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EXPERIMENTAL AND ANALYTICAL STUDIES OF DIFFERENT METHODS FOR PRODUCING STRATIFIED FLOWS

AFSHIN J. GHAJAR† and KIYOUNG BANG
School of Mechanical and Aerospace Engineering, Oklahoma State University, Stillwater, OK 74078, U.S.A.

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Abstract—Four methods for producing linear density gradients in laboratory tanks were tested experimentally in our laboratory using salt–water mixtures. The influence of important parameters on producing a linear density gradient with each method was studied. These methods were compared with respect to the time required to produce the linear profiles, linearity of density profiles, and the transient behavior of density profiles. From these comparisons, the methods of Oster are recommended. A finite-difference computer code was used to predict the experimental transient behavior of the density profiles generated by the four methods. The predictions compared very well with the experimental results.

INTRODUCTION

The environment is often stably stratified, i.e. the density decreases with elevation as is the case in the lower atmosphere. It also increases with depth in the hydrosphere. The stratification in these environments is mostly linear, except in restricted regions where a thermocline may be present due to diurnal and seasonal variations in thermal fluxes.

There are a large number of practical applications involving linearly-stratified ambients. The discharge of heated effluents from large power plants into the atmosphere and the release of heated condenser water into oceans and lakes are examples associated with thermal pollution and ecological problems that have become foci of environmental and geophysical research. Laboratory experiments dealing with these and other problems of practical interest require generation of linear density gradients in scale models of stratified fluid bodies. Several methods for generating linear density gradients in laboratory tanks have been devised and reported in the literature. In our previous work,[1] four methods used by various investigators were discussed in detail, and preliminary comparisons between the methods were made. These methods will be referred to here as Oster, modified Oster, Clark, and layer-by-layer. A brief description of each method will be presented in the next section. While all of these methods produce the desired linear density gradients, there have been no detailed studies to show how these different methods compare with one another. The time involved in producing a linear density profile with any particular method, parameters influencing the linearity of the produced density profiles, and the transient behavior of the density profiles are important aspects of each method and should be addressed. In addition, it would be desirable, through computer simulation, to have the capability of predicting the transient behavior of the produced linear density profiles.

LINEAR DENSITY PROFILE PRODUCING METHODS

Oster method

In this method, Oster[2] produced a linear density gradient by using two miscible liquids of different densities and introducing them at controlled rates into the test tank (see Fig. 1). Two

†To whom all correspondence should be addressed.

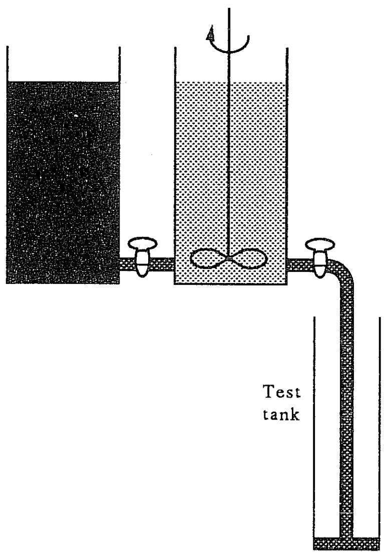

Fig. 1. The two-tank arrangement used in the Oster method.

tanks of the same shape containing equal depths of miscible liquids are joined by a pipe. The denser liquid (tank 1) is introduced into a tank containing the lighter fluid (tank 2); the two liquids are vigorously stirred while the resulting mixture flows into the bottom of the test tank. With this method, a linear density gradient can be obtained only if the rate at which the denser fluid flows into the stirred tank is equal to half of that flowing out of the stirred tank. This method has been used by several investigators.[3,4]

Modified Oster method

This is a slightly modified version of the previous method and was used by Maxworthy.[5] In this method, the lighter fluid is allowed to flow into the tank containing the heavier fluid; they are mixed and fed at twice the rate of inflow to a floating raft in the rectangular test tank (see Fig. 2).

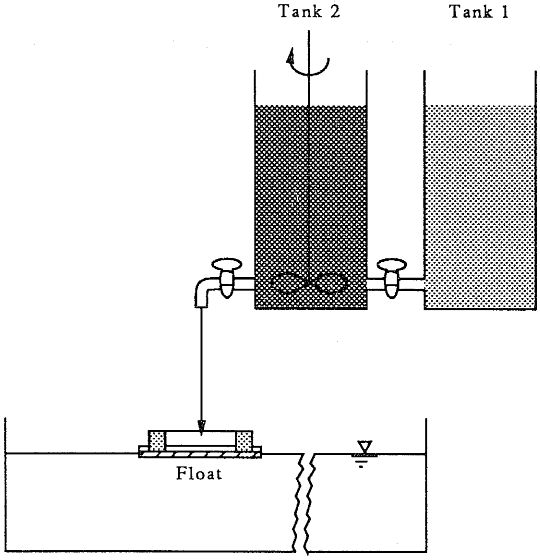

Fig. 2. Schematic of the test set-up with floating raft used in the modified Oster method.

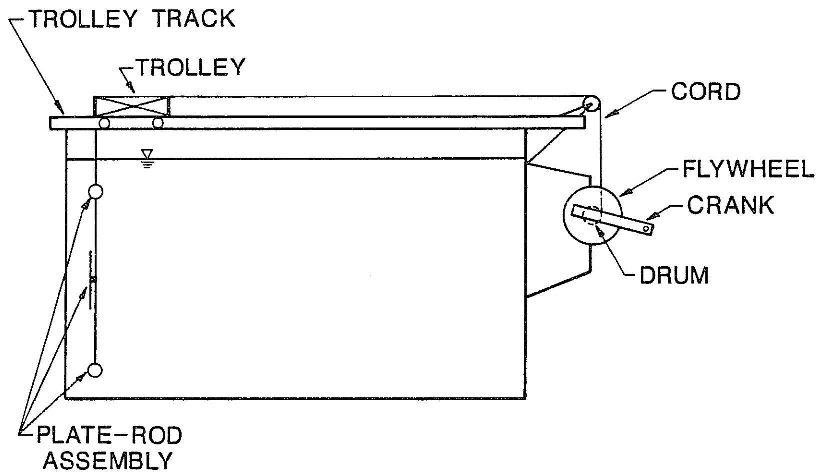

Fig. 3. Schematic of the test set-up used in the Clark method.

Clark method

This method was originally developed by Clark et al.[6] It consists of passing a flat plate (oriented normal to the direction of travel and spanning the width of the tank) and a circular rod (parallel to the plate) through an initially two-layered fluid (see Fig. 3). By properly adjusting the speed, dimensions, and positions of the plate–rod assembly, a linear density gradient can be achieved. This method has been used by Darden et al.[7]

Layer-by-layer method

This method involves introducing several layers of liquid of different densities decreasing with height into the test tank and allowing diffusion between the layers to smooth out the boundaries into a density gradient that is linear with height. This method has been used by Schooley and Stewart[8] and Koh.[9]

PREDICTIVE EXPRESSIONS FOR THE OSTER METHODS

With reference to the Oster and modified Oster methods, it was pointed out that a linear density profile is produced only if the rate at which the denser fluid flows into the stirred tank is equal to half of that flowing out of the stirred tank. This can be easily shown from a material balance on tank 2 of Fig. 4 as follows:

$$d(Vc)/dt = q_1c_1 - q_2c, \tag{1}$$

or

$$V(dc/dt) + c(dV/dt) = q_1c_1 - q_2c, \tag{2}$$

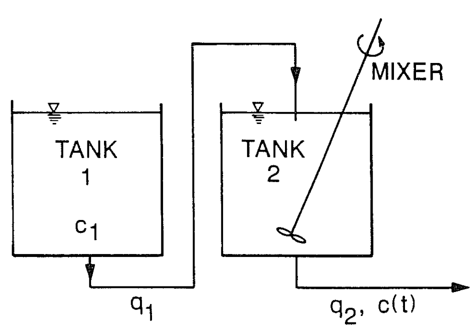

Fig. 4. The two-tank general arrangement used in the Oster and modified Oster methods.

since

$$dV/dt = q_1 - q_2. \tag{3}$$

Assuming quasi-steady motion, integration of Eq. (3) from an initial volume V_o to V yields

$$V = V_o + (q_1 - q_2)t. \tag{4}$$

Substituting Eqs. (3) and (4) into Eq. (2) yields

$$[V_o + (q_1 - q_2)t](dc/dt) + q_1(c - c_1) = 0. \tag{5}$$

With the initial condition $c = c_o$ at $t = 0$, integration of Eq. (5) yields

$$c = c_1 - (c_1 - c_o)[1 + (q_1 - q_2)t/V_o]^{q_1/(q_2 - q_1)}. \tag{6}$$

Equation (6) shows that the concentration is linear with time only if the exponent $q_1/(q_2 - q_1)$ is equal to unity, i.e. $q_2 = 2q_1$. In this case,

$$c = c_o + (c_1 - c_o)tq_1/V_o. \tag{7}$$

The time t may be expressed in terms of the test-tank height H, volume-flow rate q_2, and test-tank cross sectional area A. For the Oster method

$$t = A(H - y)/q_2; \tag{8}$$

and for the modified Oster method

$$t = Ay/q_2. \tag{9}$$

Substituting for t from Eqs. (8) and (9) in Eq. (7), we get for the Oster method

$$c = c_o + [A(H - y)(c_1 - c_o)/2V_o]; \tag{10}$$

for the modified Oster method,

$$c = c_o + [Ay(c_1 - c_o)/2V_o]. \tag{11}$$

Equations (10) and (11) show that the concentration (or density) is linear with height only if $q_2 = 2q_1$ as evidenced by Eq. (7). These equations can be used to predict the fluid concentration at any vertical location in the test-tank for the Oster methods.

It should be noted that the concentration c in the above equations is based on the volume fraction. In the experiments conducted in this study, the saline solution with the desired density was prepared based on standard solutions with known mass concentrations, c_m. In order to compare the experimental data with those calculated from Eqs. (10) and (11), the results obtained from these equations were converted to concentrations based on mass fraction by the relationship

$$c_m = [1 + (\rho_w/\rho_s)(1/c - 1)]^{-1}. \tag{12}$$

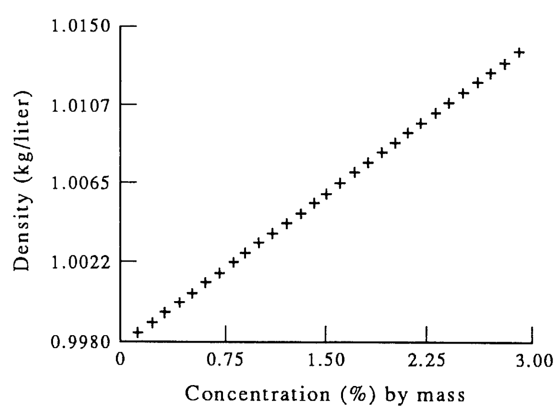

Fig. 5. Linear variation of density of salt–water mixture with salt concentration.

The density of a salt–water mixture can be related to the salt concentration based on mass by the following relationship:

$$\rho = \rho_w/[1 + c_m(\rho_w/\rho_s - 1)]. \tag{13}$$

Figure 5 shows that the variation between density and salt concentration is linear. Therefore, a linear concentration profile implies a linear density profile.

PREDICTION OF TRANSIENT BEHAVIOR OF DENSITY PROFILES

The prediction of the transient behavior of the density profiles generated by different methods is another important aspect of this study. This is achieved by the numerical solution of the one-dimensional unsteady mass-diffusion equation. In our case, the unsteady diffusion of salt in the salt–water mixture in the test tank due to a concentration gradient is given by

$$\partial c_m/\partial t = (\partial D_s/\partial y)(\partial c_m/\partial y) + D_s(\partial^2 c_m/\partial y^2). \tag{14}$$

The applicable boundary conditions are

$$(\partial c_m/\partial y) = 0 \quad \text{at} \quad y = 0 \quad \text{and} \quad y = H.$$

The diffusion coefficient of salt in a salt–water mixture (D_s) depends on the temperature of the solution and salt concentration. The dependency of D_s on the solution temperature can be minimized by insulating the test tank during the duration of the experiments. From the experimental data for the salt-diffusion coefficient at 25°C (D_s°) in different concentrations of salt–water mixtures,[10,11] the influence of salt concentration on D_s is found to be significant only in the low salt concentration regions ($c_m < 0.5\%$). Some typical values for D_s° at low salt concentrations are: $D_s^\circ = 1.559 \times 10^{-4}$ cm^2/sec at $c_m = 0.005\%$, $D_s^\circ = 1.507 \times 10^{-4}$ cm^2/sec at $c_m = 0.05\%$, and $D_s^\circ = 1.473 \times 10^{-4}$ cm^2/sec at $c_m = 0.5\%$. For values of the salt-diffusion coefficient at temperatures other than 25°C, the following approximate correlation is recommended:[10]

$$D_s = D_s^\circ T_a/(334\mu_w), \tag{15}$$

where D_s and D_s° are in cm^2/sec, T_a is in K and μ_w is in centipoise.

In Eq. (15), the absolute viscosity of fresh water (μ_w) at a given temperature can be calculated from the following empirical relation:[12]

$$1/\mu_w = 0.021482[z + (z^2 + 8078.4)^{1/2}] - 1.2, \tag{16}$$

where $z = T - 8.435$, μ_w is in centipoise and T in °C.

Equation (14) along with Eqs. (15) and (16) can now be used to determine the salt concentration in a salt–water mixture as a function of time and position, $c_m = c_m(t, y)$. In this study, the explicit finite-difference technique was chosen for the solution of Eq. (14). Suppose that the concentrations at three different positions in a salt–water mixture, y_1, y_2, and y_3 ($y_1 < y_2 < y_3$ and $y_2 - y_1 = y_3 - y_2 = \Delta y$) change during a certain time interval, Δt. Typical values used for Δy and Δt were 1 cm and 1 min. Applying the explicit finite-difference method to Eq. (14) gives

$$[c_m(t + \Delta t, y_2) - c_m(t, y_2)]/\Delta t = [(D_s, y_3 - D_s, y_1)/2\Delta y]\{[c_m(t, y_3) - c_m(t, y_1)]/2\Delta y\} + D_s, y_2\{[c_m(t, y_1) - 2c_m(t, y_2) + c_m(t, y_3)]/(\Delta y)^2\}, \tag{17}$$

where D_s, y_1, D_s, y_2, and D_s, y_3 are the respective diffusion coefficients of salt in the salt–water mixture at the y_1, y_2, and y_3 locations at a given time. The results from the numerical solution will be presented later along with the experimental results.

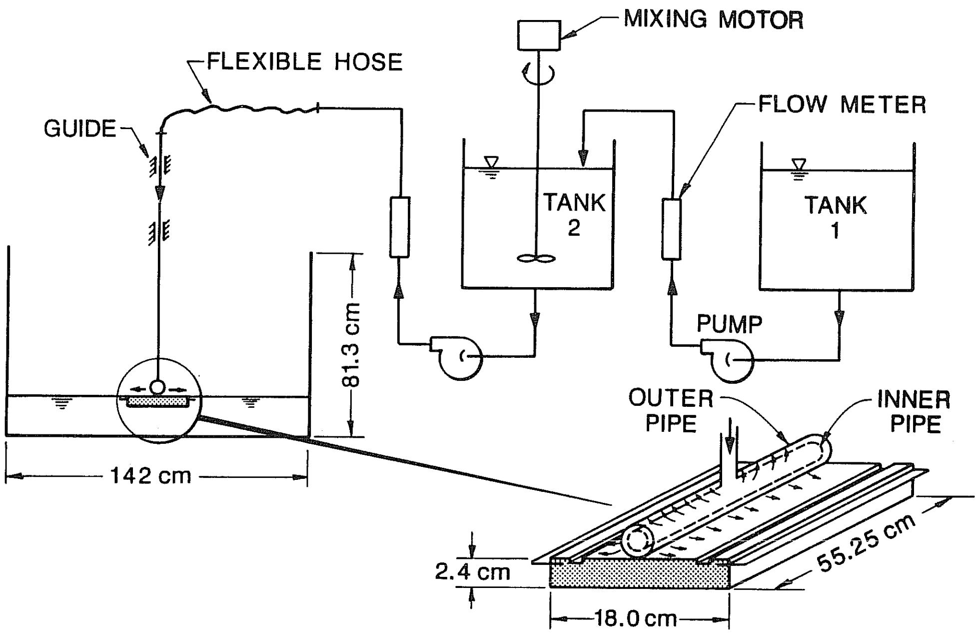

Fig. 6. Schematic of the experimental set-up used in the present work.

EXPERIMENTAL SET-UP

The experimental set-up used in this investigation is shown schematically in Fig. 6. It consists of two supply tanks (1100 l each), a plexiglas test-tank (1.42 m long, 81.3 cm high, and 61.0 cm wide), a metered flow system, and a data-acquisition system (a conductivity probe interfaced with a personal computer through a Monitor Labs model 9302 data logger). Additional hardware needed for measuring the flow distribution and mixing by different methods was constructed, i.e. a plate–rod assembly attached to a movable carriage which slides on two rails mounted on the long side rims of the tank and a floating raft for filling the test-tank that is required for use with the modified Oster, Clark, and layer-by-layer methods. The floating raft was prevented from touching the sides of the test-tank by using a fixed guide mounted on the top flanges of the tank. The plate–rod assembly resembles that used by Clark et al.[6] A second rod similar to the upper one was added in the lower part of the assembly. For the Oster method, a perforated pipe assembly located at the center of the tank bottom was used.

For salt-concentration measurements, three conductivity probes were used initially. These probes were placed 30, 71, and 101 cm from each side of the test tank and were allowed to slide vertically in the test tank. The measured concentration profiles at the same fluid height and three different positions along the tank length were identical, with the exception of slight differences in the upper and lower-end regions of the tank caused by mixing. These results indicate that at a fixed position along the length of the tank, the concentration profile only varies with the height of the fluid in the tank. Therefore, for the experiments reported in this paper, only one conductivity probe was mounted at the center and allowed to slide vertically in the test tank. The position of the probe was monitored by means of a graduated scale fixed to the probe extension. The probe was calibrated frequently to ensure the reliability of the measurements. Conductivity measurements were taken at selected stations (2.54 cm intervals) up the tank. During the experiments, the test tank was insulated to keep the test-fluid temperature constant. The test-tank fluid temperature in the experiments was about 20°C with a variation of ±1.5°C. The experiments with different methods closely followed the procedures described by their originators.

RESULTS AND DISCUSSION

In this section, the experimental results obtained by different methods will be either presented in terms of y vs c_m or dimensionless height (y^*) vs dimensionless concentration (c_m^*). The expression for dimensionless concentration is method dependent. The following equations were used for the four methods under study:

Oster method—

$$c_m^* = (c_m - c_{m,o})/(c_{m,max} - c_{m,o}), \tag{18}$$

where $c_{m,max}$ = final concentration of fluid in tank 2 [see Fig. 4 and Eqs. (10) and (12)], $c_{m,o}$ = initial concentration of fluid in tank 2 (fresh water in this method).

Modified Oster method—

$$c_m^* = (c_m - c_{m,min})/(c_{m,o} - c_{m,min}), \tag{19}$$

where $c_{m,min}$ = final concentration of fluid in tank 2 [see Fig. 4 and Eqs. (11) and (12)], $c_{m,o}$ = initial concentration of fluid in tank 2 (salt water in this method).

Clark method—

$$c_m^* = (c_m - c_{m,2})/(c_{m,1} - c_{m,2}), \tag{20}$$

where $c_{m,1}$, $c_{m,2}$ = concentration of the initial two layers, ($c_{m,1} > c_{m,2}$).

Layer-by-layer method—

$$c_m^* = (c_m - c_{m,f})/(c_{m,1} - c_{m,f}), \tag{21}$$

where $c_{m,1}$, $c_{m,f}$ = initial concentrations of the first and final layers from the bottom of the test-tank.

Some of the experimental and numerical results obtained for each method will now be presented and discussed.

Oster method

In the experiments with this method, the height of the fluid in the test-tank was kept at 70 cm. Figure 7 shows the influence of fluid-inlet velocity from tank 2 into the test tank, on the linearity of the concentration (density) profile for a fixed concentration gradient. In addition, the theoretical concentration profile predicted by Eq. (10) is also shown. It can be seen that the

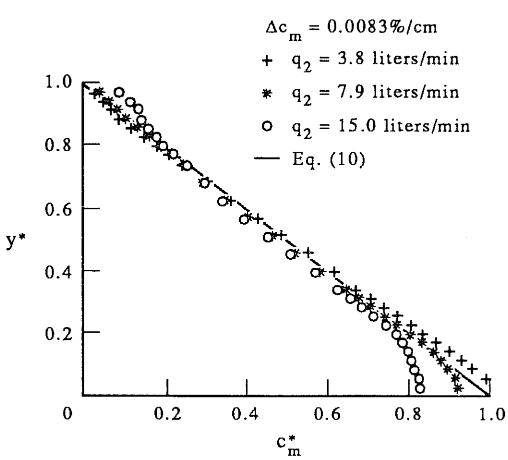

Fig. 7. The effect of flow rate on the length of the stratified region (Oster method).

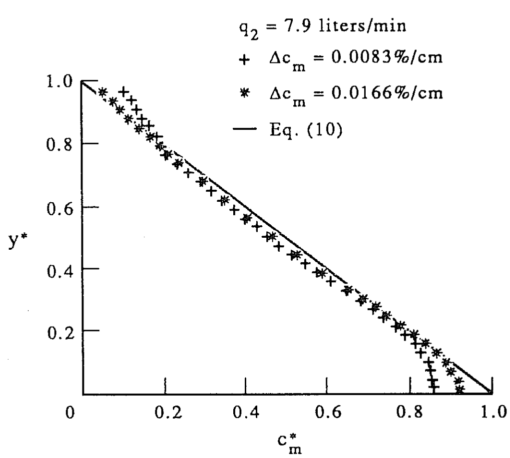

Fig. 8. The effect of the slope of the concentration profile on the length of the stratified region (Oster method).

experimental profile agrees well with the theoretical profile over most of the tank height. The disagreement in the lower part of the tank is due to the mixing caused by the flow distribution device, the perforated pipe assembly spanning the tank bottom. From these results, it can be concluded that the length of the linear concentration region is a function of the fluid-inlet velocity. Therefore, lower inlet tank velocities cause less disturbance (mixing) and, hence, give rise to wider linear stratification regions.

The effect of variation in the slope of the concentration profile (Δc_m) on the length of linear stratified region for a fixed inlet velocity to the test tank is shown in Fig. 8. The slope of the concentration profile in this figure refers to the difference between the constant concentration of tank 1 (c_1) and the initial concentration of tank 2 (c_o), as given by Eq. (10). The two different slopes of the concentration profile reported in Fig. 8 were obtained by keeping the initial concentration of fluid in tank 2 (c_o) constant and doubling the concentration of fluid in tank 1 (c_1). As shown in Fig. 8, regions with a steeper slope give rise to larger buoyancy forces, which tend to dampen the vertical motion of fluid (buoyancy reduces fluid mixing). Therefore, for the case with higher concentration gradient (steeper slope for the concentration profile), the linear stratification region is wider.

Results shown in Figs. 7 and 8 indicate that in general two factors, fluid-inlet velocity and the slope of the concentration profile, control the linearity of the concentration profile. In the experiments conducted with the Oster method, depending on the inlet velocity and the slope of the concentration profile, the linearity of the concentration profile varied between 60 and 90% of the final height of the fluid in the test tank. The time required for generating these linear profiles varied between 100 and 200 min depending on the inlet fluid velocity.

Figure 9 shows the results of computer simulation for prediction of the transient behavior of the concentration profile. The predicted transient behavior agrees very well with the experimental results (with the exception of the lower- and upper-end regions), indicating the reliability of the numerical solution. The lack of agreement between the experimental data and the simulated results in the lower- and upper-end regions is because our simple one-dimensional model does not account for the actual mixing that takes place in these regions. The experimental results shown in Fig. 9 also indicate that the linear concentration profile is relatively stable with time.

Modified Oster method

The height of fluid in the test-tank for experiments with this method was 70 cm. The experimental results obtained using this method demonstrate the same features as those of the

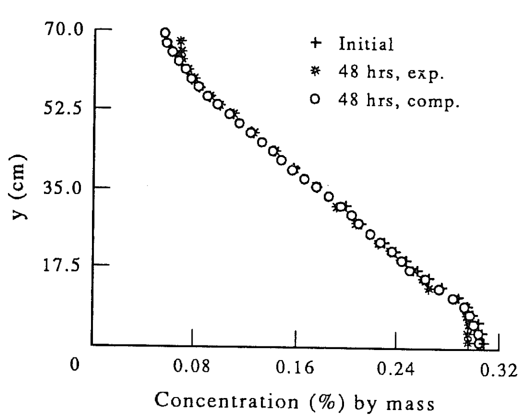

Fig. 9. Comparison of the predicted transient concentration profiles with experiments (Oster method).

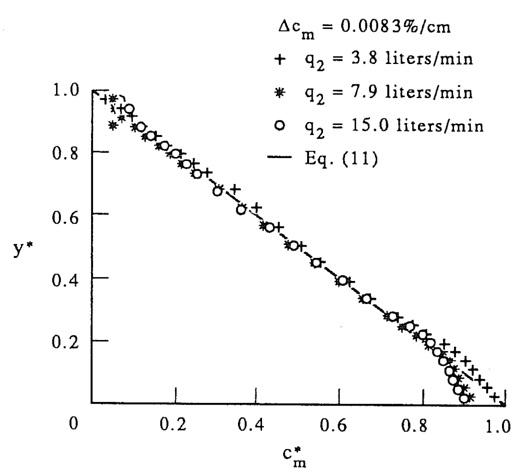

Fig. 10. The effect of flow rate on the length of the stratified region (modified Oster method).

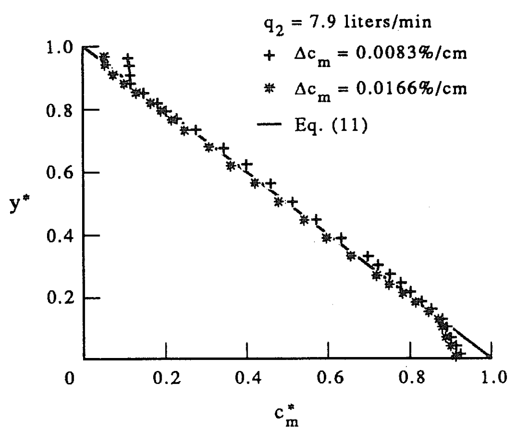

Fig. 11. The effect of the slope of the concentration profile on the length of the stratified region (modified Oster method).

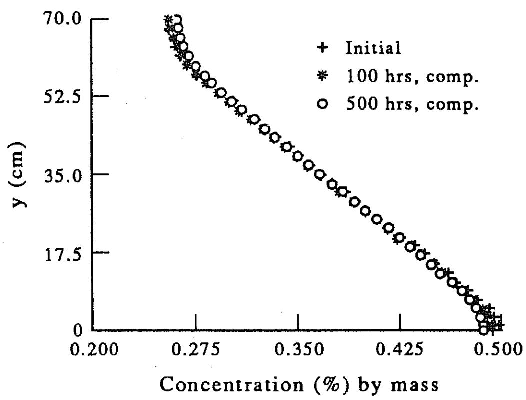

Fig. 12. Variations of predicted transient concentration profiles with time (modified Oster method).

Oster method. The influence of inlet velocity to the test tank on the linearity of the concentration profile for a fixed concentration gradient is shown in Fig. 10. With this method, due to the nature of the flow-distribution device (see Fig. 2), the region over which linear stratification can be obtained is slightly wider than for the Oster method. Figure 10 also shows the theoretical concentration profile predicted by Eq. (11). The agreement between the experiments and theory over most of the tank height is evident from this figure. Figure 11 shows the influence of the slope of the concentration profile (buoyancy) on the stratification. The slope of the concentration profile refers to the difference between the c_1 and c_o concentrations as shown by Eq. (11). The two different slopes of the concentration profile (Δc_m) shown in Fig. 11 were obtained by keeping the concentration of fluid in tank 1 (c_1) constant and doubling the initial concentration of fluid in tank 2 (c_o). The results presented in Figs. 10 and 11 point to the same two factors that influenced the linearity of the concentration profile in the Oster method, namely, the fluid-inlet velocity and the slope of the concentration profile. From the experimental results obtained with this method, it was possible to obtain a linear concentration profile over 70–90% of the final height of the fluid in the test tank, with slight improvement over the Oster method at high fluid-inlet velocities (due to a better flow-inducing device). The time required to obtain these linear profiles was comparable to that for the Oster method, about 100–200 min.

The results of the computer simulation for transient behavior of the concentration profiles are shown in Fig. 12 and indicate that the linear concentration profile is relatively stable with time.

Clark method

The experimental results presented for this method were obtained with a fluid height of 65 cm. Figures 13 and 14 show the concentration profile development after several passes of the plate–rod assembly with two different passing speeds. In both cases, the initial concentrations were identical. That is, each layer of the initially two-layered fluid had the same concentration ($c_{m,1} = 0.5\%$, $c_{m,2} = 0.035\%$) and thickness (32.5 cm). In Fig. 13, the passing speed of the plate–rod assembly was set at 20 cm/sec, and after seven passes approximately 70% of the total tank height was linearly-stratified. However, Fig. 14 shows that when the speed of the plate–rod assembly was doubled (40 cm/sec), it took only three passes for approximately 85% of the total tank height to become linearly-stratified.

Comparison of Figs. 14 and 15 shows the effect of concentration of the initial two layers of fluid on the linearity of the concentration profile. The results shown in Fig. 15 were obtained with double the initial first layer concentration of Fig. 14. In both experiments, the passing

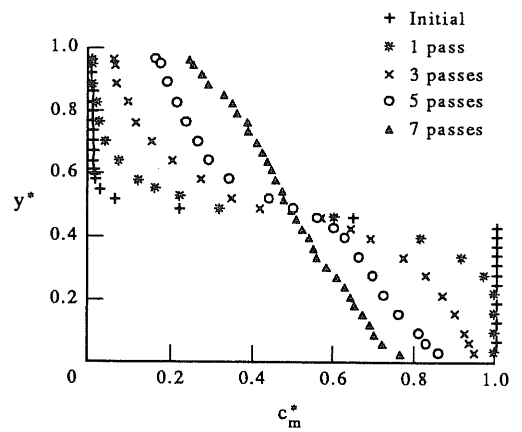

Fig. 13. Concentration profiles using the Clark method (speed = 20 cm/sec; $c_{m,1} = 0.5\%$, $c_{m,2} = 0.035\%$).

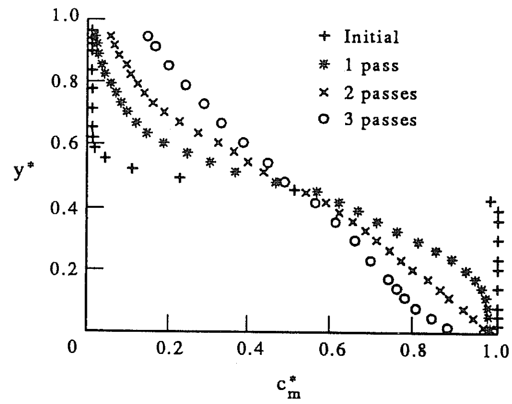

Fig. 14. Concentration profiles using the Clark method (speed = 40 cm/sec, $c_{m,1} = 0.5\%$, $c_{m,2} = 0.035\%$).

speed of the plate–rod assembly was set at 40 cm/sec. As shown in Fig. 14, after three passes the concentration profile was linear over about 85% of the total height of the tank. However, when the initial layer concentration was doubled, the concentration profile was not close to being linear even after four passes.

Results shown in Figs. 13–15 show that the passing speed of the plate–rod assembly, the number of passes, and the concentration of the initial two-layered fluid play an important role in the linearity of the resulting concentration profiles. Without a correct combination of these parameters, this method might not produce a linearly-stratified fluid. The experimental results obtained with this method showed concentration profiles which were 70–85% linear over the total tank height. The time required for producing these linear profiles was about 80 min, which is less than for the Oster methods.

The transient behavior of the concentration profile generated through computer simulation is shown in Fig. 16. This method, which is similar to the other methods discussed so far, indicates a stable behavior of the concentration profile with time.

Layer-by-layer method

In the experiments with this method, the height of the fluid in the test tank was kept at 70 cm. Figure 17 shows the generated concentration profiles. In this case, it took about 10 h to

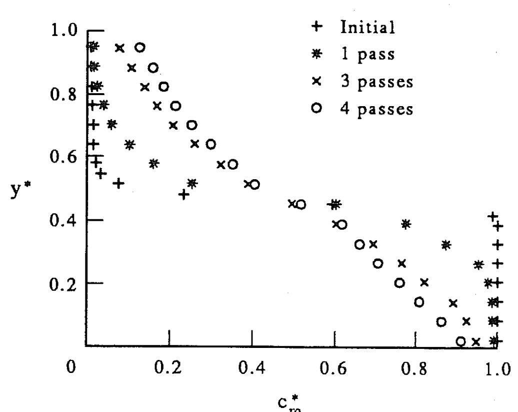

Fig. 15. The effect of initial concentration on the Clark method concentration profiles (speed = 40 cm/sec, $c_{m,1} = 1.0\%$, $c_{m,2} = 0.035\%$).

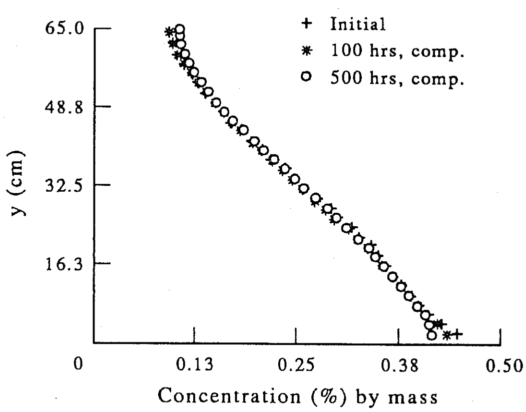

Fig. 16. Variations of predicted transient concentration profiles with time (Clark method).

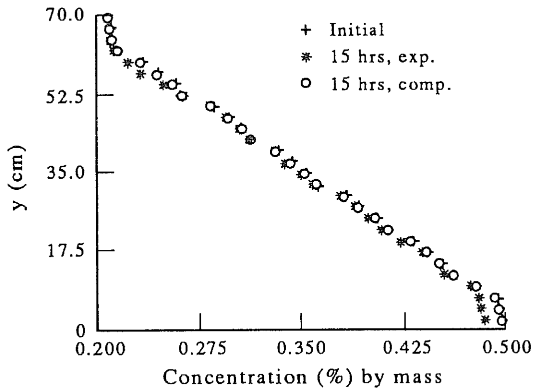

Fig. 17. Comparison of experimental and predicted transient concentration profiles (layer-by-layer method).

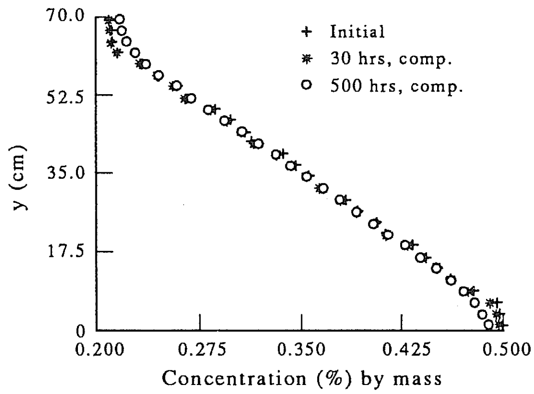

Fig. 18. Variations of predicted transient concentration profiles with time (layer-by-layer method).

fill the tank with seven layers (each 10 cm thick) of different concentrations decreasing with height (0.5, 0.45, 0.4, 0.35, 0.3, 0.25, and 0.2% by mass). In order to reduce mixing with the pre-induced layers, the flow rate was chosen to be very low (1.0 l/min).

Although the inlet velocity in these experiments was very low, there was still mixing while the fluid was filling the test tank. From Fig. 17, it can be seen that there is no distinct initial layer except the first and seventh layers from the bottom. During the 10 h fill-up period, mass-diffusion and mixing took place inside the test tank. The mass-diffusion was due to the concentration difference through the seven layers and the mixing was caused by the disturbances produced by the incoming fluid velocity. As a result, each intermediate layer showed a linear stratified profile except the first and seventh layers. The remaining five layers, though individually stratified (local stratification), collectively do not show a continuous linear profile (see Fig. 17). There exists a distinct concentration gap between each layer. After 15 h of settling time, the second and third layers were stratified together, the length of the nonstatified region (lower- and upper-end regions) increased, and the gap between each of the layers was reduced. Also shown in Fig. 17 is the predicted concentration profile after 15 h. Again, the numerical solution showed very good agreement with the experimental results. The results also pointed to the stability of the profile with time.

From observations made in Fig. 17, we can expect that after a larger settling time, the length of the nonstratified region (lower- and upper-end regions) should increase, and the middle region, which is locally stratified, will be completely stratified due to mass-diffusion. These expectations can be verified through computer simulations. From Fig. 18, it can be seen that the concentration profile became completely linear, with the exception of the lower- and upper-end regions, after 500 h of settling. Moreover, there was no change in the concentration profile with time except in the lower- and upper-end regions after the concentration profile became linear, indicating that the concentration profile of the stratified fluid is relatively stable with time.

SUMMARY AND CONCLUSIONS

The experiments showed that with the four methods tested it was possible to obtain linear density profiles. However, the degree of stratification and the time required to produce the linear profiles varied for the methods. The methods of Oster (Oster and modified Oster) provided wider stratification regions than the other methods. The linear stratification produced by these methods is a function of fluid-inlet velocity and concentration gradient. To produce these profiles, it took about 100–200 min. The theoretical expressions developed for the Oster methods [see Eqs. (10) and (11)] predicted the experimental concentration profiles with good accuracy over most of the height of the fluid in the tank. However, due to mixing, which was not allowed for in these equations, the experimentally observed concentration gradients were generally less than the predicted gradients in the lower- and upper-end regions of the tank.

The linear density profiles obtained by the Clark method took less time to produce (about 80 min) than for the other methods. In addition, the linearity of the profiles proved to be a strong function of the passing speed of the plate–rod assembly, the number of passes, and the concentration of the initial two-layered fluid. The complex dependence of the density profile on these factors makes the use of this method very difficult.

The experiments performed with the layer-by-layer method proved to be very time consuming. It took about 10 h to fill the tank and even after 15 h of settling, the concentration profile was still not linear.

The numerical solutions for the transient behavior of the concentration profile compared very well with the experimental results, indicating that the transient behavior of the concentration profile can be approximated by the one-dimensional unsteady mass-diffusion equation. The simulated results indicated that the linear concentration profiles are relatively stable with time.

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NOMENCLATURE

A = Cross sectional area of test tank
c = Salt concentration by volume
c_m = Salt concentration by mass
c_m^* = Dimensionless salt concentration by mass, see Eqs. (17)–(20)
D = Diffusion coefficient
D_o = Diffusion coefficient at 25°C
H = Final height of the fluid in the test tank
q = Volume-flow rate
t = Time
T = Temperature
T_a = Absolute temperature of salt–water mixture
V = Volume
y = Distance measured from the bottom of the test tank
y^* = Dimensionless height, y/H
Δc_m = Slope of the concentration profile by mass
μ = Absolute viscosity of water
ρ = Density

Subscripts

o = Initial
s = Salt
w = Pure water