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Project Summary

Hydraulic Characteristics of Activated Sludge Secondary Clarifiers

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The hydraulic characteristics of several common types of full-scale activated sludge secondary clarifiers were evaluated. Attempts were then made to modify and improve representative examples. The tanks' characteristics were inferred by the use of innovative dye tracer techniques. The effects of modifications were evaluated on the basis of effluent quality.

The dominant hydraulic characteristic of all clarifiers studied was density flow. In most cases, the density flow had a significant effect on effluent suspended solids concentrations. When effluent weirs were placed in the path of density flow, effluent quality was generally poor. Preventing density current formation by inlet modification was not nearly as effective as interrupting flows at mid-radius and near the weirs.

Problems also occurred with balancing flows between parallel clarifiers. The cause was improper application of mixed liquor feed valves, poor splitter box design, and inadequate flow measurement. In addition, strong evidence exists that flow transients are not attenuated by upstream unit processes and may significantly affect the solids transport through clarifiers.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Theories of clarification and secondary clarifier design standards for wastewater treatment facilities assume that inlet and outlet structures create certain patterns of flow or hydraulic characteristics within the clarifier. The major purpose of this project was to determine whether these hydraulic characteristics were actually created within several types of full-scale, activated sludge secondary clarifiers. If the anticipated hydraulic characteristics were not found, the clarifier inlets and/or outlets were to be modified, and the changes in hydraulic characteristics and improvements in effluent quality were to be measured.

The dye dispersion test has been used in the past to measure the hydraulic characteristics of clarifiers. This test may indicate whether a clarifier *has* hydraulic problems, but is useless for identifying their causes. Another purpose of this project was to evaluate a new dye tracer technique that allows visualization of the flow within full-size clarifiers.

These goals seemed straightforward at the beginning of the project, but they had to be modified after simple relationships between inlet and outlet structures, hydraulic characteristics, and effluent performance were not found. The project then evolved into a more comprehensive evaluation of the factors believed to affect clarifier performance at eight different activated sludge secondary treatment facilities.

Types of Clarifiers Studied

Activated sludge wastewater treatment facilities use many different types of secondary clarifiers. This study did not attempt to identify all types or to document their hydraulic behavior. Of the eight clarifiers studied, five different modifications were made on three tanks in an attempt to increase solids capture. It was judged that some clarifiers included in the study could not benefit from the kinds of changes that were within the budgetary scope of this project. Table 1 lists the general types of clarifiers that were studied to some degree.

Clarifier Analytical Procedures

The dispersion of dye in a clarifier following the instantaneous release of a slug has been the most common test used by clarifier analysis in the past. This study needed to show the movement of fluid from the clarifier inlet to the outlet and the distribution of solids that results from fluid motion. Since dispersion tests alone could not accomplish this goal, other test procedures were developed. Several of these tests had not previously been used in clarifier analysis.

Multi-point Dispersion Test

The multi-point dispersion test is a variation of the usual point-of-discharge dispersion test. A slug of dye is released instantaneously upstream of the clarifier, as before, but the multi-point version measures dye concentration versus time at several weir locations. The new test was intended to reveal whether tank throughflow assumed some preferred directions or pathways.

Flow Pattern/Solids Distribution Test

The flow pattern/solids distribution test has two final results:

1) A visualization of the tank throughflow route
2) A measurement of the distribution of solids resulting from throughflow

The test is conducted by continuously releasing dye upstream of the test clarifier, then "instantaneously" sampling 25 or more places in a radial or longitudinal section of the tank several times after the start of dye injection. After the samples have been analyzed for dye and suspended solids, data are contoured oı plotted as isolines of concentration of the two parameters.

Flow patterns and the resulting solids distributions were both found to be useful tools in deciding on hydraulic modifications for the clarifiers.

Weir-Wall Solids Test

The weir-wall solids test measures the suspended solids concentration versus time near the effluent walls. Originally intended to confirm a suspected wave of solids being moved around circular tanks by the rotating mechanisms, this test was helpful in identifying time-varying effects from other causes.

Sludge Dispersion/Sludge Jet Test

The sludge dispersion and sludge jet tests use a dye that readily adsorbs onto the solids floc particles, but is insoluble in water. The route and timing of solids throughflow are thereby traced.

The sludge dispersion test consists of an instantaneous release of an emulsion of mixed liquor and Oil Red "O" dye and subsequent sampling in the sludge return to define the residence time of the sludge in various parts of the tank.

The sludge jet test allows a visualization of the sludge flow route as it seeks the blanket. This procedure was conducted only once during the study. An instantaneous emulsion of Oil Red "O" and mixed liquor was released upstream of the clarifier. After a time defined by the sludge dispersion test, 30 samples were taken instantaneously at mid-radius of the circular tank in a plane parallel to the tank periphery near the sludge blanket. Lines of equal concentration of dye and suspended solids were then plotted. The two sludge tracer tests helped to confirm the existence of inlet jets that had been only minimally dispersed by inlet baffling.

Typical Hydraulic Characteristics of the Clarifiers and Modifications Implemented

The hydraulic characteristics of the clarifiers in this study were inferred from the results of all tests conducted. First the clarifier's baseline hydraulic behavior was measured at one or more flow rates. These data were used to determine whether modifications could be made within the budget of the project. In the three plants to which clarifier modifications were made, subsequent hydraulic tests were followed by long-term evaluation of the effluent quality of the modified unit compared with that of an unmodified parallel clarifier receiving the same flow and mixed liquor.

Rectangular Clarifiers

This study evaluated two different rectangular secondary clarifiers. One is a relatively small, shallow unit, and the other is longer and deeper. Characteristics were very different in the two units.

The small rectangular clarifier was part of a 4540 m^3/day (1.2 mgd) activated sludge facility. The plant had two secondary clarifiers 19.3 m (65 ft) long and 4.9 m (16 ft) wide with a 2.7 m (9 ft) sidewater depth. Mixed liquor flowed from the aeration basins to an open channel at the head of the clarifiers where it splits to the two tanks. Mixed liquor then enters each secondary clarifier through four square inlet ports at the surface. A chain and flight sludge scraper mechanism transports settled sludge to a sump at the inlet end of each clarifier.

Figure 1 shows a flow pattern that was measured in this clarifier before any modifications. Flow moves downward from the inlet to the sludge sump, then proceeds in a horizontal layer along the top of a sludge blanket. At the weir end of the tank, throughflow turns upward. This flow pattern entrained flow particles and carried excessive concentrations to the weirs.

The clarifier was modified with a reaction baffle and several other flow-modifying structures at the inlets. Figure 2 shows the final version of the baffle. Figure 3 shows that the flow pattern in the clarifier following all inlet modifications resulted in very little improvement in flow pattern. Sludge sump scouring was reduced, however. This change alone resulted in a 13.8% reduction in effluent total suspended solids (TSS).

At this plant, very large flow transients were induced at the point of secondary clarifier discharge by raw sewage lift stations in the city. As a second modification, a stop-gate was placed in a channel upstream of the aeration basins to reduce transient amplitude. This modification was tested on a 1-week-on, 1-week-off basis because it affected the performance of both clarifiers. As a result, the effluent quality of the newly baffled clarifier with the stop-gate in place was 31.5 % lower in effluent TSS than the unmodified clarifier without the stop-gate.

The second, larger rectangular clarifier is 62.8 m (206 ft) long and 22.8 m (75 ft) wide with a sidewater depth of 3.9 m (12.9 ft). Four inlet ports direct the mixed

Table 1. Types of Clarifiers Studied

Clarifier Type	*Total Number Studied*	*Total Number Modified*
Rectangular	2	1
Center Feed - Peripheral Overflow	5	2
Peripheral Feed - Peripheral Overflow	1	0

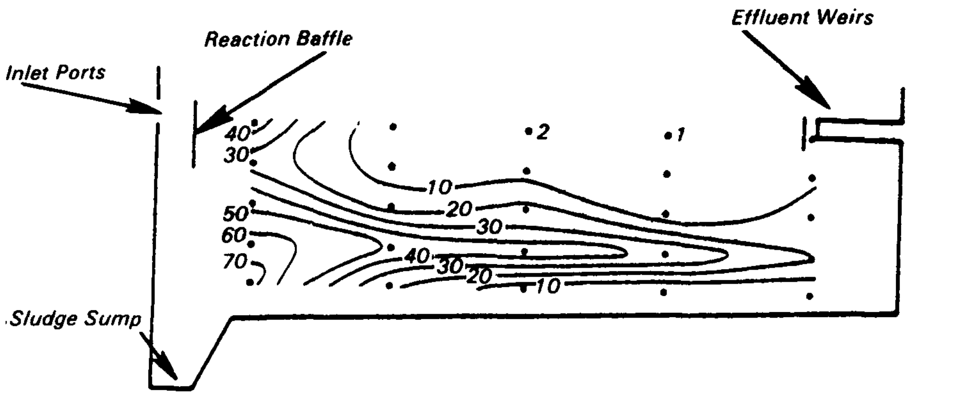

Figure 1. *Original flow pattern for small rectangular clarifier. Distribution of the dye concentration. Note: Vertical scale is exaggerated.*

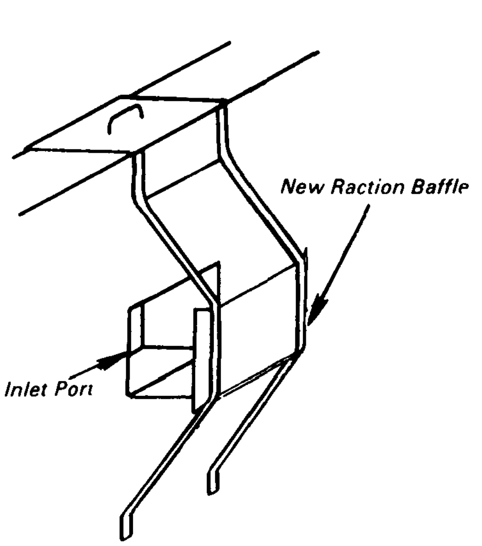

Figure 2. *New reaction baffles for small rectangular clarifier.*

liquor flow downward with the help of a deflection baffle. Longitudinal effluent weirs covering about half of the clarifier's surface area are located at the opposite end of the basin. A traveling bridge with air-lift pumps removes the sludge only during the part of the cycle in which the bridge is moving from the weir end to the inlet end of the tank.

Figure 4 shows a flow pattern for this clarifier. The hydraulic characteristic is very different from the smaller tank described earlier. The narrow horizontal flow layer that existed in the inlet region changed to a more uniform flow at the outlet. The flow distribution recommended by design standards appears to have been achieved in this clarifier. Effluent TSS concentrations were typically 10 mg/L or less.

This study did not determine the exact reasons for this clarifier's exceptional hydraulic characteristic. Gas bubbles observed near the inlet have led to one theory. The solids distribution tests indicated that the traveling bridge piles sludge near the inlet without completely removing it. The sludge then turns septic and produces fine rising bubbles that appear to help distribute the throughflow vertically. No modifications were attempted on this clarifier.

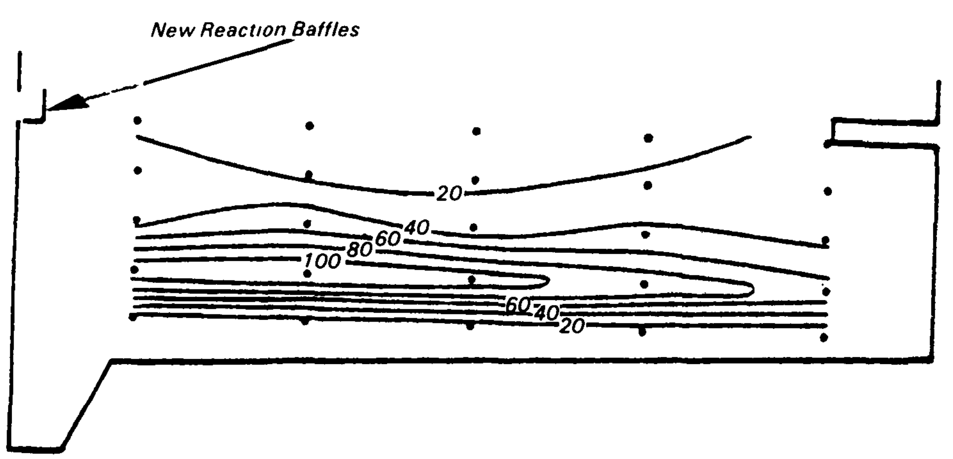

Figure 3. *Flow pattern after modification of small rectangular clarifier with new reaction baffles. Distribution of the dye concentration. Note: Vertical scale is exaggerated.*

Center-Feed, Peripheral Overflow, Circular Clarifiers

Most activated sludge facilities in the United States use center-feed, peripheral overflow, circular clarifiers. Five of these tanks were included in the study. Two modifications were made on one and a third modification was made on another one.

Figure 5 shows the flow pattern in a 24-m-diameter (80 ft), 3.1-m-sidewater depth (10 ft) clarifier in a pure oxygen activated sludge plant. A very thin, high-velocity layer of horizontal throughflow rebounded off the peripheral wall, inducing excessive floc particles to approach the weirs. In addition, a weir-wall solids test and a multi-point dispersion test suggested excessive rotational speed for the sludge removal mechanism.

The first modification slowed the sludge riser pipe mechanism to 56% of its previous speed by means of a sprocket change. This modification reduced effluent TSS by 10.5%. After completing this modification on *both* secondary clarifiers, a cylindrical ring baffle/flocculation chamber was installed at mid-radius of the test tank (Figure 6). The baffle extends from mid-depth to just off the bottom and rotates with the mechanism.

Figure 7 shows the considerable effect of the baffle on the clarifier's flow pattern. After an extended test of comparative performance, effluent TSS was found to be 37.5% lower in the newly baffled secondary clarifier.

A 39.6-m-diameter (130 ft), 40-m-sidewater depth (13 ft) secondary clarifier in an air activated sludge facility received another modification - a baffle placed just beneath the weirs at the periphery. Figure 8 shows the baffle. The post-modification flow pattern appears in Figure 9. As expected, the new baffle decreased the tendency for density flow induced upflow at the periphery.

In a 52-day, side-by-side comparison of effluent TSS from the modified and unmodified parallel secondary clarifiers, the newly baffled tank showed effluent TSS that was 38.3% lower.

Peripheral-Feed, Peripheral-Overflow, Circular Clarifier

A peripheral-feed, peripheral-overflow, circular clarifier was evaluated at 65%,

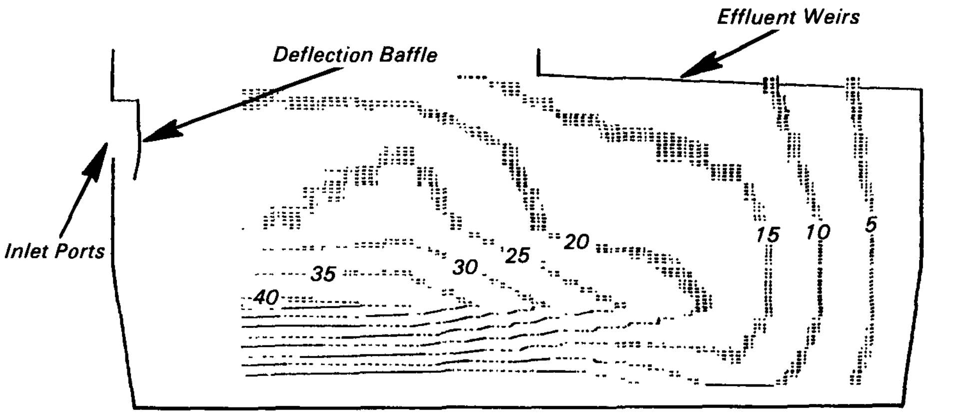

Figure 4. *Flow pattern for the large rectangular clarifier. Distribution of the dye concentration. Note: Vertical scale is exaggerated.*

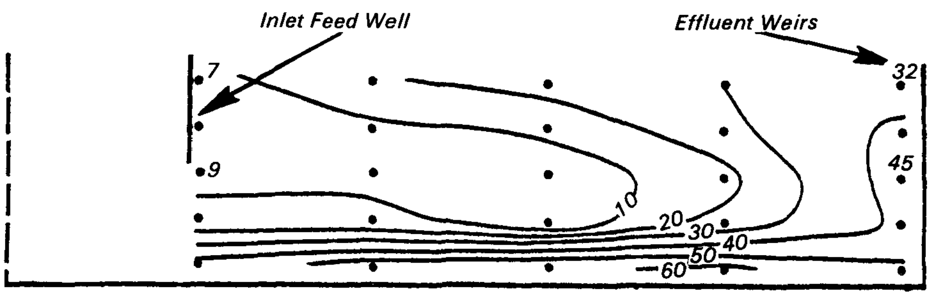

Figure 5. *Original flow pattern for a center-feed, peripheral-overflow, circular clarifier. Distribution of the dye concentration. Note: Vertical scale is exaggerated.*

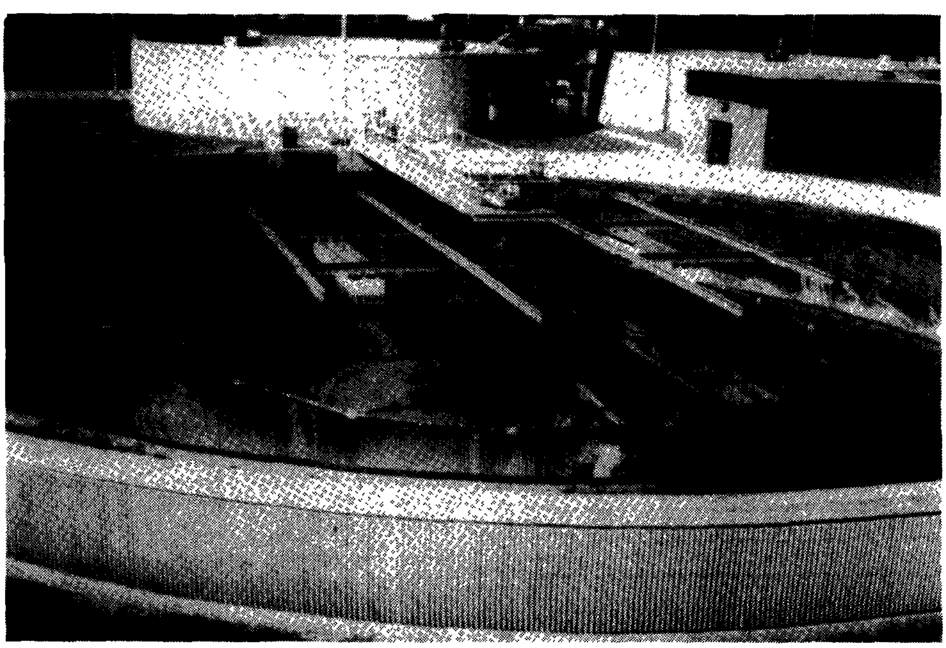

Figure 6. *Ring Baffle/Flocculation Chamber modification to a center-feed, peripheral-overflow, circular clarifier.*

100%, and 150% of design overflow rate. The secondary clarifier, in a pure oxygen activated sludge process, was one of 12 identical units. The tank is 42.7 m (140 ft) in diameter with a 4.3-m (14-ft) sidewater depth.

Figure 10 shows a typical flow pattern with the clarifier operating at a design overflow rate of 26.48 m^3/m^2 per day (650 gal/ft^2 per day). The initial flow pattern was similar to other clarifiers, with flow moving across the sludge blanket from the inlet region. In this type of clarifier, however, the flow converges at the center rather than meet an obstacle such as an end or peripheral wall. Later "snapshots" in the flow pattern time series confirmed that upflow was gradual and relatively uniform over the surface area.

Other Factors Thought To Affect Clarifier Performance

The investigators considered factors both within and upstream of secondary clarifiers—factors thought to affect the effluent quality of the tanks. Although the study did not subject their observations to rigorous proof, facility designers should at least consider them.

Sludge Removal Mechanism

Except for the small, rectangular secondary clarifier discussed, all clarifiers included in this study had so-called hydraulic sludge removal mechanisms. All appeared to have some degree of problem in uniformly removing sludge. Reasons varied from plugging of individual riser pipes or orifices with sludge or debris to operator uncertainty about how to adjust them.

The rotational speed of mechanisms might be greater than needed to maintain sludge quality. At one facility, a 10.5% reduction in effluent TSS resulted from a reduction to 56% of design speed.

Balancing of Flows Between Parallel Clarifiers—Inadequate Flow Control and Measurement Devices

Most municipal wastewater treatment plants have several identical clarifiers operating in parallel. Splitting the influent equally among the clarifiers should generally produce the best effluent, but this project found that achieving this balance of flows was usually difficult if not impossible at all flow rates.

The inability to balance the flows was caused by inadequate flow control and a lack of flow measurement devices. Gate

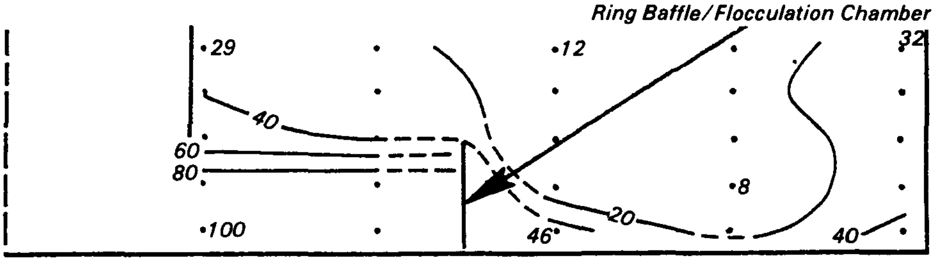

Figure 7. *Flow pattern after modification at a center-feed, peripheral-overflow, circular clarifier with a Ring Baffle/Flocculation Chamber. Distribution of the dye concentration. Note: Vertical scale is exaggerated.*

Figure 8. *Peripheral Baffle modification to a center-feed, peripheral-overflow, circular clarifier.*

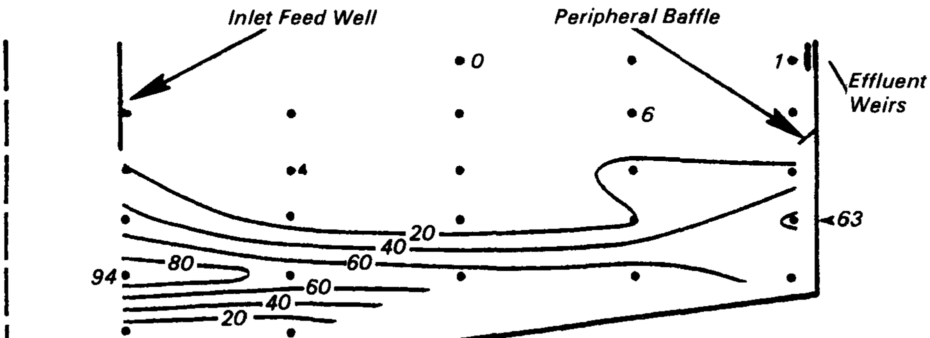

Figure 9. *Flow pattern after modification of a center-feed, peripheral-overflow, circular clarifier with a Peripheral Baffle. Distribution of the dye concentration. Note: Vertical scale is exaggerated.*

valves or slide gates were the only means of flow control at some plants. These devices are satisfactory for *stopping* flow, but they are inappropriate for control because their head loss characteristics are a nonlinear function of flow rate. Therefore, a flow split adjusted for one flow rate will change with flow. Such gates and valves also tend to collect debris when operated partially closed. Some splitter boxes also complicate the problem.

The problem of splitting and balancing flows between parallel clarifiers is further exacerbated by a lack of flow measurement devices to confirm a balanced operation. Typically, underflow is measured and mixed liquor feed and effluent flow rates are not. Elaborate flow measurement devices are not necessary, but an operator should be able to determine flow rates without installation of special equipment.

Flow Variation and Solids Transport

The general perception is that activated sludge secondary clarifiers are not significantly affected by flow variation because tanks upstream of the secondaries will equalize the flow. This is true only in a very limited sense; flow transients undergo very little attenuation in a typical plant. A mathematical model developed for this project indicates that the amplitude and frequency of flow variations may greatly increase solids transport through the clarifier, thus increasing effluent TSS.

Conclusions and Recommendations

- None of the clarifiers evaluated in this project had the hydraulic characteristics called for in design standards for wastewater treatment plants. All of the clarifiers had some similar hydraulic characteristics, characterized by a horizontal flow layer, probably caused by density flow. Performance suffered only in those clarifiers where the effluent weirs were placed in the path of the density currents. The sludge jet effect may intensify these density currents and their effect on performance.

- Baffles at the inlets of rectangular clarifiers did not prevent the formation of density currents. Breaking the density flows up after they had formed improved clarifier performance.

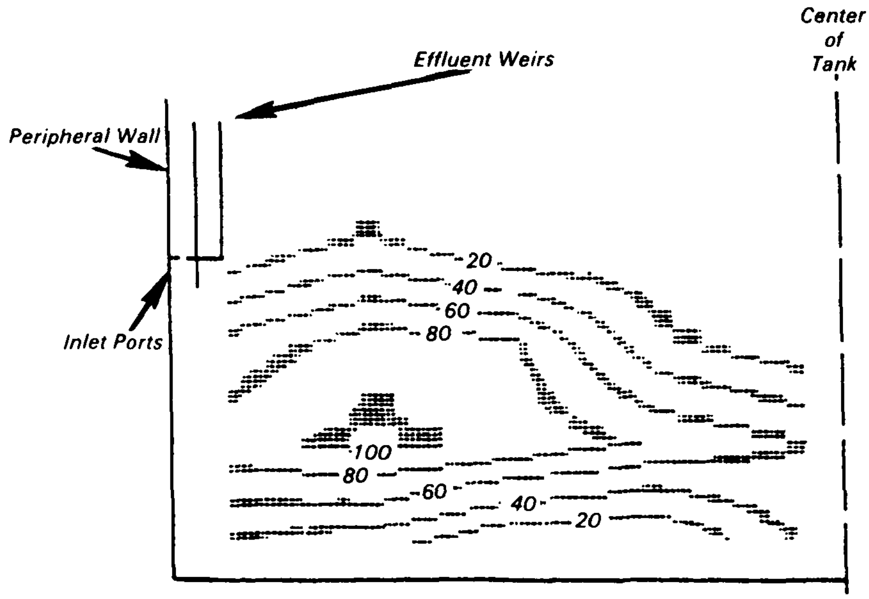

Figure 10. *Flow pattern for the peripheral-feed, peripheral-overflow, circular clarifier. Distribution of the dye concentration Note: Vertical scale is exaggerated.*

- Clarifiers with effective control of density currents may be capable of producing acceptable effluents at higher hydraulic loading rates than those of conventional design.

- Sludge blanket level affects clarifier hydraulic chacteristics. A moderate blanket level just below the bottom of the inlet baffling may be the worst condition, producing high levels of solids-transporting turbulence

- Balancing of flows between parallel clarifiers is impossible without proper control devices and some form of flow measurement device on each clarifier

- Wastewater treatment plant designers and operators must be aware that conventional treatment process tankage does not greatly attenuate flow transients and that any flow variation induced in the system could significantly increase solids transport in the activated sludge secondary clarifiers

- The flow pattern/solids distribution test is an effective technique for evaluating the hydraulic phenomena occurring within full-scale, operating, activated sludge secondary clarifiers.

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The complete report, entitled "Hydraulic Characteristics of Activated Sludge Secondary Clarifiers," (Order No. PB 84-229 665; Cost: $23.50, subject to change) will be available only from:
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