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High-Rate Sedimentation in Water Treatment Works

—Gordon Culp, Sigurd Hansen and Gordon Richardson—

A paper presented on Jun. 4, 1968, at the Annual Conference, Cleveland, by Gordon Culp, Research Mgr., Sigurd Hansen, Research Engr., & Gordon Richardson, Lab. Mgr., all of Neptune MicroFLOC, Inc., Corvallis, Ore.

IT has long been recognized that a settling basin should be as shallow as possible and that detention times of only a few minutes can be used in very shallow basins. For example, a particle settling at a rate of 1 in./min requires 120 min to fall to the bottom of a conventional clarifier of 10 ft depth. If the basin were 2 in. deep, this particle would fall to the bottom in only 2 min. In 1904, Hazen[1] presented his argument that settling basin efficiency is dependent primarily upon basin depth and overflow rate, and is independent of detention time. He proposed basin depths of as little as 1 in. Over 20 years ago, Camp[2] proposed settling basin depths of 6 in. and total settling basin detention times of 10 min.

A detailed literature review by the authors[3] showed that there have been many attempts at applying the shallow depth sedimentation principles proposed by Hazen and Camp. Wide, shallow trays were generally inserted within basins of conventional design. These attempts met with only limited success because of two major problems: (a) the unstable hydraulic conditions encountered with very wide, shallow trays, and (b) the minimum tray spacing was limited by the vertical clearance required for mechanical sludge removal equipment. The authors have overcome both problems by using very small diameter tubes rather than wide, shallow trays. Longitudinal flow through tubes with a diameter of a few inches offers theoretically optimum hydraulic conditions for sedimentation and overcomes the hydraulic problems associated with tray settling basins. Such tubes have a large wetted perimeter relative to the wetted area and thereby provide laminar flow conditions, as evidenced by very low Reynold numbers. Fischerstrom[4] felt a Reynolds number of less than 500 in settling basins would be most beneficial to the settling process. A 1 in. diameter tube, 4 ft long, through which water is passed at a rate of 10 gpm/sq ft of cross-sectional area has a Reynolds number of only 24, while providing an equivalent surface overflow rate of 235 gpd/sq ft. The 3 min detention time of such a tube settling device under these conditions certainly makes the cost and space saving potential apparent. The authors now have tube settling devices in operation in many water treatment plants that are providing excellent clarification with settling detention times of *less than 10 min.* The authors recently made detailed presentations of their research on techniques for applying shallow depth tubes as sedimentation devices.[5] The purpose of this article is to present operating experiences with applications in water treatemnt plants, as well as additional research data.

Basic Tube Configurations

The authors have described [3, 5] two basic tube configurations shown in Fig. 1: (a) essentially horizontal and (b) steeply inclined. The operation of the essentially horizontal tube settlers [3] is coordinated with that of the filter used to clarify the tube settler effluent. Each time the filter backwashes, the tube settler is drained completely. The falling water surface scours the sludge deposits from the tubes and carries them to waste. The water drained from the tubes is replaced with the last portion of the filter backwash water. The tubes are inclined only slightly in the direction of flow (5 deg) to promote the drainage of sludge during the backwash cycle. If the inclination of the tubes is increased sharply (45–60 deg), continuous gravity drainage of the settleable material from the tubes can be achieved.[5] The incoming solids settle to the tube bottom and then exit

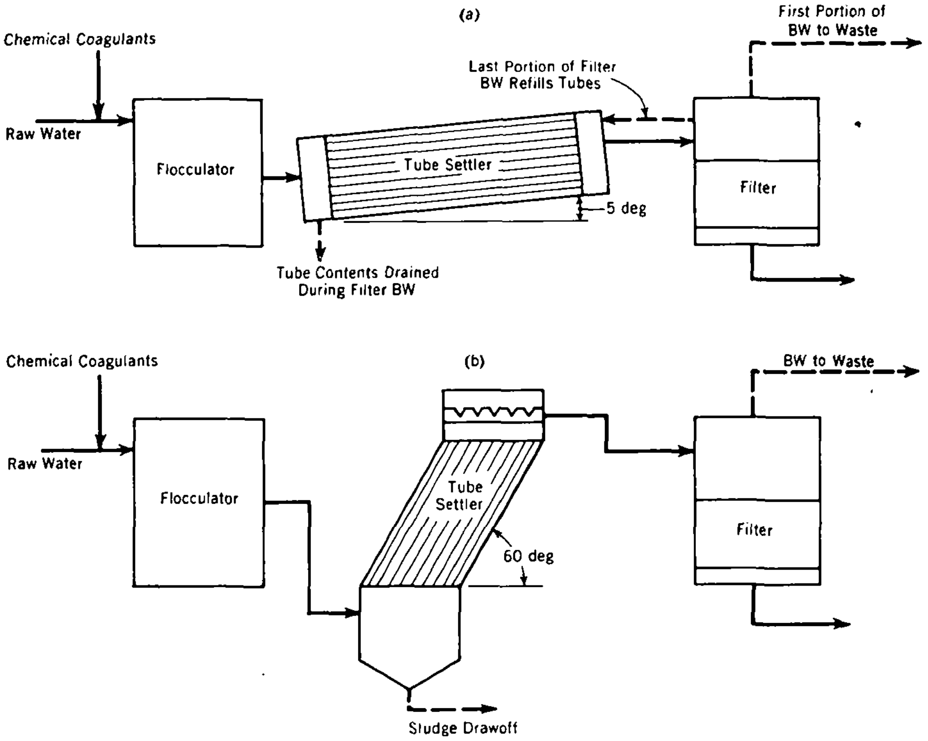

Fig. 1. Basic Tube Settler Configurations

(A) is essentially horizontal tube settler; (B) is steeply inclined tube settler.

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New Mexico	Rec
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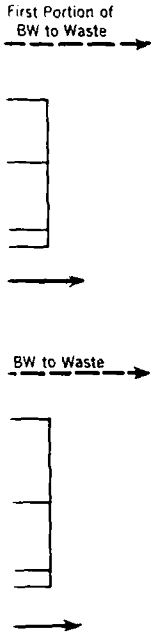

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from the tubes by sliding downward along the tube bottom. A flow pattern is established in which the solids settling to the tube bottom are trapped in a downward flowing stream of concentrated solids. This countercurrent flow of solids aids in agglomerating particles into larger, heavier particles that settle against the velocity of the upwardly flowing liquid. The continuous sludge removal achieved in these steeply inclined tubes eliminates the need for drainage or backflushing of the tubes for sludge removal.

Horizontal Tube Settler

The essentially horizontal tube settler has been used primarily in small (15,000 gpd) to medium sized (10 mgd) water treatment plants, where the elimination of operator attention for sludge removal from the clarifier is a significant benefit. By draining the tubes each time the filter backwashes, positive sludge withdrawal from the clarifier is achieved. The entire backwash—tube drainage cycle is automated. Thus, no operator judgment on when or how much sludge to withdraw from the clarifier is required. A schematic or package water treatment in which tube settling has been used is shown in Fig. 2. The detention time within the tubes, at design flow, is 6 min. The impact of this low residence time on the plant dimensions is well illustrated by the 6 ft high by 6 ft wide by 14 ft length dimensions for a complete 100 gpm water treatment plant providing flocculation, sedimentation and filtration in one rectangular, prefabricated, steel plant. As shown in Fig. 2, the coagulated raw water may first be passed upwards through a fluidized calcite column that automatically maintains the pH in the proper

TABLE 1

Partial List of Installations of Water Treatment Plants Using Horizontal Tube Settlers and Mixed-Media Filtration

Location	Facility Served	Plant Capacity *gpm*	Treatment Problem
Alabama	Paper mill	100	10–100 JTU turbidity
Ohio	Subdivision	20	10–65 JTU turbidity
Alabama	Nuclear reactor	100	2–28 JTU turbidity
Tennessee	Recreational area	20	2–30 JTU turbidity
Oregon	Recreational area	20	30–150 JTU turbidity, 20 color
Venezuela	School	20	10–40 JTU turbidity
Manitoba	Municipality	60	10–35 JTU turbidity
Pennsylvania	Power station	100	5–15 JTU turbidity, pH 3.5, iron 2.8 mg/l, manganese 1.0 mg/l
Wyoming	Oil field reuse	200	Oil and suspended solids
Mississippi	Municipality	2,000	3–5 mg/l iron
Massachusetts	Municipality-pilot	20	200 color
New Mexico	Recreational area	20	10-20 JTU turbidity
West Virginia	Municipality	350	10 JTU turbidity
British Columbia	Municipality	350	4.5 mg/l iron, 160 color
Pennsylvania	Power Station	100	25 JTU turbidity, 1 mg/l iron, 20 color
Idaho	Municipality	100	10–1000 JTU turbidity, 20 color
Oregon	Municipality	500	5–10 JTU turbidity, 20 color, algae

range for good coagulation. If alum is overfed, the calcite will automatically buffer the coagulated water. The use of calcite for this purpose eliminates one possible cause (overdosage of coagulant) of poor finished water turbidity.

The tubes used in these essentially horizontal tube settlers are hexagonal in shape. The hexagonal tubes nest together to form a honeycomb pattern (Fig. 3). The tremendous wetted perimeter of such a tube configuration relative to its wetted area provides extremely low Reynolds numbers, well within the laminar flow range.

Tube diameters of 1–2 in. and lengths of 2–4 ft are used in most water treatment applications. Hydraulic loading rates of 3–5 gpm/sq ft of tube entrance area are generally used. Data have been presented[8] showing that the tube settler, mixed-media filter combination in a plant with total detention time of less than 30 min provides efficient clarification of very turbid waters (1,000 JU), highly colored waters, waters containing filter-clogging algae, waters containing iron and manganese, and raw waters with taste and odor. After these data were published, confirming operating data from several plants with capacities of 30,000 gpd to 3 mgd have been obtained from field installations. The partial list of these plants shown in Table 1 illustrates the wide range of water quality being subjected to treatment in plants employing the basic flow pattern shown in Fig. 2. The majority of these plants are being used for potable supplies and are operating at total plant detention times of about 30 min. Although this detention time is much less than that in plants employing conventional sedimentation techniques, data collected in prototype studies indicate the plants are actually rated conservatively. To illustrate this, Fig. 4 presents data collected during one of these studies with a plant, as shown in Fig. 2. During this test, each of the plant components was operated at rates considerably higher than the design criteria normally used for these plants, that is, tube settler detention of 3 min rather than 6 min, filter rates of 8.5 gpm/sq ft rather than 5 gpm/sq ft, flocculation times of 5.4 min rather than 10 min. The plant operating with an overall detention time

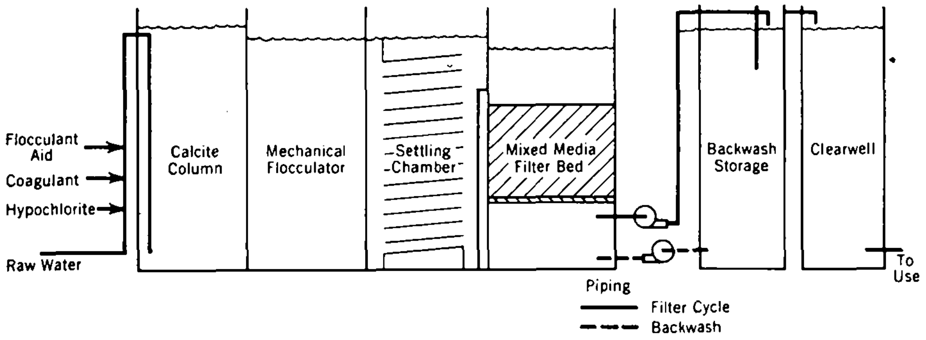

Fig. 2. Package Water Treatment Plant

Tube settling is used and the detention time within the tubes, at design flow, is 6 min.

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Hydraulic Loading, Settling Tubes (*gpm/sq ft of end area*)	Polyelectrol Dose —*mg*
3.7	0
3.7	0.1
4.0	0.2
4.0	0.5
5.0	0.2
5.0	0.2
5.0	0
6.75	0
6.75	0.2
8.5	0
8.5	0.2

* Added ahead of flocculato

of 16 min reduced average raw water turbidity of 1,000 JU to an average of less than 0.1 JU. Although the filter rate of 8.5 gpm/sq ft resulted in a relatively high initial headloss (2.7 ft H_2O), the percentage of backwash water at the end of the 8 hr run was only 2.5 per cent. If the run had been continued to the normal backwash headloss value of 8 ft, the backwash requirement would have been less than 2 per cent. These data well illustrate how the mixed-media filter (coal, sand, garnet) complements the tube settler to accomplish what may certainly be classed as "high rate" clarification.

Flow Distribution

Flow distribution problems are much less severe in the tube settler than in earlier tray settling devices. One of the major reasons is the extremely stable hydraulic condition established within the tubes. As discussed earlier, laminar flow conditions are established in the tubes. Thus, there are no turbulent flow conditions to promote short circuiting. Also, it has been found that the sludge deposits within the tubes act as flow distribution aides. If one tube is receiving more flow than another, the more rapid buildup of sludge in the first tube will cause some flow to be diverted to the second tube. The sludge deposits themselves thus act as a "self-orificing" device in the horizontal tube settlers. Of course, care must be taken in the design of the tube inlet and outlet conditions so that no great velocity gradients are established across either the inlet or outlet faces of the tube modules.

Flow distribution analyses have been made in a 20 gpm plant, utilizing the

TABLE 2

Tube Settler Efficiency in Preliminary Field Tests (Tube Length—2 ft, Tube Diameter = 1.5 In.)

Hydraulic Loading, Settling Tubes (*gpm/sq ft of end area*)	Polyelectrolyte Dose—*mg/l**	Aver. Raw Turbidity *JU*	Aver. Tube Settler Eff. Turbidity *JU*	Change-in Filter Headloss—*in. Water/hr*	Filter Rate *gpm/sq ft*
		Tubes Inclined at 5°			
3.7	0	250	37	1.0	6.3
3.7	0.1	250	17	3.0	6.3
4.0	0.2	250	70	1.75	6.8
4.0	0.5	230	16	0.5	6.8
5.0	0.2	250	21	4.0	8.5
		Tubes Inclined at 60°			
5.0	0.2	260	6	0.8	8.5
5.0	0	290	26	0.8	8.5
6.75	0	270	45	0.85	8.5
6.75	0.2	240	13	2.3	8.5
8.5	0	250	45	2.0	10
8.5	0.2	250	14	1.0	10

* Added ahead of flocculator.

salt tracer technique, as shown in Fig. 2.[6] A batch addition of a solution containing 50 g/l of sodium chloride was dispersed into a stabilized flow of untreated source water in the flocculator.

Conductivity analyses of samples collected at 5 min intervals from the influent and twelve vertical and lateral effluent settler locations showed a variation in peak value of ±10 μmho on triplicate runs. Comparing the variation in conductivity with the corresponding salt as chloride concentration indicated that sufficient linearity existed to allow the data to be evaluated on the basis of conductivity.

Distribution of the inlet flow to the individual tubes can be considered satisfactory based upon the minor variation experienced in peak effluent conductivity and that the individual tube samplings were found to have retention times 4 per cent less than the theoretic sampling retention period.

Analyses of the tube effluent composite sample with time indicated a minimum of short circuiting existed in that the volumetric displacement efficiency was found to be 84 per cent as compared with that of 63 per cent listed[6] for ideal basins.

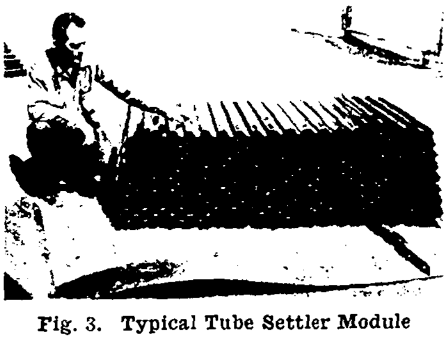

Fig. 3. Typical Tube Settler Module

This is for use in plants similar to the one shown in Fig. 2.

TABLE 3

Performance of Pilot Plant with Steeply Inclined Tube Modules

Flow Rate *gpm/sq ft*	Floc Time *min*	Polyelectrolyte Dosage *mg/l*	Average Raw Turbidity *JU*	Average Settled Turbidity *JU*
4	7	0	50	18
4	7*	0	92	20
4	7*	0.1	50	20
4	7*	0.2	54	13
6	4.5	0.1	53	27
6	4.5	0.2	52	21
6	4.5	0.2	231	27
6	4.5*	0.2	246	54
6	4.5*	0	49	35
6	4.5	0	255	51

* Flocculator drive motor not operated.

Steeply Inclined Tube Settlers

The solids that settle to the bottom of a tube inclined at a steep angle (greater than 45°) will slide down the tube bottom continuously. This enables sludge removal to be achieved without draining or backflushing the tubes.

Although the benefits of this continual sludge removal phenomenon are obvious, the effects of steeply inclining the tubes on the path of the particles as they settle requires more detailed consideration. The path traced by a particle settling in a tube is the resultant of two vectors: V, the velocity of flow through the tube and v_s, the settling velocity of the particle. It can be seen in Fig. 5 that if the settling surfaces are inclined upward in the direction of flow, the settling path of the particle is altered because the component of the settling velocity that is parellel to the tube wall, v_{sh}, is opposite in direction to the velocity vec-

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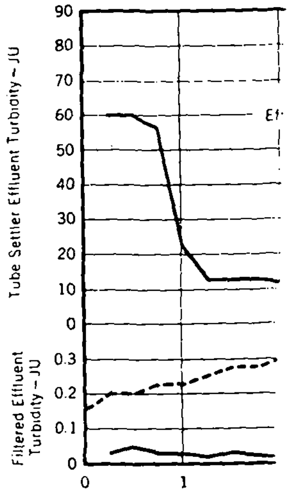

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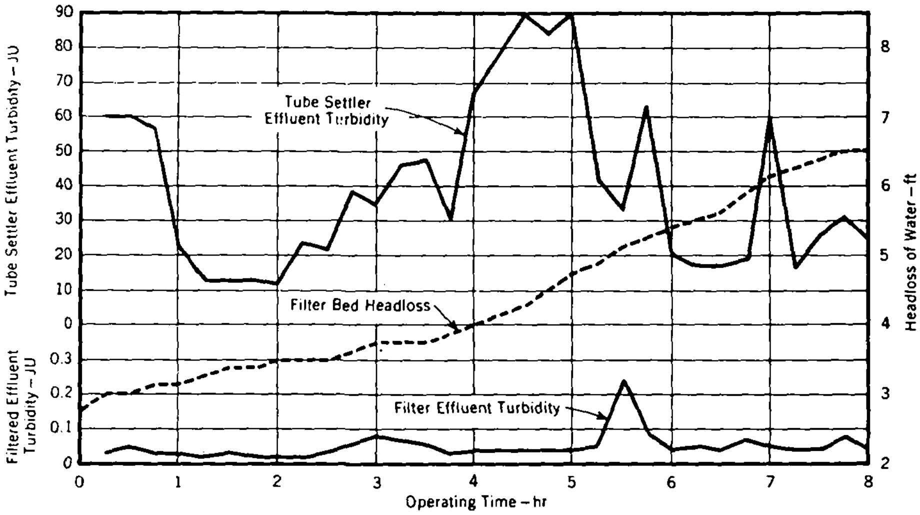

Fig. 4. Operational Data From Package Water Treatment Plant

The plant operating with an overall detention time of 16 min reduced average raw water turbidity of 1,000 JU to an average of less than 0.1 JU. The filter was operating at 8.5 gpm/sq ft and the time settler at 5 gpm/sq ft.

tor V. If V is greater than v_s, the required length of the settling surface decreases as the angle increases from zero up to about 25–30 deg (at $V = 2.5\ v_s$) and then increases, approaching infinity as the angle of inclination is increased to 90 deg. For $V < v_s$ the tray length continues to decrease with increasing angle.

The research data on performance of steeply inclined tube settlers in waste water treatment applications have been published.[5] The following sections of this article present research and field data on water treatment applications.

Laboratory Studies

During a continuation of the research studies published earlier,[3] an apparatus was designed to study the effects of tube inclination on settling efficiency (Fig. 6). It was during the operation of this equipment that the "self-cleaning" phenomenon was first observed. Initial tests were carried out with five individual tubes inclined at angles of 0, 5, 20, 45, and 90 deg. The sludge settling to the bottom of the tube inclined at 45 deg was observed to be moving continuously downward and eventually falling into the inlet plenum.

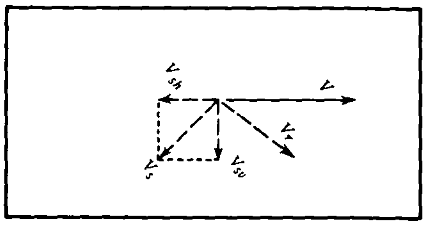

Fig. 5. Effect of Tube Inclination on Settling Path of Discrete Particle

Some of the data collected on tube settling efficiency at the various angles of inclination are summarized in Fig. 7. It was noted that tube efficiency showed an increase as the angle of inclination was increased to 35–45 deg and then began to decrease as the angle of inclination was increased further. Results comparable to those obtained at 5° inclination, however, were

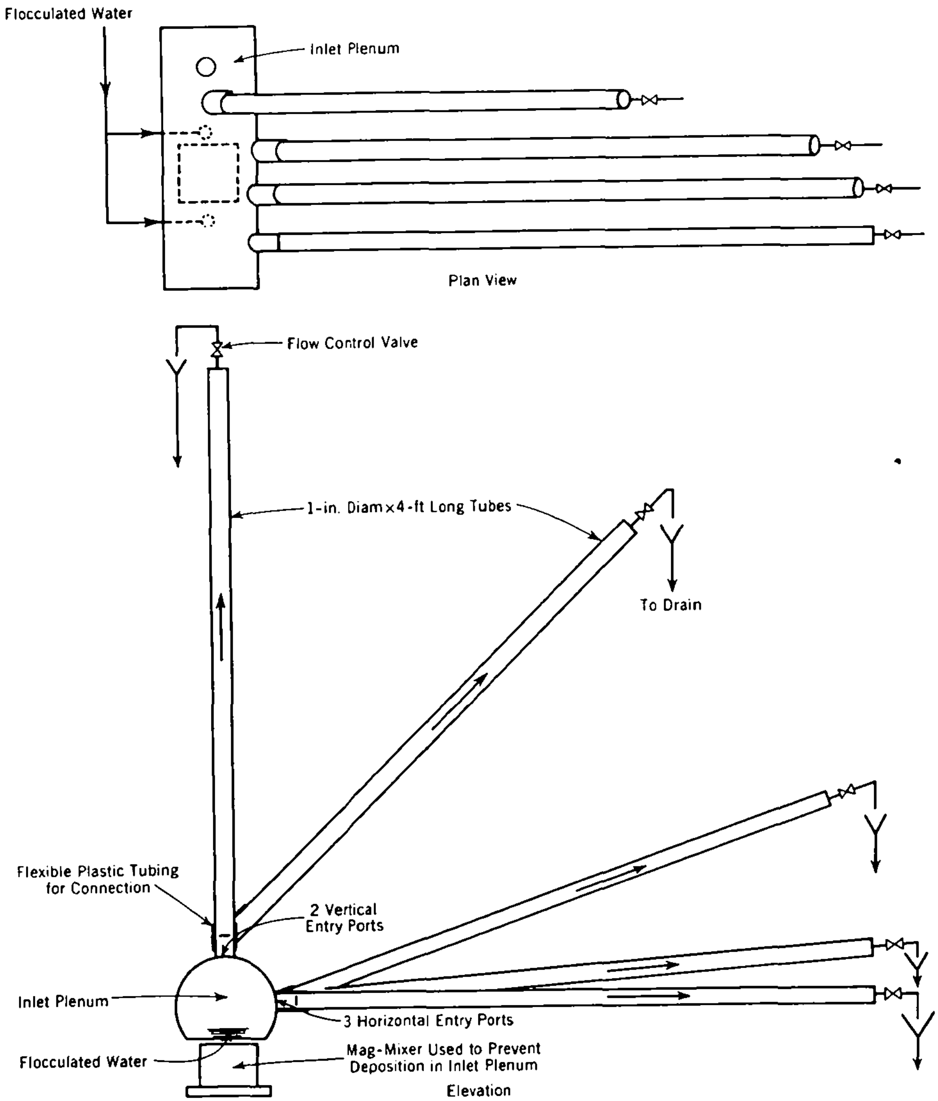

Fig. 6. Diagram of Test Apparatus Used in Evaluating Effects of Tube Inclination

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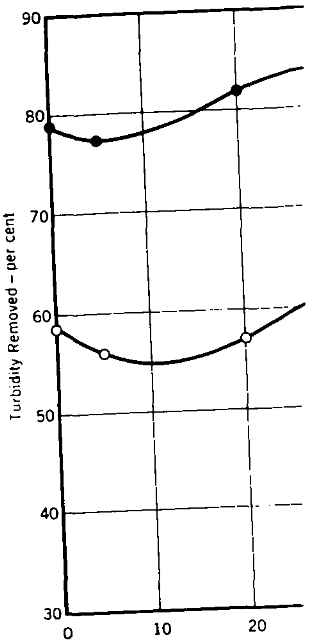

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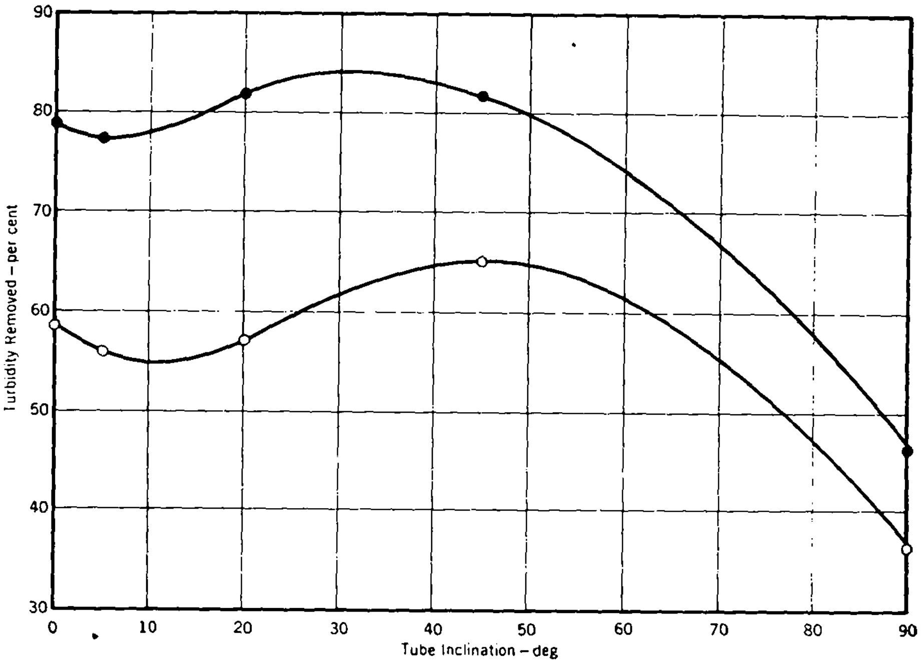

Fig. 7. Effect of Tube Inclination on Settling Performance

The tubes used were 1 in. in diameter and 4 ft long.

achieved at angles as steep as 60 deg. It appeared that, as the angle of inclination was increased to the point where the settled sludge began to move down the tube bottom, additional flocculation occurred as the heavier floc settled and collided with the smaller, upward moving floc, contributing to the increased efficiency over that achieved at 5 deg. A continuing increase in angle eventually results in the tube acting as an upflow clarifier, however, and the advantages of the shallow tube depth are lost, resulting in a decrease in efficiency.

Following observation of this self-cleaning principle, the apparatus shown in Fig. 6 was modified to better define the effects of various inclinations on sludge cleaning and on sedimentation

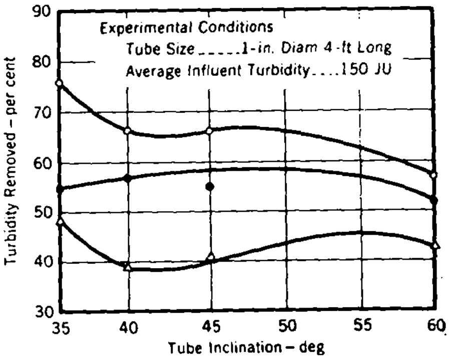

Fig. 8. Effect of Tube Inclination on Settler Performance

efficiency. The tubes were repositioned at angles of 35, 40, 45, and 60 deg. A slight decrease in efficiency (Fig. 8) was noted as the angle of inclination approached 60 deg. The self-cleaning action, however, was enhanced as the angle was increased from 45–60 deg. To insure adequate sludge removal from the tubes, an angle of inclination of 60 deg was used in the subsequent tests of multi-tube units.

the tests with 2 ft tubes inclined at 5 deg. The tubes were installed so that the inlet and outlet conditions and the total tube entrance area were the same for both the 5 and 60 deg tubes. The same mixed-media (coal, sand, garnet) filter was used to filter the tube effluent in both cases. The surface water being treated was coagulated with alum and, as noted in Table 2, polyelectrolyte was added in some cases. The data shown in Table 2 show that the water quality produced by the 60 deg tubes at 8.5 gpm/sq ft was lower in turbidity than that produced by the 5 deg tubes at 5 gpm/sq ft, with 0.2 mg/l polyelectrolyte used in both cases. The tube effluent quality was compatible with the mixed-media filter in all cases and filter runs to 8 ft of headloss were greater than 18 hr, in all cases. Data collected during one run of the 60 deg tubes is shown in Fig. 10. The effect of poly-

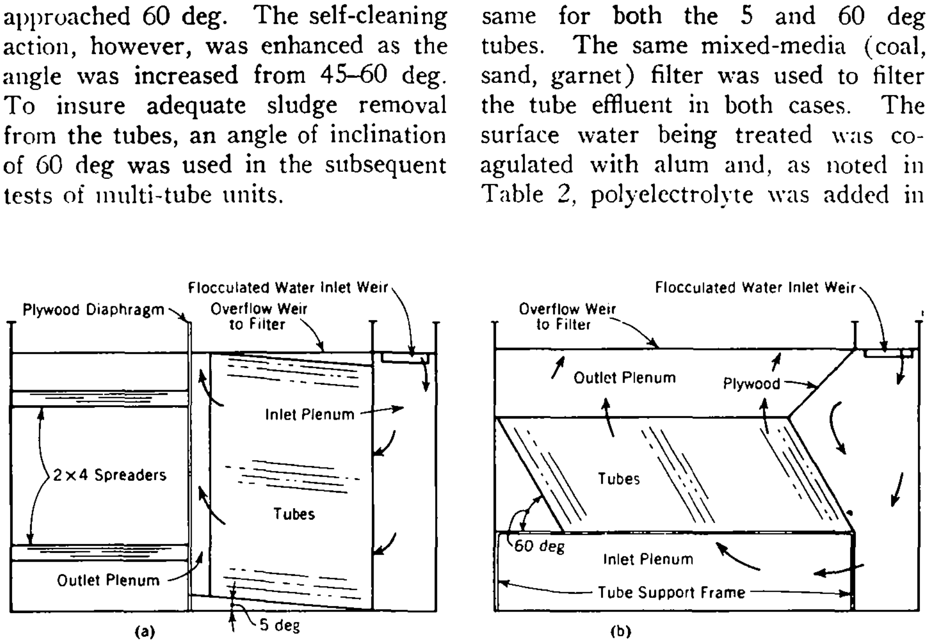

Fig. 9. Apparatus Used in Preliminary Field Evaluation of Steeply Inclined Tube Settler

(a) is section view of plant with tubes installed in unit at 5 deg; (b) is section view of plant with tubes inclined at 60 deg.

Field Evaluation—Pilot Plant Scale

A plant of the type shown in Fig. 2 was modified for the first field evaluations of the steeply inclined tubes. As shown in Fig. 9, the plant was evaluated with the tubes at a 5 deg inclination and at a 60 deg inclination. The tubes used were 2 ft in length and 1½ in. in diameter. Because the tube chamber was originally designed for 4 ft long tubes inclined at 5 deg, a portion of it was blocked off by the plywood diaphragm shown in Fig. 9 for

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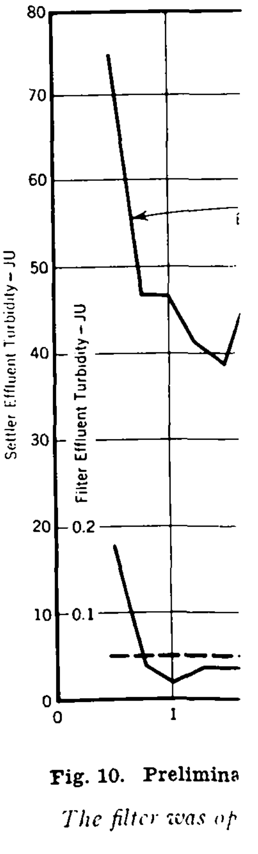

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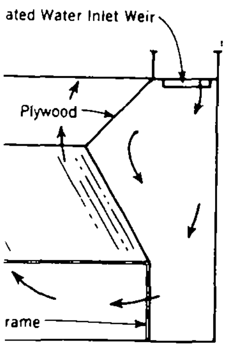

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Modular Tube Units

Because of the very encouraging results obtained in the preliminary field tests, work was begun on the design of a modular unit of steeply inclined tubes that would minimize installation problems. Following preliminary evaluation of a great many potential designs, this development work resulted in the tube module design shown in Fig. 11 (patent pending) in which the material of construction is normally PVC. Extruded PVC channels are installed at a 60 deg inclination between thin sheets of PVC. By inclining the tube passageways, rather than inclining the entire module, the rectangular module can be readily mounted in either rectangular or circular basins. By alternating the direction of inclina-

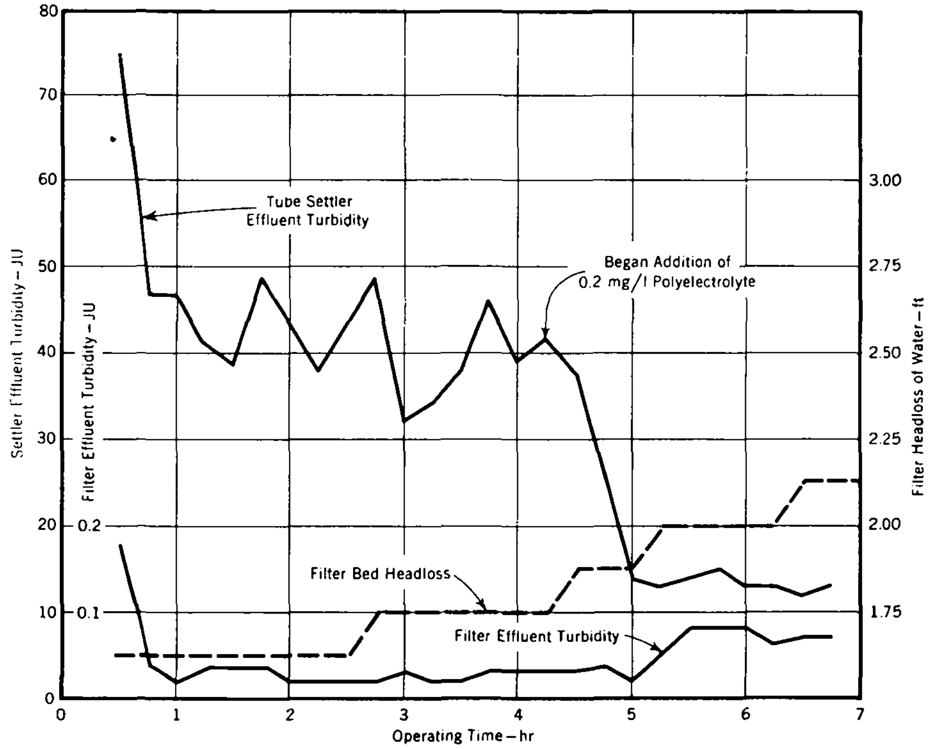


Fig. 10. Preliminary Field Test Data From Run of Steeply Inclined 60 deg Tubes

The filter was operating at 8.5 gpm/sq ft and the tube settler at 6.5 gpm/sq ft.

tion of each row of the channels forming the tube passageways, the module becomes a self-supporting beam which needs support only at its ends. Following the development of this module, field tests of its efficiency as a sedimentation device were begun. A tube cross-section of 2 × 2 in. and a tube length of 24 in. was used in the following tests.

The apparatus (Fig. 12) was set up at the authors' laboratory. The laboratory ground water supply was used. A mud slurry was mixed with the incoming water to provide various levels of raw water turbidity. Alum (40 mg/l) was added as the primary coagulant with the polyelectrolyte additions made in some tests. Tube loading of 4–6 gpm/sq ft were investigated (tube entrance area = 9 sq ft) with raw water turbidities of 50 and 250 JU. The data from these tests are summarized in Table 3. In some runs, as noted, the flocculator drive motor was turned off to evaluate the tube efficiency without prior mechanical flocculation.

At the lower rate of 4 gpm/sq ft, the addition of polyelectrolyte did not markedly improve the effluent clarity. When the flow rate was increased to 6 gpm/sq ft, however, the higher settling velocities imparted by the polyelectro-

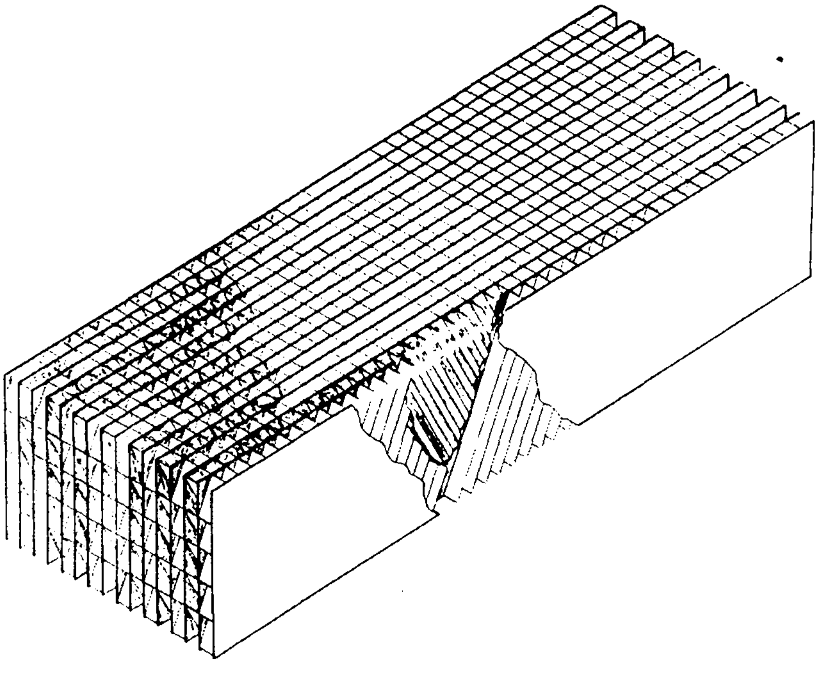
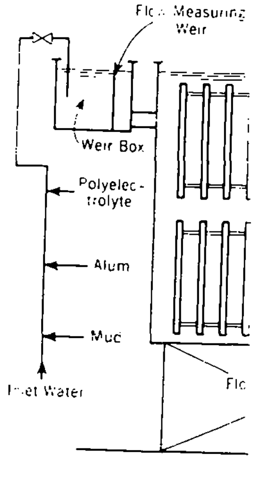


Fig. 11. Module of Steeply Inclined Tubes



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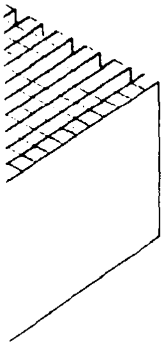

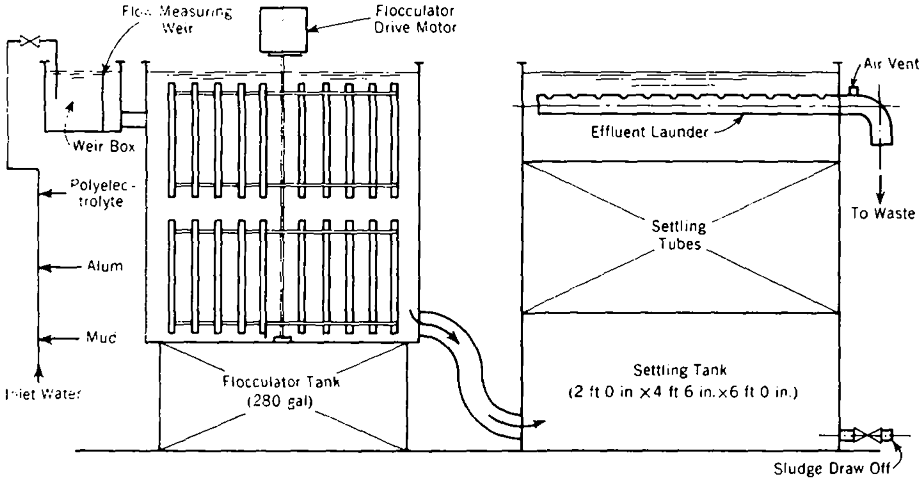

Fig. 12. Diagram of Flocculator and Settling Tank

This is used in evaluating tube module designs.

lyte were of significant benefit. When the flocculator was operated, the turbidities were fairly constant throughout the run. When the flocculator motor was not operated, however, it was found that the effluent turbidity decreased with time as the solids concentration beneath the tubes increased. This is not surprising as solids contact in and beneath the tubes was the prime source of flocculation in this case. Although it was found that the sludge blanket could be established with the steeply inclined tube settler without subjecting the incoming water to mechanical flocculation, flocculation hastened the development of the blanket. After the sludge blanket was well established, the flocculator could be turned off with no noticeable effect on the clarified effluent quality. This observation suggests that by maintaining an upflow of newly coagulated water through a region of high solids concentration, the external flocculation requirements can be reduced significantly. This principle, of course, is recognized and capitalized on by solids contact clarifier manufacturers.

These tests indicated the steeply inclined tube modules shown in Fig. 11 performed well as a sedimentation device and were capable of producing

Fig. 13. Newport, Oregon, Water Treatment Plant

settled water turbidities consistent with the capabilities of the mixed-media filter under all the conditions shown in Table 3.

Field Evaluation—Plant Scale

The next logical step in the development of the steeply inclined tube settling process was a plant scale application. Fortunately, the city of Newport, Oregon, and their consulting engineer were faced with a water treatment plant expansion when the tube settling experiments were being completed. The existing 1.5 mgd plant (Fig. 13) consisted of a circular flocculator-clarifier followed by rapid sand filters. The raw water characteristics are as follows: turbidity—10–20 JU; color—50–130 units; pH—7.6; iron—4.7 mg/l; temperature—66°F; alkalinity—85 mg/l; and hardness—17 mg/l. The plant operator normally applies about 35 mg/l alum and several mg/l of activated carbon to the raw water to produce an acceptable finished water quality. Pilot tests were conducted using a plant of the type shown in Fig. 2. It was found that an alum dose of 30 mg/l polyelectrolyte feed of 0.3 mg/l, and 1.5 mg/l chlorine would enable the tube settler-mixed-media filter combination to produce a finished water quality of 0.15 JU turbidity, 5 color units, and 0.1 mg/l iron. The tube settler and mixed-media filter were both operated at 5 gpm/sq ft in these pilot tests.

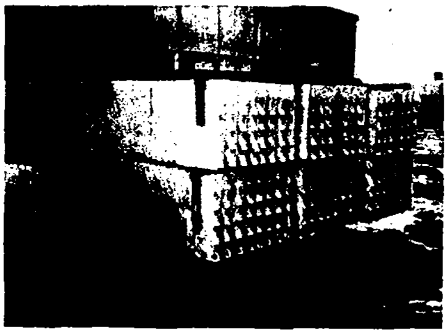

Fig. 14. Tube Modules Used in Newport Clarifier Conversion

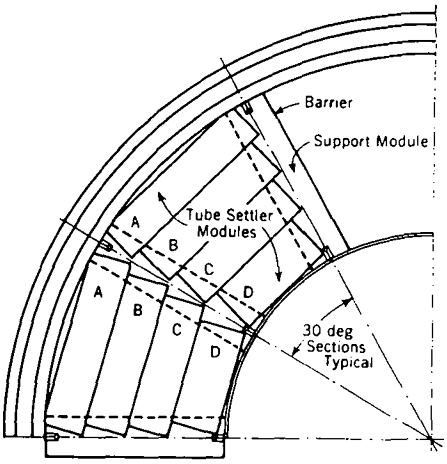

Fig. 15. Plan View of Modified Newport Clarifier

The modules are labeled A-D for purposes of identification.

Based upon the pilot test results, modification of the full scale plant was begun late in 1967 in order to increase the plant capacity from 1.5 to 3.0 mgd by installation of tube modules in the existing clarifier, and by conversion of the rapid sand filters to mixed-media beds. As a first step, tube modules were to be installed in the existing clarifier to evaluate their performance on a plant scale.

Because the available water supply to the clarifier was to be limited by the existing 1.5 mgd raw water pump during the early tests, tubes were installed in only a portion of the basin. Tube

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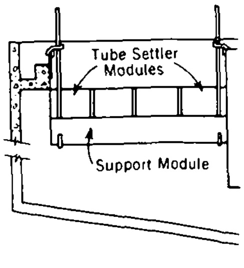

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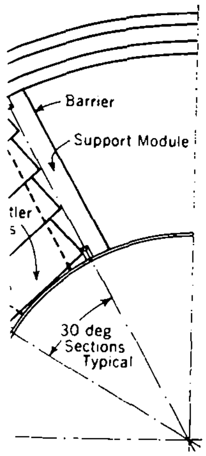

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modules of the type shown in Fig. 11 were used. The tubes were installed over $\frac{1}{6}$ of the clarifier surface, as shown in Fig. 15. Tube modules were also used as support beams for the upper modules, see Fig. 15 and 16, so that none of the clarifier surface was lost due to a support structure. These radial support beams were attached by PVC pipe to support brackets on the inlet well on one end and the effluent weir at the other end. The supporting brackets, pipe, and modules are pictured in Fig. 17 while the installation of a support module is shown in Fig. 18. Once the support beams were in place, the remaining tube settler modules were placed in position. The portion of the basin in which tubes were installed (Fig. 19) was isolated from the remaining part of the clarifier by a plastic barrier attached radially to the clarifier on each side of the tube section. Flow through the tube section was regulated by closing off portions of the effluent weir in the rest of the basin by a galvanized sheet steel plate clamped to the weir plate. Preliminary tests quickly led to closing off this entire weir area and passing the entire plant flow through only the 210 sq ft of the basin covered with tubes. Although the nominal plant flow was 1.5 mgd, flow measurement during the test period indicated the raw water pump was actually delivering only 910 gpm. Thus, the hydraulic loading on the tube area was 4.3 gpm/sq ft.

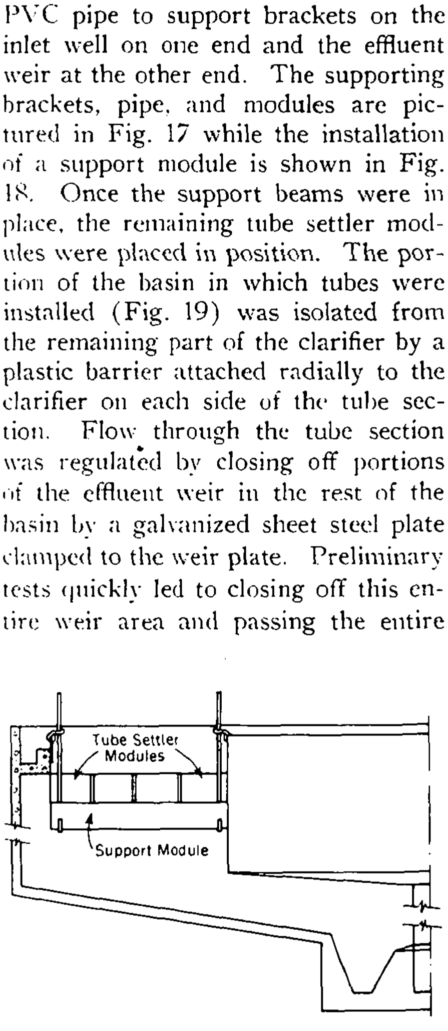

Fig. 16. Section of Modified Newport Clarifier

Fig. 17. Support Module Prior to Installation

Evaluation of Data

Flow distribution analyses and effluent quality determinations were made. Because only the existing peripheral effluent weir was used, less-than-perfect flow distribution was anticipated. Although radial collection weirs would greatly aid in flow distribution, it was desired to first evaluate the performance using only the existing weir.

The rise rate of hydrochloric acid injected into each tube module at several points was used to determine the velocity in each module. For purposes of identification, the modules were labeled A, B, C, and D, as shown in Fig. 15. The resulting flow distribution data are shown in Fig. 20. As was expected, the outer modules nearest the effluent weir were receiving the bulk of the flow and were operating at 6.6 gpm/sq ft as compared to the average of 4.3 gpm/sq ft based upon the entire surface area covered by tubes. Even with this flow distribution, the tubes were performing as efficient sedimentation devices. As shown in Fig. 20, the tube effluent turbidity increased only slightly as the flow rate increased from 2 gpm/sq ft in module D to 6.6 gpm/sq ft in module A. The tube effluent contained no settleable solids while samples collected earlier from the existing clarifier indicated that its effluent frequently contained 0.2–1 ml/l settleable solids and an average turbidity of 5.1 JU. The fact that the tube modules operating at 4.3 gpm/sq ft (average) were producing better effluent than the clarifier previously did operating at 0.7 gpm/sq ft was further confirmed by the fact that the length of filter runs increased from 26 to 60 hr following the modification of the clarifier.

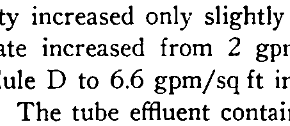

Fig. 18. Support Module Being Installed

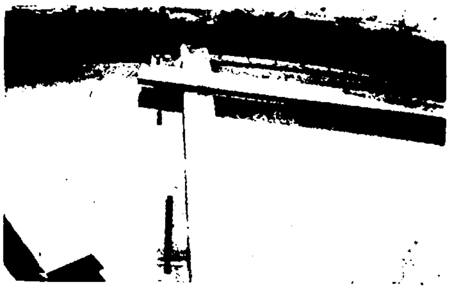

Fig. 19. Tube Modules in Place

At the time of this writing, the final Newport plant conversion is being made. The filter media conversion is underway with the design rate for the mixed-media filter being 5 gpm/sq ft. The final clarifier conversion is being made with a ring of tube modules being installed completely around the periphery of the basin. The tube ring will operate at a rate of 5 gpm/sq ft at 3 mgd. The peripheral location of the modules was selected to take advantage of the existing effluent collection system and the resulting flow distribution. If more of the clarifier surface is eventually covered with tubes to further increase the basin capacity, additional effluent collection weirs to better distribute the flow would be needed to realize the full advantage of the additional tube modules.

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Summary

Shallow tubes are very efficient sedimentation devices. Two basic tube configurations have been used: (a) essentially horizontal and (b) steeply inclined. Sludge is removed from the essentially horizontal tubes by automatically draining them each time the filter backwashes and refilling them with filter backwash water. Over 20 water treatment plants employing these horizontal tubes with sedimentation detention times of less than 10 min with capacities of 20–2,000 gpm are now in operation. In tests described in this paper, a plant providing flocculation, tube sedimentation, and mixed-media filtration, produced potable water (0.1 JU turbidity) from a raw water turbidity of 1,000 JU with an overall plant detention time of 16 min. Flow distribution analyses show the shallow horizontal tubes enable good flow distribution to be readily achieved.

The continuous self-cleaning of sludge from tubes inclined at a steep angle allows sludge removal to be achieved without the need for draining the tubes. Laboratory and field tests show that an angle of 60 deg provides continuous sludge removal while still allowing the tube to function as an efficient sedimentation device. Pilot plant tests have shown these steeply inclined tubes to remove alum floc efficiently at rates as high as 8.5 gpm/sq ft. These tests led to the development of tube modules which were installed in an existing clarifier to increase its capacity from 1.5 mgd to 3.0 mgd. Analyses of the full scale installation showed good clarification at rates of 6.6 gpm/sq ft. The installation of the tube modules in an existing clarifier and the conversion of the filter to a mixed-media bed provides plant expansion with substantial savings in cost and space. The coupling of tube settlers and mixed-media filters allows a reduction in the size and cost of new treatment facilities. This combination provides new design concepts to achieve efficient treatment plant design produce a given quality finished water from a given raw water or waste-water.

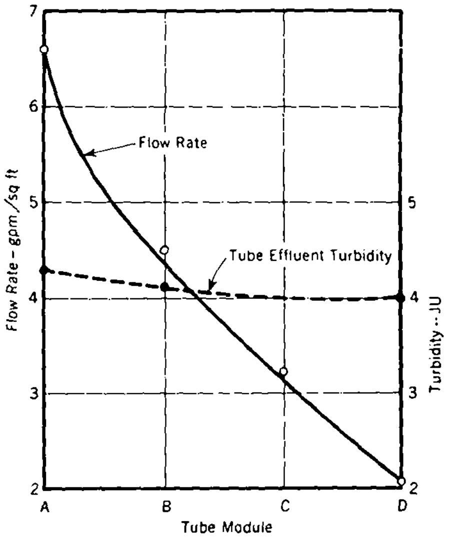

Fig. 20. Flow Distribution and Turbidity Data in Initial Newport Tube Module Installation

Acknowledgments

The steeply inclined tube modules shown in Fig. 11 and the techniques for installing the modules in the Newport clarifier were devised by Curt McCann and Stan Aikins, Design Engineers, Neptune MicroFLOC. The valuable contributions of these two gentlemen are gratefully acknowledged.

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