88	109	110	118	135	45	156	169	169	180	177
150	43	134	156	145	230	267	43	100	109	113	117	134
200	47	94	126	125	200	107	47	176	186	155	206	167
250	44	100	116	125	93	107	44	210	212	235	193	207
300	30	82	99	119	110	122	30	222	311	253	254	335
Total	209	416	606	624	751	738	209	864	987	925	950	1020
Average	42	83	121	125	150	143	42	173	197	185	190	204

Table 5. Variation of dosing rate with inlet and outlet flocs. at discharge of 63.27 ml/s.

Q = 63.27 ml/s												
Dosing rate (ml/s)	**Vertical baffles**						**Horizontal baffles**					
	0.00 (control)	0.15	0.35	0.55	0.75	0.95	0.00 (control)	0.15	0.35	0.55	0.75	0.95
Floc. $c_i\ (g) \times 10^{-4}$	52.0	45.0	35.7	27.9	18.3	8.5	45.0	44.9	35.9	27.9	18.3	8.4
Baffle spacing (mm)	Floc. for vertical baffles $c_0\ (g) \times 10^{-4}$						Floc. for horizontal baffles $c_0\ (g) \times 10^{-4}$					
100	52	175	173	175	178	170	45	152	149	151	100	147
150	205	141	136	128	127	128	136	695	715	681	711	678
200	47	136	134	130	130	134	79	542	526	494	490	493
250	302	207	201	201	187	200	83	337	331	319	317	331
300	153	343	339	331	346	339	30	122	119	114	124	119
Total	759	1002	983	974	968	971	373	1848	1840	1759	1742	1768
Average	152	200	197	195	194	194	75	368	368	352	348	354

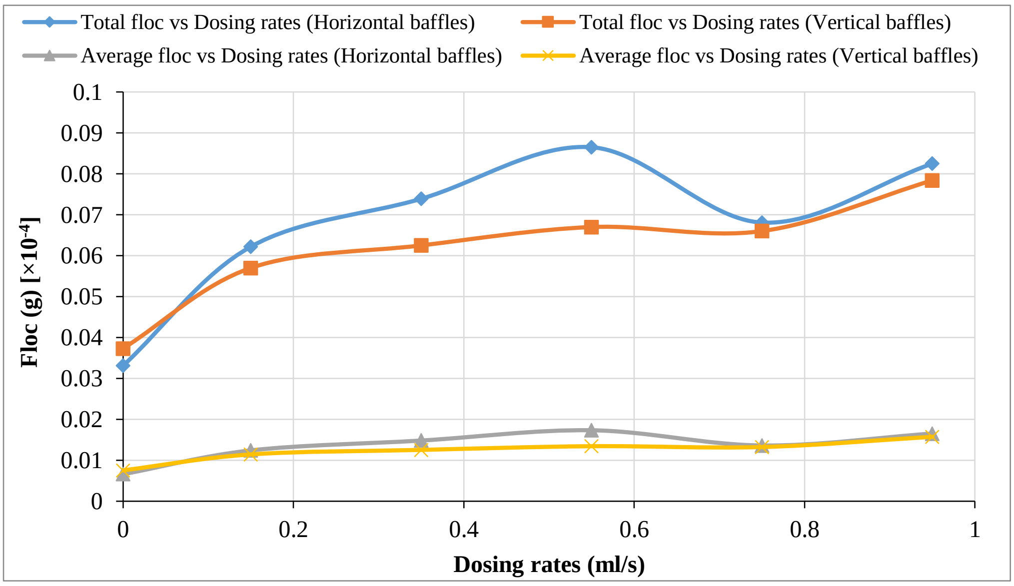

Figure 2. Variation of total and average floc with dosing rates for horizontally and vertically placed baffles at 48.75 ml/s discharge.

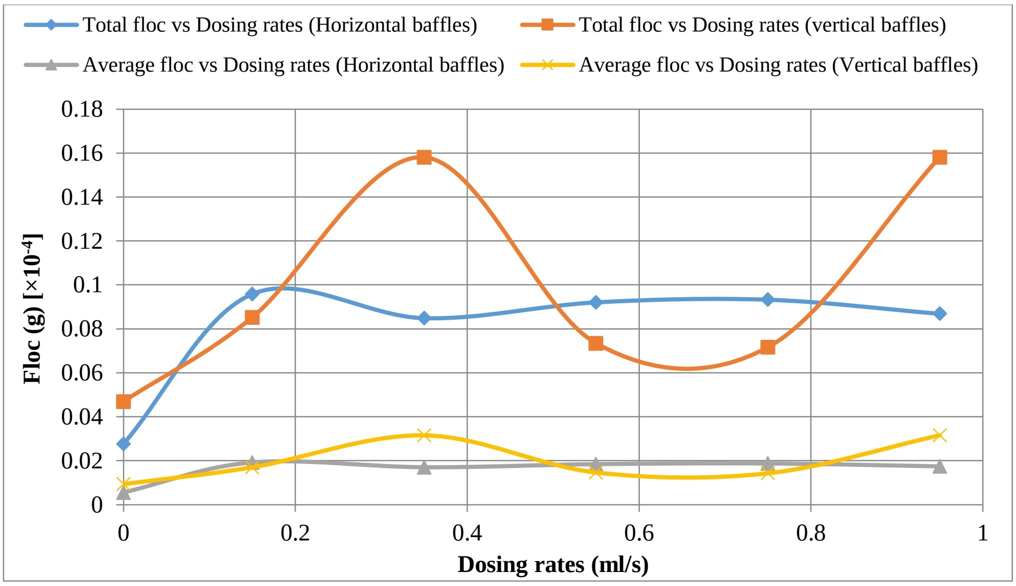

Figure 3. Variation of total and average floc with dosing rates for horizontally and vertically placed baffles at 55.07 ml/s discharge.

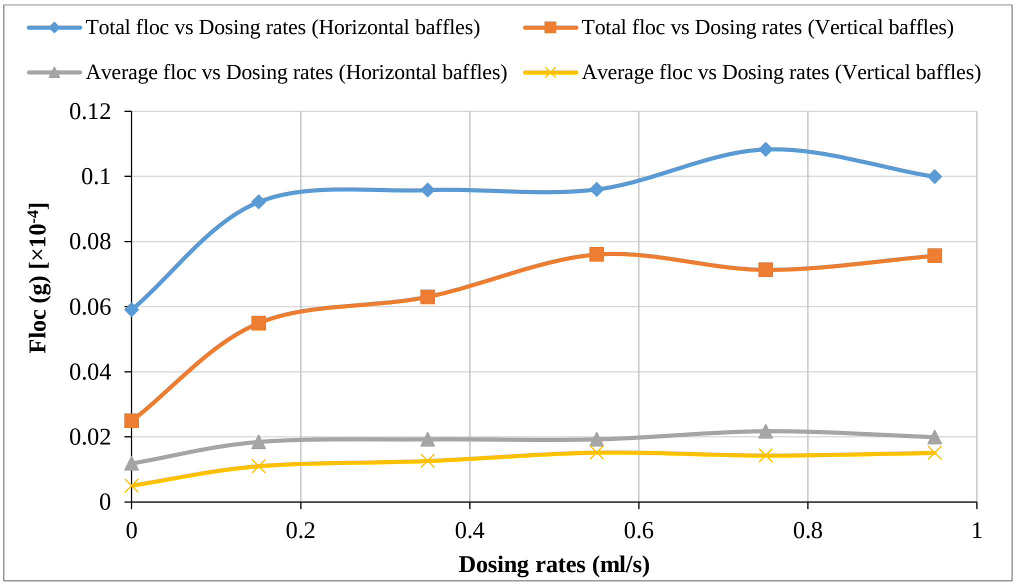

Figure 4. Variation of total and average floc with dosing rates for horizontally and vertically placed baffles at 60.34 ml/s discharge.

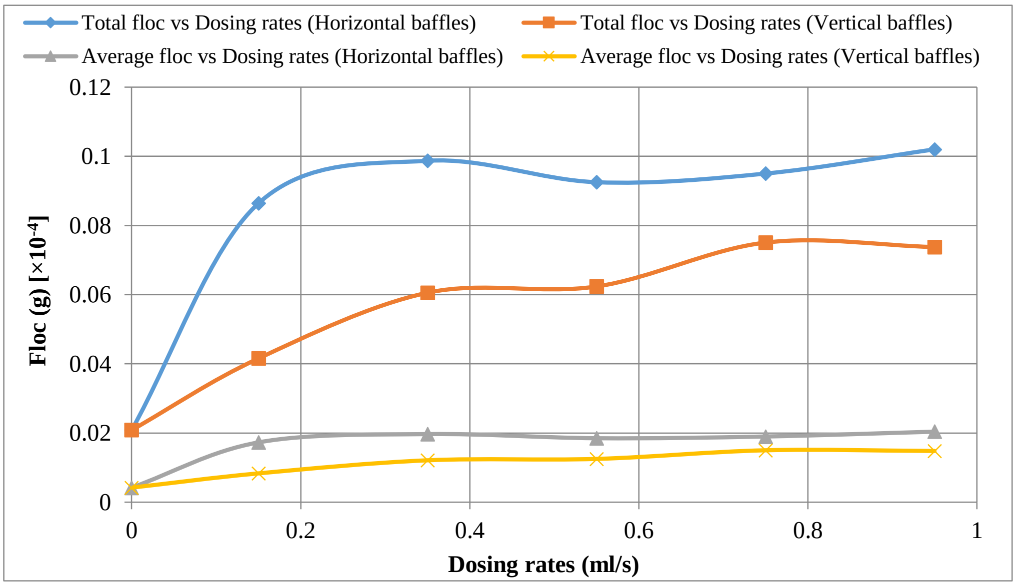

Figure 5. Variation of total and average floc with dosing rates for horizontally and vertically placed baffles at 62.45 ml/s discharge.

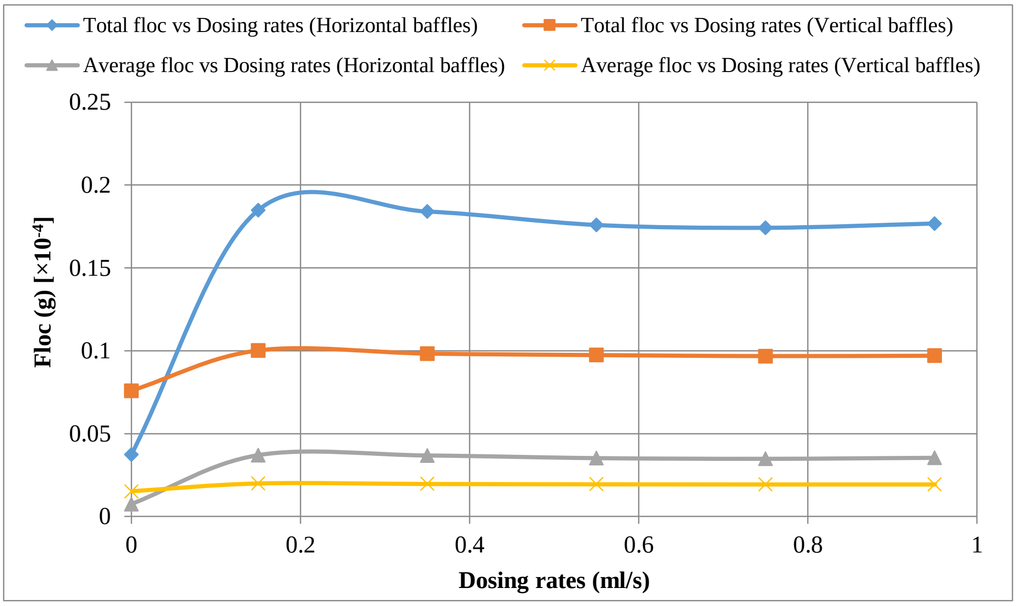

Figure 6. Variation of total and average floc with dosing rates for horizontal and vertical mixers at 63.27 ml/s discharge.

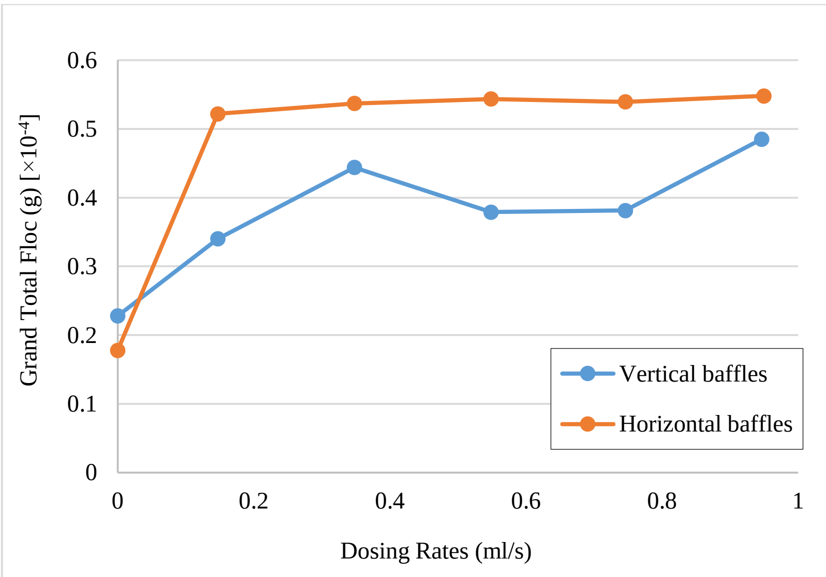

Figure 7. Variation of grand total floc with dosing rates.

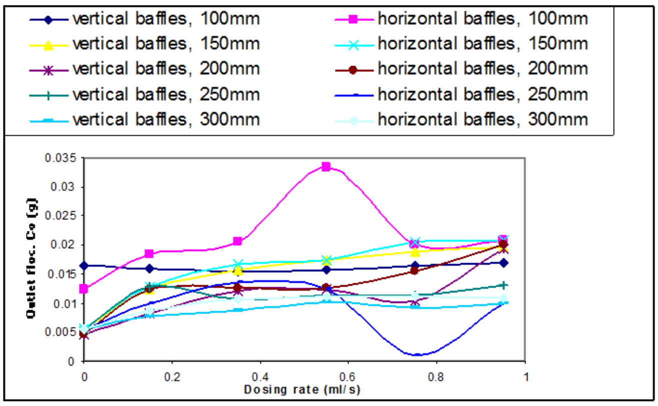

Figure 8. Variation of dosing rates with outlet floc at different baffle spacing for horizontal and vertical mixers at 48.75 ml/s discharge

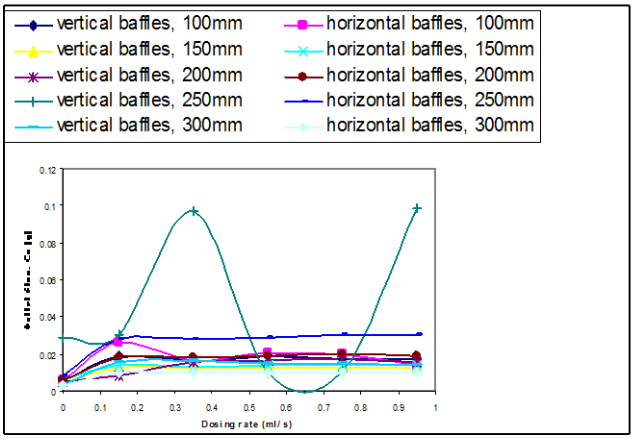

Figure 9. Variation of dosing rates with outlet floc at different spacing for horizontal and vertical mixers at 55.07 ml/s discharge.

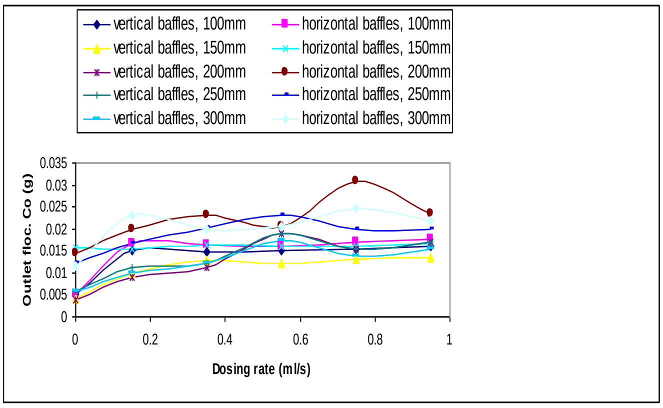

Figure 10. **Variation of dosing rates with outlet floc at different baffle spacing for horizontal and vertical mixers at 60.34 ml/s discharge.**

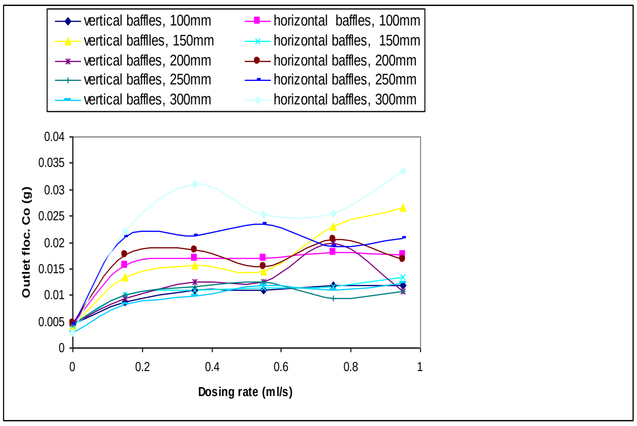

Figure 11. **Variation of dosing rates with outlet floc at different spacing for horizontal and vertical mixers at 62.45 ml/s discharge.**

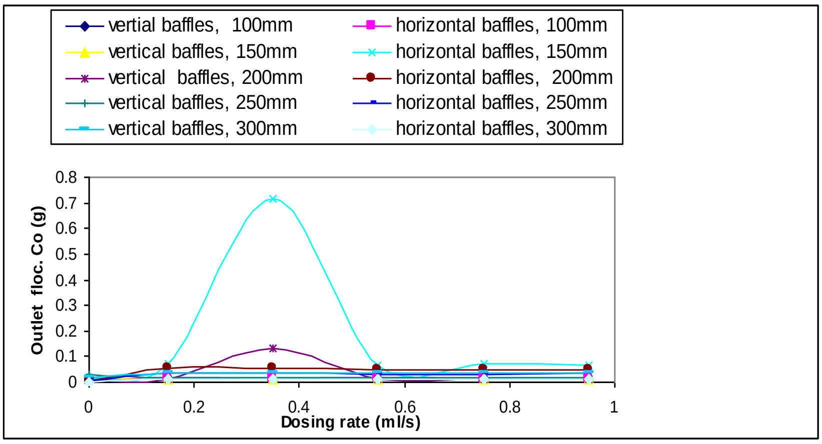

Figure 12. **Variation of dosing rates with outlet floc at different baffle spacing for horizontal and vertical mixers at 63.27 ml/s discharge.**

Table 6. **Summary of results of Tables 1 to 5.**

Discharge (ml/s)	Dosing rate (ml/s)	Baffle spacing (mm)	Maximum sediment (g) $\times 10^{-4}$	Inference (better)
48.75	0.55	100	333	Horizontal
55.07	0.95	250	985	Vertical
60.34	0.75	250	307	Horizontal
62.45	0.95	300	335	Horizontal
63.27	0.35	150	715	Horizontal

The Horizontal Data Analysis

```
              Estimate   Std. Error t value  Pr(>|t|)
(Intercept)  8.6100e+01  1.4435e+02  0.5965  0.552020
x1          -2.0722e+00  5.0703e+00 -0.4087  0.683517
x2           2.0106e+02  3.8946e+01  5.1626 1.031e-06 ***
x3          -3.2416e-01  1.6614e-01 -1.9511  0.053478 .
x1:x2       -3.0040e+00  5.9655e-01 -5.0357 1.781e-06 ***
x1:x3        7.3597e-03  2.3862e-03  3.0843  0.002556 **
x2:x3        3.5396e-02  4.5774e-02  0.7733  0.440948
x1^2         2.7151e-02  4.4886e-02  0.6049  0.546444
x2^2        -2.3286e-01  1.3678e+01 -0.0170  0.986446
x3^2        -3.6854e-04  2.1884e-04 -1.6840  0.094889 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Multiple R-squared:  0.6009,    Adjusted R-squared:  0.5697
```

```
F-statistic: 19.24 on 9 and 115 DF,  p-value: < 2.2e-16

Analysis of Variance Table

Response: response
                 Df  Sum Sq Mean Sq F value    Pr(>F)
FO(x1, x2, x3)    3 14089.7  4696.6 44.8299 < 2.2e-16
TWI(x1, x2, x3)   3  3715.9  1238.6 11.8230 8.314e-07
PQ(x1, x2, x3)    3   335.5   111.8  1.0674    0.3659

Stationary point of response surface:
        x1         x2         x3
 70.636018   1.402526 332.864704

Eigen analysis:
$values
[1]  1.4048373929 -0.0002796582 -1.6106323153

$vectors
           [,1]        [,2]         [,3]
x1  0.736924750 0.011370558  0.675879148
x2 -0.675942728 0.002657424  0.736949365
x3 -0.006583429 0.999931822 -0.009644168
```

What we see in the summary is the usual summary for a l.0 m object (with a subtle difference), followed by some additional information particular to response surfaces. The subtle difference is that the labelling of the regression coefficients is simplified. The analysis-of-variance table shown includes a breakdown of lack of fit and pure error, and we are also given information about the direction of steepest ascent. In this particular example, the steepest-ascent information is of great use, because there is significant fit for this model ($p < 0.01$) for the first order. It suggests that for this work, a first order model may suffice. However, augmenting the first order model with a higher order model may produce a better optimum for the levels. For example, we could add two-way interactions and the quadratic terms as shown in the summary table:

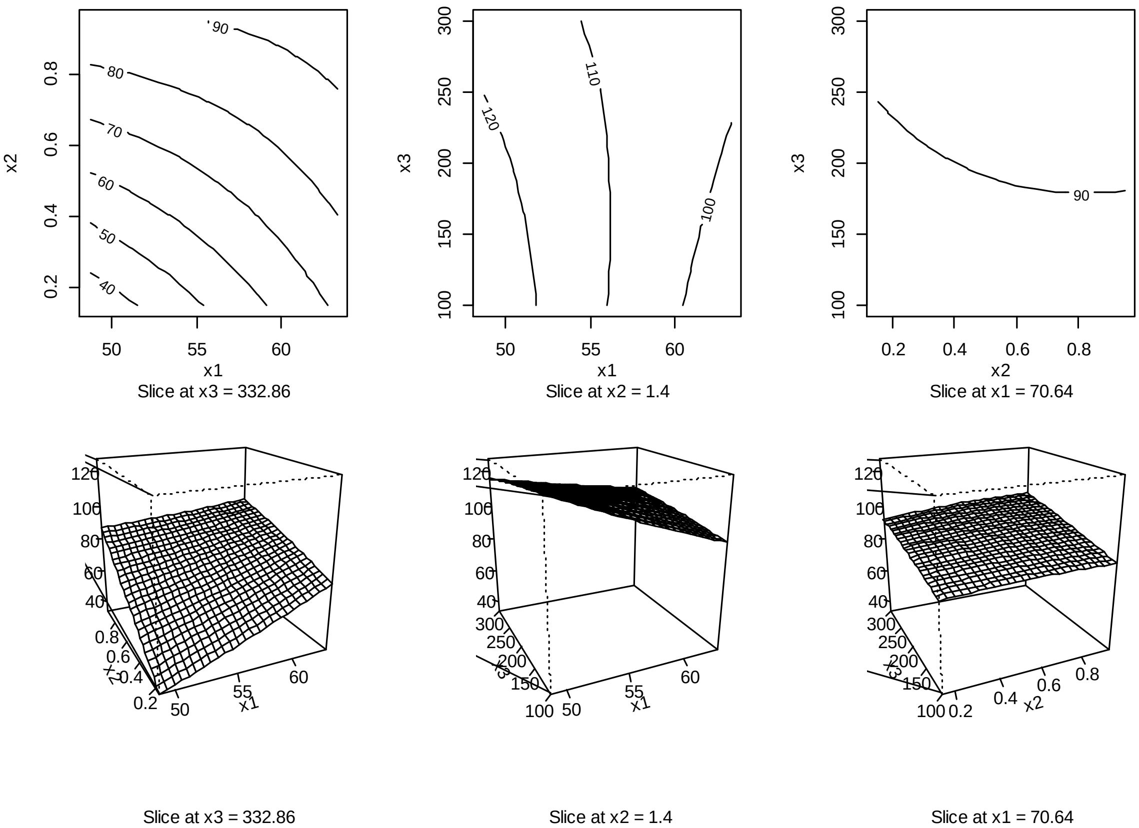

Figure 13. **Contour and surface plots of x1, x2 and x3 variables for horizontally fixed baffles.**

From the analysis of variance, it is clear again that the second-order (TWI and PQ) terms contribute slightly significantly to the model, so the canonical analysis maybe relevant in obtaining the maximum points. From the canonical values, the stationary point is fairly near the experimental region, since the Eigen values are of negative sign, indicating that it is a maximum. The residual analysis is also given by:

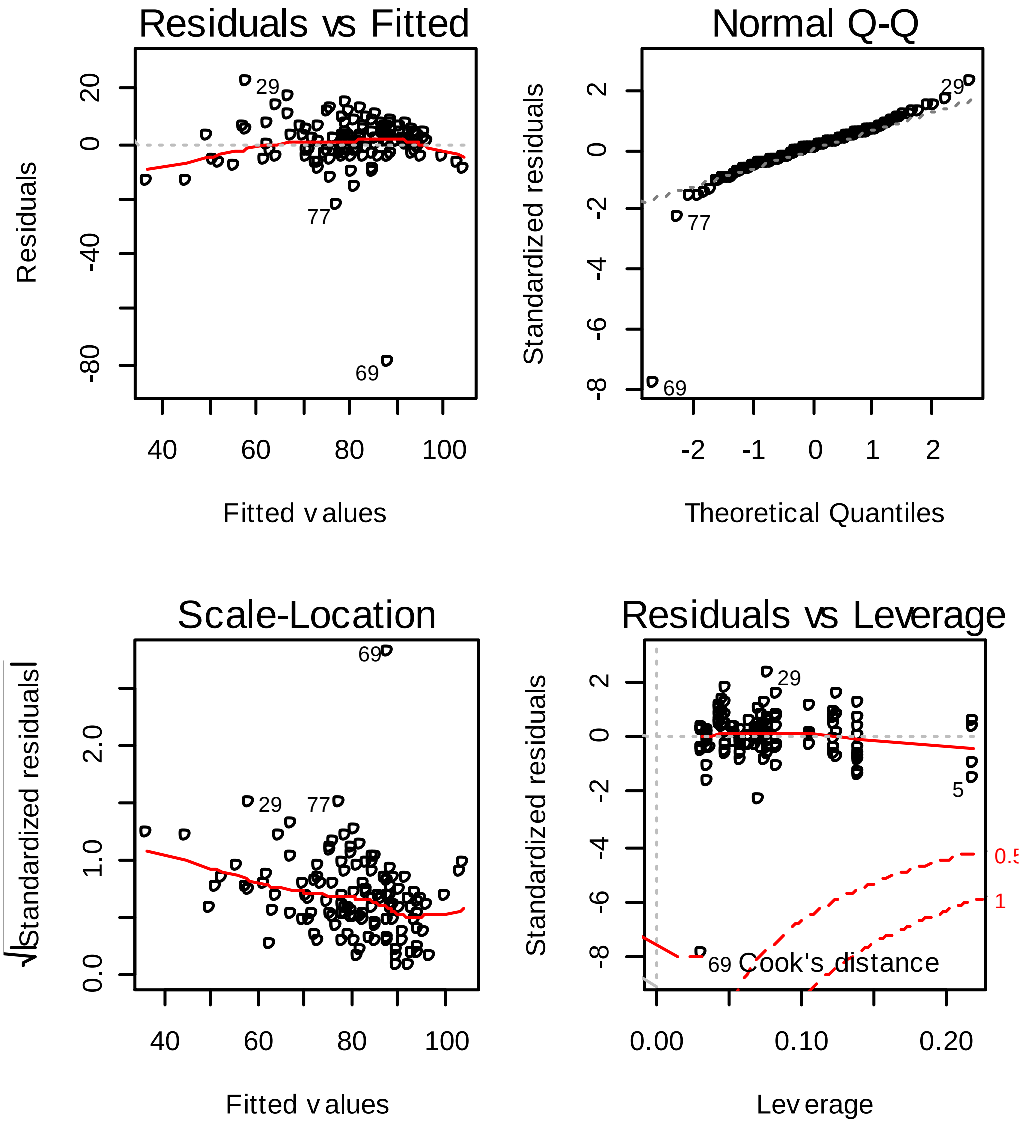

Figure 14. Residual plots of the model for horizontal baffles.

The Vertical Data Analysis

```
                  Estimate   Std. Error t value   Pr(>|t|)
(Intercept)     3.5055e+01  1.3199e+02  0.2656   0.791032
x1              1.4949e-01  4.6363e+00  0.0322   0.974334
x2              2.0039e+02  3.5612e+01  5.6270  1.311e-07 ***
x3             -4.5266e-01  1.5192e-01 -2.9796   0.003522 **
x1:x2          -2.4423e+00  5.4548e-01 -4.4773  1.791e-05 ***
x1:x3           6.1729e-03  2.1819e-03  2.8291   0.005509 **
x2:x3           1.7240e-02  4.1856e-02  0.4119   0.681189
x1^2            4.4163e-03  4.1044e-02  0.1076   0.914501
x2^2           -1.5682e+01  1.2507e+01 -1.2539   0.212429
x3^2            1.8995e-04  2.0011e-04  0.9492   0.344486
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Multiple R-squared:  0.7048,    Adjusted R-squared:  0.6817
F-statistic:  30.5 on 9 and 115 DF,  p-value: < 2.2e-16
```

```
Analysis of Variance Table

Response: response
                 Df  Sum Sq Mean Sq F value    Pr(>F)
FO(x1, x2, x3)    3 21358.9  7119.6 81.2774 < 2.2e-16
TWI(x1, x2, x3)   3  2471.9   824.0  9.4065 1.309e-05
PQ(x1, x2, x3)    3   217.7    72.6  0.8283    0.4809
Residuals       115 10073.6    87.6
Lack of fit     115 10073.6    87.6
Pure error        0     0.0

Stationary point of response surface:
          x1            x2            x3
  80.56762847    0.04965779 -119.85103597

Eigen analysis:
$values
[1]  9.896774e-02  1.359878e-04 -1.577664e+01

$vectors
          [,1]         [,2]          [,3]
x1  0.99672337 -0.024298710 -0.0771498093
x2 -0.07711320  0.002441587 -0.9970193546
x3  0.02441465  0.999701761  0.0005598353
```

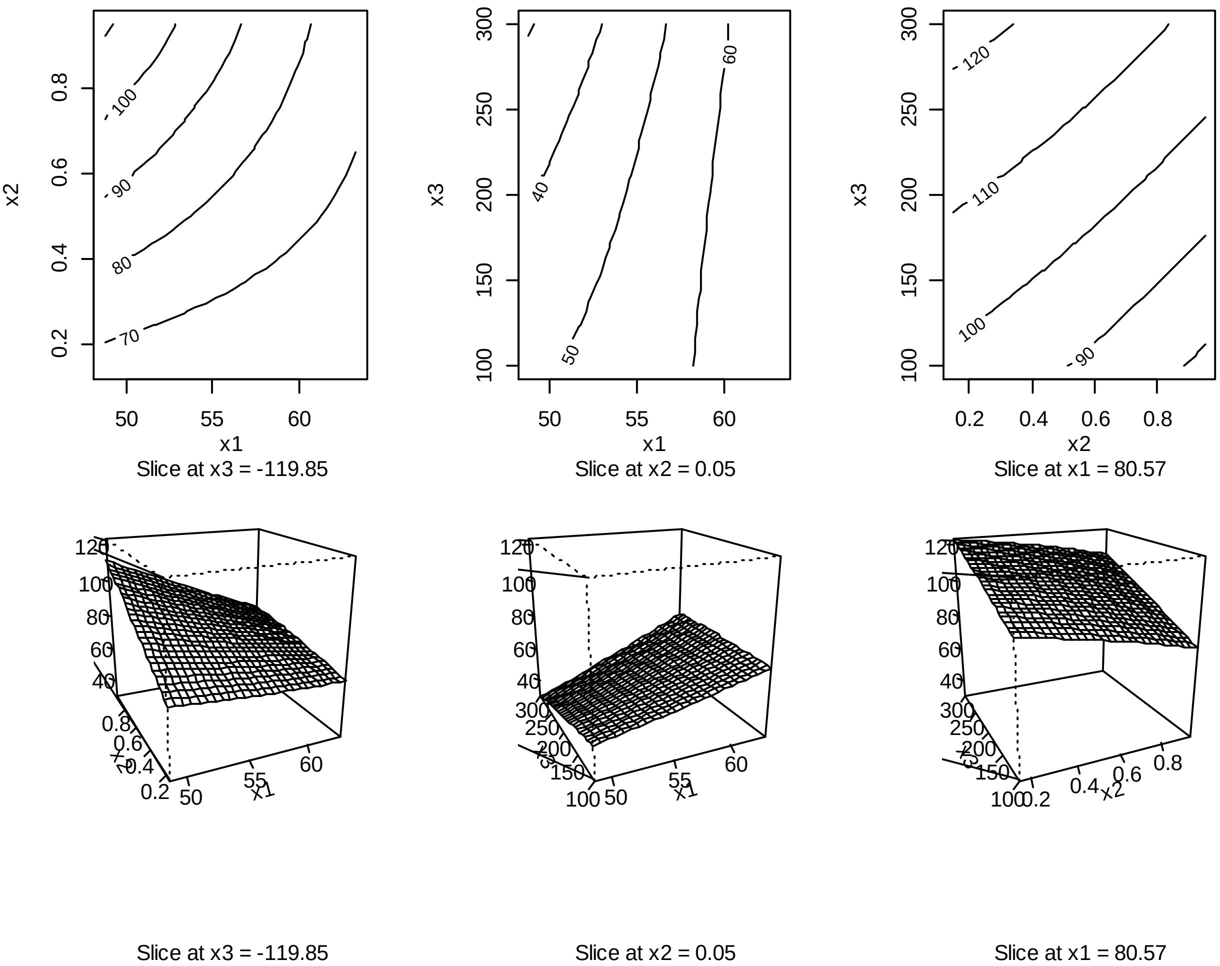

Figure 15. **Contour and surface plots of x1, x2 and x3 variables for vertical baffles.**

The residual analysis is given by:

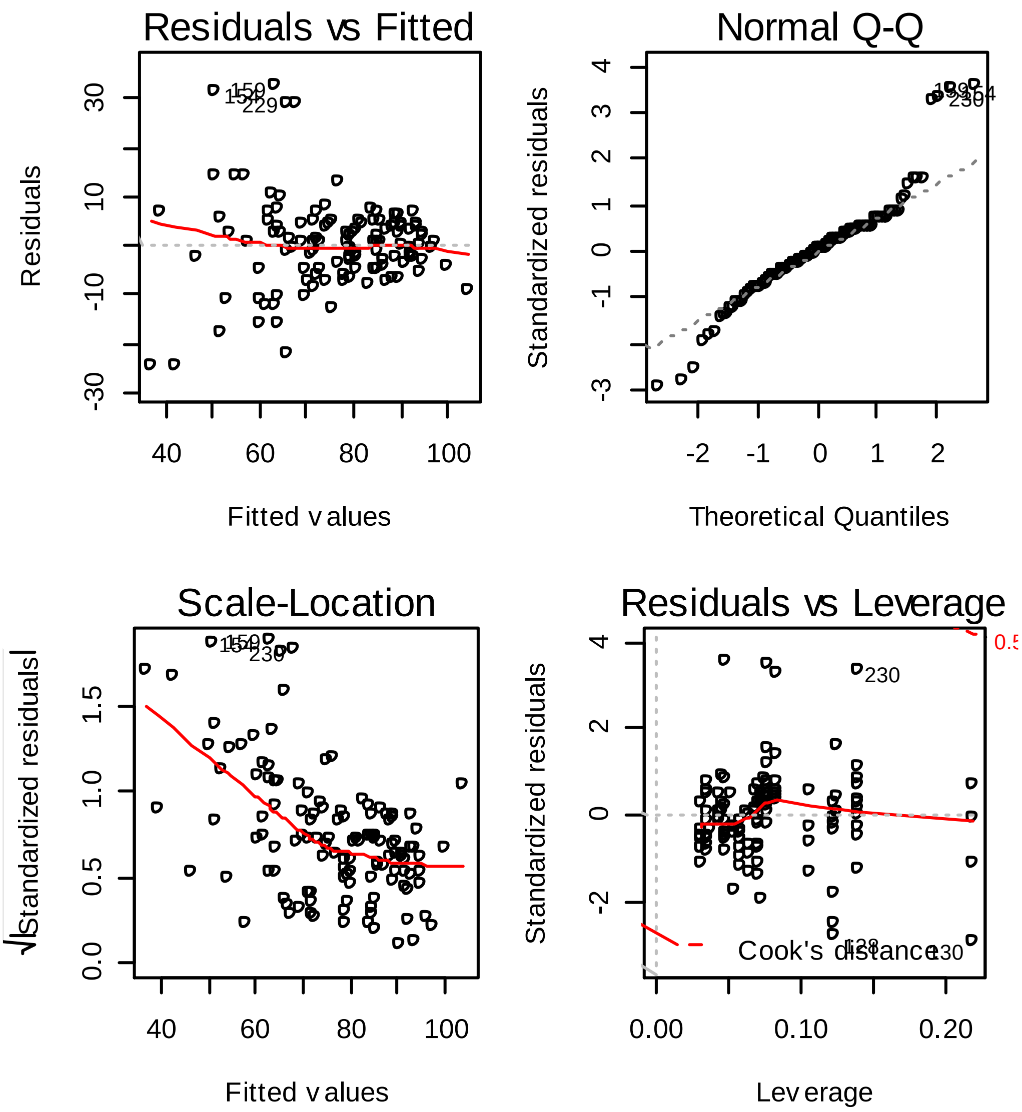

Figure 16. Residual plots of the model for vertical baffles.

4- Conclusion

From the analysis and the results associated with, it can be seen that horizontal baffles are better than vertical baffles. This is evident from the optimization of the responses of the three variables that controlled clarification in the sedimentation tanks by response surface methodology. Better result was achieved in the vertical baffle at discharge of 48.75 ml/s, but horizontal baffles exhibited better clarification at discharges of 55.07 ml/s, 60.34 ml/s, 62.45 ml/s, and 63.27 ml/s. Grand total sediment/flocs at various dosing rates also favor horizontal baffles. Response surface methodology presented by Montgomery, 2008 further used for analyses of data in this study indicate that the stationary points of response surface for discharge, baffle distance from the inlet and dosing rates are 80.56762847 ml/s, 100.000000 mm and 0.04965779 ml/s for vertical baffles. It was 70.636018 ml/s, 332.864704 mm and 1.402526 ml/s for horizontal baffles. It is true that the baffle distance of 332.864704 mm from inlet for horizontal baffles contradict with the work of Razmi et al. (2013) [27], however, results from the response surface which optimized the system revealed that horizontal baffles gave better performance than vertical baffles.

5- Conflict of Interest

The authors declare no conflict of interest.

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