SEDIMENTATION SINCE CAMP[1]

By Richard I. Dick[2]

Thomas R. Camp's achievements were in diverse areas. Many engineers, of course, have broad interests, but Thomas Camp made important and lasting contributions in a number of areas. The first American Society of Civil Engineers publication on "Engineering Classics" (2) featured some of the important contributions of Thomas Camp. These were categorized in such diverse areas as sewerage, filtration, distribution systems, flocculation, and sedimentation.

In this paper, Thomas R. Camp's contributions related to sedimentation are reviewed. Their significance is considered vis à vis developments in sedimentation technology since Camp's work so as to evaluate the current state-of-the art of sedimentation tank design. Such retrospective evaluations are the fate of famous men and women. It will be shown that Thomas R. Camp's sedimentation contributions withstand the test of time, but that the record of the engineering profession in making use of his work is far less impressive.

---

[1] Thomas R. Camp Lecture presented to the Boston Society of Civil Engineers on March 11, 1981.

[2] The Joseph P. Ripley Professor of Engineering, Cornell University, Ithaca, New York.

The Importance of Sedimentation in Water Quality Control

Before evaluating Camp's work on sedimentation, it seems appropriate to justify my own choice of sedimentation as a topic for discussion in 1981. It is neither an "innovative" nor an "alternative" process[c]. In an era of concern about topics such as priority pollutants, TSCA, RCRA, BAT, and NPDES (all terms which would have puzzled Camp's audiences)[c] is it reasonable to be concerned with a mundane topic such as sedimentation? Sedimentation, after all, is the oldest of all water quality control processes - indeed, it was an old process when Camp worked on it.

The answer to the question of whether sedimentation is a pertinent, current water quality control topic is an emphatic yes! Solids-liquid separation processes continue to be the major means by which pollutants are separated from water. And of the techniques for solids-liquid separation, sedimentation continues to be the most economical and common. Not only are pollutants that exist in the suspended form removed by solids-liquid separation, but, also, chemical or biological processes are used to convert soluble pollutants to the suspended form so that they can be removed by solids-liquid separation processes. There are, of course, exceptions to this usual scheme (for example, ion exchange, reverse osmosis, and adsorption processes), but these

---

[c] It is hoped that any future readers who were not yet born when this paper was written also will be puzzled by these symbols of excessive governmental involvement in environmental engineering.

processes are used for only a small fraction of the water and wastewater currently being treated.

Some indication of the economic significance of sedimentation in water quality control is available from data presented in the U.S. Environmental Protection Agency's "Needs Surveys" (37, 38). If it is assumed (conservatively) that each primary wastewater treatment facility, trickling filter installation, and activated sludge process is served by an average of at least two sedimentation tanks, then, according to the 1976 EPA Needs Survey (37), at least 20,750 sedimentation tanks were in operation in United States municipal wastewater treatment facilities. At a rough (and conservative) replacement cost of $250,000, this represents about $5.2 billion. Using the same assumption of two sedimentation tanks per primary, trickling filter, or activated sludge installation, the Needs Survey indicated that at least 17,650 new tanks needed to be constructed, and, again assuming a construction cost of $250,000 per tank, this represents $4.4 billion. The 1978 Needs Survey (38) indicated an estimated need of $14.6 for sedimentation and flocculation facilities to control of combined sewer overflows stormwater discharges as necessary to protect recreation areas. To these costs must be added the cost of sedimentation facilities for industrial wastewater treatment and for municipal and industrial water treatment. The total expenditure for sedimentation tanks in water and wastewater treatment is, perhaps, roughly in the order of $50 billion[d]. To use President Reagan's (30) analogy that a millionaire is a person with a four inch stack of 1,000 dollar bills in his hand, then $50 billion of expenditures for sedimentation tanks can be portrayed as a stack of 1,000 dollar bills over 3 miles high. These total expenditures for sedimentation facilities are in the same order of magnitude as public expenditures for placing a man on the moon, constructing the interstate highway system, or developing the space shuttle or the MX missile system. It does seem pertinent, therefore, to examine the cost effectiveness of expenditures for sedimentation tanks.

Camp's Sedimentation Contributions

Thomas R. Camp's published contributions to understanding of sedimentation spanned two decades. They began[e] with a paper in Sewage Works Journal in 1936 (6), and extended through a discussion (9) of Ingersoll, McKee, and Brooks' paper (25). These

---

[d] This assessment of the economic significance of sedimentation facilities is admittedly crude - it is intended only to remind the reader that much money has been, is being, and will be spent for sedimentation tanks. Another approach would have been to observe that roughly one-third of conventional municipal water pollution control expenditures are for primary and secondary sedimentation facilities. Based on federal expenditures for construction grants for publicly owned treatment facilities in recent years, the annual federal subsidy for wastewater sedimentation tanks must be about $1 billion/yr. Note that, based on usual industrial levels of expenditures for research and development, this justifies an annual sedimentation tank research budget in the order of $35 million/yr!

[e] Many of the ideas in Camp's first major sedimentation paper were published by Camp earlier in 1936 in discussion (5) of a paper by Slade (32).

contributions drew heavily upon the early sedimentation paper by Hazen (23), but Hazen's work was clarified and extended by Camp.

Camp clearly demonstrated the relationship between the sedimentation velocity of particles in water or wastewater and the theoretical performance of sedimentation tanks. To do this, he considered a rectangular horizontal flow sedimentation tank from which all imperfections had been removed. As illustrated in Fig. 1[f], Camp considered that the sedimentation tank had an inlet zone that accomplishes uniform distribution of flow and particles across the entire cross-sectional area of the tank. A sludge zone was designated, and particles that settled into the zone were considered to be removed - resuspension was not possible. A third portion of the tank was designated as the outlet zone, and any particle entering that zone was considered to be lost in the effluent. Camp confined his analysis to the remaining part of the tank, the ideal settling zone, through which horizontal plug flow was considered to occur while particles settled at their characteristic sedimentation velocities.

To develop the relationship between the sedimentation velocity of a particle and the performance of a continuous-flow gravity sedimentation basin, Camp considered the trajectory of the slowest settling particle that would be completely removed. This trajectory is illustrated in Fig. 2 in which h_o, w, and L

---

[f] Figures 1 through 6 are from Dick (12).

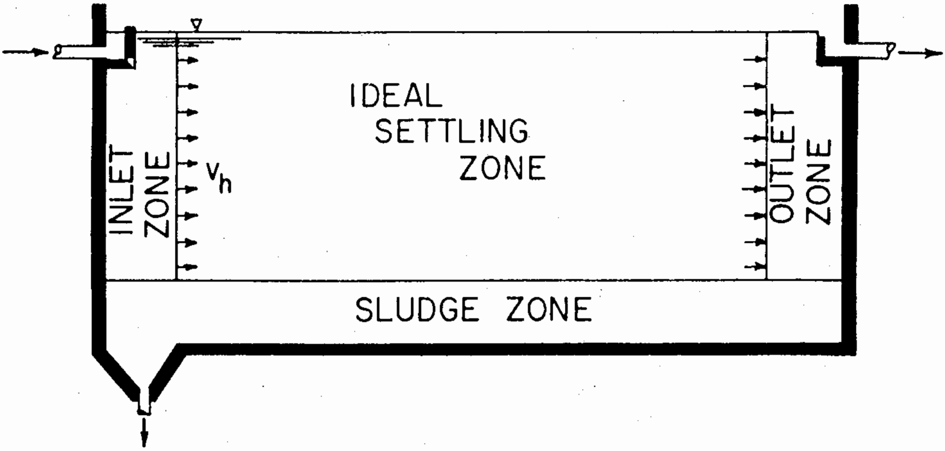

Figure 1. Definition Sketch for Camp's Ideal Sedimentation Tank.

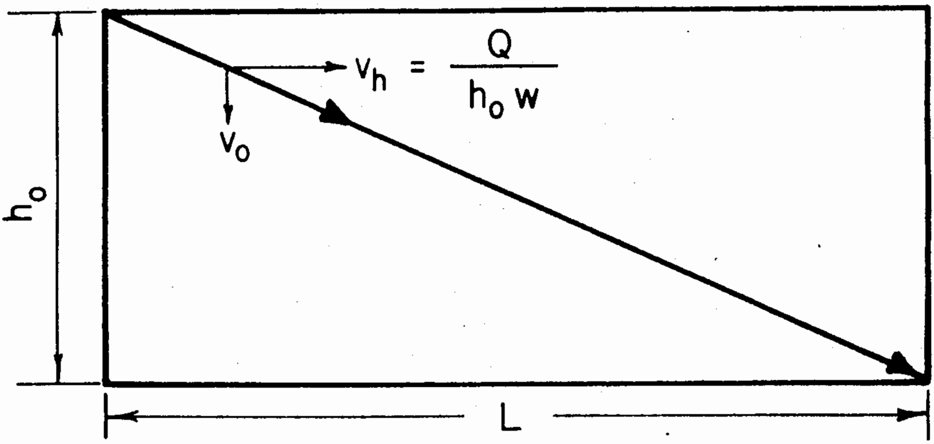

Figure 2. Trajectory of the Slowest Settling Particle Completely Removed in an Ideal Sedimentation Tank.

are the depth, width, and length, respectively, of an ideal settling tank, v_h is the horizontal fluid velocity created by flow through the tank at rate Q, and v_o is the sedimentation velocity of the slowest settling particle that is completely removed. From similar triangles:

$$\frac{v_o}{v_h} = \frac{h_o}{L} \tag{1}$$

or

$$v_o = \frac{v_h h_o}{L} = \frac{Q}{wL} = \frac{Q}{A} \tag{2}$$

The "hydraulic loading", "overflow rate", or "surface settling rate", Q/A, of a settling tank, thus, is equal to the sedimentation velocity of the slowest settling particle that is completely removed[g].

Camp showed that, depending upon the elevation at which they entered the ideal sedimentation tank, some fraction of particles that settled slower than v_o will be removed. This is illustrated in Fig. 3 in which v_p is the sedimentation velocity of a slow settling particle. Note that discrete particles with settling velocity, v_p, that enter above elevation h in Fig. 3

---

[g] Camp confined his analysis to horizontal flow rectangular sedimentation basins. However, it can be readily shown that both Eqs. 2 and 3 apply to radial flow circular tanks with either center or peripheral feed. Also, Eq. 2 obviously applies to vertical flow sedimentation tanks. However, partial removal of slower settling particles (Eq. 3) does not occur in vertical flow tanks (unless it occurs by flocculation or entrapment of particles in a suspended sludge blanket).

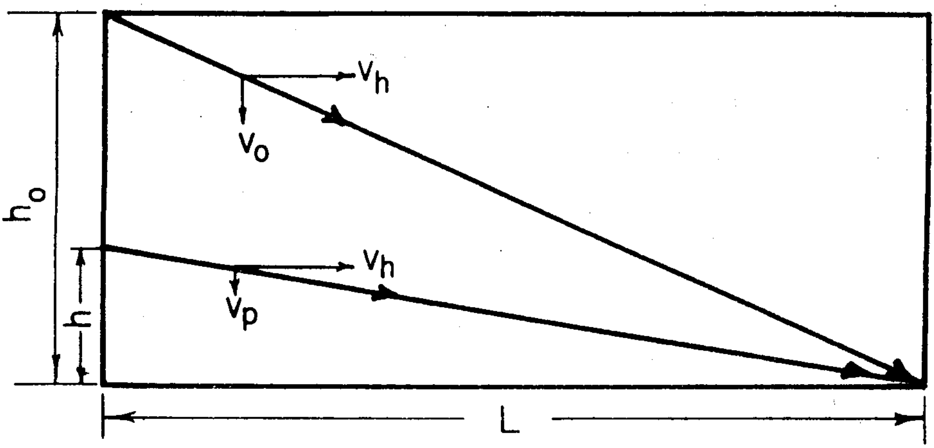

Figure 3. Partial Removal of Particles that Settle Slower than the Hydraulic Loading Rate, Q/A.

will not be removed because they will enter the outlet zone. Camp showed that the fractional removal, f, of particles that settle slower than v_o is[9]:

$$f = \frac{h}{h_o} = \frac{v_p t}{v_o t} = \frac{v_p}{Q/A} \qquad (3)$$

where t is the hydraulic residence time in the ideal sedimentation tank.

Camp emphasized the absence of retention time or sedimentation tank depth or volume in Eqs. 2 and 3, and sought means for economically increasing the effective area of sedimentation basins. As illustrated by Fig. 4, reducing the depth of an ideal settling tank by half does not alter particle removal efficiency, and, thus, the most economical sedimentation tank for discrete particles would be the shallowest tank possible. In Camp's words, "it follows from the simple theory that the most economical tank will have the least possible depth for the required overflow rate" and "for economy, therefore, the...depth should be made as small as is consistent with no scour" (7).

In his 1946 paper on "Sedimentation and the Design of Settling Tanks" (7), Camp proposed a primary sedimentation tank of

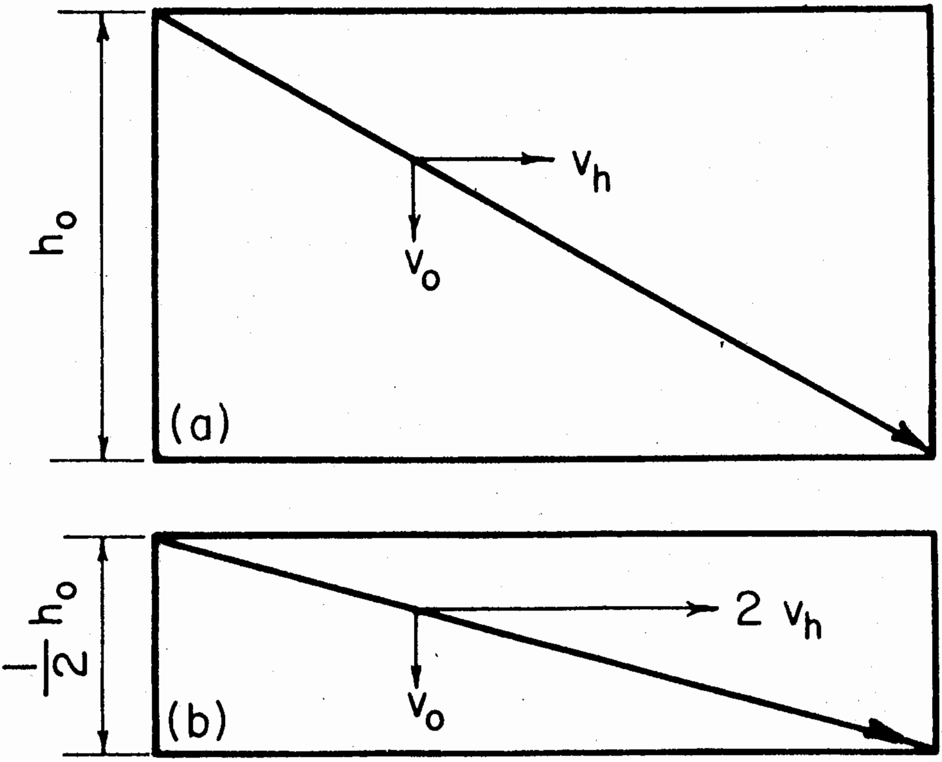

Figure 4. The Removal of Discrete Particles in Ideal Sedimentation Tanks is Independent of Depth.

normal depth with nine horizontal trays to cause a ten-fold increase in the effective capacity of the tank. Camp proposed a design for a reciprocating scraper mechanism on each of the trays that would move sludge laterally.

In a later paper, Camp (8) described implementation of his sedimentation concepts in improving existing sedimentation basins at the Cambridge, Massachusetts water treatment plant[h]. In upgrading the Cambridge facilities, two horizontal trays were constructed in the existing 16 ft (5 m) deep sedimentation tanks. Mechanical sludge collection equipment was not provided in the Cambridge basins[i]. In the same paper, Camp expressed his hope that sludge removal equipment suitable for use in tanks with shallow trays "will be perfected in the not-too-distant future." The problem of effective mechanical sludge removal from shallow horizontal trays still has not been solved, but it has been avoided by inclining the trays (or tubes) at an angle sufficient to achieve removal of sludge by gravity (21). The solution represents a compromise because only the horizontal area of the inclined trays is effective in sedimentation.

Camp recognized that flocculation of particles in a sedimentation tank complicates the analysis of settling tank

---

[h] A more detailed description of Camp Dresser and McKee's design of the Cambridge, Massachusetts water treatment plant sedimentation tank refurbishments was presented by Dresser (15).

[i] The Cambridge tank was designed to be desludged periodically by taking it out of service. Nozzles were installed to assist in removing sludge from the tank (15).

performance. Fig. 5 illustrates that, if particle agglomeration occurs within a sedimentation tank, then particle sedimentation velocity will increase and a particle whose trajectory at the inlet end of the tank seemed destined to convey it to the outlet zone can, in fact, be removed. If flocculation occurs at the same temporal rate in a deep tank as in a shallow tank, then the concept that sedimentation tank depth is of no significance (which was developed by considering discrete particles) needs to be modified. This is illustrated in Fig. 6, which shows that in a shallow basin a flocculant particle may not achieve sufficient size and sedimentation velocity to be removed when tank depth is reduced.

Camp's assessment of the significance of flocculation in sedimentation tank design was a bit ambivalent. He was critical of Hazen's (23) failure to consider flocculation and, in his 1936 paper (6) indicated that "removal of suspended matter is more nearly a function of detention time than of tank surface area for most suspensions." However, particularly in his later work, he was a consistent advocate of shallow tanks or tanks designed with trays to increase the effective surface area. Camp's 1953 paper (8) contains the fascinating speculation that in primary sedimentation tanks, the use of shallower depths (limited only by the need to avoid scour of deposited sludge) was warranted to achieve an increase in turbulence in the tank. Camp's argument was that as horizontal velocity increased (due to reduced tank depth) turbulence would increase and this would cause

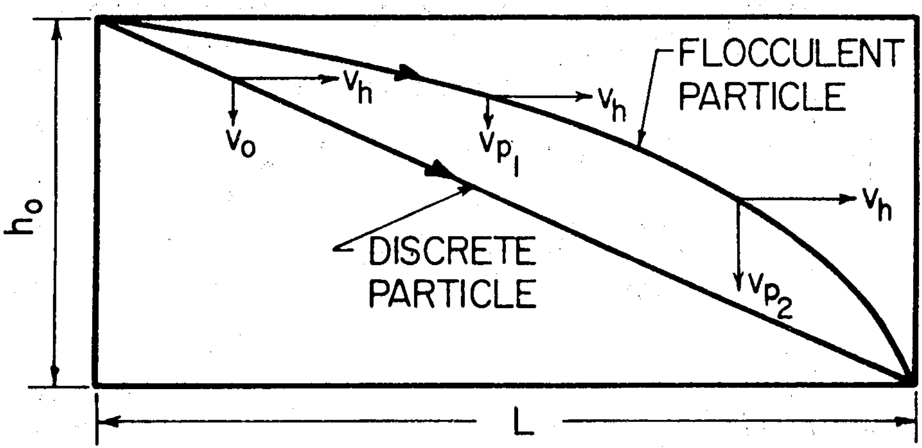

Figure 5. Particle Agglomeration can Influence the Performance of Ideal Sedimentation Tanks.

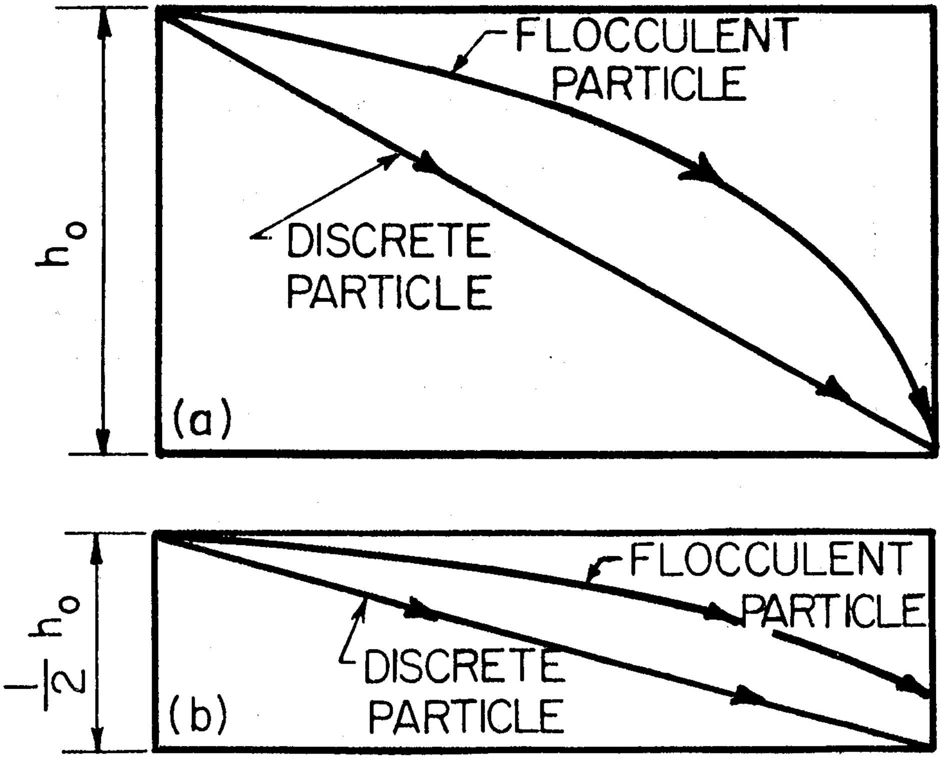

Figure 6. Sedimentation Tank Depth May Be Important With Flocculant Particles.

increased removal of particles because of improved flocculation. Camp speculated that the improved flocculation would more than compensate for the reduction in sedimentation tank performance due to increased turbulent diffusion (14). Camp's argument cannot be discounted in the absence of experimental evidence. Regrettably, such evidence still does not exist in spite of Camp's provocative assertion.

Camp apparently felt that whatever the effect of sedimentation tank depth on removal of flocculant particles, money was ineffectively spent to achieve improved flocculation within sedimentation tanks. Note, for example, that the improvements to the Cambridge, Massachusetts wastewater treatment plant (15) involving installation of trays also included provision of flocculation basins prior to sedimentation. More recently Parker, et al. (28) have argued that flocculation of activated sludge is warranted prior to its introduction into sedimentation tanks.

Because Camp's description of the relationship between the sedimentation velocity of a particle and the extent to which the particle is removed in sedimentation basins were so clearly presented, they were readily accepted by the profession. The analysis of the expected performance of an ideal sedimentation tank is a standard part of most water quality control process texts, and design standards of regulatory bodies [for example, see "Ten State Standards" (19)] have come to include the surface settling rate, Q/A, as a basic sedimentation design parameter (whereas, in the absence of Camp's work, they probably would have emphasized hydraulic residence time).

Comparisons of Observed Performance With Predictions Based on Camp's Work

In assessing the state-of-the-art of sedimentation tank design and the impact of Camp's work on sedimentation practice, it is appropriate to compare actual sedimentation tank performance to predictions founded on Camp's work. If the conditions assumed by Camp are fulfilled, predicted results should be obtained with mathematical inevitability.

Fig. 7, adapted from Ingersoll, et al. (25) provides a basis for determining the theoretical performance of sedimentation basins. The upper curve represents the sedimentation velocity distribution of particles in the influent to a sedimentation tank and the lower curve represents the expected effluent particle size distribution. The lower curve is obtained by applying Camp's principles[j]. By considering different values of Q/A, the expected relationship between the hydraulic loading and sedimentation tank performance can be determined for a particular suspension. Fig. 8 shows the results of such computations for a particular suspension [indeed, the one considered by Camp in his 1946 paper (7)].

---

[j] Thus, all particles with settling velocity greater than Q/A should be removed, one half of the particles with settling velocity equal to Q/2A should be removed, etc. Hence, all particles represented by the cross-hatched area in Fig. 6 should be removed.

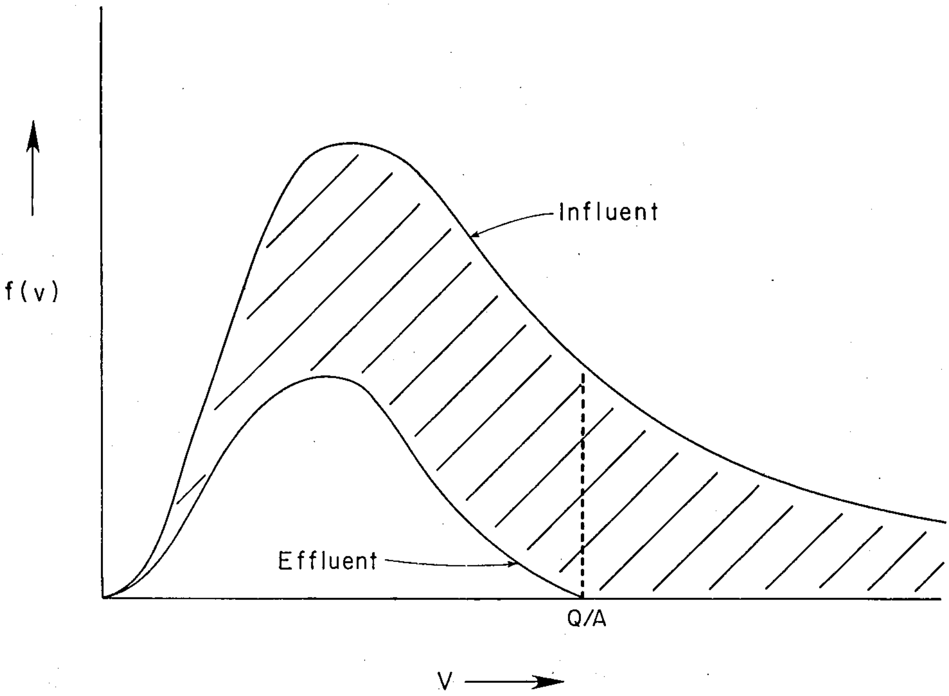

Figure 7. The Anticipated Performance of an Ideal Sedimentation Tank Receiving Particles with a Spectrum of Sedimentation Velocities [after Ingersoll, et al. (25)].

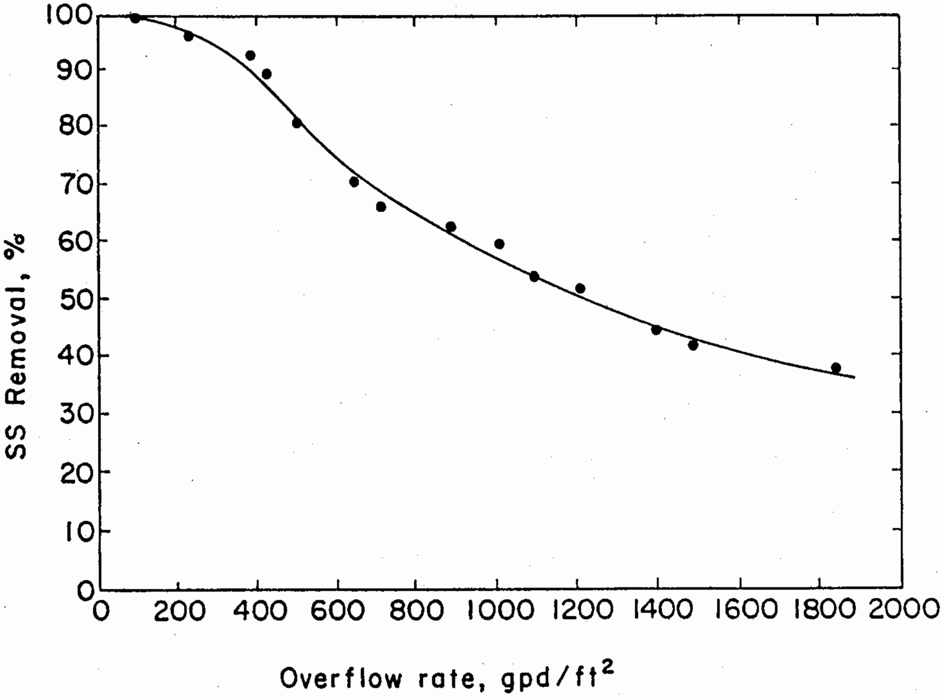

Figure 8. The Expected Performance of an Ideal Settling Tank Receiving a Particular Suspension.

Clearly, it was Camp's intention that the performance of sedimentation tanks would be evaluated by comparing observed removal to theoretical removal such as plotted in Fig. 8. Regrettably, this approach has not been adopted by the profession. Only in very few cases [for example, El-Baroudi (16)] have comparisons with ideal settling tank performance been made.

In the absence of data to allow rigorous comparison of theoretical predictions and actual performance, some assessment of the conformance of sedimentation tank performance to theoretical predictions can be made by observing whether or not the general shape of the percentage particle removal versus hydraulic loading curve is like the expected curve shown in Fig. 8[k]. Regrettably, the most abundant source of data on the relationship between the sedimentation tank hydraulic loading and particle removal is small-scale laboratory and pilot studies. While small-scale, continuous-flow sedimentation studies often have been conducted to model full-scale performance, the hydraulic similitude problems are, in fact, very severe. I regard such data as being interesting results from miniature sedimentation basins that can be closely regulated and easily modified - not as useful bases for scale-up.

---

[k] The reason this approach is unsatisfying is that a settling tank achieving, say, 50 percent removal of suspended solids could be of inferior design to one removing, say, 25 percent removal of suspended solids. This would be true if the tank achieving 50 percent removal was, according to the analysis illustrated in Figs. 7 and 8, expected to achieve 90 percent removal while the one achieving 25 percent removal was theoretically expected to be capable of removing only 30 percent of suspended solids.

Data presented by El-Baroudi (16) are illustrative of small-scale studies and are shown in Fig. 9. His sedimentation tank was 24 in (61 cm) wide and 58.5 in (149 cm) long with a water depth of 14.5 in (37 cm). A dispersing agent was used in El-Baroudi's research to control particle flocculation. It is seen that hydraulic loading exerted the expected effect on particle removal. Other evidence of the conformance of the results of small laboratory and pilot-scale settling tank data with expectations based on Camp's analysis of the performance of the ideal sedimentation tanks are available [Tebbutt (34), Villemonte (39), Baumann, et al. (3), and Hayden (22)]. Data from full-scale sedimentation tanks are, however, far more pertinent. As shown in the paragraphs that follow, these data are also less reassuring.

Data from a 94 ft (29 m) diameter primary sedimentation tank at Sao Paulo, Brazil as presented by Bradley (4) are shown in Fig. 10. The data are daily values obtained over a four-month period. While it is not surprising that the data are more scattered than those from closely controlled, small-scale tanks, little hint of a relationship between Q/A and performance is indicated by the data[1]. Heinke, et al. (24) conducted extensive

---

[1] Note that the authors who presented the data shown in Figs. 10, 11, 12, and 13 are not responsible for the sedimentation tank designs that caused the data to be as they are. Bradley (4) and Dallas (10) fit curves to the data shown in Figs. 11 and 12, respectively, and Lin and Liao (27) derived an equation from the data in Fig. 13. I have elected not to suggest any cause-effect relationships.

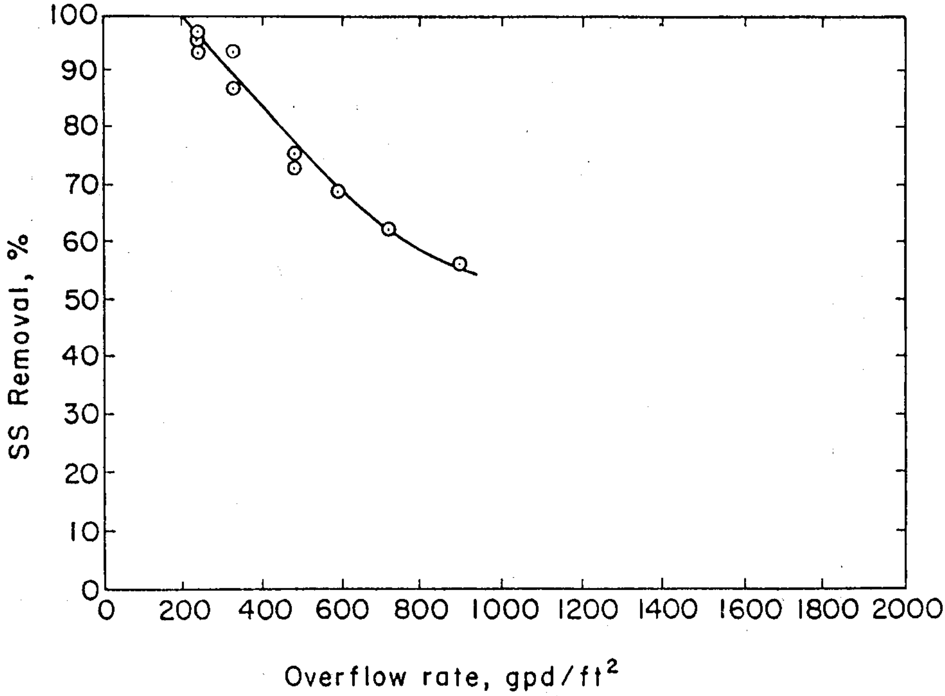

Figure 9. The Performance of a Closely Controlled Laboratory-Scale Settling Tank Illustrating Conformance with Expected Influence of Hydraulic Loading [from El-Baroudi (16)].

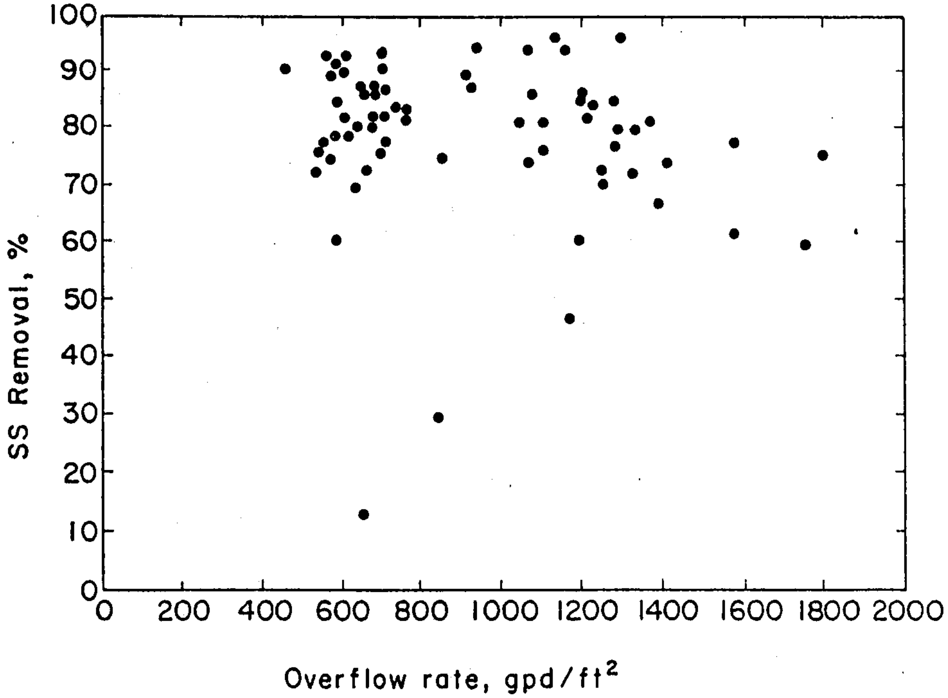

Figure 10. Independence of the Performance of a Full-Scale Primary Sedimentation Tank from Hydraulic Loading [data from Bradley (4)].

studies with two full-scale primary sedimentation tanks in Canada that were operated with and without chemical coagulants. They concluded that, within the range of hydraulic overflow rates considered in the studies [up to about 2,000 gpd/ft^2 (imperial) (100 m^3/m^2/day)], hydraulic loading had no significant effect on effluent quality. Thus, at loadings up to two to three times normal, factors other than Q/A (the parameter that limits ideal settling tank performance) controlled actual primary sedimentation tank performance. Similarly, Hamlin (20) presented results from a 80 ft (25 m) long experimental primary settling tank that showed "that there is very little change in tank performance with increasing overflow rate".

Activated sludge final sedimentation tank performance data (Figs. 11 and 12) also do not indicate a relationship between hydraulic loading and clarification performance. Data in Fig. 11 are for a 60 ft (18 m) diameter final settling tank at Dallas, Oregon (10)[1] while those in Fig. 12 are for a small [11 ft (3.4 m)] tank serving a salmon processing wastewater treatment plant as reported by Lin and Liao (27)[1]. As in the case of primary sedimentation tanks, it is difficult to sense any relationship between hydraulic loading and suspended solids removal from the data presented in Figs. 11 and 12.

Data on the effect of hydraulic loading on the performance of final sedimentation tanks following first and second stage trickling filters developed from results presented by Pierce (29) are shown in Fig. 13. These data are from a variety of full-scale

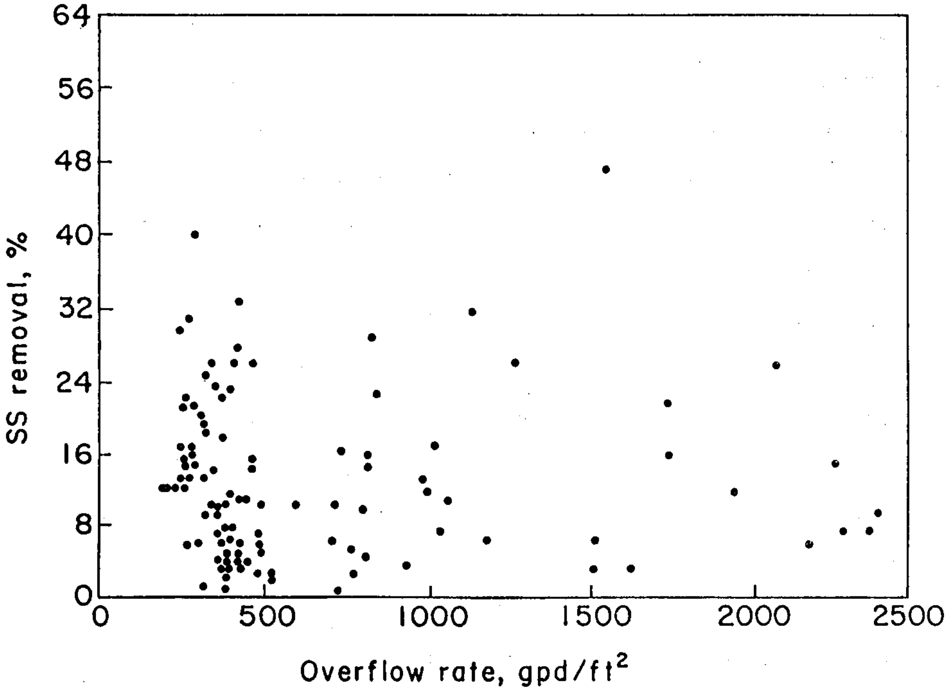

Figure 11. Absence of Influence of Hydraulic Loading on Performance of a Full-Scale Activated Sludge Final Sedimentation Tank [data from Reference 10].

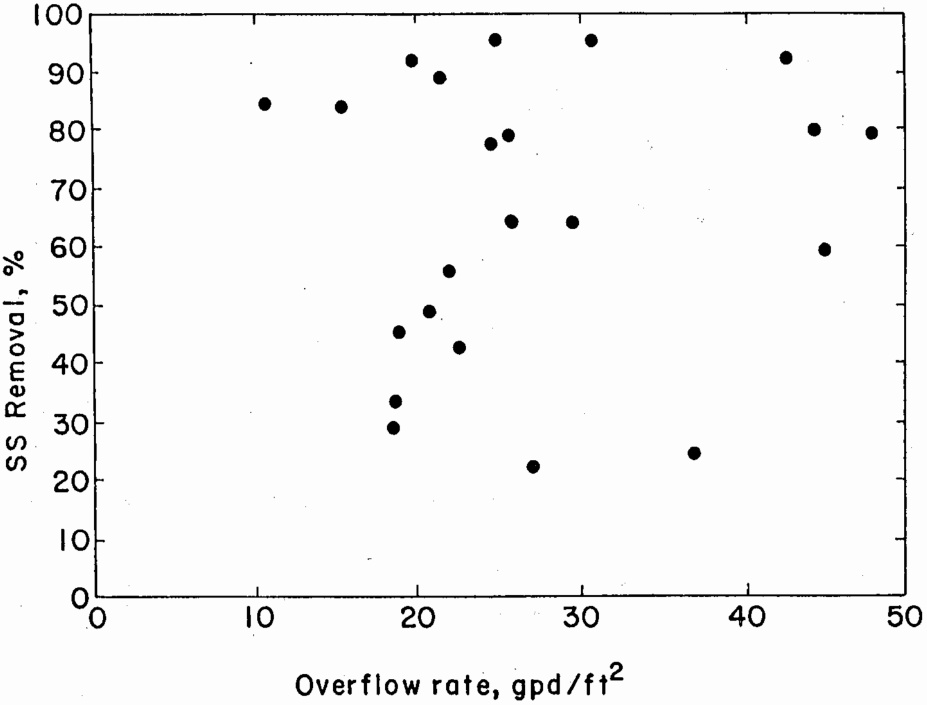

Figure 12. Lack of Effect of Hydraulic Loading on the Performance of an Activated Sludge Final Sedimentation Tank [data from Lin and Liao (27)].

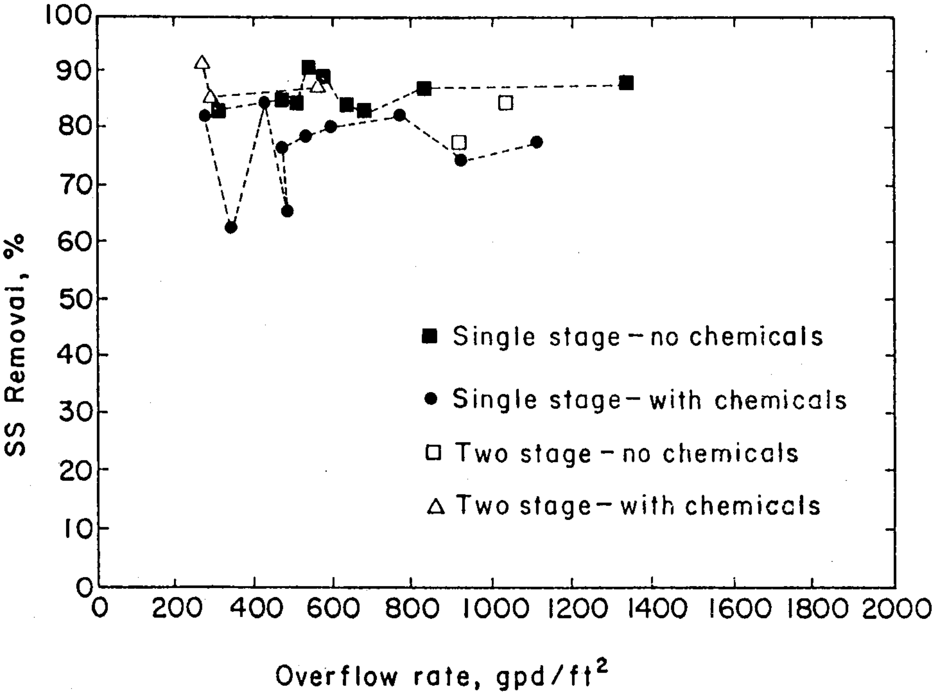

Figure 13. Absence of Influence of Hydraulic Loading on the Performance of Sedimentation Tanks Following Trickling Filters [data from Pierce (29)].

sedimentation tanks operated with and without chemicals for improving suspended solids removal. Again, factors other than the hydraulic loading per unit area apparently governed performance[1].

What's Wrong

Given Camp's convincing identification of the hydraulic loading, Q/A, as the principal factor controlling sedimentation tank performance and the long acceptance by the profession of hydraulic loading as the major sedimentation tank design parameter, the actual performance data shown in the previous section are distressing. Camp's work provides a basis for suggesting causes for the discrepancies.

Camp assumed that all particles that reached the bottom of the ideal settling zone were irrevocably removed. Common sedimentation tank design practices limit horizontal fluid velocities to avoid scour of particles, but the possibility of resuspension due to locally high velocity gradients at the sludge zone is not eliminated. Also, work since Camp has led to the realization that solids can be transmitted upward from the sludge zone by mechanisms other than scour. If the solids handling capacity of the sludge zone is less than the rate of application of solids, then solids propagate upward. This is most likely to occur in sedimentation tanks with high solids loadings such as final sedimentation tanks in the activated sludge process (13).

In developing the principles that have come to serve as bases for sedimentation tank design, Camp assumed that uniform velocity distribution was achieved at the inlet to the ideal settling zone. Data demonstrating that common inlet design practices achieve this condition are not available. Data from small-scale studies [such as by Villemonte, et al. (39), and Baumann, et al. (3)] serve to illustrate the importance of inlet design. The data of Villemonte, et al. [from a 3 ft (1 m) by 3 ft (1 m) by 14 ft (4.3 m) rectangular sedimentation tank] and those of Baumann, et al. [obtained using a 5 ft (1.5 m) circular tank 16 in (0.4) deep] are shown in Figs. 13 and 14, respectively[m]. The results confirm the importance of inlet design, but it is not clear how the inlet designs used in the experimental facilities can be scaled up so as to be applied in full-scale sedimentation facilities.

Camp's development also was based on the assumption of adequate sedimentation tank outlet design. Conventionally, outlet conditions have come to be designed by limiting the hydraulic loading per unit length of overflow weir to some arbitrary value [such as 15,000 gpd/ft (190 m^3/day/m) (19)]. Graber (18) used potential flow analysis to show that "weir loadings are of no

---

[m] Note that, like the results in Fig. 9, data from carefully designed and operated small-scale settling tanks shown in Figs. 13 and 14 show the expected form of the relationship between hydraulic loading and suspended solids removal.

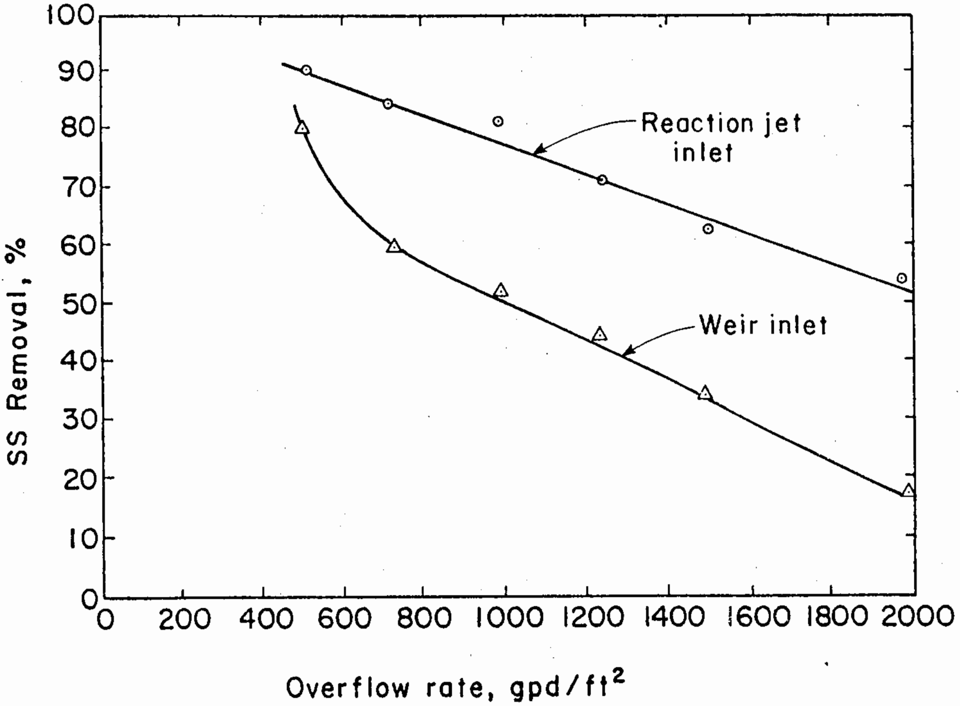

Figure 14. Effect of Inlet Design on the Performance of a Laboratory-Scale Rectangular Sedimentation Tank [from Villemonte, et al. (39)].

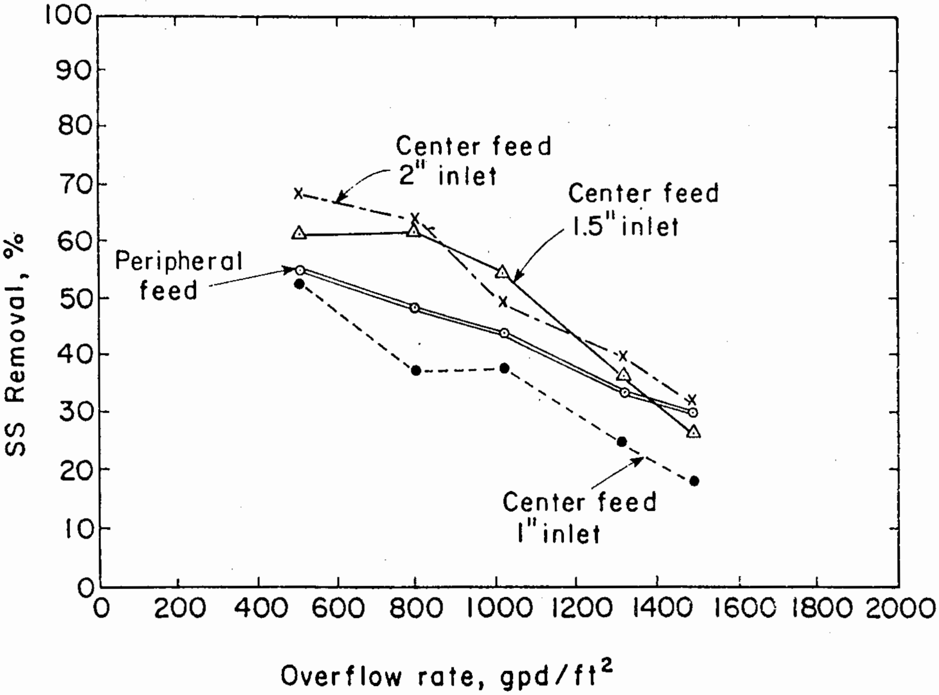

Figure 15. Effect of Inlet Design on the Performance of a Laboratory-Scale Circular Sedimentation Tank [from Baumann, et al. (3)].

direct consequence in primary settling tank analysis." This is in contrast with an earlier similar analysis (33) that may have served as part of the justification for weir loading restrictions. I am not aware of data that demonstrate the validity of common weir loading limitations, but contrary data are available. Theroux and Betz (35) plotted suspended solids removal data from 17 wastewater treatment plants as a function of weir overflow rate [up to 300,000 gpd/ft (3,700 m^3/day/m)] which showed little suggestion of a cause-effect relationship. They also conducted full-scale experiments in which effluent weirs were blocked to increase loadings from 40,000 gpd/ft (500 m^3/day/m) to 70,000 gpd/ft (880 m^3/day/m) and found "no obvious advantage, as far as suspended solids removal is concerned, in using longer weirs." Johnstone, et al. (26) reported on studies in which clarification effectiveness was improved by a change which drastically increased the hydraulic loading on weirs. Johnstone and his coworkers improved the performance of a full-scale sedimentation tank equipped with an inboard launder with weir plates on both sides by blanking off the outboard weir (and, thus, more than doubling the hydraulic loading per length of weir). They concluded that "the use of weir loading as a design criterion is of little relevance for this type of tank."

Results from tracer studies on sedimentation tanks are another source of data that demonstrate the ineffectiveness of conventional sedimentation tank design techniques. Regrettably, again, most such data are for small laboratory or pilot scale facilities.

In recent decades there have been a large number of studies of turbulent dispersion in sedimentation tanks [for example, by El-Baroudi (16), El-Baroudi and Fuller (17), and Thirumurthi (36)] and on means of anticipating the expected performance of tanks with nonideal characteristics [for example, by Alarie, et al. (1), Cordoba-Molina, et al. (11), Heinke, et al. (24), Tebbutt (34), and Shiba, et al. (31)]. Little progress, however, can be reported concerning improved design of sedimentation tanks.

State-Of-The-Art

One to two generations of water quality control engineers have received academic training on rational analysis of sedimentation tank performance. These principles they have been taught are based largely on the work of Camp.

When graduates enter professional practice, they find established sedimentation tank design practices to be seemingly compatible with their fundamental academic training. The surface area of sedimentation tanks is sized on the basis of hydraulic loading per unit area, and this is basic to Camp's analysis. Minimum hydraulic retention times are sometimes used, but graduates are aware that hydraulic retention time may be important with flocculant suspensions. Hydraulic loading on effluent weirs is restricted, and this seems compatible with the need emphasized by Camp to provide adequate outlet facilities.

Additionally, attention is given to inlet design and to high average horizontal velocities. Everything seems copacetic.

In fact, as demonstrated in previous sections, actual hydraulic design is inferior to that presumed by Camp in his analysis. Concepts based on his analysis are, thus, not applicable, and performance of settling tanks is inferior to that which might occur with improved design practices.

Manufacturers of sedimentation equipment, for their part, have provided the profession primarily with empty style changes since the time of Camp's work[n]. Improvements in materials of construction and means for removing sludge have occurred, but rational and well documented improvements in the clarification efficiency of settling tank equipment have not been offered.

Summary

Thomas R. Camp's rational assessment of the performance of sedimentation tanks was readily and widely adopted by the profession. His concepts have guided the design of tens of billions of dollars worth of sedimentation tanks and continue to serve as the foundation for current design techniques.

The profession failed, however, to heed the stipulations set forth by Camp as prerequisites for application of his

---

[n] In presenting this paper, I showed a collage of advertising artistry and slogans used by manufacturers of sedimentation equipment to be considered vis à vis the actual records of performance of sedimentation tanks. Discretion dictated its elimination from published version of the paper.

concepts. Analysis of data from full-scale sedimentation tanks indicates that they do not perform in accordance with predictions based on Camp's work. Thus, major expenditures for water and wastewater treatment are being ineffectively spent.

In spite of Camp's monumental sedimentation contributions, in one sense he did not succeed in achieving his objectives. The first sentence of Camp's first paper on sedimentation (6) was:

> "It is the purpose of this paper to describe briefly some of the factors influencing clarification by sedimentation in an effort to stimulate interest in discussions leading to improvements in the methods of design of settling tanks."

Perhaps Camp presented his arguments too convincingly, for they were embraced too eagerly by the profession. The discussion and improvements that Camp sought to stimulate never occurred and the design of the most commonly used process in water and wastewater treatment still is not performed effectively. It is to be hoped that future developments will lead to an ability to design real settling basins that perform like the ideal basins accurately described by Camp.

References

1. Alarie, R.L., McBean, E.A., and Farquhar, G.J., "Simulation Modeling of Primary Clarifiers," Journal of the Environmental Engineering Division, ASCE, Vol. 106, No. EE2, 1980, pp. 293-309.

2. American Society of Civil Engineers, "Civil Engineering Classics - Outstanding Papers of Thomas R. Camp," American Society of Civil Engineers, New York City, New York, 1973, 410 pp.

3. Baumann, E.R., Cleasby, J.L., and Morgan, P.E., "Performance of Sedimentation Tanks in Model Tests," paper presented at National Symposium on Sanitary Engineering Research, Development and Design, Pennsylvania State University, July 29, 1965.

4. Bradley, R.M., "The Operating Efficiency of Circular Primary Sedimentation Tanks in Brazil and the United Kingdom," *The Public Health Engineer*, Vol. 13, 1975, pp. 5-19.

5. Camp, T.R., Discussion of "Sedimentation in Quiescent and Turbulent Basins," by J.J. Slade, Jr., *Proceedings ASCE*, Vol. 62, 1936, pp. 281-290.

6. Camp, T.R., "A Study of the Rational Design of Settling Tanks," *Sewage Works Journal*, Vol. 8, 1936, pp. 742-758.

7. Camp, T.R., "Sedimentation and the Design of Settling Tanks," *Transactions ASCE*, Vol. 111, 1946, pp. 895-936.

8. Camp, T.R., "Studies of Sedimentation Basin Design," *Sewage and Industrial Wastes*, Vol. 25, 1953, pp. 1-12.

9. Camp, T.R., Discussion of "Fundamental Concepts of Rectangular Settling Tanks," by A.C. Ingersoll, J.E. McKee, and N.H. Brooks, *Transactions ASCE*, Vol. 121, 1956, pp. 1205-1209.

10. City of Dallas, Oregon, "Combined Treatment of Domestic and Industrial Wastes by Activated Sludge," U.S. Environmental Protection Agency Publication No. 12130EZR05/71, 1971, 125 pp.

11. Cordoba-Molina, J.F., Hudgins, R.R., and Silveston, P.L., "Settling in Continuous Sedimentation Tanks," *Journal of the Environmental Engineering Division*, *ASCE*, *Vol. 104, No. EE6, 1978, pp 1263-1275.*

12. Dick, R.I., "Some Fundamental Aspects of Sedimentation," *Water and Wastes Engineering*, Vol. 6, Nos. 2 and 3, 1969, pp. 47-50 and 44-45.

13. Dick, R.I., "Role of Activated Sludge Final Settling Tanks," *Journal Sanitary Engineering Division*, *ASCE*, Vol. 96, No. SA2, 1970, pp. 423-436.

14. Dobbins, W.E., "Effect of Turbulence on Sedimentation," *Transactions ASCE*, Vol. 109, 1944, pp. 629-656.

15. Dresser, H.G., "Trays Nearly Triple Settling Tank Capacity," *Engineering News Record*, Vol. 147, No. 22, 1951, p. 32

16. El-Baroudi, H.M., "Characterization of Settling Tanks by Eddy Diffusion," *Journal Sanitary Engineering Division*, *ASCE*, Vol. 95, No. SA3, 1969, pp. 527-544.

17. El-Baroudi, H.M. and Fuller, D.R., "Tracer Dispersion of High Rate Settling Tanks," *Journal of the Environmental Engineering Division*, *ASCE*, Vol. 99, No. EE3, 1973, pp. 347-368.

18. Graber, S.D., "Outlet Weir Loadings for Settling Tanks," Journal Water Pollution Control Federation, Vol. 46, 1974, pp. 2355-2362.

19. Great Lakes-Upper Mississippi River Board of State Sanitary Engineers, "Recommended Standards for Sewage Works," Health Education Service, Inc., Albany, New York, 1978.

20. Hamlin, M.J., Discussion of "Hydraulic and Removal Efficiencies in Sedimentation Basins," by J.R. Villemonte, G.A. Rohlich, and A.T. Wallace, Advances in Water Research, Proceedings of the Third International Conference on Water Pollution Research, Munich, Germany, 1966, pp. 404-408.

21. Hansen, S.P. and Culp, G.L., "Applying Shallow Depth Sedimentation Theory," Journal American Water Works Association, Vol. 59, 1967, pp. 1134-1148.

22. Hayden, R., "Concentration of Slimes at Anaconda, Montana," Transactions American Institute of Mining Engineers, Montana, Vol. 46, 1913, p. 239 [as reported by Ingersoll, et al. (25)].

23. Hazen, A., "On Sedimentation," Transactions ASCE, Vol. 53, 1904, pp. 45-71.

24. Heinke, G.W., Qazi, A.T., and Tay, A., "Design and Performance Criteria for Settling Tanks for Removal of Physical-Chemical Flocs," Vol. II, Research Report No. 56, Environmental Protection Service, Ottawa, Ontario, Canada, 1977, 115 pp.

25. Ingersoll, A.C., McKee, J.E., and Brooks, N.H., "Fundamental Concepts of Rectangular Settling Tanks," Transactions ASCE, Vol. 121, 1956, pp. 1179-1204.

26. Johnstone, D.W.M., Rachwal, and Hanbury, M.J., "Settlement Characteristics and Settlement-Tank Performance in the Carrousel Activated Sludge System," Water Pollution Control, Vol. 78, 1979, pp. 337-356.

27. Lin, S.S. and Liao, P.B., "Evaluation of an Extended Aeration Process for Skokomish Salmon Processing Wastewater Treatment," U.S. Environmental Protection Agency Publication 600/2-79-027, 1979, 117 pp.

28. Parker, D.S., Kaufman, W.J., and Jenkins, D., "Characteristics of Biological Flocs in Turbulent Regimes," University of California, Berkeley, Sanitary Engineering Research Laboratory Report No. 70-5, 1970, 156 pp.

29. Pierce, D.M., "Upgrading Trickling Filters," U.S. Environmental Protection Agency Publication No. 430/9-78-004, 1978, 61 pp.

30. Reagan, R., Speech Delivered Before Joint Session of Congres on February 18, 1981, Congressional Quarterly Weekly Report, Vol. 39, No. 8, 1981, p. 361

31. Shiba, S., Inoue, Y., and Ueda, Y., "Estimation of Settling Basin Performance," Journal of the Environmental Engineering Division, ASCE, Vol. 105, No. EE6, 1979, pp. 1113-1129.

32. Slade, J.J., "Sedimentation in Quiescent and Turbulent Basins," Proceedings ASCE, Vol. 61, 1935, pp. 1435-1451.

33. Subcommittee on Sewage Treatment, National Research Council, "Sewage Treatment at Military Installations," Sewage Works, Journal, Vol. 18, 1946, pp. 789-1028.

34. Tebbutt, T.H.Y., "Pilot-Scale Wastewater Treatment Studies," The Public Health Engineer, Vol. 17, 1975, pp. 129-135.

35. Theroux, R.J. and Betz, J.M., "Sedimentation and Preaeration Experiments at Los Angeles," Journal Water Pollution Control Federation, Vol. 31, 1959, pp. 1259-1266.

36. Thirumurthi, D., "A Break-Through in the Tracer Studies of Sedimentation Tanks," Journal Water Pollution Control Federation, Vol. 41, Part II, 1969, pp. R405-R418.

37. U.S. Environmental Protection Agency, "1976 Needs Survey - Cost Estimates for Construction of Publicly-Owned Wastewater Treatment Facilities," Publication No. 430/9-76-011, 1977.

38. U.S. Environmental Protection Agency, "1978 Needs Survey - Cost Estimates for Construction of Publicly-Owned Wastewater Treatment Facilities," Publication No. 430/9-79-001, 1979.

39. Villemonte, J.R., Rohlich, G.A., and Wallace, A.T., "Hydraulic and Removal Efficiencies in Sedimentation Basins," Advances in Water Research, Proceedings of the Third International Conference on Water Pollution Research, Munich, Germany, 1966, pp. 381-399.