

9.0 EXTRAPOLATION OF MODELS TO A PRACTICAL DESIGN SITUATION

9.1 SOME ADVANTAGES OF CONES OVER RECTANGULAR PLATES

From the theoretical design equations developed in CHAPTER 7, it can be shown that the surface area of the rectangular plates is equal to that of the cones for similar Q , n , v and d . This is because the equations have been derived assuming that the volumes occupied by the various lengths are equal and since d is common to both types of units, so the surface area will also be equal.

The reductions in L_d that are experienced when using cones instead of rectangular plates, result in different vertical projections of the plate and cone areas onto the horizontal:

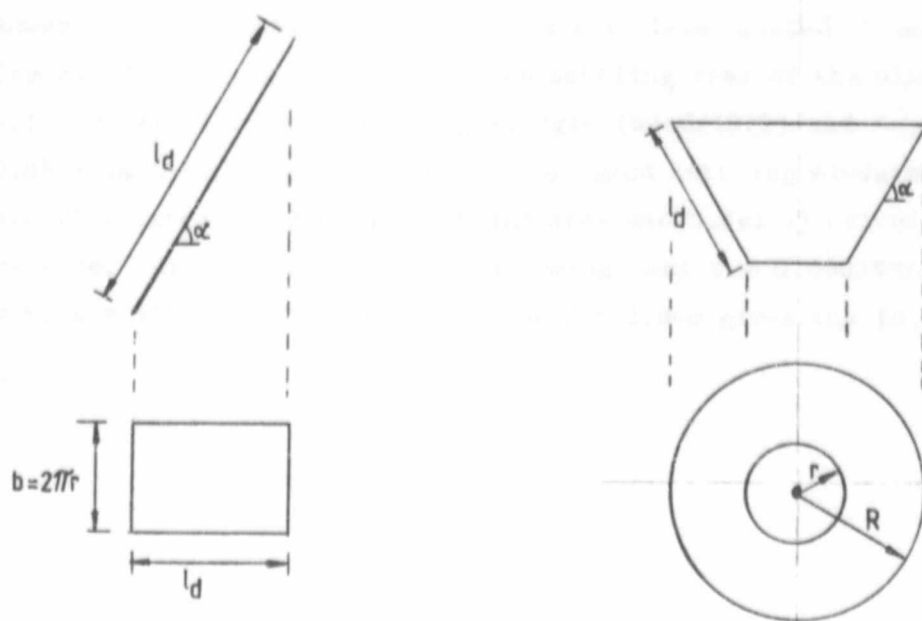


Figure 64. Vertical projection of the areas onto the horizontal.

The projected area of a ||l plate is given as:

$$A_p = L_d \cdot \cos \alpha \cdot 2\pi r \cdot d \quad \text{---(39)}$$

The projected area of a cone is given as:

$$\begin{aligned} A_c &= \pi [(L_d \cdot \cos \alpha \cdot d + r)^2 - r^2] \\ &= \pi [(L_d \cdot \cos \alpha \cdot d)^2 + 2L_d \cdot \cos \alpha \cdot r \cdot d] \quad \text{---(40)} \end{aligned}$$

The flow rates Q can be converted to operating overflow rates for the total horizontal projected settling areas (U), ie.

$$\begin{aligned} U_p &= Q / (A_p \cdot n) \quad \text{for ||l plates} \\ U_c &= Q / (A_c \cdot n) \quad \text{for cones} \quad \text{---(41)} \end{aligned}$$

Overflow rates quoted in the literature are sometimes based on the free air/liquid surface. This results in very high values of U (5 - 30m/h). Values based on the projected area ie. the settling surface area, are however more useful but unfortunately less quoted than the former. Practical values of U based on the settling area of the plates range from 0,1 - 0,5m/h for poor settling sludges (Ward(1979) and Schade(1984)) and 0,85 - 1m/h to slightly over 1m/h for good settling sludges. Plotting the overflow rates U (based on settling area and Model 5) calculated from (41) vs r for various Q' values and assuming that $v = 0,00038\text{m/s}$ (1,37m/h), $n = 5$, $\alpha = 55^\circ$, $\nu = 1,01 \times 10^{-6} \text{m}^2/\text{s}$ and $d = 0,04\text{m}$ gives the following figure:

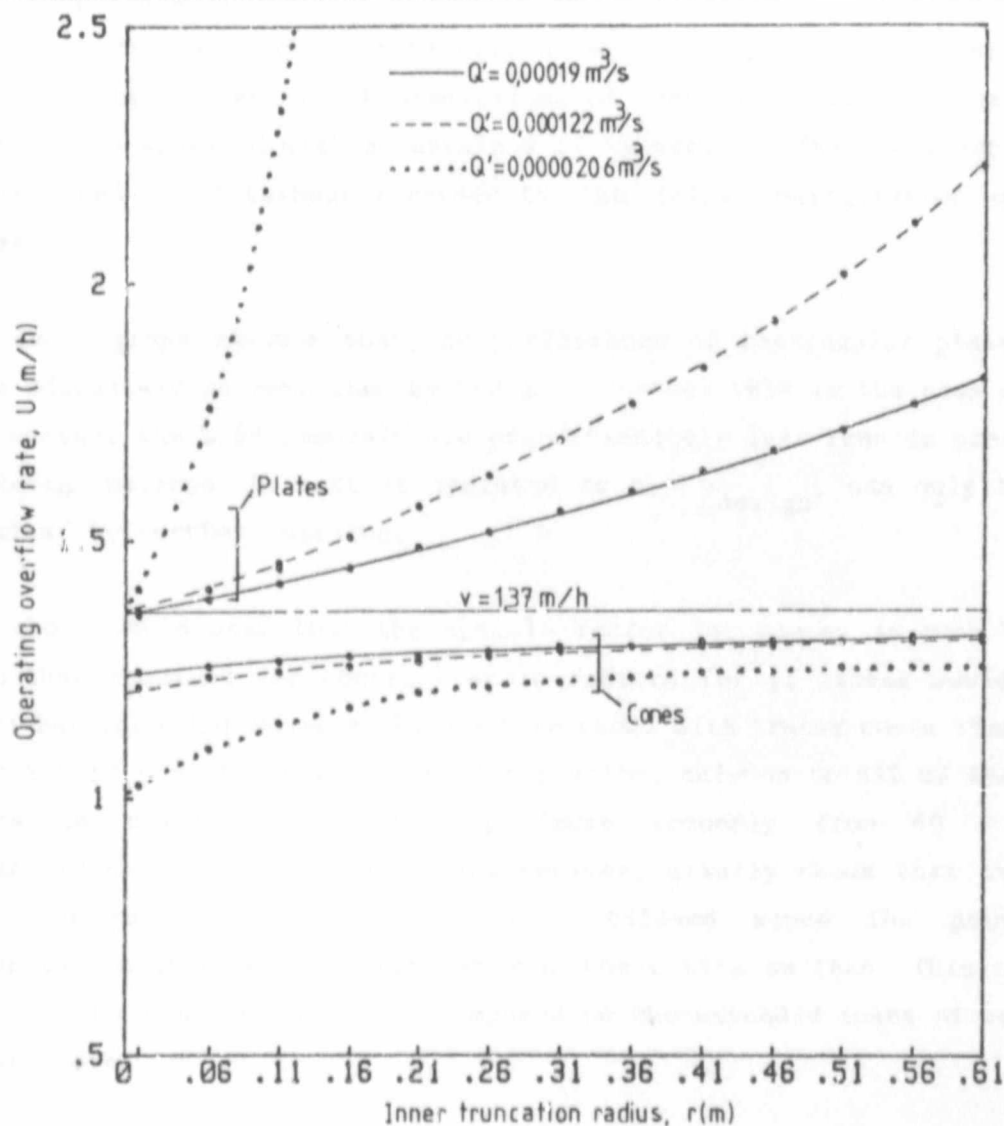


Figure 65. Operating overflow rate U vs inner truncation radius r for plates and cones.

The choice of $v = 0.00038 \text{ m/s}$ (1.37 m/h) means that at a certain influent SS concentration, if a lamella unit is operated at a lower v , then the desired % SS removal (say 70%) will be achieved. The operation of the unit at $v > 1.37 \text{ m/h}$ means that a proportionally lower % SS removal will be achieved. The above figure shows that a conical lamella unit is always operated at a lower v than stipulated by the batch settling tests. The theory for rectangular plates however, shows that plates are always operated at a higher overflow rate than stipulated by design and hence the

% SS removals will be considerably less than theoretically predicted. The fact that this should theoretically never occur in conical lamella, is borne out by the excellent predictions of Model 5 of effluent qualities that can be achieved with a certain v ($< 5\%$ error). The small error can be ascribed to disturbances caused by the inlet configuration of the cones.

The above graph assumes that the performance of rectangular plates can also adequately be described by Model 5. Whether this is the case or not and whether the % SS removals are proportionately less than is predicted by design because the unit is operated at $v > v_{\text{design}}$, can only be determined by further research.

The above would mean that the upscale factor for plates is much higher than that required for cones. Upscale factors for $\parallel$ plates would also be higher for other reasons. It has been shown with tracer tests that even with a very good inlet velocity distribution, only up to 85% of the full plate is utilised for settling (more commonly from 60 - 70%, Grimes(1978)). The photograph below however, clearly shows that the entire conical surface is uniformly utilised since the potassium permanganate is evenly distributed over the entire surface. This can be ascribed to a narrow inlet as compared to the extended inlet of rectangular plates.

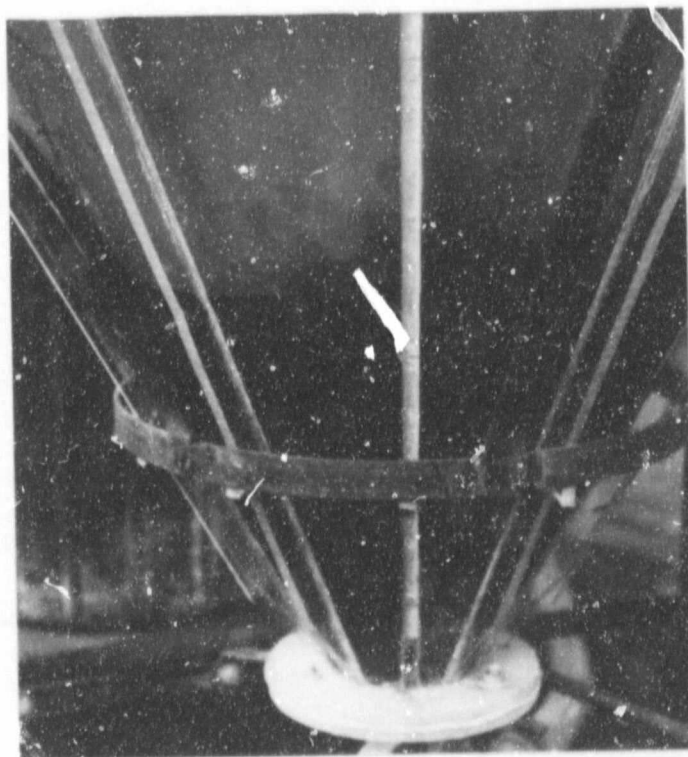


Figure 66. Potassium permanganate tracer in the conical lamella settler.

One way of characterising the type of flow between parallel plates, ie. whether the flow is laminar or turbulent, is through the Reynolds number. For efficient settling to occur, $Re \leq 500$. The Re number is given by:

$$Re = v_0 d_e / \nu \quad \text{---(42)}$$

where d_e is the effective hydraulic radius given in equation (43). For parallel plates d_e :

$$d_e = 2b \cdot d / (b + d) \quad \text{---(43)}$$

The effective hydraulic radius of a conical annulus is given by:

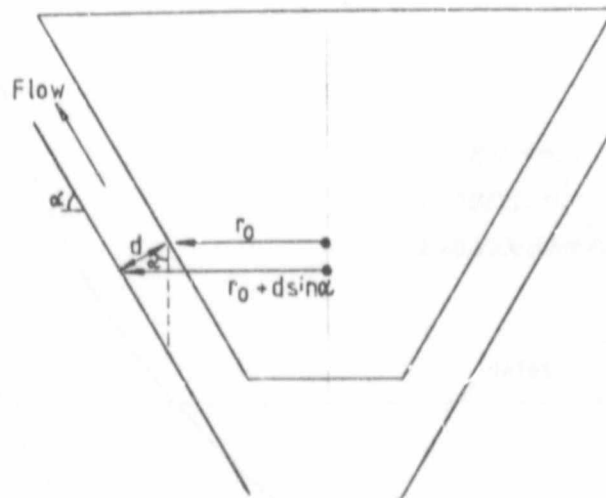


Figure 67. Effective hydraulic radius of a conical annulus.

$$\begin{aligned} d_e &= 4 \times [2\pi d(r_0 + d \sin \alpha / 2)] / [2\pi(r_0 + r_0 + d \sin \alpha)] \\ &= 2d \quad \text{---(44)} \end{aligned}$$

The average velocity between one plate is given by:

$$v_s = Q / (n \cdot b \cdot d) \quad \text{---(45)}$$

Substituting d_e and v_s into (42) for plates and cones and putting $b = 2\pi r$ for || plates and $b = 2\pi r_0$ for cones gives the following formulae for Re:

$$Re = 2Q / (v \cdot n \cdot (2\pi r + d)) \quad \text{for || plates}$$

$$Re = Q / (v \cdot n \cdot \pi r_0) \quad \text{for cones} \quad \text{---(46)}$$

The above formulae clearly show that the Re number for parallel plates is a theoretical constant whereas for conical plates Re varies as r_0 varies between r and R . For $n = 5$, $v = 1,01 \times 10^{-6} \text{ m}^2/\text{s}$, $d = 0,04\text{m}$ and varying P $\leq r_0 \leq 0,3975\text{m}$, gives the following plot:

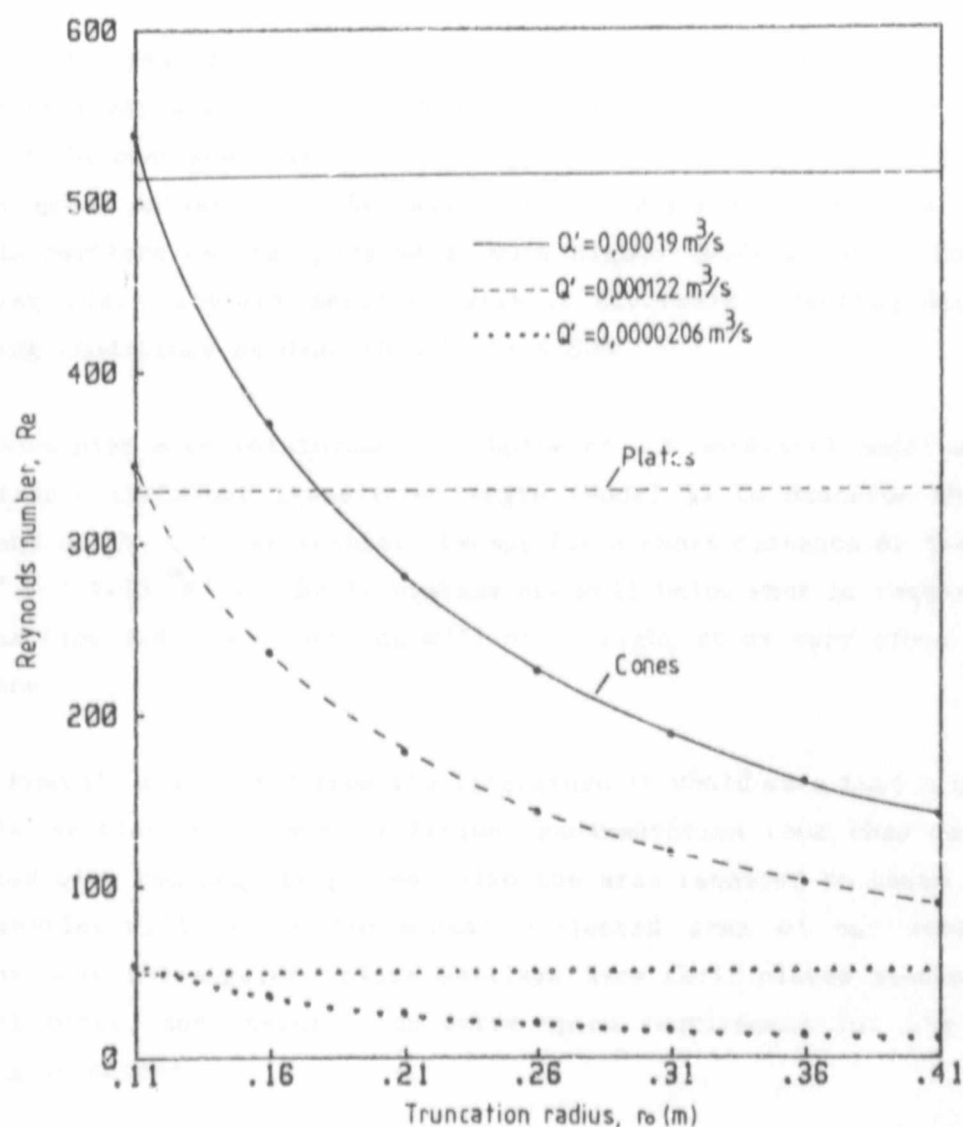


Figure 68. Reynolds number Re vs truncation radius r_0 for rectangular and conical plates.

The plot of Re vs r_0 highlights most dramatically the advantages of flow through conical plates as apposed to rectangular ones. This is because the Re number drops with an increase in r_0 thus making the flow more laminar as it progresses through the plate, whereas Re remains constant throughout for rectangular plates. Re for cones is higher than that for plates but only for a very short distance at the inlet and then drops dramatically below the Re value for rectangular plates, especially for high Q' . For instance at $Q' = 1.9 \times 10^{-4} \text{ m}^3/\text{s}$, $Re = 514$ for rectangular plates. This is an unacceptable operation of a lamella settler since Re

4 500. At the same Q' however, $Re = 544$ at the inlet for the conical plates and drops right down to $Re = 146$ at the outlet. Also the region at the inlet of the cone where $Re > 500$ is very small and will not affect settling to any great extent since Re falls very rapidly below 500. Thus conical lamella settlers can be operated at much higher loading rates than rectangular plate lamella settlers without adversely affecting desirable settling conditions as described by $Re \leq 500$.

The above plot also reinforces the choice of a theoretical model without an entrance turbulent transition length (Model 5) to describe the performance of the conical settler. Except for a short distance at the inlet for $Q' = 1,9 \times 10^{-4} \text{ m}^3/\text{s}$, the Re numbers are well below what is required for laminar flow and hence settling will occur right at or very close to the entrance.

Hence from the theory and from the literature it would seem that a conical lamella settler is a more efficient sedimentation tank than one constructed with rectangular plates. Also the area required to house a conical settler will be the horizontal projected area of one cone only whereas most rectangular plate settlers have their plates stacked next to each other, and therefore an extra space requirement for the plate spacing is needed.

9.2 TYPICAL PROCEDURE THAT CAN BE FOLLOWED IN UP-RATING AN EXISTING HYDRAULICALLY OVERLOADED CLARIFIER.

Assume that a cylindro conical upward flow tank with the following dimensions is operating satisfactorily underground in a mine:

Outer diameter = 7,3m

Stilling box diameter = 1m

Depth of cylindrical section = 3m

Hydrostatic de-sludge with a 60° conical section

$$\begin{aligned}\text{Effective settling area} &= \pi/4((7,3)^2 - (1)^2) \\ &= 41,07\text{m}^2\end{aligned}$$

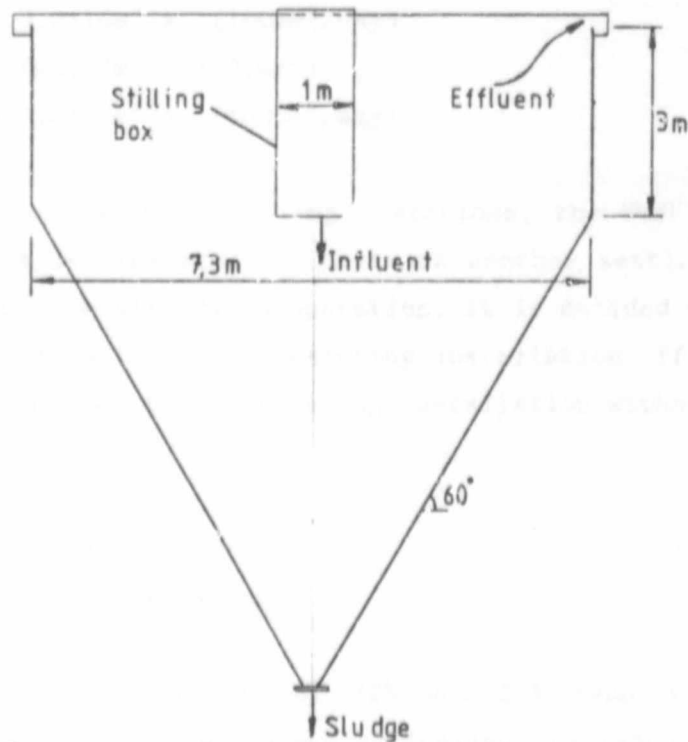


Figure 69. Dimensions of sedimentation tank.

Assume that the average SS concentration is 2000mg/l and that the batch settling results in APPENDIX A are valid for a settling depth of 3m. Also assume that a 70% SS removal is regarded as satisfactory operation of the settler.

From the batch settling data and from figure 21 an overflow rate of 4,11m/h is theoretically permissible for a 70% SS removal efficiency. However full-scale tests on the sedimentation tank have shown that, because of turbulence in the settler, an overflow rate of only 3,05m/h is permissible for satisfactory performance (upscale factor of 1,35). It has however been stipulated that the settler is to operate satisfactorily at all flows. Hence critical operation will be at peak wet weather flow (PWWF). The PWWF is estimated as 3×ADWF (average dry weather flow) and therefore $v = 3,05\text{m/h}$ at PWWF and $v = 1,02\text{m/h}$ at ADWF. The % SS removal at ADWF is therefore 88% (figure 21) which is well above that which is required. The capacity of the settler at the two operating conditions is therefore:

$$\begin{aligned}\text{ADWF} - Q &= (41,07\text{m}^2) \cdot (1,02\text{m/h}) \\ &= 0,0116\text{m}^3/\text{s} \quad (1005\text{m}^3/\text{day}) \\ \text{and PWWF} - Q &= (41,07\text{m}^2) \cdot (3,05\text{m/h}) \\ &= 0,0348\text{m}^3/\text{s} \quad (3006\text{m}^3/\text{day})\end{aligned}$$

As a result of extensions in mining operations, the PWWF and ADWF have doubled. Since it is expensive to construct another settler of the same dimensions as the one already in operation, it is decided to investigate the feasibility of up-rating the existing installation. If the increased flow rate (2.Q) is fed to the existing installation without alterations an overflow rate of:

$$\begin{aligned}\text{ADWF} - v &= 2,04\text{m/h} \\ \text{and PWWF} - v &= 6,1\text{m/h} \quad \text{will result.}\end{aligned}$$

This results in % SS removals of 82% and 32% respectively and the sedimentation tank is therefore hydraulically overloaded since it performs very poorly at the PWWF.

To overcome this problem, it is envisaged that conical lamella plates are a possible solution. Batch settling tests (as described in APPENDIX A) are carried out for a concentration of 2000mg/l and the batch settling overflow rate v for a settling depth of $h' = d/\cos\alpha$ where $d = 0,04\text{m}$ and

$\alpha = 55^\circ$, is calculated (as shown in APPENDIX H). From this procedure a value of $v = 1,57\text{m/h}$ is obtained for $h' = 0,07\text{m}$ and a 70% SS removal efficiency (read off from graphs of % SS removal vs v).

It has however been shown from tests conducted with the model perspex tank, that this value needs to be upscaled. From figure 42 (CHAPTER 6) an upscale factor of 1,1 is required for an influent SS concentration of 2000mg/l. Hence the allowable overflow rate is:

$$\begin{aligned} v &= (1,57\text{m/h})/1,1 \\ &= 1,43\text{m/h} \\ &= 0,0003972\text{m/s} \end{aligned}$$

To proceed with the design of the cones various parameters have to be fixed. The maximum number of cone spacings that can be fitted into the settler is:

$$n = [3 + (7,3/2) \cdot \tan 60^\circ - F - (R-r) \tan 60^\circ] / (d/\cos \alpha) - 1 \quad \text{---(47)}$$

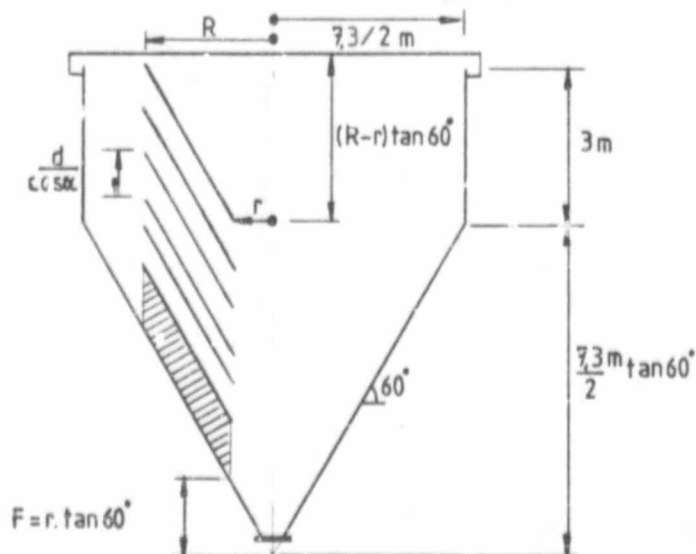


Figure 70. Maximum number of cone spacings that can be fitted into the tank.

n is decreased by one since since it is inadvisable to use the lower spacing, ie. the one between the conical wall of the clarifier and the lowest lamella cone (shaded spacing in the above figure), since the coefficient of friction of concrete (it is assumed the settler walls are constructed of this) is much higher than that of smooth perspex or PVC. The lower spacing could therefore become blocked due to inadequate continuous de-sludging. It should also be noted that the space requirement of the cones is calculated using the gutter angle of 60° instead of the cone angle $\alpha = 55^\circ$, since the gutters are the critical criteria determining the total height requirement. Equation (47) simplifies to (for $\alpha = 55^\circ$ and $d = 0,04\text{m}$):

$$n = 132,67 - 24,84.R \quad \text{---(48)}$$

As n is now a function of R , equation (34) for Model 5 has to be solved iteratively, substituting the new value of Q at PWWF. Plotting n vs r and L_d vs r gives the following graphs:

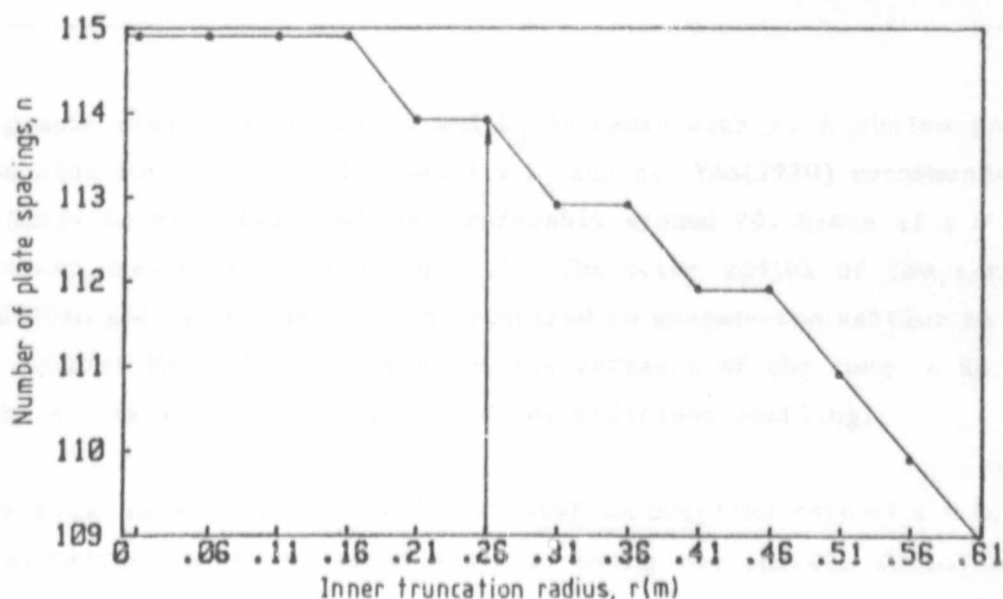


Figure 71. Number of plate spacings n vs inner truncation radius r .

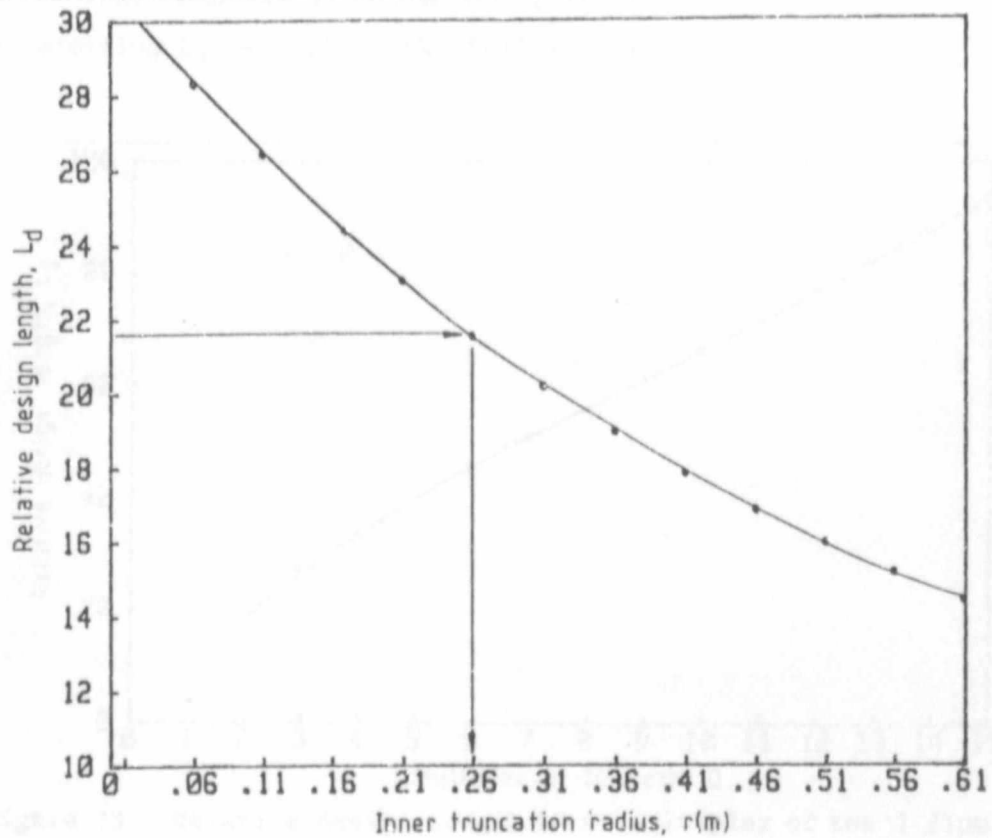


Figure 72. Relative design length L_d vs inner truncation radius r .

The graphs clearly show that n and L_d decrease with r . A choice now has to be made for r which will then fix L_d and n . Yao(1970) recommends that L_d should be kept below 40 and preferably around 20. Hence if $r = 0,26\text{m}$ is chosen then $L_d = 21,71$ and $n = 114$. The outer radius of the cones is $R = 0,758\text{m}$ and 115 of them will be required to up-rate the settler to twice it's initial PWWF. The Re number at the entrance of the cone is $Re = 370$ which is less than the 500 required for efficient settling.

For a flow rate of $Q = 0,232\text{m}^3/\text{s}$ at ADWF an overflow rate of $v = 0,48\text{m}/\text{h}$ is maintained in the up-rated settler. Using the upscale factor of 1,1 gives a value of $v = 0,53\text{m}/\text{h}$. The % SS removal at this overflow rate can be read off from the graphs of % SS removal vs overflow rate given in APPENDIX H. For $v = 0,53\text{m}/\text{h}$ a % SS removal of 90% is achieved which is well above the minimum 70% stipulation.

If r is kept constant at 0,26m and Q is increased in multiples of one, then plotting L_d vs Q gives the following figure:

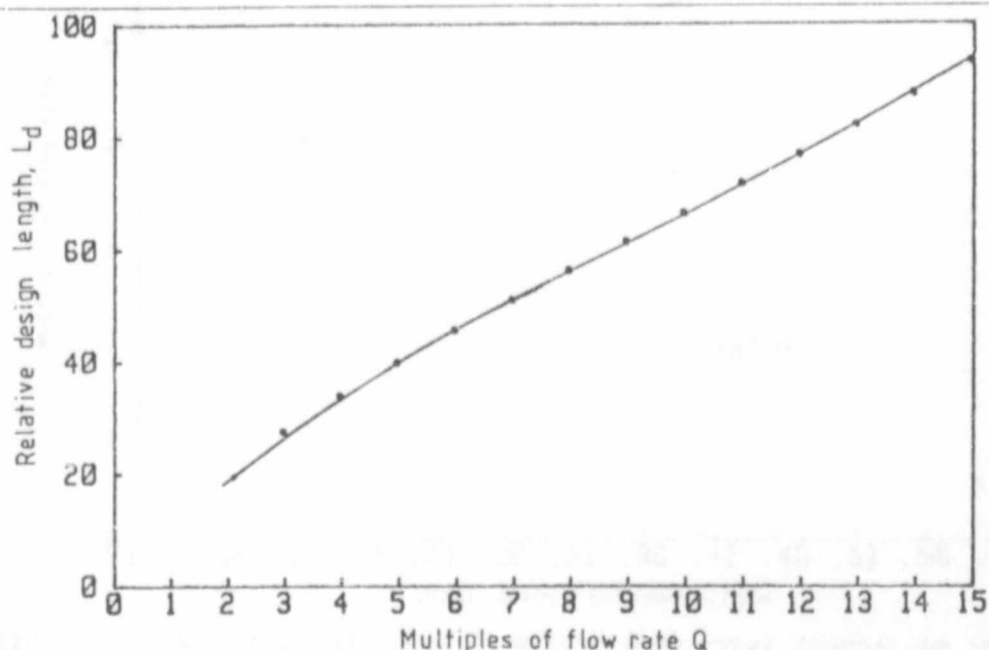


Figure 7.3 Relative design length L_d vs multiples of total flow rate Q for a constant $r = 0,26\text{m}$.

Clearly L_d increases with Q and at $15 \times Q$ the outer radius R of the cone is $R = 2,436\text{m}$. Such a size cone can still be accommodated in the cylindro conical settler and therefore even more than 15 times the PWWF can be passed through the up-rated settler. This can represent considerable cost savings. The sizes of the cones required for such high flow rates are however considerably bigger and structural and support problems might be encountered. Also flow instabilities might result as the cones become longer than a certain length and the laminar flow will convert to turbulent flow resulting in decreased % SS removals. If the recommendation of $L_d < 40$ is adhered to, then the above figure shows that the capacity of the original settler can be up-rated 5 times its original PWWF for $r = 0,26\text{m}$. This up-rating value is even bigger if r is increased, ($L_d \approx 40$) as shown below:

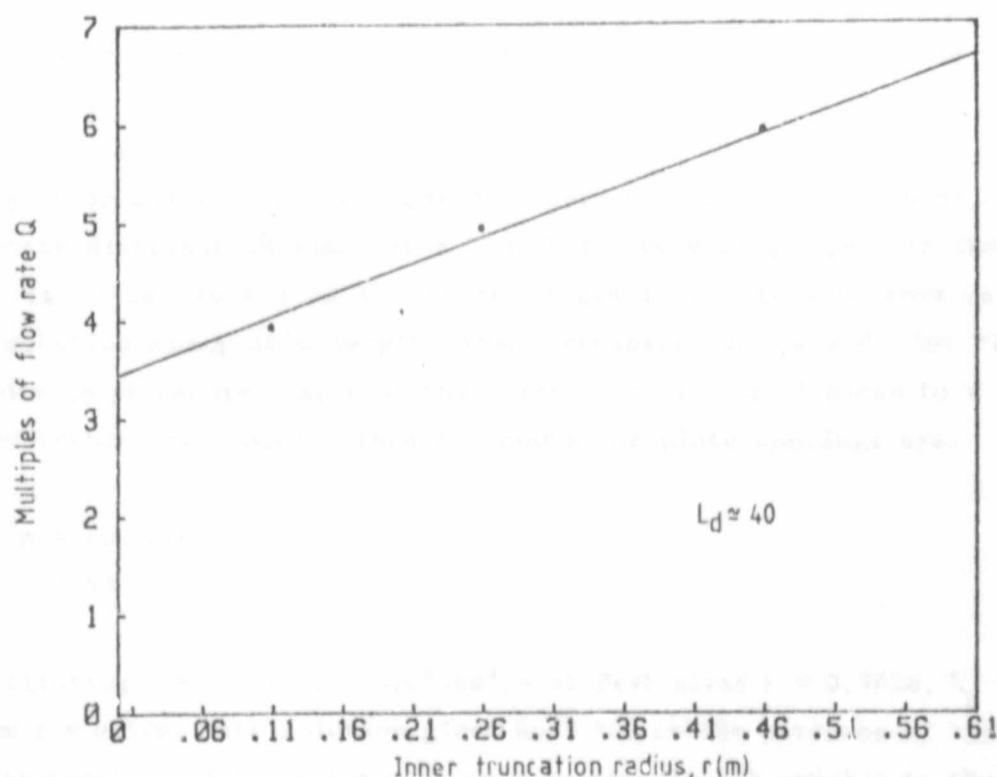


Figure 74. Multiples of total flow rate Q vs inner truncation radius r .

The figure shows that the minimum up-rating factor for any value of r is ≈ 3.5 for the constraint $L_d \approx 40$ and that as r is increased so is the total flow rate Q which can be passed through the settler.

It must be remembered that the results presented in the design example are extrapolated from a model tested in the laboratory. When introducing plates on a full scale into an existing settler, bigger deviations from the theory than were obtained in the laboratory can be expected. The extrapolated results are however presented with a certain confidence since Model 5 is very accurate ($< 5\%$ error) and also highly consistent with varying flow rates. At the most, the upscale factor used in the design example could be higher for a full scale operation. The above design procedure can therefore serve as a good first estimate. Also, since the edges of the cones are fairly distant from the edge of the settler walls and effluent launders, side wall effects caused by the constriction of

the flow lines, will be a lot smaller than what they were in the laboratory model.

A region in which problems might be experienced is the inlet pipe and the velocity distribution along it's length for very long pipes. If the inlet slot is to be limited to a certain length to obtain a uniform velocity distribution along it's length, then provision can be made for this in the design procedure. Say that the inlet slot is to be limited to a length of 3m (arbitrary choice). Then the number of plate spacings are:

$$n = (3\text{m})/(0,07\text{m}) \\ \approx 43$$

Substituting $n = 43$ and $Q = 0,0348\text{m}^3/\text{s}$ at PWWF gives $R = 0,961\text{m}$, $L_d = 19,7$ at an $r = 0,57\text{m}$. This solution gives $Re = 500$ at the entrance of the cone. The restriction of the inlet slot to a certain length results in the cones having the following configuration within the up-rated tank.

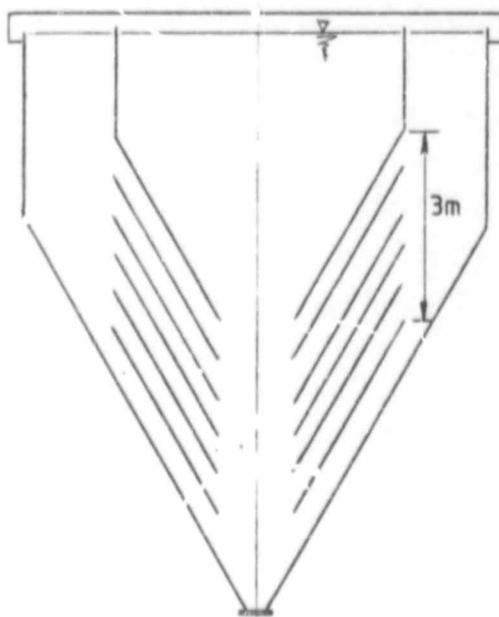


Figure 75. Conical lamella pack position in the up-rated clarifier.

Whether it is necessary to limit the length of the inlet slot and also how closely a full scale operation follows the theory can only be determined by further research.

Alternatively a new settler can be designed for only the ADWF and conical plates can be installed to cope with the PWWF. If the $PWWF = 3 \times ADWF$ then this means a 3 fold reduction in the surface area required for the sedimentation tank. Clearly the introduction of conical plates within a sedimentation tank results in considerable cost savings, so much so that one settler can do the work of up to 6 or 7 settlers.

10.0 LIMITATIONS AND ACCURACY OF REPORTED RESULTS

Although the previous chapters clearly show that substantial advantages in the form of cost and space savings and improved effluent qualities are to be had in up-rating an installation using conical lamella plates, there are several aspects which require serious thought and research to try and make conical lamella plates as generally applicable as possible.

• Flocculation

Flocculation is the addition of chemicals to the water which result in the coagulation of non-settleable or colloidal particles and hence their removal by settling. Flocculation essentially occurs in two stages. The first is a flash mix stage in which the chemical is added to the influent and thoroughly mixed to produce an extremely rapid and uniform distribution of the coagulating chemical throughout the water. In a redimentation tank in which up-rating is envisaged and in which flocculants have been previously added to the feed, this flash mixing unit is already present in some form or another and no extra provision has to be made for it. The second stage in flocculation is the floc formation and conditioning stage. During the floc formation stage colloidal particles collide and are able to stick to one another because the electrical charges which kept them apart before flocculation have now been neutralised by the chemicals. The small flocs then combine with one another to form larger flocs which settle out faster. This is the conditioning stage. These stages occur under reduced turbulence with only gentle agitation taking place. The retention time in the flocculating basin to achieve this second stage can vary anything from 2 minutes to 30 minutes depending on the sludge type and chemicals used.

In conventional sedimentation tanks with depths of 3 to 5m, the retention time is of the order of one or more hours. There is therefore sufficient time for the floc formation and conditioning stage to take place within the clarifier without the need of an additional flocculating basin. Also

many upward flow tanks are operated as upward contact clarifiers. This type of clarifier is operated such that a sludge blanket is maintained at a certain depth within the clarifier. The sludge blanket consists of the settling floc and is situated at a level where the vertical velocity of the flow equals the settling velocity of the floc particles in the blanket. The sludge blanket serves an important purpose in that it filters the upward flow of particles which have not been chemically coagulated in the floc formation stage.

The operation of a lamella settler under the above conditions is not possible since the retention time within the settler is less than 15 minutes. There is therefore insufficient time for the floc formation and conditioning stage to take place within the settler and must therefore occur outside the unit. A separate flocculating basin is thus required. The cost of such a flocculating basin however, can be offset by the reduced long term cost of chemicals required since the clarification properties of the lamella settler are so much more better than that of upward flow clarifiers. Also the results obtained in the laboratory show that the conical lamella settler is fairly insensitive to changes in the SS concentration in the influent. This is important in that the chemical requirement needed to remove the colloidal content of the SS increases with an increase in feed SS concentration. Hence the optimum operation of a conventional upward contact clarifier requires an experienced operator on hand who is able to detect any change in the incoming feed SS concentration and change the chemical dosage accordingly. The insensitivity of the conical lamella settler to feed SS concentrations will alleviate the need for such close monitoring of the unit.

Care must also be taken to limit the flow velocities of the feed water to a certain maximum after the floc formation and conditioning stages to prevent breaking up of the flocs. It is the feeling of the author that the inlet pipe utilised in the laboratory model has a limited application to non-chemically flocculated waters since the inlet pipe might result in too high velocity gradients which will break up the already conditioned flocs. An inlet arrangement as shown in figure (38) would be more appropriate, but only further research into the matter could tell for sure.

The use of cones as an up-rating mechanism is therefore limited to non-chemically flocculant and discreet settling sludges as well as chemically flocculated feeds with the provision of a flocculating basin or the polishing of effluents from a previously under-designed unit process. The use of the cones as a lamella settler without the intention of up-rating seem endless with many advantages over rectangular plates due to the constriction of the inlet into a circle and the reduction of velocity with an increase in the radius.

6. The role of the shape of the cone

For efficient continuous de-sludging of the settled material on the cones an angle of not less than 55° is required. The triangular gutters are however at an angle of 60° and are the critical criterion determining the space requirements for the cone. Some sedimentation tanks, especially the radial flow type, have a floor slope of only 10° . This physical constraint of the tank does not pose any problems in up-rating the installation as is shown in the figure below:

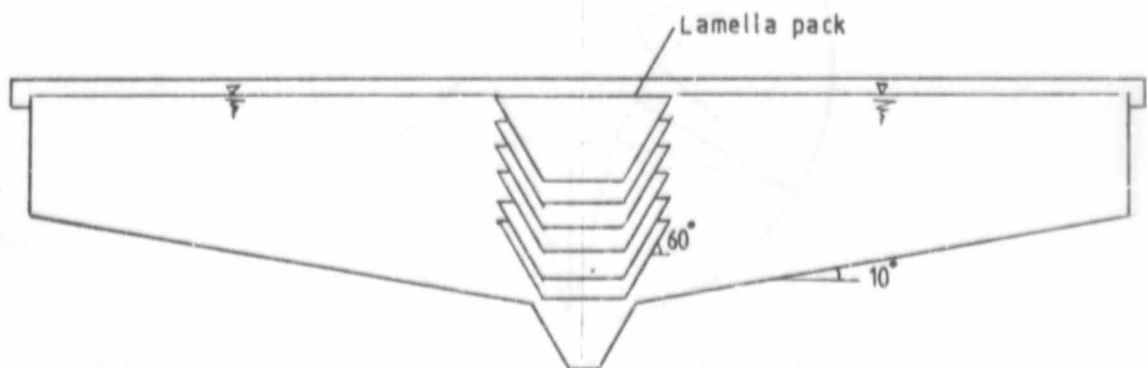


Figure 76. Up-rating of a radial flow sedimentation tank.

Also the above figure clearly shows that the periphery of the cones are fairly distant from the effluent launders. Hence the side wall effects

experienced in the laboratory model (50mm from the edge of the cones to the weirs) is not present. Also particles not captured in the plates still have time to settle on their way from the central cones to the effluent weirs. The distance between the cones and the weirs makes it possible to up-rate square or rectangular tanks if desired. The conical lamella plates are therefore not restricted in the use of circular clarifiers only.

Since the sludge is concentrated and funnelled directly into the central sludge hopper of the radial flow tank, less sludge needs to be removed by the mechanical scrapers resulting in lower power requirements and hence also less maintenance of the scrapers.

The inner truncation radius of the cones in the laboratory model is $r = 0,11m$. In a full scale operation this will need to be bigger. The use of four triangular gutters for a larger r results in a flatter triangular gutter and possibly less efficient de-sludging. This problem can easily be overcome by designing the cones with more gutters as shown below:



Figure 77. Plan view of cone with 6 triangular gutters.

The above figure shows a cone with 6 triangular gutters. Apart from better de-sludging because of the steeper side slopes of the gutters, they also provide more support in the form of beams for the larger cones.

- o Accuracy of the reported results

As mentioned before, the sludge tested in the laboratory was dehydrated mine sludge without the addition of chemicals or flocculants in the sedimentation tanks. Hence the maximum physical removal of SS possible is only that portion of the SS that is settleable. The colloidal or non-settleable material is therefore continuously circulated in the system used in the laboratory and increases in magnitude every time an increase in the influent SS concentration is measured. Now had the system been discontinuous as occurs in practice then the increase in non-settleable matter would not have an effect on the % SS removals if the grading of the incoming SS in the feed remains constant. The continuous system however, results in an initial build up of colloidal material with every addition of dehydrated mine sludge. This is because the settleable material settles on the conical surfaces and requires a certain amount of time to slide down the inclined surface before it is de-sludged and returned to the feed bucket. During this retention time of the settleable material on the conical surfaces, the colloidal material is circulating in the system and an analysis of an influent and effluent sample will show poor % SS removals and would seem to indicate poor settling abilities of the sedimentation tank whereas, in actual fact all the settleable material has been removed but is still on its way down the inclined surface before it is returned to the system.

For this reason a continuous system is not an ideal way of testing % SS removals and would seem to indicate that the % SS removals reported are actually better in a non-continuous system especially at low feed concentrations. Notwithstanding the above, the conical lamella settler still produces much improved effluent qualities. It is for the above reasons that the feed concentrations tested on the model were $> 500\text{mg/l}$ and also that it was run for ± 1 hour to give the settled material enough time to return to the system via the extended settling surfaces.

Another problem experienced with the system was the air entrainment at high flow rates. This was caused by the mechanical stirrer and was minimised by flattening the propeller blades. The air entrainment re-

sulted in particles being flotated to the surface and washed out with the effluent. Much of the scatter in the reported results can be attributed to this. The above problems are easily avoidable in non-continuous flow circuits.

11.3.3. Method of Measurement

The method of measurement used in this study was a gravimetric method. The sample was weighed on a balance and then placed in a container. The container was then filled with a liquid of known density. The container was then sealed and the liquid was allowed to settle. The weight of the container was then measured. The weight of the sample was then calculated by subtracting the weight of the container from the weight of the container plus the sample. The density of the sample was then calculated by dividing the weight of the sample by the volume of the sample.

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11.0 CONCLUSIONS AND RECOMMENDATIONS

11.1 SUMMARY AND CONCLUSIONS

An attempt was made to develop a method for up-rating existing hydraulically overloaded sedimentation tanks. Emphasis was placed on eliminating the uneven velocity distributions that result in the use of tube modules as well as the additional effluent launder systems required to overcome this problem. A mass producible mechanism to achieve this was designed and took the shape of cones stacked one on top of the other thus forming the conical lamella settler. From the performance results of the conical lamella settler and a conventional upward flow tank several conclusions can be made:

- Upward flow tanks are very inefficient settling devices if their performance is seen relative to the batch settling results. It is for this reason that upscale factors in the region of 1,25 - 1,75 are used in practice for their design to account for the turbulence and other non-idealities occurring in the tank.
- The conical lamella settler produces much improved effluent qualities compared to the conventional upward flow tank especially at high flow rates. It is therefore much more resistant to shock loadings, producing still acceptable effluent qualities at high overflow rates whereas the upward flow tank settling characteristics result in a dramatic drop in effluent quality with an increase in the overflow rate. This phenomenon of the conical lamella settler makes it very suitable for the design of average loadings only. It's resistance to hydraulic loading will take care of the peak loads. This design approach is not possible with conventional sedimentation tanks which have to be designed for the peak loads if acceptable effluent qualities are desired throughout. Hence the conical lamella settler will

result in considerable space savings compared to conventional systems.

- o Generally, because the removal efficiency of the conical lamella settler is all that much better than the conventional system, the % sludge concentration for the lamella system will be higher than that for the upward flow tank for a constant sludge withdrawal rate. If a certain % sludge concentration is required in the lamella system, a mass balance can be done across it to determine the sludge withdrawal rate.
- o The mathematical model which predicts the conical lamella results the most accurately and consistently is the Yao model with no transition length to dissipate inlet turbulence. The discrepancy between theory and practice for $d = 40\text{mm}$ is a consistent 3% - 4%; the theory consistently predicting better removals. The 3% - 4% discrepancy is attributed to inlet turbulence caused by the gutter arrangement and not the existence of a transition length. The fact that no transition length is required as a safety factor in the design of the conical lamella system would seem to back Yao's (1970) feeling that a mixture of turbulent and laminar flow occurs at the inlet which results in a form of uniform flow in which settling is just as good as under laminar flow conditions.
- o The incorporation of the Nakamura model for quiescent settling under inclined plates results in theoretical % SS removals that are too high.
- o For the sludge tested in the laboratory a plate spacing of $d = 40\text{mm}$ performs better than $d = 32\text{mm}$ even though the theory predicts better % SS removals for $d = 32\text{mm}$. The fact that $d = 40\text{mm}$ produces better results than $d = 32\text{mm}$ is ascribed to lower inlet velocities and a wider plate spacing which allows for less or no re-suspension of settled sludge into the influent, as compared to the $d = 32\text{mm}$ case.

- The discrepancy between theory and practice for the conical lamella settler, results in much smaller upscale factors for the lamella in comparison with the upward flow tank. This means that the conical lamella settler is a much more efficient form of settling unit process.
- The geometry of conical plates in comparison with rectangular plates allows for many theoretical advantages for cones. These theoretical advantages are calculated assuming that the performance of rectangular plates is also adequately described by the same model used for conical lamella. Theoretically it would seem that rectangular plates always operate above their design overflow rates resulting in proportionately reduced % SS removals, whereas the conical lamella operate below the design overflow rate resulting in almost theoretical % SS removals (as was observed in the laboratory).
- Theoretically it would be advantageous to make rectangular plates as wide as possible. In practice the plate width is however limited to approximately 1,2m or smaller depending on the inlet arrangement. This is because it is difficult to achieve a uniform velocity distribution over a wide inlet. The conical plates do not suffer from this disadvantage as the inlet is constricted into a circle. It has also been shown that usually only 60% to 70% of a rectangular plate is utilised due to non-uniform velocity distributions at the inlet. Colour tracer tests show that the entire conical surface is utilised for settling.
- Theoretically conical lamella settlers can be operated at much higher Q' than rectangular plate lamella sedimentation tanks. This is because the Re number drops rapidly from the inlet of the cones to the outlet at their periphery whereas the Re number remains constant throughout the length for the rectangular plate.
- By correctly sizing the cone, up-rating factors many times the original loading can be achieved.

- o The consistency of the experimental results indicates that the inlet pipe which was designed on a trial and error basis performs adequately or either the system sorts itself out to produce consistent results.
- o It is the author's feeling that the inlet pipe utilised in the laboratory experiments is limited to the use of feed sludges which have not been chemically flocculated, as inlet velocity gradients might be too high and will break up the conditioned flocs. Other inlet arrangements could overcome this problem, but only further research will substantiate this.
- o The retention time of the influent is less than 15 minutes in the conical lamella settler for overflow rates that produce acceptable effluent qualities. This is insufficient time for adequate floc formation and conditioning to take place within the unit for chemically treated waters. A flocculating basin with the correct retention time is required ahead of the conical lamella settler. This adds to the cost of the sedimentation unit process but can be offset by the reduced long term cost for chemicals and also the much reduced size of the sedimentation tank. Also the conical lamella settler is a lot more insensitive to changes in the SS in the feed concentration. Therefore such a clarifier will require less supervision in the chemical feed dosage rate compared to say an upward flow clarifier where constant monitoring of the influent SS concentration is essential if uniform effluent qualities are desired.
- o As an up-rating mechanism for existing installations fed with chemically treated waters, the conical lamellas are only suitable if provision is made for a flocculating basin or if they are used to polish the waters after sedimentation, ie. an intermediate step between say sedimentation and filtration. The use of the conical lamellas in a contact clarifier is not feasible.
- o The conical lamella settler is in its development stages only and much more research is required to perfect the system and to check whether some of the assumptions made are correct in practice. Research

is especially required in the sensitivity of the conical lamella settler to parameters such as r , R and Q' . Full scale pilot plant operation is also required to test the system under operating conditions experienced in practice as well as to see whether there are any scale effects.

11.2 RECOMMENDATIONS

As stressed throughout the document much research is still required in certain aspects of the conical lamella settler. Some of the main ones are:

- The performance of the conical lamella settler, treating chemically flocculated waste waters.
- The sensitivity of the conical lamella to a change in it's physical dimensions, mainly parameters such as R , r , and Q' .
- Full scale pilot plant operation.
- The effect of some of the variations to the inlet as proposed in the text.
- Further research into the performance of rectangular plates to verify the theoretical advantages of conical plates as compared to rectangular plates.
- The settling efficiencies of different types of sludges in the conical lamella settler, eg. sewage sludges.
- A cost analysis to verify the feasibility of up-rating a system using cones instead of tube modules.
- Cost savings, if any, which can be incurred due to the reduced usage of flocculants with the installation of cones.

APPENDICES

12.0 APPENDIX A. BATCH SETTLING TEST APPARATUS AND RESULTS

Batch settling tests were carried out in a 187,5mm diameter PVC pipe with sampling taps at different levels (see figure below).

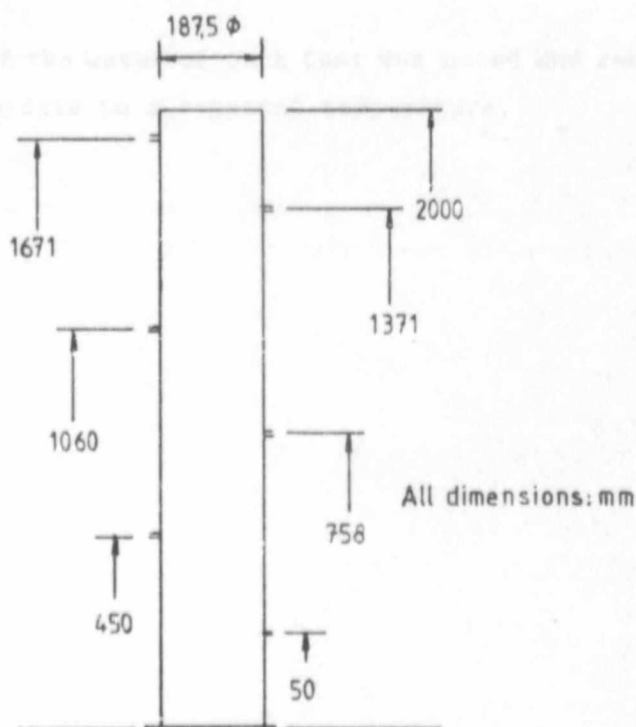


Figure 78. Dimensions of batch settler.

A well mixed sample of water at a specific concentration was introduced into the pipe and allowed to settle under quiescent conditions. Samples were withdrawn from the upper three sampling taps at various time intervals and analysed for suspended solids concentrations. Six batch settling tests were done with the concentrations ranging from 500 - 3000 mg/l. The desired sludge concentrations were obtained by mixing dehydrated mine sludge and tap water. The mine silt was first passed through a 300µm sieve to remove all coarse particles that could cause blockages in the pipes of the model settler.

All subsequent calculations were limited to the depth of 400mm (depth of the perspex settling tank) since the depth of the test cylinder should equal the depth of the prototype tank. The concentrations of SS measured were expressed as a percent of the original concentration and the fractional removal is the difference between 100 and this value. Curves of SS removal vs time and depth as well as % SS removal vs overflow rate were drawn up. Detailed procedures of the methods employed to obtain these curves are given in "Water and Wastewater Treatment, M Humenick, pp 64".

The temperature of the water of each test was noted and recorded for later adjustment of the data to a constant temperature.

BATCH SETTLING RESULTS FOR INITIAL CONCENTRATION = 570mg/l

TIME (min)	Percent removal by depth from top of settling column		
	369mm	680mm	982mm
5	34	22	12
10	51	43	34
20	71	64	61
40	85	82	76
60	87	85	83
90	90	90	89

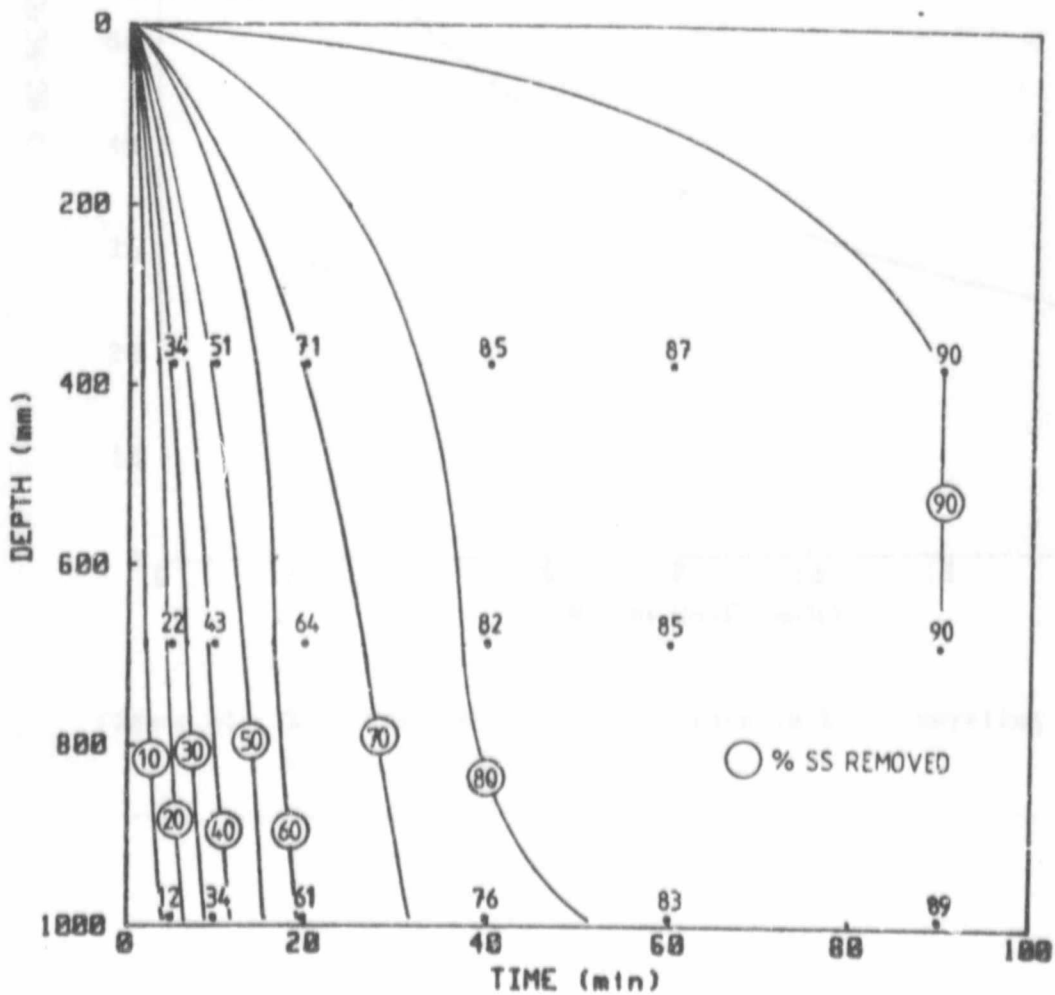


Figure 79. SS Removed vs Time and Depth. $C_o = 570\text{mg/l}$.

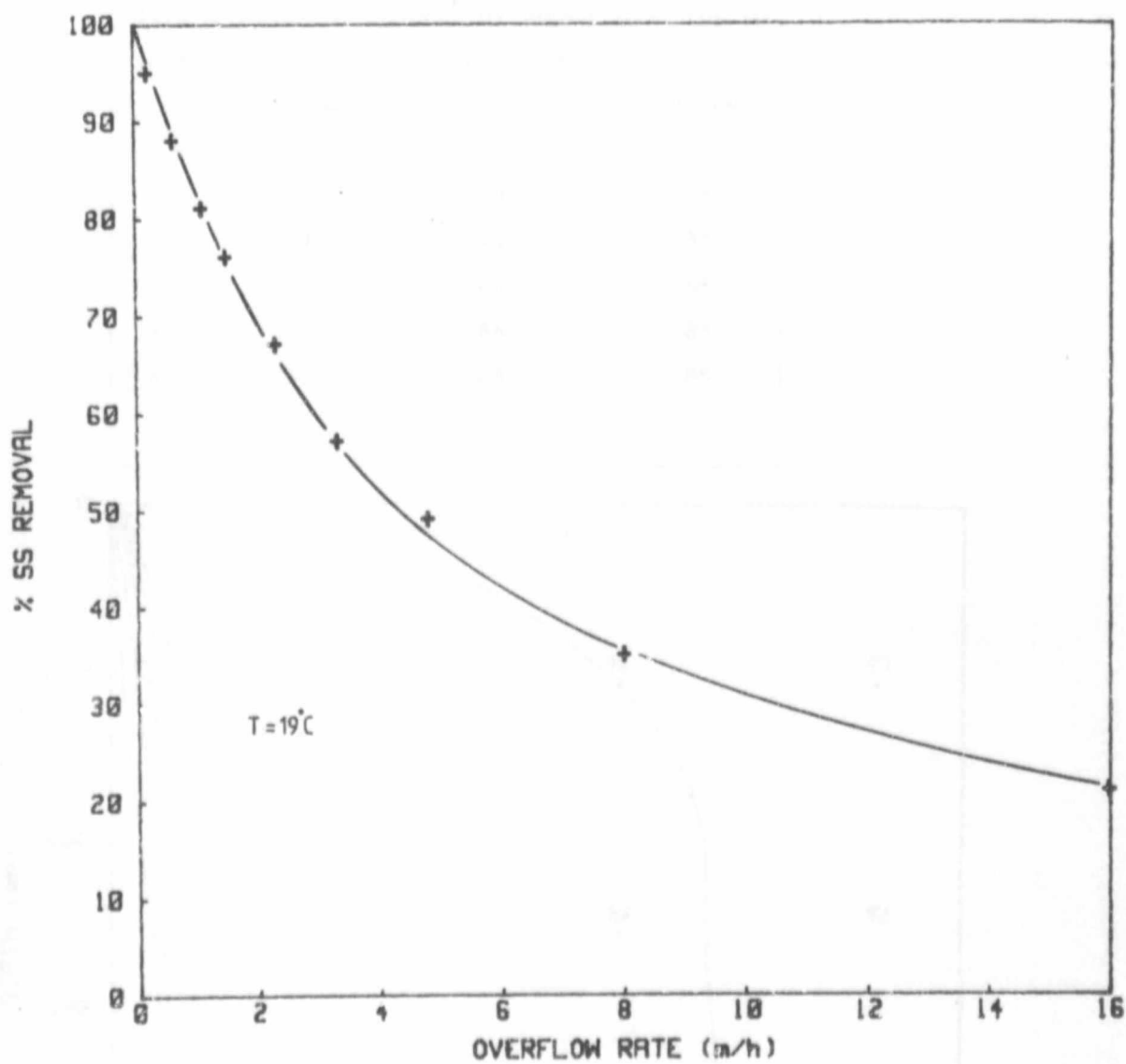


Figure 80. % SS Removed vs Overflow rate (m/h).: Settling depth = 400mm. $C_o = 570\text{mg/l}$.

BATCH SETTLING RESULTS FOR INITIAL CONCENTRATION = 860mg/l

TIME (min)	Percent removal by depth from top of settling column		
	204mm	504mm	815mm
5	30	9	6
10	59	44	33
20	76	69	68
40	88	84	83
60	90	89	88
90	92	92	93

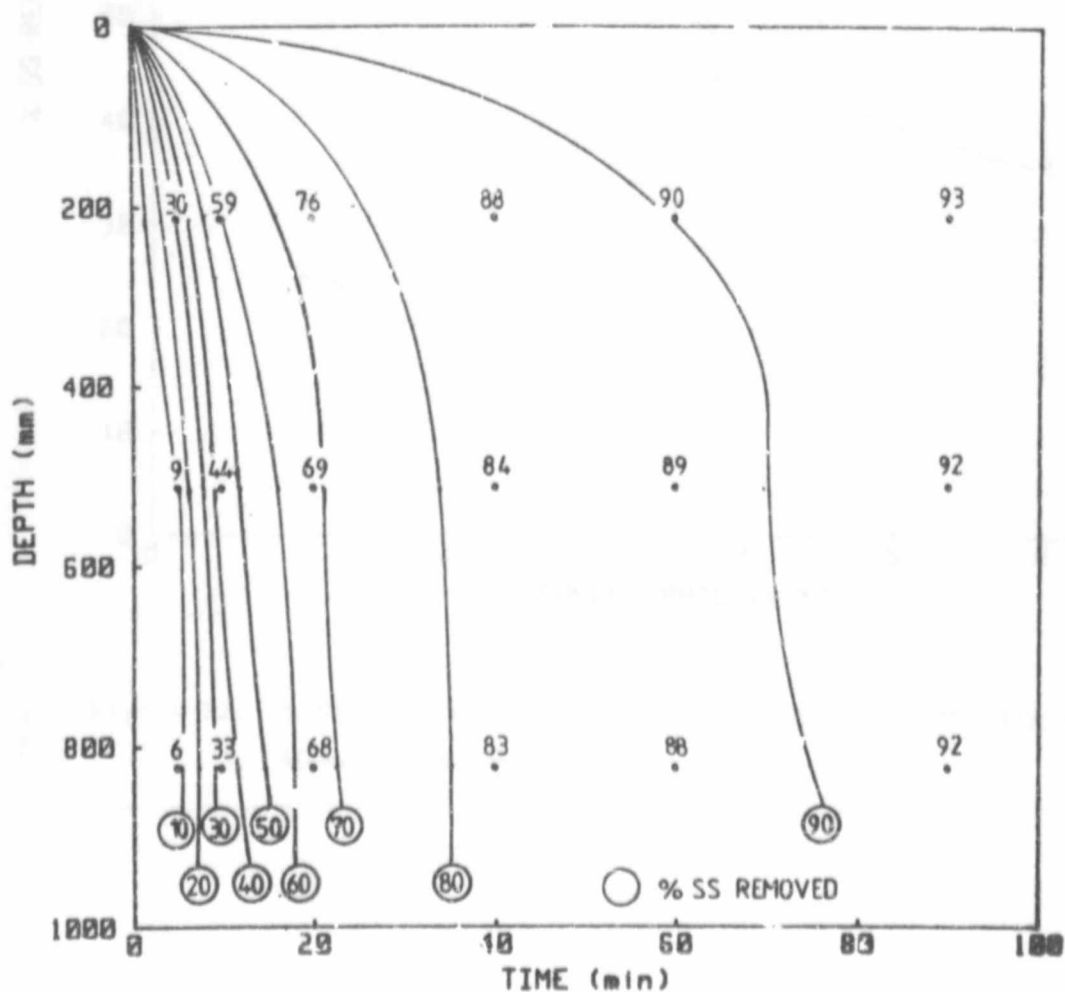


Figure 81. SS Removed vs Time and Depth. $C_0 = 860\text{mg/l}$

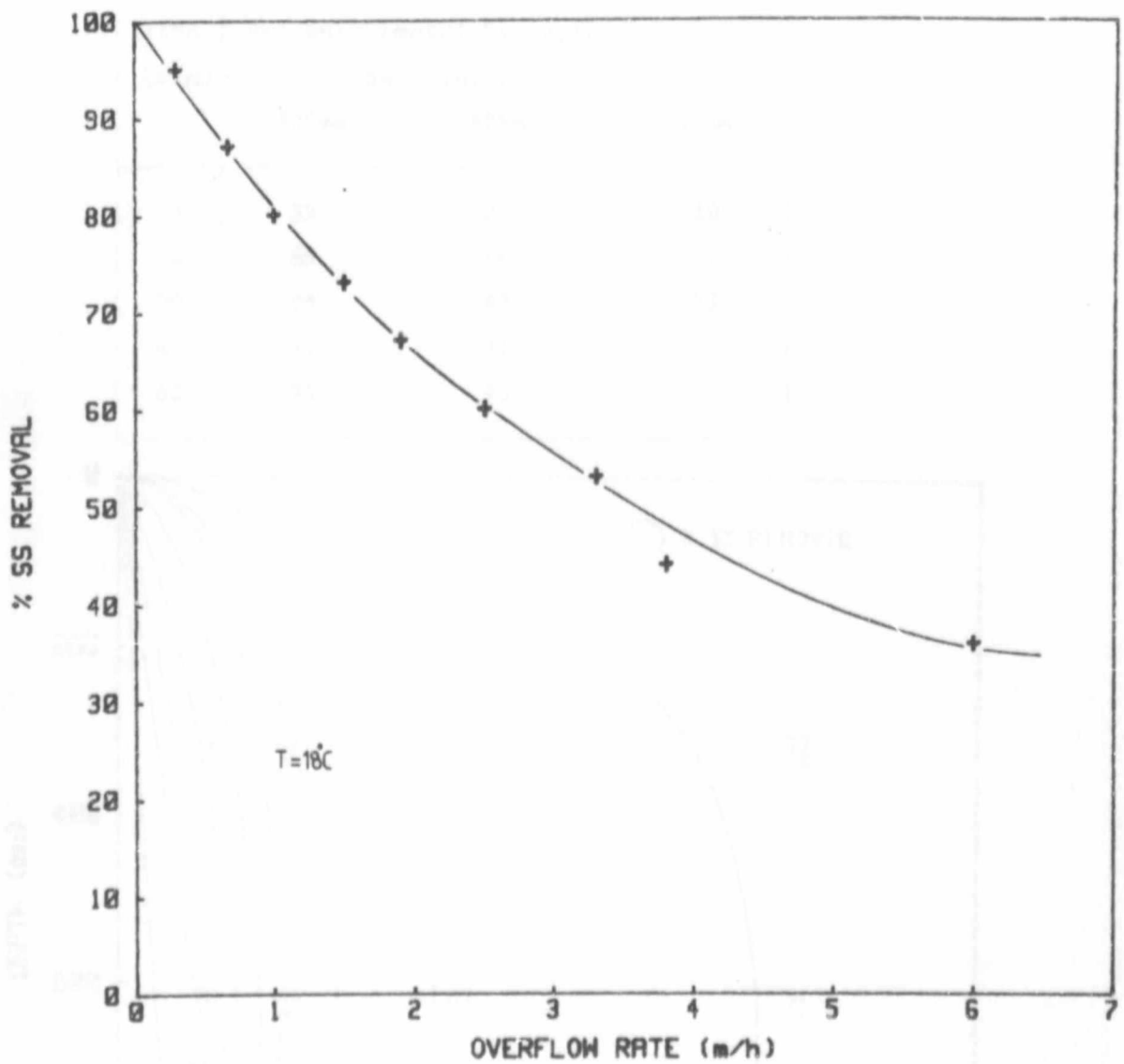


Figure 82. % SS Removed vs Overflow rate (m/h).: Settling depth = 400mm. $C_0 = 860\text{mg/l}$.

BATCH SETTLING RESULTS FOR INITIAL CONCENTRATION = 1356mg/l

TIME (min)	Percent removal by depth from top of settling column		
	329mm	629mm	940mm
5	39	21	10
10	69	64	62
20	85	83	85
40	92	91	92
60	94	93	

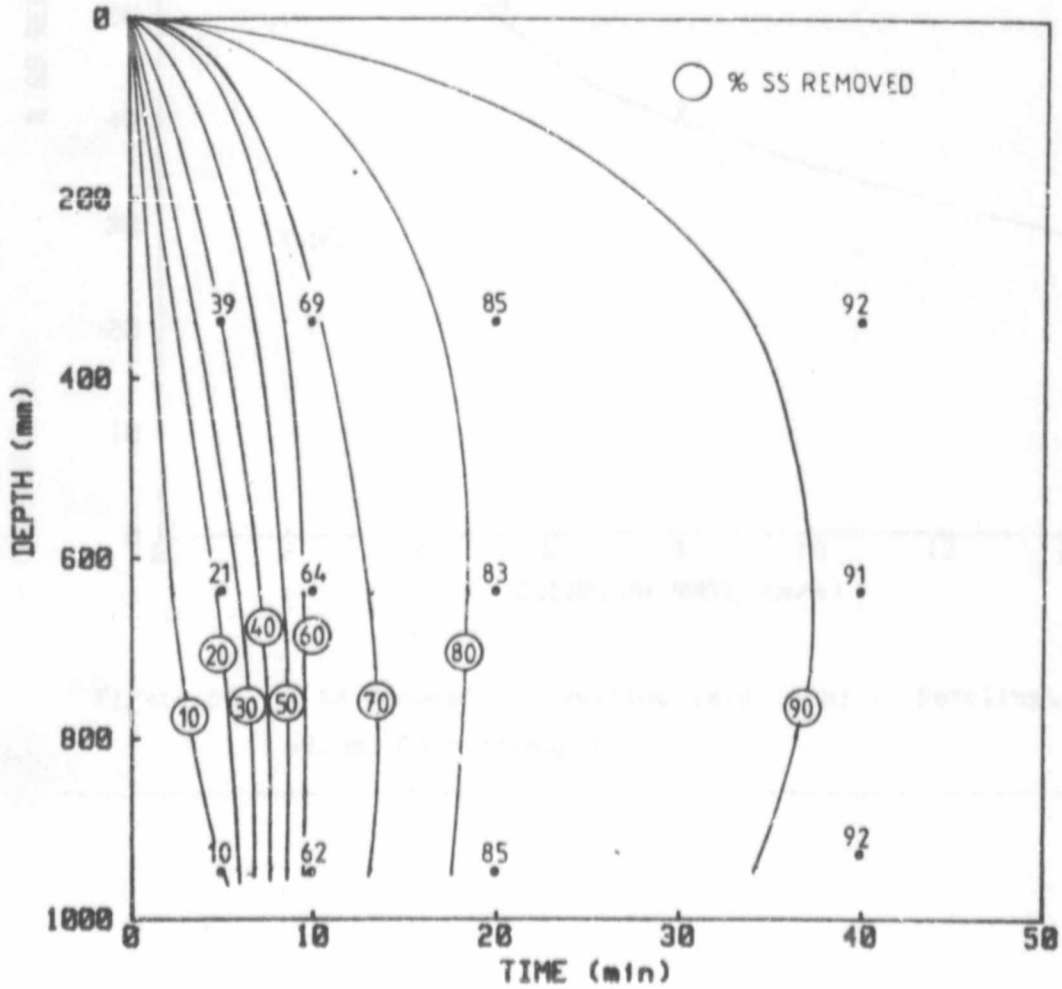


Figure 83. SS Removed vs Time and Depth. Co = 1356mg/l.

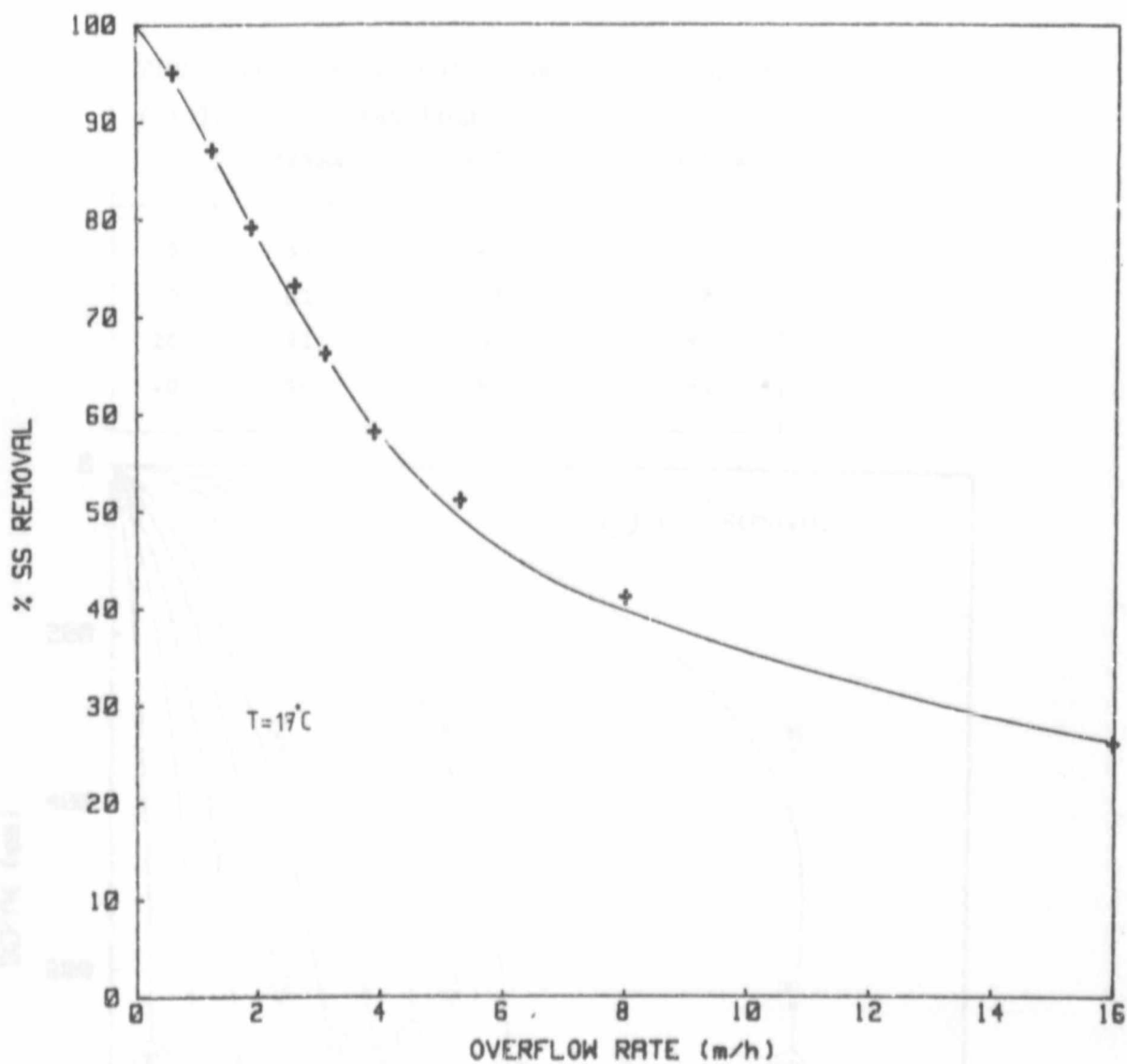


Figure 84. % SS Removed vs Overflow rate (m/h).: Settling depth = 400mm. $C_o = 1356\text{mg/l}$.

BATCH SETTLING RESULTS FOR INITIAL CONCENTRATION = 1717mg/l

TIME (min)	Percent removal by depth from top of settling column		
	329mm	629mm	940mm
5	55	40	21
10	81	78	78
20	91	90	91
40	96	91	95

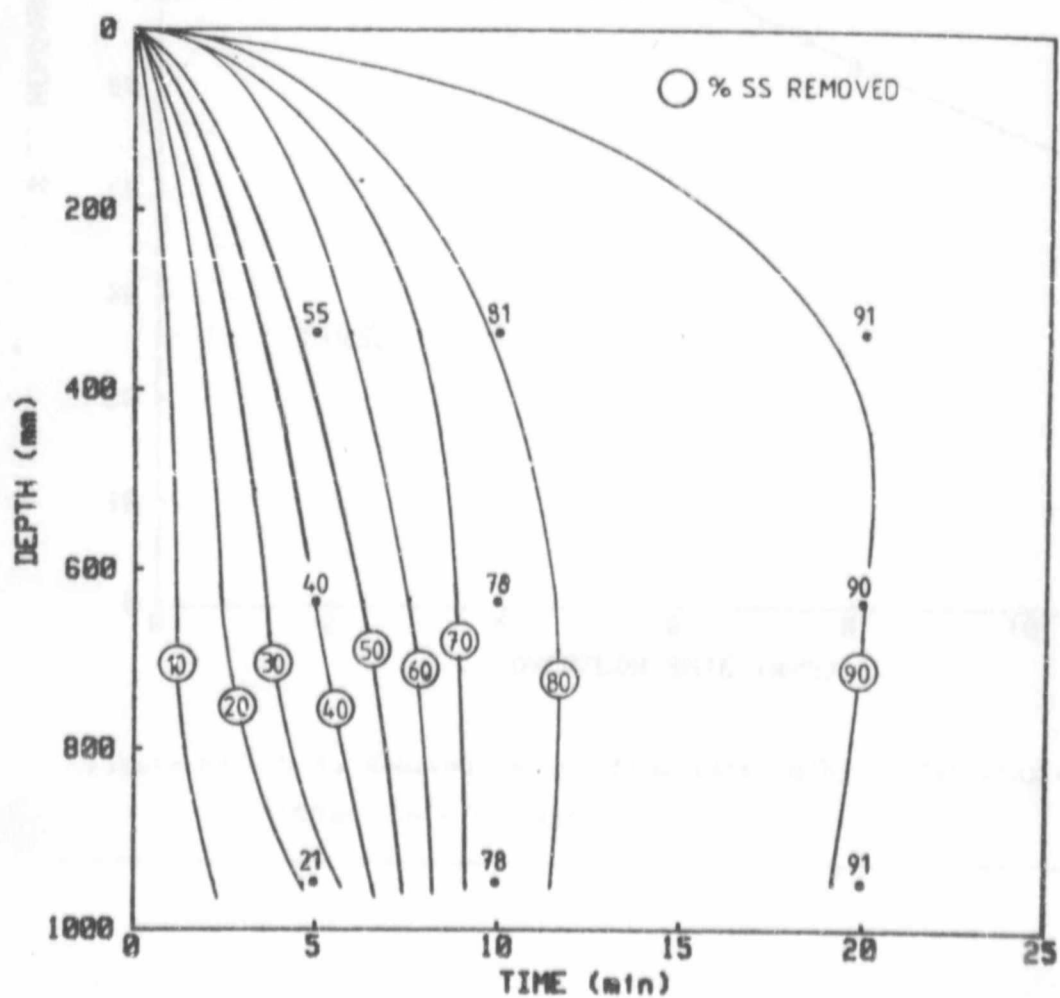


Figure 85. SS Removed vs Time and Depth. $C_o = 1717\text{mg/l}$.

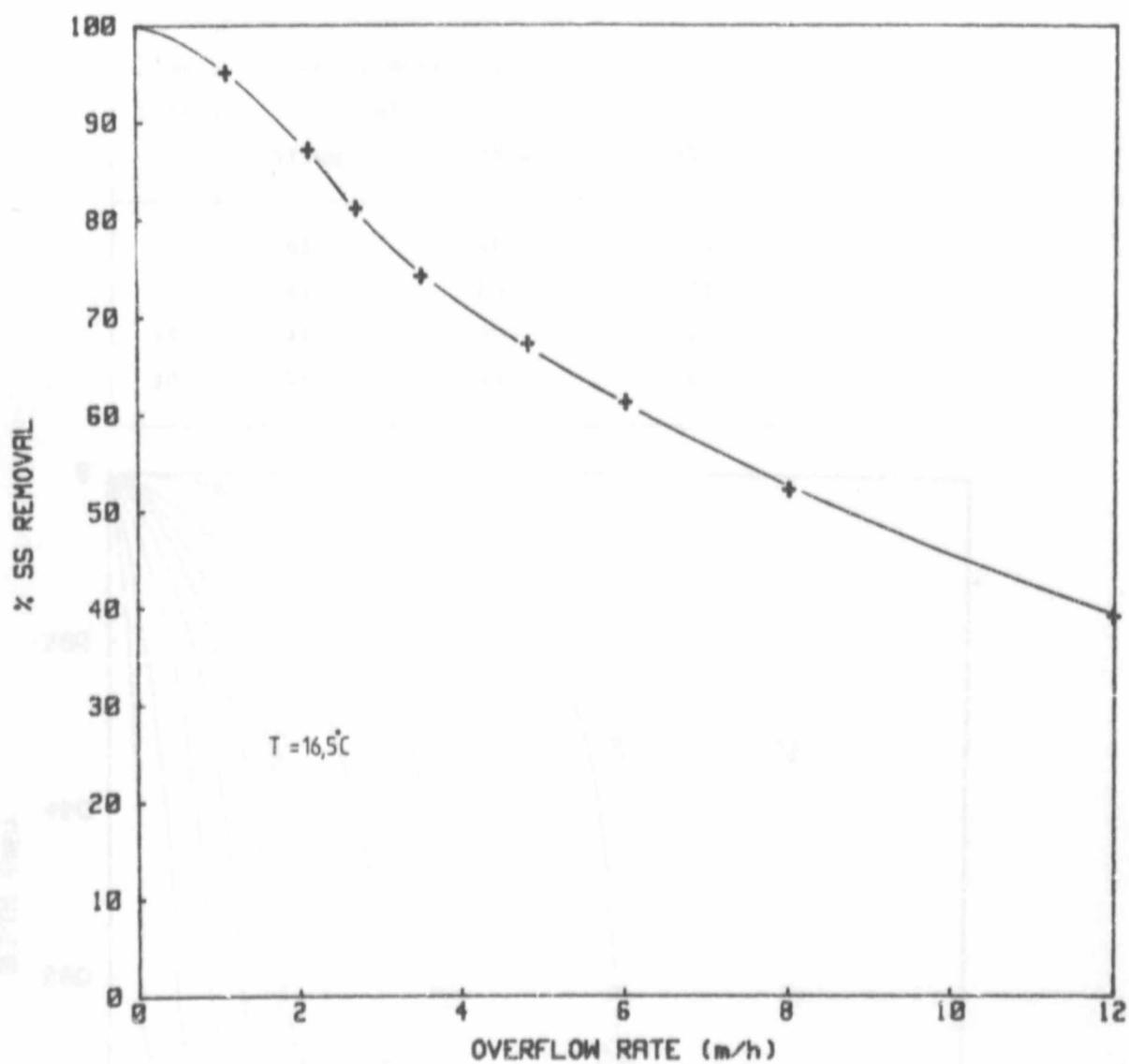


Figure 86. % SS Removed vs Overflow rate (m/h).: Settling depth = 400mm. $C_o = 1717\text{mg/l}$.

BATCH SETTLING RESULTS FOR INITIAL CONCENTRATION = 2164mg/l

TIME (min)	Percent removal by depth from top of settling column		
	329mm	629mm	940mm
5	61	48	9
10	84	83	81
15	91	90	92
20	94	93	94

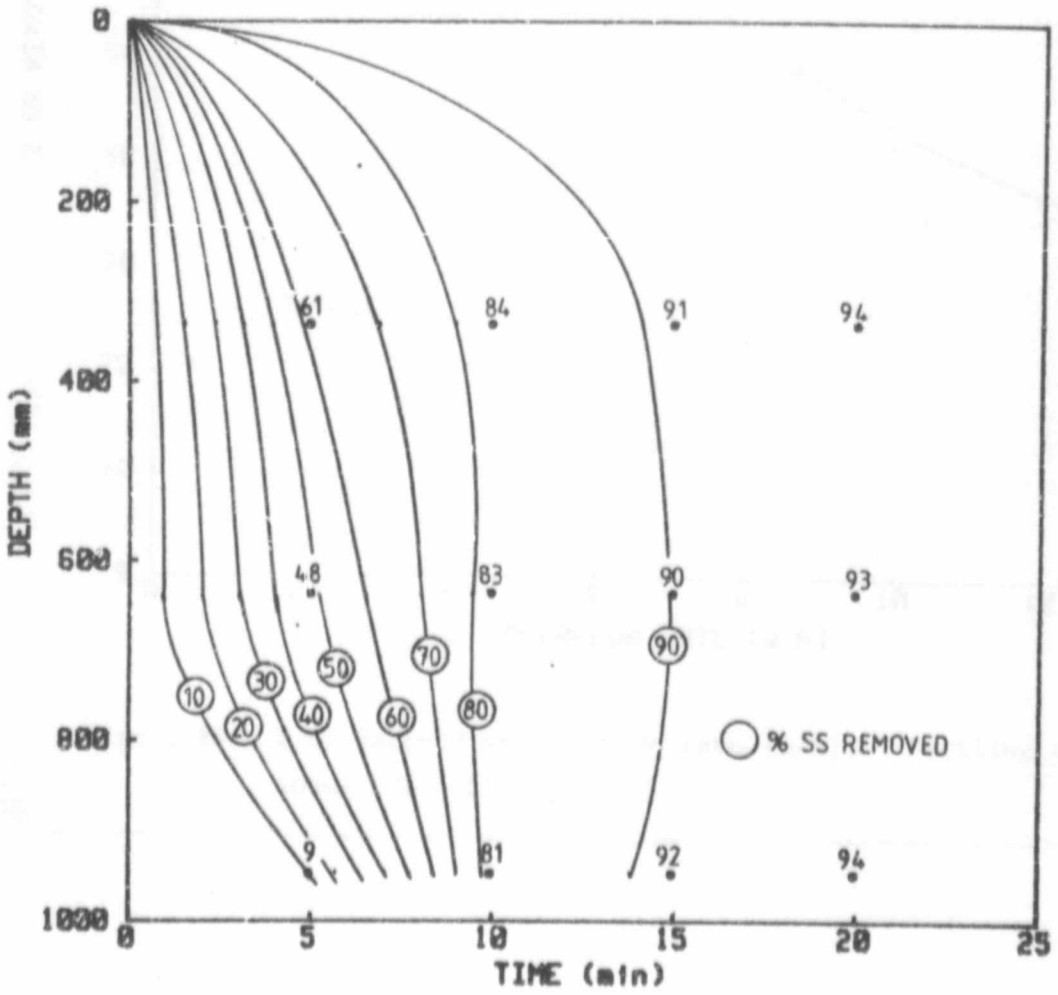


Figure 87. SS Removed vs Time and Depth. Co = 2164mg/l.

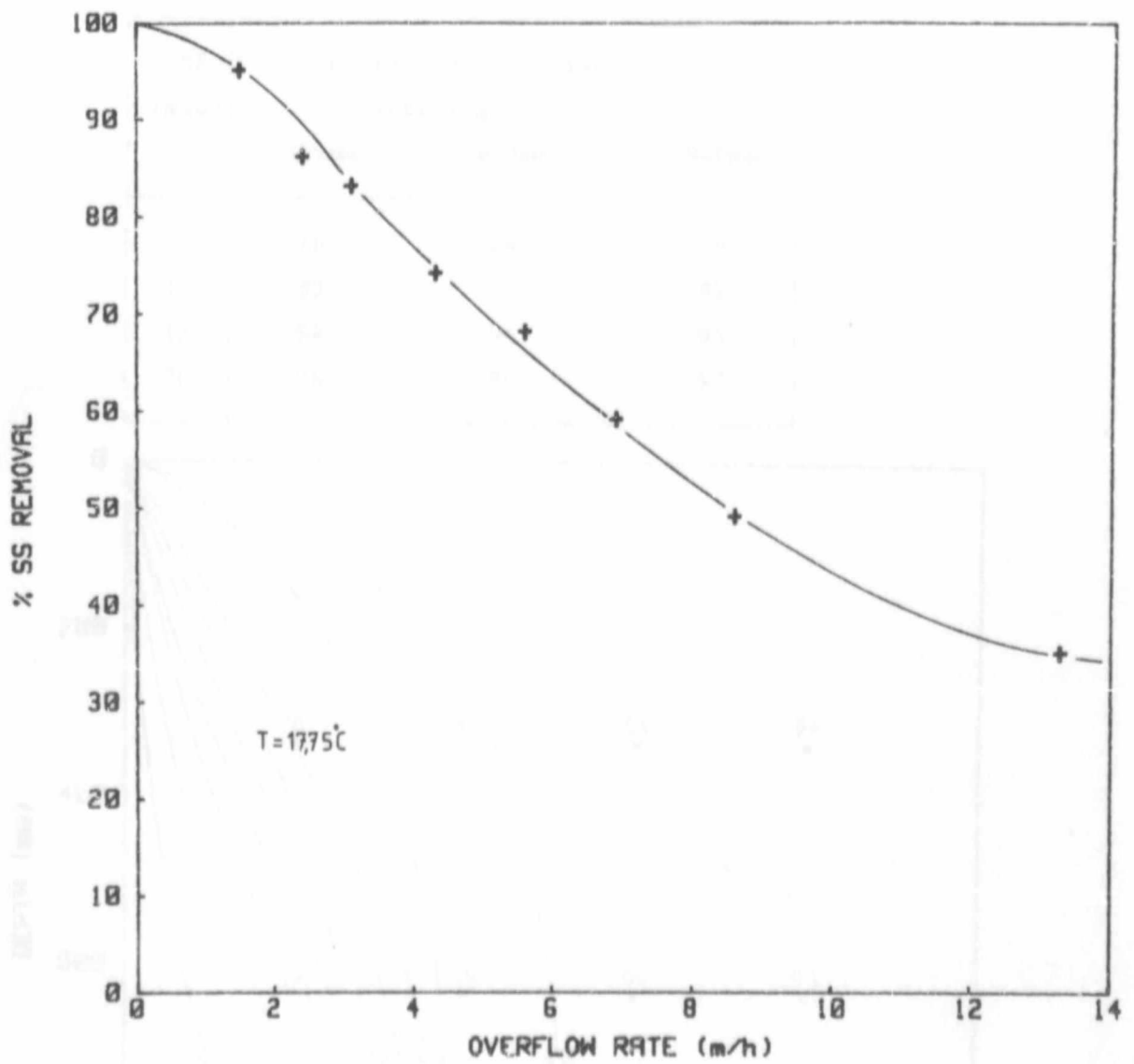


Figure 88. % SS Removed vs Overflow rate (m/h).: Settling depth = 400mm. $C_o = 2164\text{mg/l}$.

BATCH SETTLING RESULTS FOR INITIAL CONCENTRATION = 2846mg/l

TIME (min)	Percent removal by depth from top of settling column		
	329mm	629mm	940mm
5	70	24	9
10	89	85	82
15	94	94	95
20	96	95	97

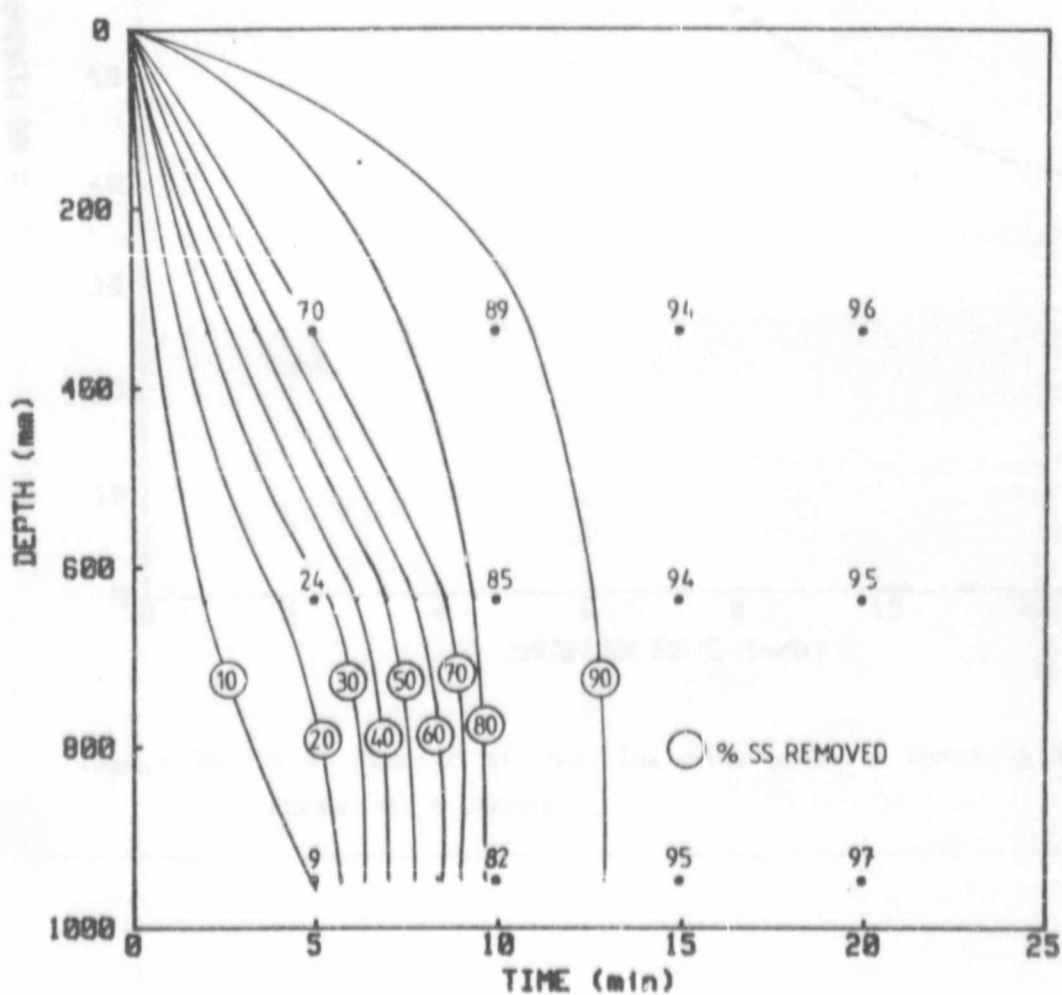


Figure 89. SS Removed vs Time and Depth. Co = 2846mg/l.

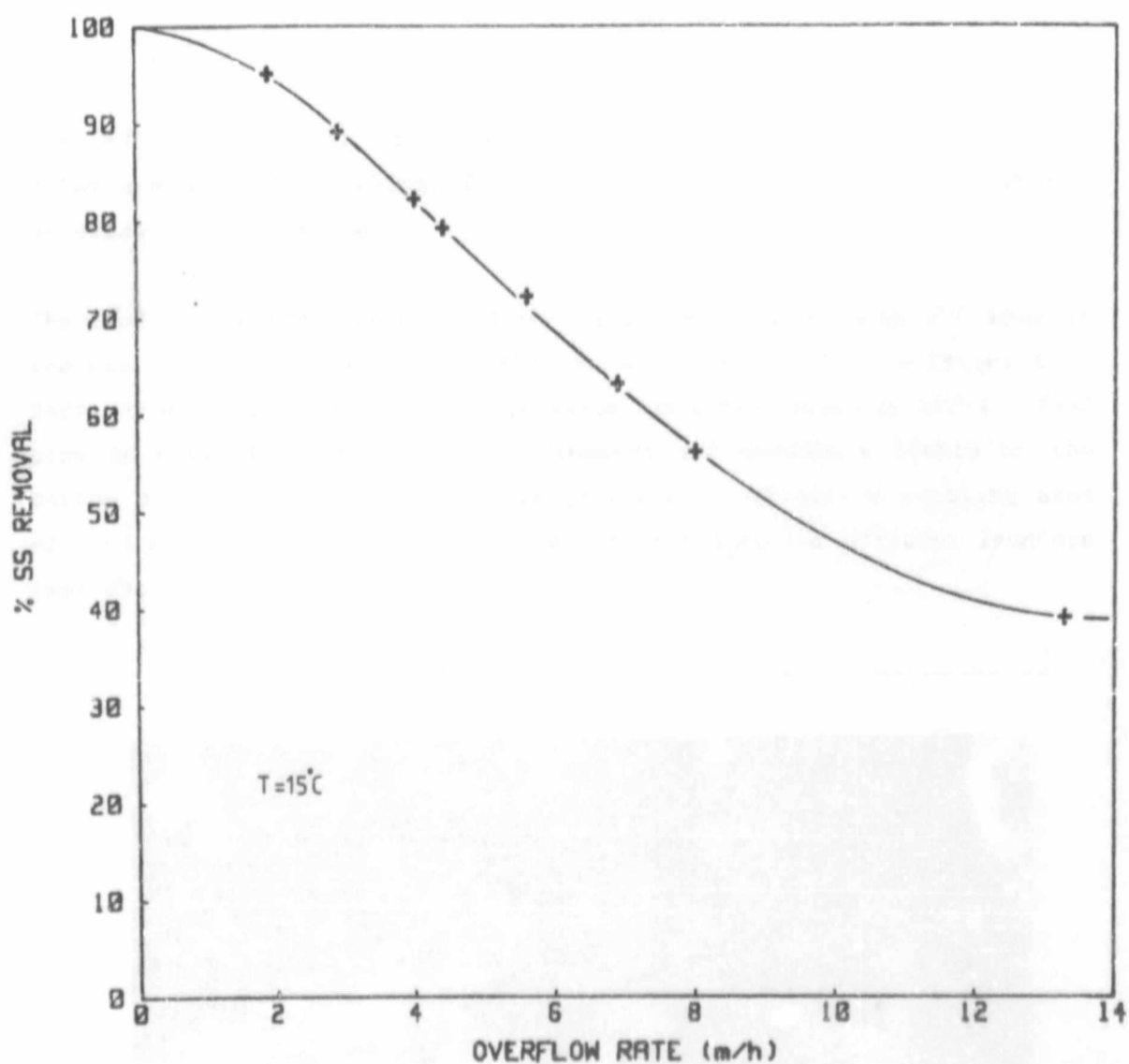


Figure 90. % SS Removed vs Overflow rate (m/h).: Settling depth = 400mm. $C_o = 2846\text{mg/l}$.

Author Barthelme Sven-Helmut

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