IV PRESENTATION AND DISCUSSION OF RESULTS

Charactesistics of Synthetic Raw Water.

Synthetic raw water turbidity was varied from 55 to 65 FTU., with an average of 60 FTU. The pH value was varied from 7.1 to 7.8, no pH adjustment was needed during the test. The alkalinity varied from 80 to 120 mg/l and the temperature varied from 27 to 34 deg.C

Performance of Tube Settler.

The experimental results obtained from performance of inclined tube settlers under various conditions are summarized in Table 1. The alum dosage used in this study was kept constant at 50 mg/l. Effect of each parameter, tube length, overflow rate, tube size on removal efficiency are shown in Fig 23 to Fig 31.

Effect of Tube Size on Settling Performance.

From Fig 23 and 24, it is obvious that the removal efficiency decreased as the tube size increased. At lower overflow rate the change in removal efficiency due to change in tube amplitude is not significant. It can be noted that for asbestos cement corrugated sheet, the decrease in removal efficiency was rather high compared with galvanized steel corrugated sheet.

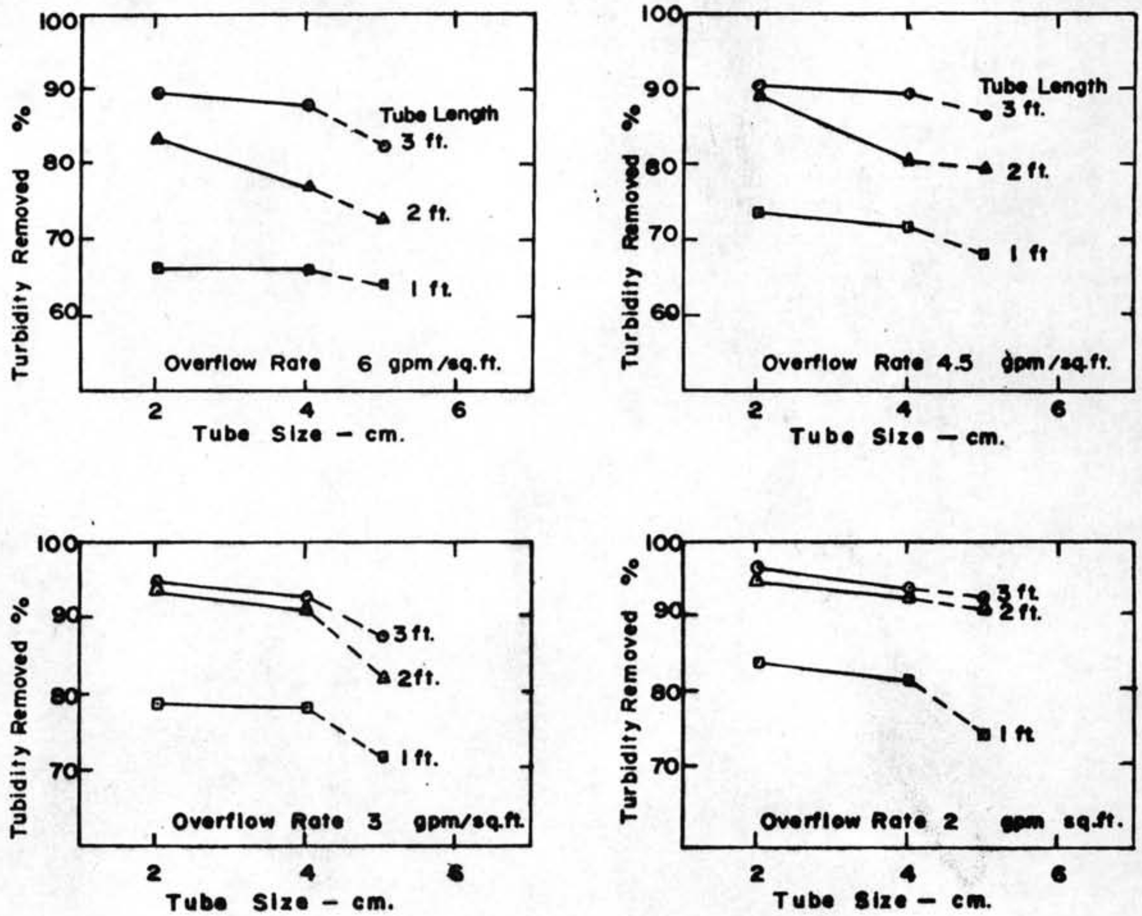
The effect of tube size found in this experiment was not so significant as that obtained from HANSEN and CULP (1967). This could be explained as follows, firstly, the raw water had been synthesized from tap water and fine clay powder, therefore the turbidity can be removed more easily than

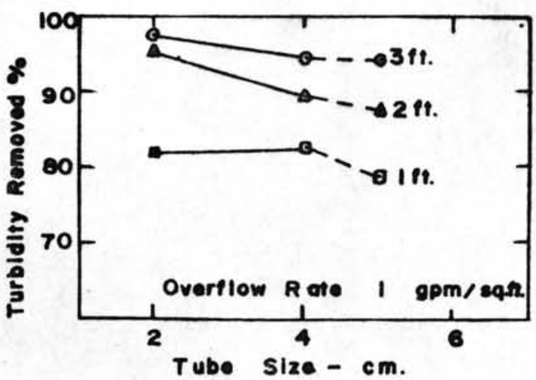
Table I. Experimental Results

Run no.	Overflow rate gpm./sq.ft.	tube size	tube length (ft.)	temp. °C	Raw water turb.	Raw water pH.	Effluent turb.	Effluent pH.	Turb. removed (percent)	detention time (min.)
1	6	small galvanized steel corrugated sheet	3	26	63	7.2	6.6	6.7	89.5	3.16
2	4.5		3	25	57	7.3	5.6	6.7	90.2	4.22
3	3		3	27	65	7.1	3.6	6.5	94.5	6.34
4	2		3	27	64	7.0	2.0	6.6	96.9	9.43
5	1		3	27	62	7.1	1.6	6.7	97.4	18.99
6	6		2	30	60	7.3	10.0	6.7	83.3	2.11
7	4.5		2	30	55	7.2	6.0	6.5	89.1	2.81
8	3		2	29	60	7.0	3.7	6.5	93.8	4.22
9	2		2	30	58	7.1	3.0	6.5	94.8	6.33
10	1		2	29	57	7.1	2.7	6.5	95.3	12.66
11	6		1	30	56	7.2	19	6.7	66.1	1.05
12	4.5		1	31	60	7.2	16	6.8	73.3	1.41
13	3		1	31	61	7.4	12	7.1	78.7	2.11
14	2		1	31	63	7.5	10	6.7	84.2	3.16
15	1		1	31	55	7.4	10	6.6	81.9	6.33
16	6	medium galvanized steel corrugated sheet	3	32	63	7.3	7.6	6.8	87.9	3.21
17	4.5		3	32.5	63	7.2	6.6	6.9	89.5	4.29
18	3		3	30	65	7.2	4.8	6.4	92.6	6.40
19	2		3	30.5	63	7.1	3.9	6.4	93.8	9.61
20	1		3	30	60	7.3	3.3	6.5	94.5	19.23
21	6		2	32	51	7.2	13.0	6.7	77.2	2.14
22	4.5		2	31	56	7.2	11.0	6.3	80.4	2.86
23	3		2	30	59	6.9	5.3	6.4	91.0	4.28
24	2		2	30	60	7.1	4.3	6.3	92.8	6.41
25	1		2	30	57	7.1	6.0	6.3	89.5	12.82
26	6		1	27	59	7.2	20	6.7	66.1	1.07
27	4.5		1	29	56	7.4	16	6.7	71.4	1.43
28	3		1	30	55	7.2	12	6.3	78.2	2.14
29	2		1	30	55	7.3	10	6.7	81.8	3.21
30	1		1	31	57	7.1	10	6.4	82.5	6.41

Table I. (Cont.)

Run no.	Overflow rate gpm./sq.ft.	tube size	tube length (ft.)	temp. °C	Raw water Characteristic turb.	Raw water Characteristic pH.	Effluent turb.	Effluent pH.	turbidity removed (percent)	detention time (min.)
31	6	Asbestos cement corrugated sheet.	3	33	62	7.4	11.0	6.9	82.3	2.6
32	4.5		3	32	60	7.4	8.1	6.9	86.5	3.45
33	3		3	31	56	7.2	7.0	7.2	87.5	5.17
34	2		3	31	63	7.3	4.8	7.1	92.4	7.8
35	1		3	31	63	7.3	3.5	7.1	94.4	15.5
36	6		2	30	62	7.1	17.0	6.9	72.6	1.72
37	4.5		2	30	58	7.1	12.0	6.8	79.3	2.30
38	3		2	32	56	7.1	10.0	7.2	82.1	3.45
39	2		2	33	62	7.3	5.6	7.2	91.0	5.18
40	1		2	33	50	7.2	6.3	7.2	87.4	10.40
41	6		1	32	61	7.3	28.0	6.8	63.9	6.86
42	4.5		1	31	56	7.3	18.0	6.8	67.9	1.15
43	3		1	31	56	7.2	16.6	7.1	71.4	1.72
44	2		1	32	55	7.3	14.0	6.9	74.5	2.59
45	1		1	32	56	7.3	12.0	6.9	78.6	5.18
46	3	No. tube	3	33	10	7.2	10	6.8	83.4	6.45
47	2		3	33	63	7.4	8.2	6.7	8.75	9.7
48	1		3	33	55	7.1	5.5	6.6	90.0	19.5
49	3		2	29	62	7.2	20	6.7	64.5	4.3
50	2		2	30	63	7.3	15	6.5	68.7	6.45
51	1		2	30	60	7.3	12	6.9	80.0	12.9
52	3		1	30	58	7.8	30	6.4	48.5	2.2
53	2		1	29	61	7.4	22	6.7	64.0	3.2
54	1		1	28	60	7.3	18	6.6	70.0	6.45





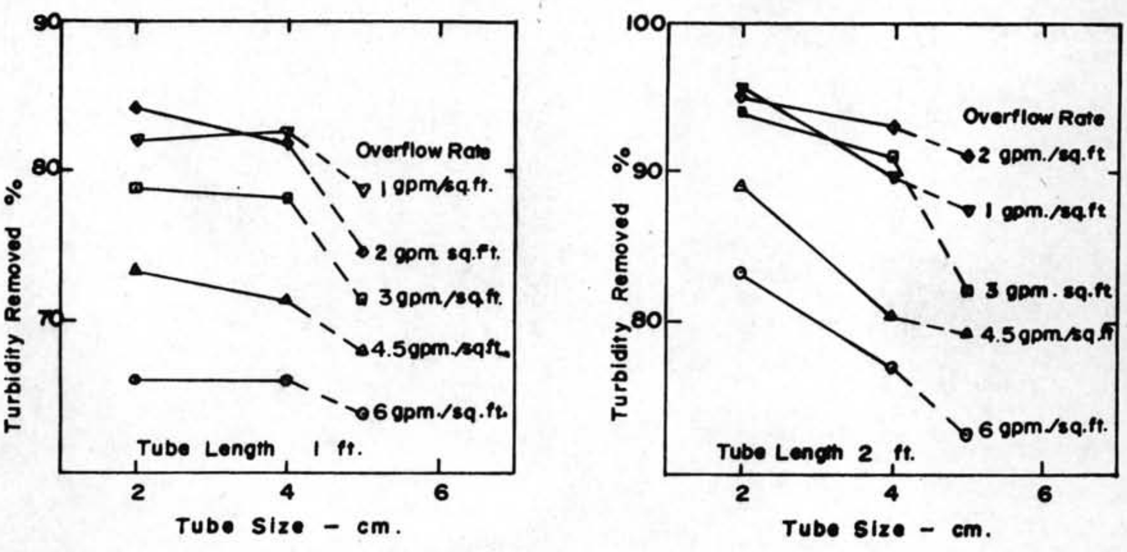
Test Conditions

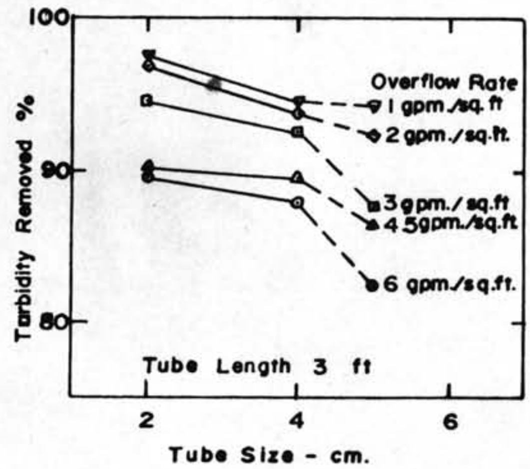
Average Raw Turb. 60 JTU

Alum Dosage 50 mg/l

Flocculation Time 20 min.

Fig 23 Effect of Tube Size on Settling Performance at various Overflow Rates





Test Conditions

Average Raw Turb.	60	JTU
Alum Dosage	50	mg/l
Flocculation Time	20	min.

Fig 24 Effect of Tube Size on Settling Performance at various Tube Length

that obtained from natural one. The other reason is that only three levels of tube size had been studied in this research, due to the limitation of material produced from the factory, but much more levels had been studied by HANSEN and CULP.

If a percentage of turbidity removal of 90% was acceptable, as it may be seen from Fig 23, that both small and medium galvanized steel corrugated sheet could be used at overflow rate of 3 gpm./sq.ft. and at length of 2 ft. In practical design medium galvanized steel corrugated sheet can be used effectively and economically instead of small corrugated sheet because a large number of the latter is needed in the same surface area of the tank.

Effect of Tube Length on Settling Performance.

The effect of tube length on settling performanced at various overflow rate (for both galvanized steel and a.c.sheet) are shown in Fig 25 and 26 respectively. From Fig 25 and 26 it can be seen that the efficiency of turbidity removal decreased as the length of the tube decreased. For small corrugated sheet the effect of tube length on the settling performance was less significant than that in larger tube.

It can be seen form Fig 25. that effects of tube size and tube materials were less signigicant when higher tube length was used. When results from experimentation with and without tube media were compared, there was not much different in tubidity removal at length of 3 ft. but it was at length of 1 and 2 ft. The only reason might be that at length of 3 ft. laminar flow could be developed easier than that at 2 ft.

By comparing the results obtained from this experiment to that obtained from CULP et.al. (1968) it could be seen that the relatively

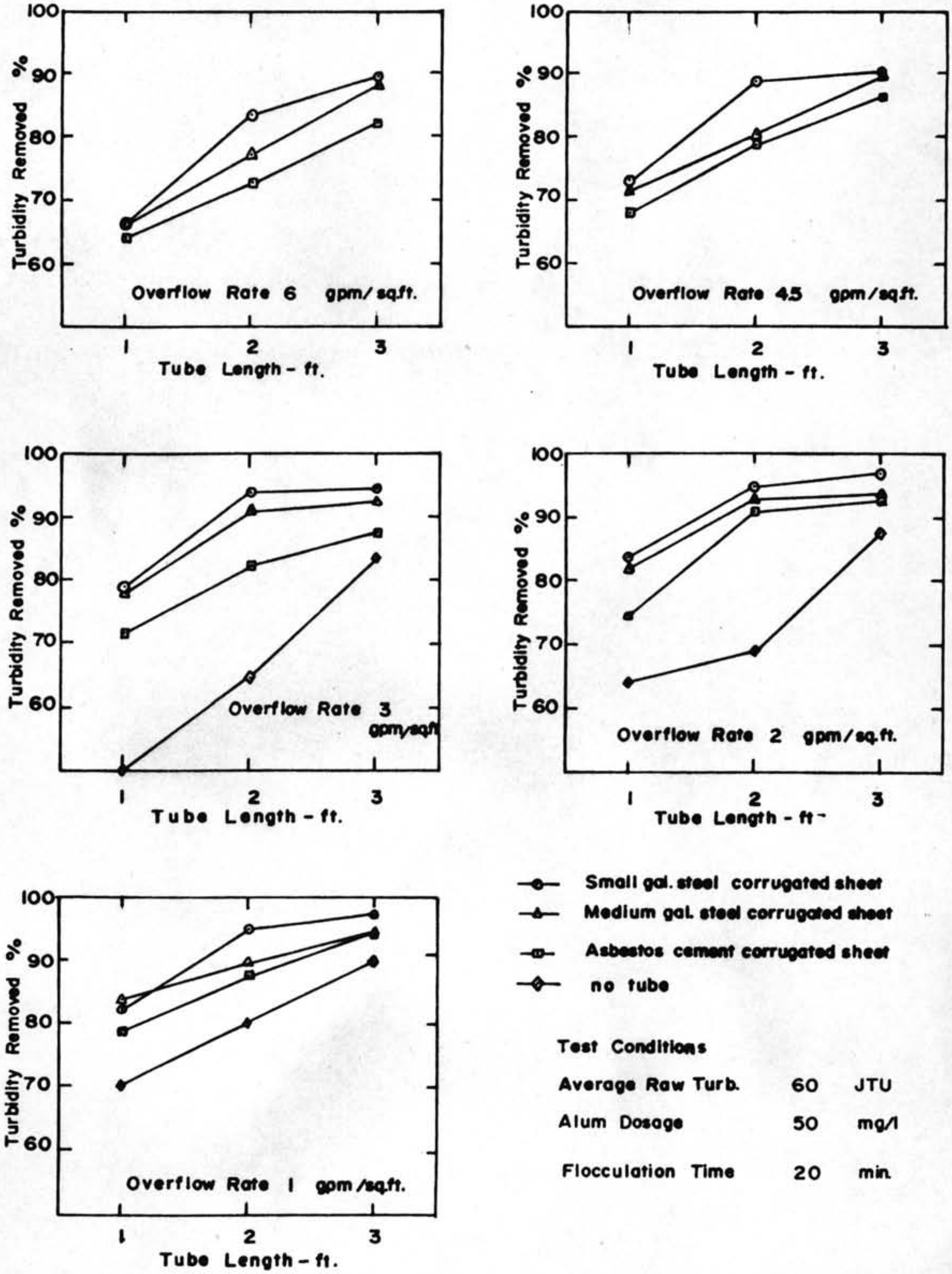
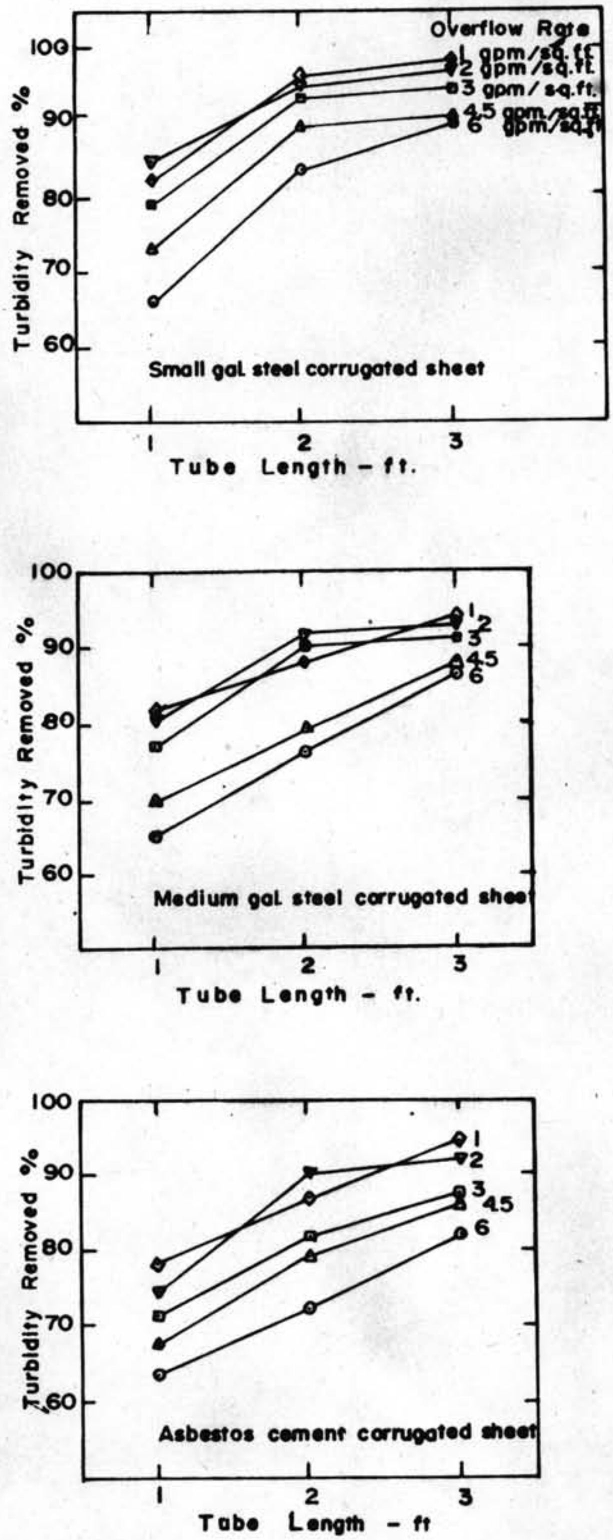


Fig 25 Effect of Tube Length on Settling Performance at various Overflow Rate



Test Conditions

Average Raw Turb.	60 JTU
Alum Dosage	50 mg/l
Flocculation Time	20 min.

Fig 26 Effect of Tube Length on Settling Performance at various materials Used

higher turbidity removal efficiency was obtained in this experiment. For example, at equal tube length of 2 ft., medium corrugated sheet gave the removal efficiency of 80.4 percent at a flow rate of 5 gpm./sq.ft., but according to CULP et.al.[1] the removal efficiency was 60 percent at flow rate of 4 gpm./sq.ft. When compared to the experiment of HANSEN et.al. (1969)[2] the removal efficiency was 80 percent at flow rate of 5 gpm./sq.ft. with polyelectrolyte dosage of 0.1 mg./l.

It can be noted that at tube 1 ft., the removal efficiency was very low, this might be due to unstable hydraulic condition, YAO (1970) explained that there had to be some length of the tube for transition zone to develop laminar flow in the tube and another explanation might be because of time in operation was too short to develop laminar flow at tube length of 1 ft. within two hours of operation.

YAO (1970) also reported the influent of the relative length of the settler on settler performance by using the equation $\frac{V_{sc}}{V_0} = \frac{Sc}{\sin\theta + L\cos\theta}$ Fig.27 is the plotting of this equation, assuming $Sc = 1.35$ and $\theta = 60°$, for system using corrugated sheets as tube settler. From Fig.27 for a fixed V_0, V_{sc} decreases rapidly with L, when L is relative small. This indicated that suspended particles with much smaller fall velocities are removed completely as L increases. The rate of decrease in V_{sc} drops appreciably after L reaches 20 and becomes rather insignificant with L

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(1) Test conditions: Raw water turbidity 50 JTU., flocculation time 7 min., and tube size was 2 in x 2 in square.

(2) Test conditions: Raw water turbidity 50 JTU., flocculation time 10 min., and tube size was 2 in x 2 in square.

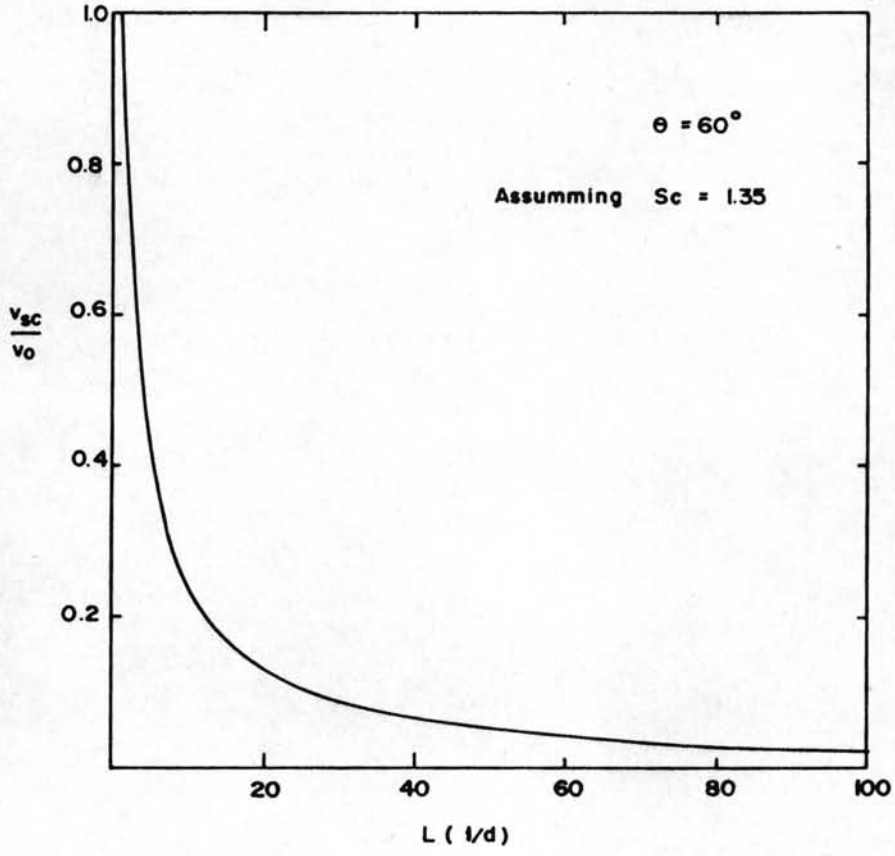


Fig 27 Relative Settler Length v.s. Performance ($\theta = 60°$)

greater than 45 which is agree with YAO's (1970) study that L should be kept below 40 and preferably around 20. In this experiment the range of relative length used was between 6.1, for asbestos cement of 1 ft. long and 45.7, for small galvanized steel corrugated sheet of 3 ft. long. The experimental results indicated that the best relative length, L, obtained from this study was above 15.

Effect of Overflow and Flow Rate on Settling Performance

It has to be noted that the overflow rate used in this study was the flow per unit area of the tank surface area. The flow rate was the flow velocity within the tube which was the flow per unit area of the tube entrance area.

The effects of overflow rate and flow rate on turbidity removal efficiency are shown in Fig.28 to 30. As mentioned before that the overflow rate used in this study was the flow per unit surface area of the tank but the flow rate was the flow velocity within the tube (eg. for medium galvanized steel corrugated sheet at overflow rate of 3 gpm./sq.ft. equivalent to the flow rate of 3.5 gpm./sq.ft.). From Fig.29 it can be seen that the removal efficiency decrease as the overflow rate increase. If the removal efficiency of 90 percent is a acceptable, overflow rate should be kept below 3 gpm./sq.ft. for medium galvanized steel corrugated sheet at length of 2 ft. and asbestos cement at length of 3 ft.

In this experiment it was found that flocculation was achived in the tube as a result of solid contact between smaller floc and sludge blanket of highly concentrated solid which formed in and beneath the tube. Due to this reason, the high removal efficiency could be obtained from the experi-

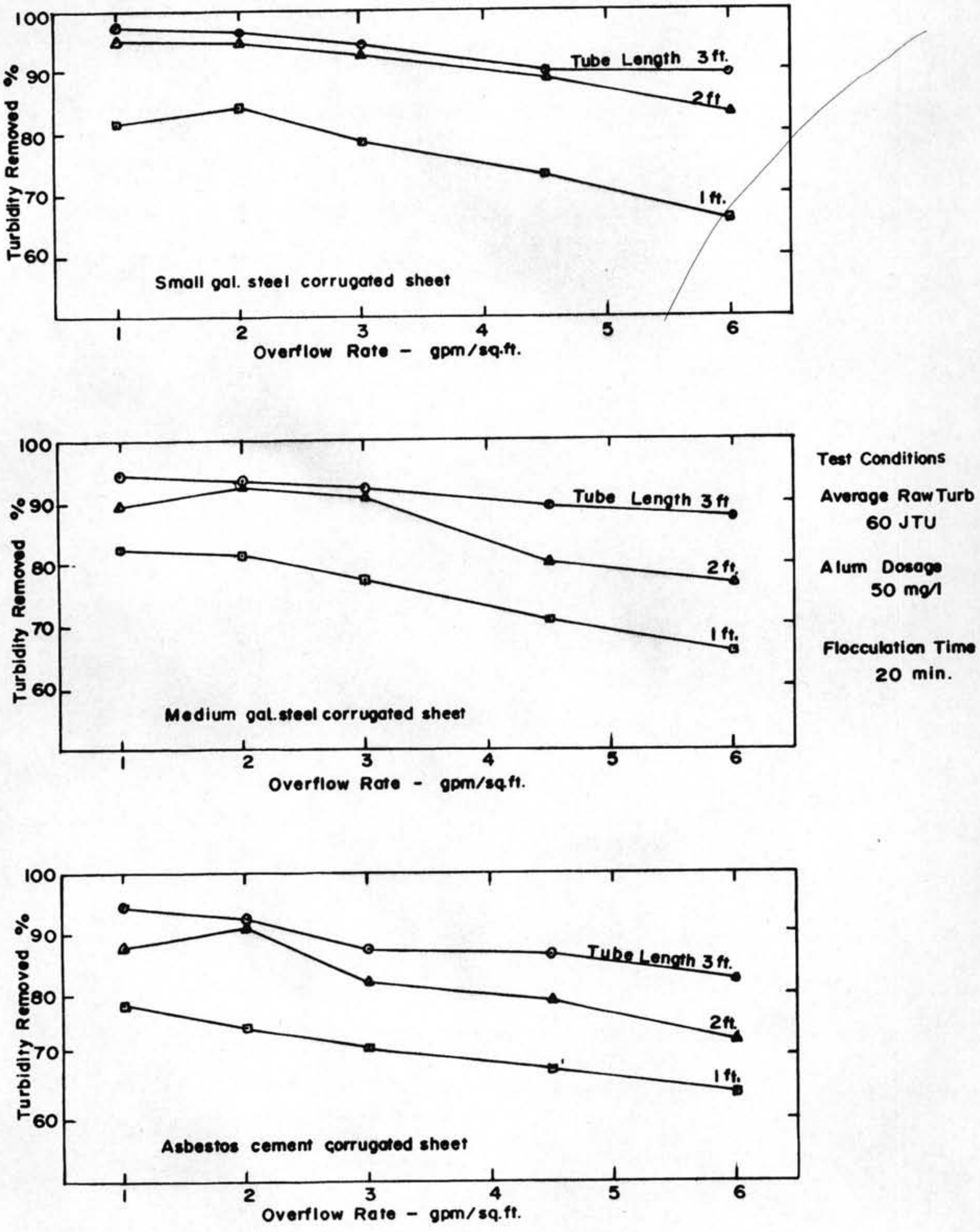


Fig 28 Effect of Overflow Rate on Settling Performance at various Material Used

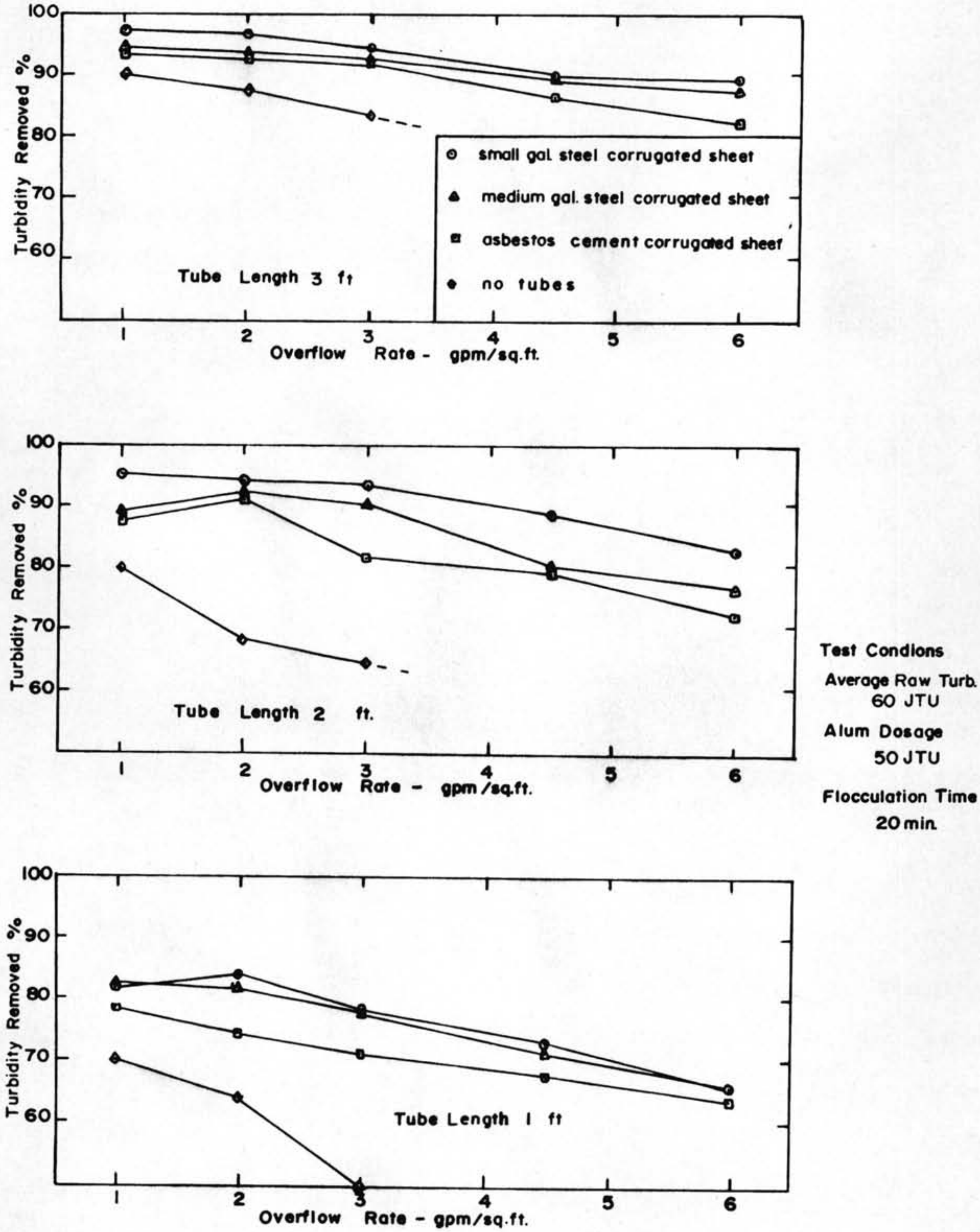


Fig 29 Effect of Overflow Rate on Settling Performance at various Tube Length

ment. It has to be noted that some low overflow rates, such as 1 gpm. /sq.ft., resulted in relatively low removal efficiency when compared with overflow rate of 2 gpm/sq.ft. The explanation might be that the time for each run was so short (2 hrs.) that the sludge concentration beneath the tube was very low and sludge blanket length was small.

At the same overflow rate the tube made from medium galvanized steel tended to give better settling performance than that made from asbestos cement. This might be because of the dead space occupied by the thickness of asbestos cement. It can be seen from Table 2. that at the same overflow rate, the flow rate of tube made from asbestos cement gave the higher value than that obtained from medium galvanized steel. It can also be seen from Fig 30 that, at equal flow rate there was almost no different in removal efficiency obtained from medium galvanized steel and asbestos cement. This might be due to tube entrance area was almost the same.

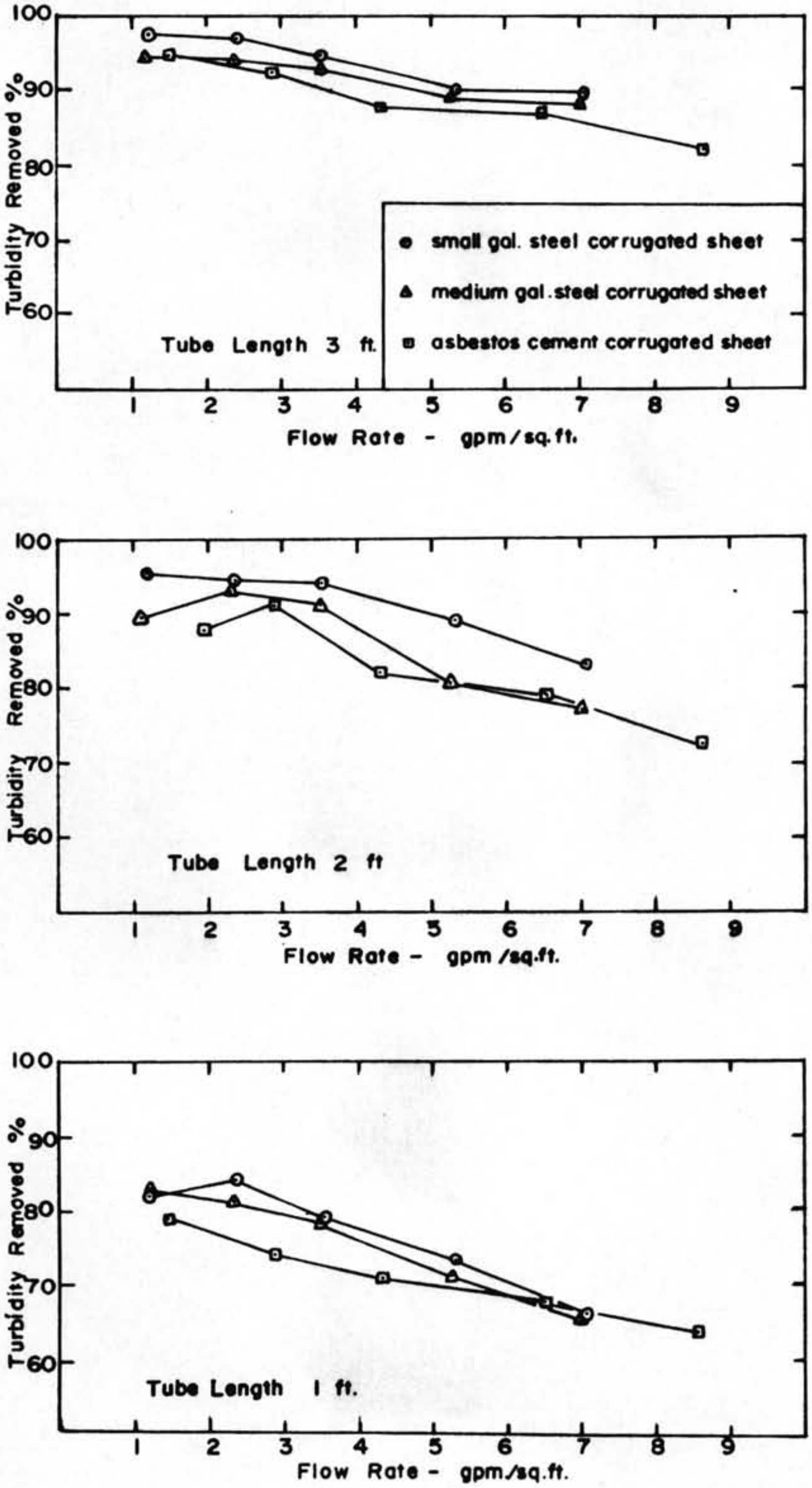
In practical design of conventional settling tanks, the parameter overflow rate expressed as flow rate per unit area is normally used. The design overflow rate of a settling tank is actually the settling velocity of the suspended particles completely removed, theoretically at least, in the settling tank. YAO (1970) stated that this parameter overflow rate was exactly the same as the critical velocity, Vsc, used in the derivation of the general equation (Equation 6). By rearranging Eq 6 and inserting a unit adjustment, C, ageneral design equation for highrate settler in term of overflow rate could be obtained as follow.

$$\text{Overflow rate } (V_{sc}) \quad = \quad CSc \frac{V_0}{\sin\theta + L\cos\theta} \quad \ldots\ldots\ldots (12)$$

The magnitude of C depended on the units used for the various terms of

Table II Equivalent of Flow Rate to Overflow Rate

Overflow rate gpm./sq.ft.	Tube size	Flow Rate fpm.	Flow Rate gpm/sq.ft.
6	small galvanized	0.947	7.05
4.5	steel	0.710	5.30
3	corrugated sheet	0.474	3.53
2		0.316	2.35
1		0.158	1.18
6	medium galvanized	0.934	7.6
4.5	steel	0.700	5.25
3	corrugated sheet	0.469	3.5
2		0.312	2.30
1		0.156	1.17
6	Asbestos cement	1.16	8.65
4.5	corrugated sheet.	0.87	6.50
3		0.58	4.38
2		0.39	2.83
1		0.19	1.44



Test Conditions

Average Raw Turb.	60 JTU
Alum Dosage	50 mg/l
Flocculation Time	20 min.

Fig 30 Effect of Flow Rate on Settling Performance at various Tube Length

Eq.12. In British units with V_0 in foot per minute and overflow rate in U.S. gallon per day per square foot, $C = 1.08 \times 10^4$. In the metric system with V_0 in centimeter per minute and overflow rate in cubic meter per day per squaremeter, $C = 14.4$

In this study, overflow rate (V_{sc}) was computed from Eq.12 by assuming $Sc = 1.35$ (an average value of circular and square settlers). The value of L ranged from 45.7 to 6.1, θ was kept constant at 60 deg.. Fig.31 shows the turbidity removal efficiency at various overflow rate (V_{sc}). As expected, the removal efficiency decreases with the increase of the overflow rate (V_{sc}). By comparing the results obtained fron this experiment to that obtained from YAO (1973) it could be seen that the relative low turbidity removal efficiency was obtained in this experiment. For example, if a removal efficiency of 80% is acceptable, an overflow rate of 1100 gpm./sq.ft. was obtained from this study but from YAO (1973) an overflow rate of 1500 gpm./sq.ft. was obtained. As could be seen from Fig.31 that a high rate settling system using corrugated sheet is capable of handling overloading without sacrificing too much in turbidity removal efficiency.

Suggested Tube Settler Formular and Design Criteria.

Formalized Design Criteria using V^2R/L value

HERNANDEZ and WRIGHT (1970) reported that various combination of variables and curve-fitting devices were tried in efforts to develop generalized design criteria. The best graphical fit was obtained when settler-effluent turbidity, or turbidity removed, was plotted on semi-log paper against the ratio V^2R/L where

R = hydraulic radius of the tube in ft.

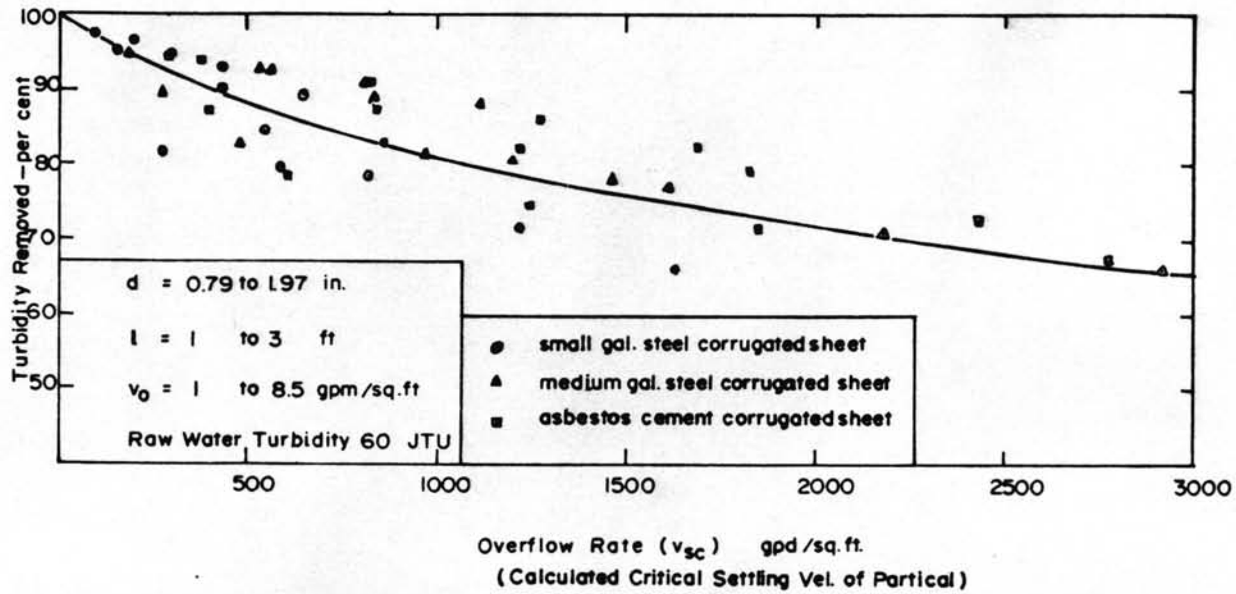


Fig 31 Experimental Efficiency Curve of Tube Settlers using Corrugated sheets

V = velocity of flow in fps.

L = length of the tube in ft.

Fig.32 and 34 are the semilog plot of this factor versus percent turbidity removed, with the plot showing the data points (see Table A-1) for various flow rates, with a water with an average intial turbidity of 60 JTU being settled in a 60 deg tube nest with tubes of various sizes and lengths. The curves were drawn by mean of curve fitting using least square method (statistical analysis of test data was shown in Appendix A) and the following formula were callulated.

a) $E = -9.88 \log (V^2R/L) + 98.675$ for tube length of 3 ft.

b) $E = -17.76 \log (V^2R/L) + 103.90$ for tube length of 2 ft.

c) $E = -13.587 \log (V^2R/L) + 96.25$ for tube length of 1 ft.

where E = percent turbidity removal

Analysis from Fig.32 show that for tube length of 3 ft. decrease in removal efficiency due to increase in V^2R/L value is almost the same for various kind of meterial used. Similar results can be obtained from tube length of 2 ft. but for tube length of 2 ft. (see Fig. 33) increase in V^2R/L value show rapid decrease in removal efficiency. From the experiment for tube length of 3 ft., the change in V^2R/L value from 0.30×10^{-7} to 31.5×10^{-7} caused the change in removal efficiency from 97.4 to 82.3 percent. For tube length of 2 ft., the change in V^2R/L value from 0.45×10^{-7} to 31.85×10^{-7} caused the change in removal efficiency from 95.3 to 37.2 percent.

For tube length of 1 ft. statistical analysis show the standard error of 2.765, which is the double value obtained from the tube length of 3 ft. Fig.34 shows almost no relation of V^2R/L value and removal efficiency.

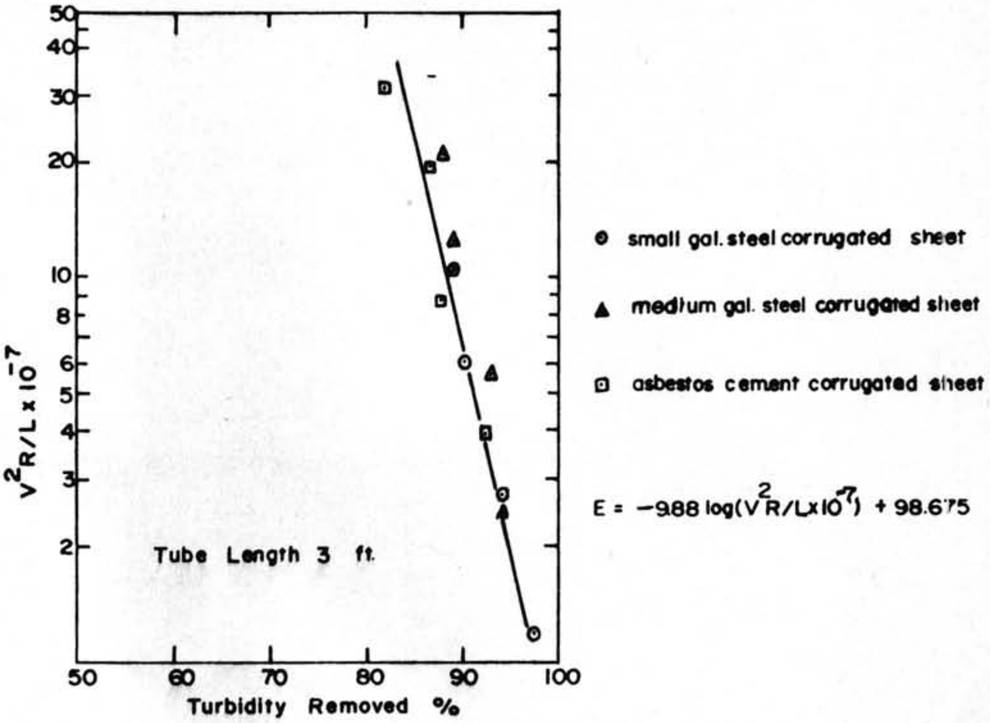


Fig 32 V^2R/L versus Turbidity Removal

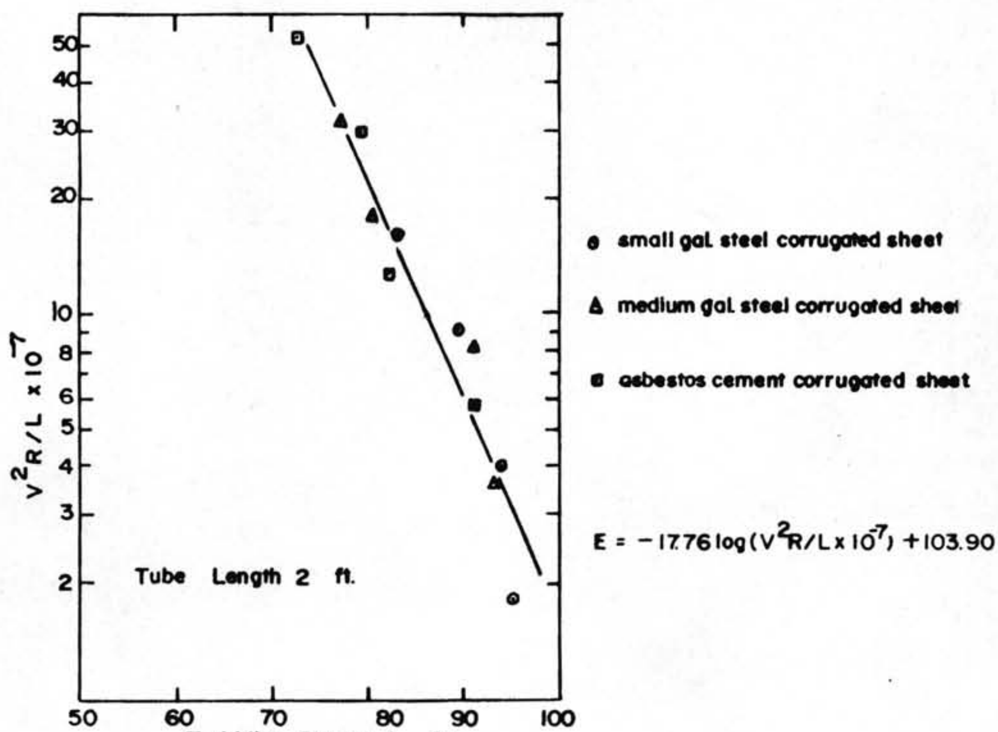


Fig 33 V^2R/L versus Turbidity Removal

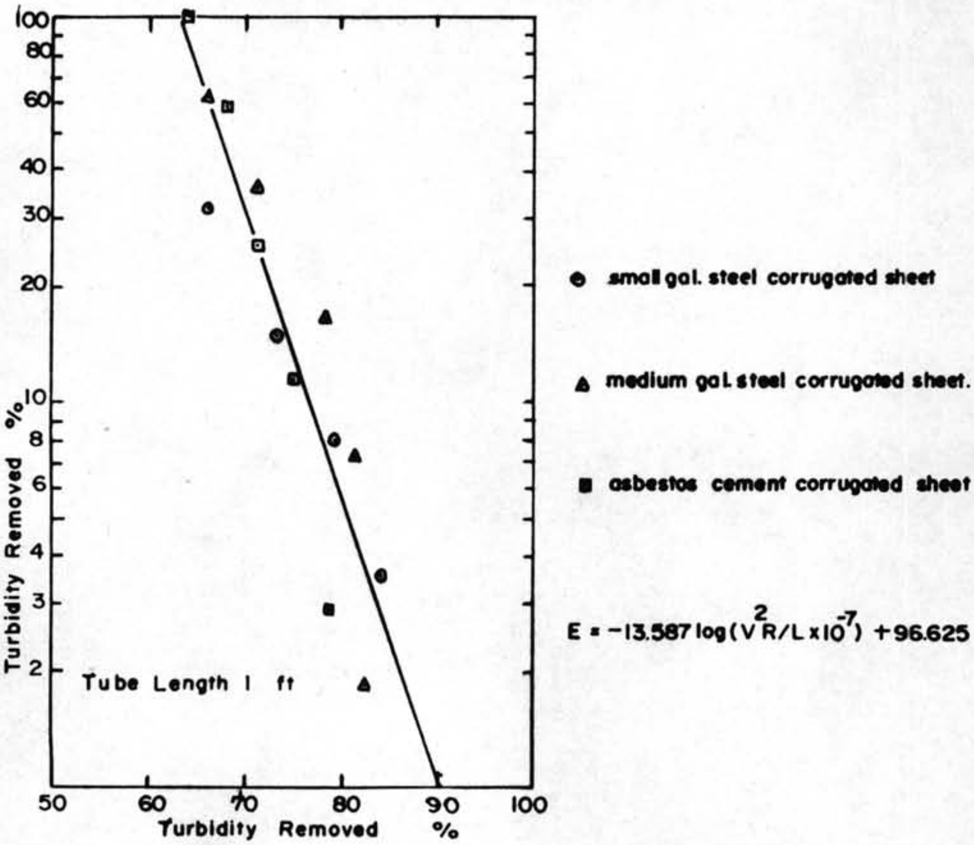


Fig 34 V^2R/L versus Turbidity Removal

This may be because of unstable hydraulic condition within the tube of 1 ft. long.

Recommended Process Design

According to the results of this experiment, the process design showing in Table III and IV are recommended for the design of full scale tube settler utilizing corrugated sheets.

Table III Suggested Overflow Rate in gpm./sq.ft.

(Turbidity removal of 90 percent)

Corrugated sheets	Tube Length (ft.)		
	1	2	3
Small gal. steel	-	4	6
Medium gal. steel	-	3	4.5
Asbestos cement	-	1	2.5

Table IV Suggested Overflow Rate in gpm./sq.ft.

(Turbidity removal of 80 percent)

Corrugated sheets	Tube Length (ft.)		
	1	2	3
Small gal. steel	3	6	6
Medium gal. steel	2	4.5	6
Asbestos	-	3	6