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The Bridge Between Research and Use

Hydraulic Considerations That Affect Secondary Clarifier Performance

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Introduction

Properly designed and operated clarifiers are essential to the overall performance of virtually every municipal wastewater treatment process. Present design guidance for clarifiers is generally incomplete because it is based on idealized hydraulic and process conditions that do not exist in most clarifiers. In many cases, clarifier design has been reduced to specifications of size without consideration of the internal and external factors which affect the process.

Concern about clarifier design prompted the initiation of a research project to define flow regimes by adapting existing and developing new measurement and analytical techniques.

The project involved a study of eight full-scale units, including both center- and peripheral-feed circular and rectangular clarifiers, where problems were thought to exist. With the problems identified, modifications were to be attempted and any performance improvements documented.

This article presents the preliminary conclusions of the investigators, based on a mixture of the data collected and other observations, though all of the observations are not completely quantified. It is the intent of the authors to generate feedback from other members of the profession with knowledge and experience in clarifier design.

Analytical Procedures

The facilities listed in Table 1 were selected for study: Historically, settling basin hydraulic characteristics have been examined by measuring the dispersion of a slug of tracer as it moves from inlet to point of discharge. From a plot of tracer concentration versus time at the discharge one can infer the flow regime within the basin. However, these results give no indication of the fluid movements within the clarifier.

One analytical tool adapted for this study is a boundary- and time-limited version of a technique more commonly used by oceanographers to trace the source and fate of pollutants in estuarine and coastal waters. Its purpose here was to acquire a series of "snapshots" of the dye plume's progress in a representative radial or longitudinal section of the tank.

The tests began with continuous injection of Rhodamine WT dye just upstream of the clarifier inlet. Subsequently, samples for dye concentration measurement were taken within several sequential 3- to 5-minute periods at 25 predetermined points in the tank. Usually three or four sets of 25 samples were taken at about 30-minute intervals. The complete test series took from 1½ to 2 hours. For this study, each sample included sufficient fluid volume for total suspended solids (TSS) measurement, after removal of the small quantity needed to determine the dye concentration.

TABLE 1. PROJECT FACILITIES

Location	Process Type	Design ($m^3/d \times 10^3$)	Clarifier Type	Dimensions (m)	Depth (m)	Design Surface Overflow Rate ($m^3/m^2/d$)	Sludge Removal Mechanism
Albuquerque, NM	Air Activated Sludge	148.00	CFPO	41 (diam)	4.0	27.8	Siphon
Dallas, TX - Ten Mile Creek Regional Waste Treatment Plant	Air Activated Sludge	25.50	CFPO	32 (diam)	3.7	32.1	Siphon
Holly Hill, FL	Mechanical Activated Sludge	4.54	R	20 (L) 4 9 (W)	2.7	23.5	Chain & Flight
Morganton, NC	Pure O_2 Activated Sludge	30.30	CFPO	24 (diam)	4.9	32.6	Siphon
Oakland, CA - East Bay Municipal Utility District							
Main Plant	Pure O_2 Activated Sludge	636.00	PFPO	43 (diam)	4.3	26.5	Siphon
Process Water	Air Activated Sludge	3.78	CFPO	14 (diam)	3.0	25.6	Siphon
Orange County, FL Sand Lake Waste Water Treatment Plant	Air Activated Sludge	114.00	R	63 (L) 23 (W)	4.0	19.7	Traveling Bridge Siphon
Stamford, CT	Mechanical Activated Sludge	75.70	CFPO	40 (diam)	4.0	30.6	Siphon

CFPO - center feed, peripheral overflow
PFPO - peripheral feed, peripheral overflow
R - rectangular

The "snapshot" was produced by drawing the contours, or lines of equal tracer or TSS concentration, on a scaled sectional drawing of the clarifier. The timed series of contour drawings provided a clear picture of the fluid's path. Figure 1 is a plot of the flow pattern test of a 20-m rectangular secondary clarifier.

A second adaptation of traditional dye tracer methodology was the test to measure dispersion. After release of a dye slug upstream of the inlet, frequent samples were taken at three to six widely separate weir locations rather than at the point of discharge. This technique provided information on direction preferences, often showing peaks which correlated closely with physical disturbances such as those created by sludge removal mechanisms.

The third test, "solids wave," was developed for this study to determine the effect of sludge removal mechanisms on clarifier performance. This involved frequent vertical profiles of TSS concentration at one location near the effluent weirs. The "solids wave" is depicted by a plot of solids concentration versus time at each depth in the vertical profile.

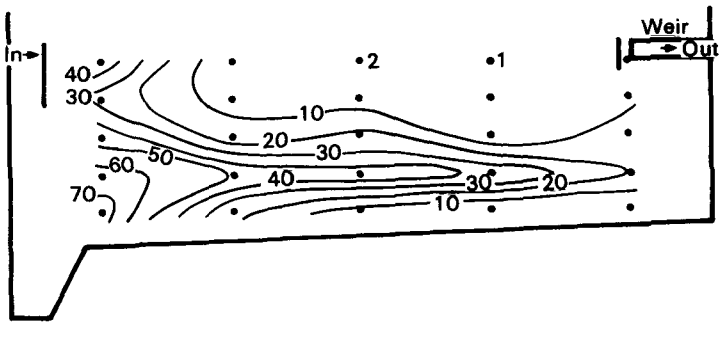


Figure 1. Typical results of flow pattern test showing dye concentrations in a longitudinal section of clarifier after 15 minutes of continuous dye release. (Note: vertical scale exaggerated)

Results and Preliminary Conclusions

Influence of System Physical Features on Process Performance

Balance Between Parallel Clarifiers—It seems axiomatic that the best use of available hydraulic capacity, when two

or more clarifiers operate in parallel, is when both receive the same influent flow rate and solids loadings and have equal amounts of sludge removal. In five of the six plants included in this study with two or more parallel clarifiers, adequate means for either measuring or adjusting the overflow rate of individual clarifiers was not available. Flow measurements by dye dilution techniques or newly installed flow measurement weirs revealed imbalances of 5 to 20% during normal peak flow hours.

Gate valves on the influent lines were commonly used to control flow. The hydraulic characteristics of gate valves are nonlinear, requiring in some cases almost complete closure to balance flows at one rate. In situations where one valve is partially closed to balance flows, variations in flow rate will be greater through the open valve and make manual balancing of diurnal flows difficult.

A satisfactory design solution would be to provide equal distribution by means of hydraulic drops across equivalent weirs exiting a level head channel or basin upstream of the clarifiers. Regardless of head loss downstream of the drop, each unit would then receive equivalent flows. Additional head (<.3m) may be necessary for this flow splitting scheme to be implemented. To assure flow balance, operators must have some means to measure flows. This usually can be accomplished at low cost by providing flow measurement weirs and staff gauges at each clarifier's discharge.

Inlet-To-Inlet Balance—A gross imbalance between inlet port flows was observed (but not measured) at one of the rectangular clarifiers studied. Downstream ports received a majority of the mixed liquor flow, as shown in Figure 2.

A similar phenomenon, but on a larger scale, resulted in imbalance between several parallel rectangular clarifiers on a common mixed liquor channel. Obviously, inadequate consideration had been given to influent flow distribution during the design of these clarifiers. It is also possible that the algorithms commonly used for head calculations and channel design do not adequately address the dynamic effects of flow variations.

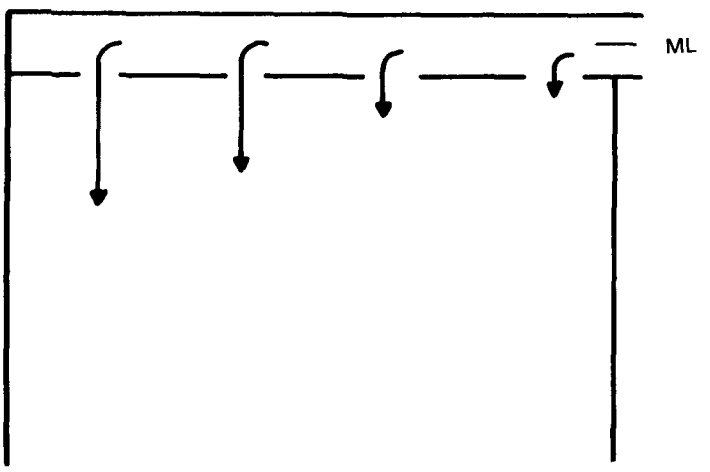


Figure 2. Inlet imbalance observed in one rectangular clarifier with a 4.9-m long mixed liquor channel.

Inlet Design—Clarifier theory and common design standards suggest that inlet velocities should be minimized, flows distributed equally, both horizontally and vertically in the inlet zone, and short circuiting prevented. Though this guidance appears rational, it is actually difficult to implement in practical design. This general type of guidance has resulted in the use of solid skirted baffles in most common designs to direct the influent flows towards the bottom of the clarifier. Rationale for this practice is not consistent but is generally based upon a belief that short circuiting in the basin will be minimized and flow brought in contact with the sludge blanket will enhance solids capture.

Typical results from the flow pattern shown in Figure 3 indicate that a dead or back-eddy region is developed by the solid skirt baffle and good vertical distribution of the incoming mixed liquid is prevented. This is shown by the large areas of low dye concentration directly in front of the baffle. Instead of good vertical distribution, the flow proceeds along the sludge blanket in a relatively narrow path until it strikes the far wall and flows toward the effluent weirs. These data substantiate the presence of density currents which are generally accepted as existing in secondary clarifiers.

It is interesting to note that for each of the three center-feed circular clarifiers in Figure 3, the height of the flow layer between the sludge blanket and the dead region (density current) varied. At Albuquerque, the flow layer utilized approximately 70% of the tank's depth; Stamford's and Morganton's utilized substantially less, 45 and 25%, respectively. Intuitively, the Albuquerque clarifier would appear to have superior hydraulic characteristics. Effluent TSS data substantiated this, with Morganton, Stamford and Albuquerque each having successively better performance.

Presently, it is not known why the depth of the flow layers of these clarifiers differed so greatly. There were physical differences and also differences in the mixed liquor quality among the three clarifiers. It is interesting to note that Albuquerque had the highest Sludge Volume Index (SVI = 110), while Stamford and Morganton had SVI's of 82 and 47, respectively. These data suggest that settling properties of sludge may have an impact on the flow layer in the clarifier. A more closely controlled experiment at one site would be required to substantiate any relationship.

At Holly Hill, Florida, inlet baffles were modified to provide better vertical distribution of the mixed liquor. Flow pattern tests performed after modification showed that most of the liquor above the sludge blanket was included in the flow

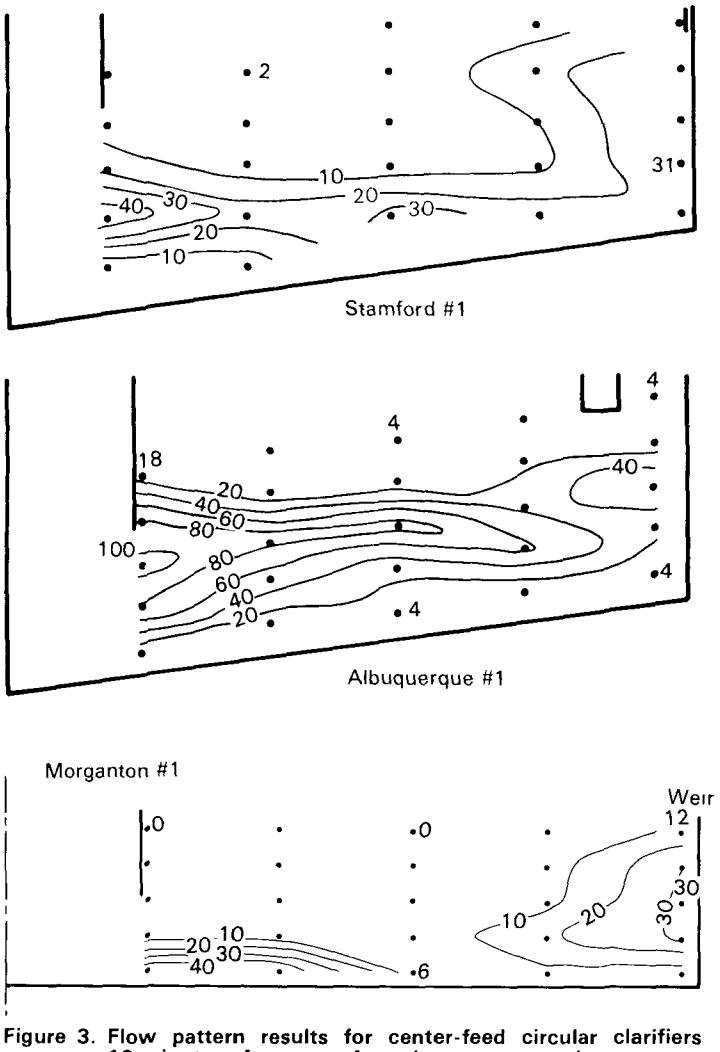


Figure 3. Flow pattern results for center-feed circular clarifiers 19 minutes after start of continuous tracer release. (Note: vertical scale exaggerated)

layer. Even with dramatic improvements in flow patterns, only small improvements in performance were seen. Additional modification of the inlet baffles further eliminated downward flows. After these modifications, the flow pattern was almost identical to that seen before the clarifier was modified. Small performance improvements still were seen over the unmodified clarifier, but clarifier hydraulics appeared to be controlled by other factors in addition to the inlet configuration.

It is obvious from this study that hydraulic conditions recommended by classical theory or current design standards are difficult to achieve through design of inlet structures. At this time no definitive recommendations can be made regarding inlet design since its impact on clarifier hydraulics is not completely understood.

Outlets—The usual clarifier outlet is a length of overflow weir placed at the surface in a region believed to be most distant, in terms of fluid movement, from the inlet region. Current design standards suggest that weirs should be adjustable for leveling; located to optimize hydraulic detention time and minimize short circuiting, and related, in terms of length, to the rate of discharge of the basin.

There is no question about the value of weir adjustability. The rationale for standards of weir length appears to be related to predicted upward velocities of particle-entraining fluid However, upward velocities are seldom uniformly distributed. In seven of the eight cases studied, highest upward velocities were found at end or circumferential walls where weirs are generally placed to meet length requirements. Thus, selection of weir location is typically not given adequate consideration.

Weir Leveling—There is direct evidence from this study that weir height adjustment is critical for good horizontal distribution of flow. A good example of this is in the center-feed, peripheral-overflow unit at Morganton, where there is direct correlation of weir elevation with total flow in various directions. The nondimensional dispersion curves from three weir locations on the periphery of Morganton's test clarifier were integrated. The area under the curves is proportional to the inventory of tracer dye which overflowed the weir at each location. This is interpreted as the relative flow in each direction as shown in Table 2. Subsequent measurements of weir elevations and calculations of flow rates from weir formulas confirmed that lower elevations coincided with greater flow rates as shown by the tracer. It was possible to calculate that, at the existing flow rate, a variation in elevation of ± 3.0mm would result in a flow direction preference of ± 20%. This is, in effect, a short circuit by direction preference.

TABLE 2 TOTAL RELATIVE DYE INVENTORY AT THREE WEIR LOCATIONS (MORGANTON DISPERSION TEST—APRIL 29, 1979)

Weir Station	Area Under Curve (Nondimensional)	Expected Flow Variability (%)
1	0 5063	-20 7
2	0 6608	+ 3 5
3	0 7474	+17 1
Average	0.6382	

A frustration faced during this study was the tedious nature of weir leveling in order to minimize direction preference. Weir leveling using common surveying instruments may not be accurate enough. Leveling on the surface of a shut-down clarifier is the easiest, most accurate method, but is sometimes difficult if weirs are sealed in place by a mastic compound.

Weir Length—Results of this study have shown that the influent flow in a clarifier is across the top of the sludge blanket then upward on the peripheral or end wall.

Momentum of the through-flowing liquor often carries particulates directly to the weirs, especially if they are located on end or peripheral walls. However, since the greatest weir length can be achieved at the peripheral wall of a circular clarifier, this is where weirs are usually placed. This is also the simplest and cheapest structural alternative. It is suggested that the mere specification of weir length per unit overflow may be counter-productive since the alternative may be to place weirs in the path of the higher solids concentrations. Longer weir lengths also make leveling more difficult.

Weir Position—Flow patterns in clarifiers at Holly Hill, Morganton and Stamford indicate that weir locations are far from optimum under the initial conditions measured. Figure 1 illustrates the progression of tracer dye in the Holly Hill clarifier 15 minutes after start of the continuous release. The higher value contours outline the major horizontal through-flow route. Upturn of fluid near the weirs is just apparent in the 10 ppb contour, but frequent solids clouds could be observed at the end wall. The distribution of TSS in a radial section at Stamford, Figure 4, offers more direct evidence. Rising solids at the peripheral wall seem common in center-feed circular units. In selecting a location for clarified liquid overflow, consideration should be given to evidence showing that a flow layer is developed by some combination of inlet configuration and mixed liquor character, which may persist to the outlet wall. Unless a structural means is provided to prevent it, the overflow path will follow a relatively thin pathway atop the sludge blanket, undergoing only minimal vertical dispersion. A modification now being evaluated at Stamford is intended to interrupt the layer of upflow on the peripheral wall. From initial observations, with only one-fourth of the tank's circumference baffled, it appears that significant improvement in effluent quality might result if the baffle were extended the full circumference of the tank.

This study has not fully answered the question of where to locate weirs. Given an "ideal settling zone" immediately upstream, the optimum location for overflow is predictably as far downstream as possible. The flow regimes measured in this study indicate the point of discharge should not be adjacent to the outer (or far) walls.

Sludge Arm Induced Solids Waves—This study included an evaluation of the solids disturbing effects of rotating continuous suction sludge removal devices in five circular tanks and the hydraulic implications of intermittent sludge removal in a large rectangular tank with a traveling bridge. Only the circular tank devices are discussed in this subsection; intermittent sludge removal is covered later.

It is evident from the five circular clarifiers examined that settling performance is adversely affected by rotational speeds commonly specified. A time-varying velocity increase (time-varying directional short circuit) is induced by the rotation of the mechanisms. This is evident in the individual weir station dispersion curves. At a given weir location, solids overflow also correlates well with rotational period.

The phenomenon was first noted in this study at one weir location on Oakland's peripheral-feed clarifier #11. The overall dispersion curve for the unit, measured at the point of discharge, presented no evidence of disturbance. However, weir sampling station #1, which produced the partial dispersion curve shown in Figure 5, displayed peaks which closely correlated with time of passage of the single arm sludge collector, every 35.5 minutes. (In nondimensional terms, plotted in these dispersion figures, 35.5 minutes is equivalent to 0.162 T/T_o units.) Similar effects were noted in Oakland's small process water secondary at Morganton, Stamford and, to a lesser degree, at Albuquerque. These last four clarifiers are all center-feed circular units.

The influence of the trailing "solids waves" is clearly illustrated by measurements from one depth of the time series of solids profiles at Stamford, Figure 6. Here peaks occurred about 90 degrees behind the sludge header.

The data collected are strong evidence of excessive sludge header rotational speeds in the units studied. At Morganton, the sludge header on the test clarifier was

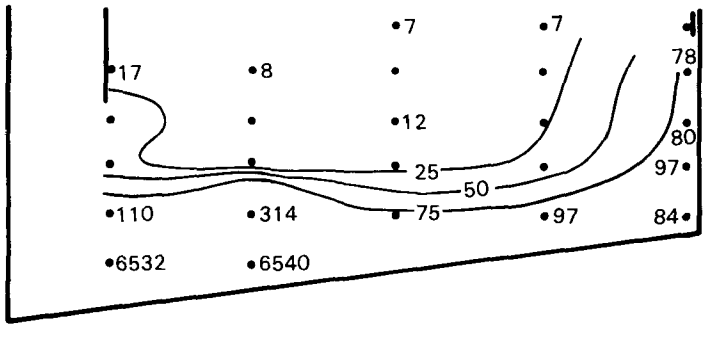


Figure 4. Distribution of TSS in a radial cross-section of Stamford's clarifier #1. The effects of localized upflow are apparent. (Note: vertical scale exaggerated)

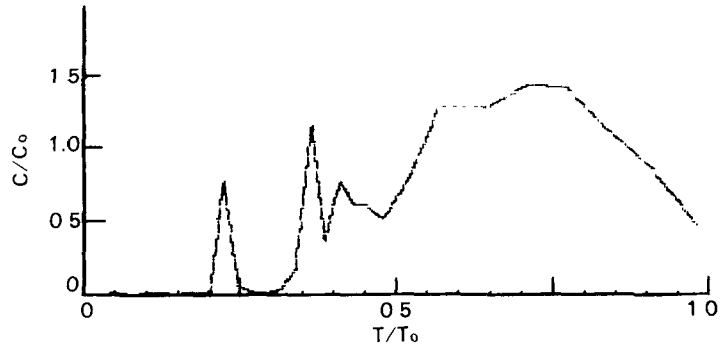


Figure 5. Dispersion curve from one of six individual weir sampling stations on the periphery of Oakland's clarifier #11.

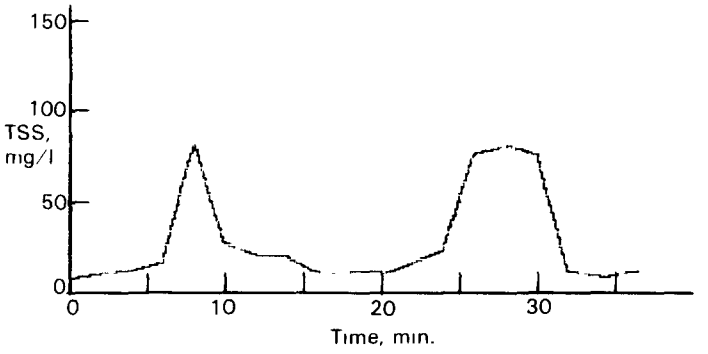


Figure 6. Solids wave at depth of 1.4 m near the peripheral wall of Stamford's clarifier #1.

slowed to 56% of design rate in order to evaluate the implications of header speed. Because of a persistent imbalance in flows between the test and control clarifiers, data comparing their performance, Table 3, are presented in terms of normalized values of TSS or performance expected if flows were equal.

Influence of Hydraulic and Flow Phenomenon on Process Performance

Subordinate Influences on Flow—The first four factors to be discussed (wind, temperature, seiche, and speed of hydraulic response) are termed "subordinate influences" because they may be implicated in flow disturbance to some degree. The primary concern is the effect these factors have on flow and its variability. In itself, flow is subordinate to velocity which is, in its turn, the closest we can now come to a definition of the mechanism by which solids are transported to the clarifier's discharge point.

Wind—The effects of wind on the surface of a clarifier are often apparent only by the position or distribution of scum. Casual observation of subsurface particles leads to the conclusion that the fluid a few millimeters beneath the surface is not affected. Yet, it is well known from analysis of ocean currents and lake levels that wind effects are not negligible.

It is useful to examine a simplified analogy between lakes and clarifiers. By assuming a linear water surface slope, no water loss over the weirs, and a rectangular basin, it can be shown (Table 4) that a 2.0-mm difference in end-to-end water elevation can result from commonly observed steady wind speeds. On typical clarifiers with V-notch weirs, a 3.0-mm difference in elevation is equivalent to a 20% difference in flow. Thus, though the effects of wind are not readily observed (unless waves are present) results in flow-distribution may be significant.

Temperature—Inlet and overflow temperatures were measured at most sites during this study. At no time during the moderate weather encountered was there any temperature difference greater than 0.06°C. In the commonly measured case, in which flow is along the tank

TABLE 4. APPROXIMATE WIND SPEEDS CAPABLE OF CAUSING SURFACE ELEVATION DIFFERENCES OF 2mm IN A RECTANGULAR BASIN

Water Depth (m)	Basin Length (m)	Wind Speed (m/sec)	Wind Speed (miles/hr)
2	10	15.4	34
2	30	5.1	11
2	50	3.1	7
4	10	30.8	69
4	30	10 2	23
4	50	6.2	14

TABLE 3. COMPARISON OF EFFLUENT TSS VALUES IN MORGANTON'S TEST AND CONTROL CLARIFIERS*

	Test Clarifier (header slowed to 56%)			Control Clarifier (normal header speed)		
Week of Average	% of Total Flow	Actual TSS (mg/l)	TSS Adjusted for Flow Split (mg/l)	% of Total Flow	Actual TSS (mg/l)	TSS Adjusted for Flow Split (mg/l)
1	55.1	22.8	20.7	44.9	23.4	26.1
2	50.7	24 4	24 1	49.3	43.3	43.9
3	48.0	34.0	35.4	52 0	61 0	58.7
4	52 9	27.3	25 8	47 1	26.3	27.9
5	53.1	22.9	21.6	46.9	24.6	26.3
		Average	25 5		Average	36.6

*Normalization of TSS valves were accomplished by dividing measured values of the composite samples by two times the flow fraction

bottom, there would seem to be only one condition under which differential temperatures could conceivably result in flow disturbance: in the case of a heated influent accompanied by a surface temperature approaching the maximum water density value of 4°C. In a still-lake, overturn from this cause may occur once or twice a year. In clarifiers, nearly complete mixing occurs in an hour or two. The mechanism of overturn is not well known. One theory involves the formation of small cold-water cells at the surface; these cells gradually assume a pendulous shape and greater density which carries them downward through the underlying fluid. The phenomenon, if real, is not easy to measure.

Seiche—In larger water bodies, on the scale of the Great Lakes, surface level oscillation due to wind or other atmospheric disturbances is well documented. It is instructive to examine whether this type of oscillation (seiching) can occur in a basin the size of a clarifier.

The period of the fundamental oscillation is related to the horizontal and vertical scale of a *rectangular* water body, as follows:

$$T = \frac{2L}{\sqrt{gh}}$$

where T = period (seconds)
h = basin depth
L = basin length
g = acceleration of gravity.

In a clarifier, however, there are often two "free" surfaces: the visible water surface and the sludge blanket surface. An approximation of the period of the first harmonic of sludge blanket seiches can be made by the following related expression:

$$T_i = \frac{2L}{\sqrt{\dfrac{g(S.G. - 1)\,h}{\left(\dfrac{h}{h_e} + \dfrac{h}{h_n}\right)}}}$$

where T_i = period of sludge blanket surface (seconds)
L = basin length
g = acceleration of gravity
S.G. = specific gravity of the sludge
h = overall basin depth
h_e = depth of clarified liquor above the blanket
h_n = thickness of the blanket.

Calculations for surface seiche periods of representative clarifier scales are presented in Table 5. Oscillation periods for the blanket may be double the time shown.

For a *circular* basin, two types of seiching can occur. One type, which is symmetric about the vertical centerline of the tank, produces wave periods of approximately

TABLE 5 PERIODS OF NATURAL (HARMONIC) SURFACE OSCILLATION FOR SEVERAL CLARIFIER SCALE RECTANGULAR BASINS

Water Depth (m)	Basin Length (m)	Time (sec)
2	10	4 5
2	50	25 0
4	10	3 2
4	50	16 0

$$T = 1.64\,\frac{R}{\sqrt{gh}}$$

where R = the tank radius.

For a 3.0-m deep circular clarifier with a 20-m radius, a seiche period of about 6 seconds would be characteristic. A second type of seiche, called "sloshing," is asymmetric about the centerline, extending across the diameter of the basin. This type of seiche has a characteristic period of

$$T = 3.41\,\frac{R}{\sqrt{gh}}.$$

For the same clarifier described above, the sloshing period would be about 12.6 seconds.

The major concern about seiche is the possibility that such disturbances may be caused by wind gusts or transient flow phenomena, such as those induced by lift stations or in-plant process pumps. Because of the enormous variation in tank sizes and the frequencies and amplitudes of seiche, a quantitative assessment of the potential impact of this form of motion has not been attempted.

Speed of Hydraulic Response—The majority of waste treatment plants utilize gravity to move fluids from the front end to the point of discharge. Since "retention time" is such an important part of the design language, there is a tendency to overlook the fact that a level (or pressure) change at the influent point will be followed *very* quickly by a level change downstream at approximately the small amplitude wave speed $c = \sqrt{gh}$. In a 3.0-m deep tank, for example, $c \cong 5.5$ m/sec. Thus, a rapid change in influent flow rate will cause nearly as rapid a change in flow rate in a secondary clarifier, often within seconds.

Rapid flow rate changes, which can be important disturbing influences, can be caused by intermittent lift station or internal process pump operation or simply from severe sewer system inflow. Figure 7 is a plot of secondary clarifier discharge rate at Holly Hill. Measurements were taken at 12-second intervals during a period of high flow.

The rate of discharge from Orange County's clarifier #1, the result of on-off operation of return sludge collectors, is

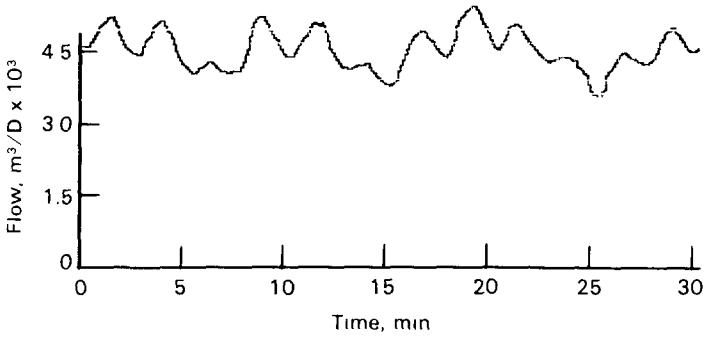


Figure 7. Short-term record of Holly Hill's clarifier discharge during a period of high plant flow.

shown in Figure 8. Several pertinent features of the *system's* flow regime can be derived from this plot. At times A and C, intermittent sludge return pumps were started. At B, pumps were shut off. This is the normal cycle. The periods A-D and C-I represent the time required for the leading edge of the return sludge wave to have travelled throughout the plant complex and back to the point of clarifier discharge, all by gravity. The two humps between E and G are believed to result from whole plant seiche.

Average Horizontal Flow Velocity Toward Weirs—As discussed previously, regardless of tank slope and dimension, or inlet configurations, all measured flow patterns appeared to assume parabolic profiles of various thicknesses on top of the sludge blanket. This flow layer or density current, flowing horizontally, persisted to the peripheral wall, where it turned upward toward the weirs. Although this article has not provided sufficient data for a complete explanation of this phenomena, preliminary results indicate that the depth of the flow layer associated with the horizontal flow toward the weirs may be related to inlet configuration and mixed liquor quality.

The unscaled velocity profiles, presented in Figure 9, have been estimated from the flow pattern measurements at Albuquerque, Stamford and Morganton. Albuquerque's effluent quality was excellent; Stamford's and Morganton's were successively poorer. It should be noted,

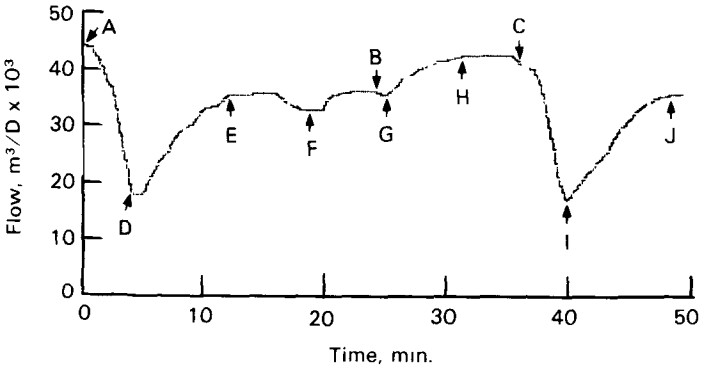
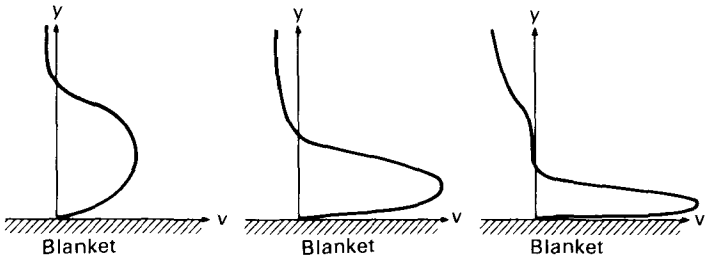


Figure 8. Short-term record of the discharge of Orange County's clarifier #1.



Time, min	Settled Sludge Volume		
	Albuquerque	Stamford	Morganton
0	1000	1000	1000
5	550	350	300
10	450	260	225
15	380	230	195
20	340	210	185
30	270	200	170
60	240	180	150
MLTSS	2450 mg/l	2430 mg/l	3600 mg/l
SVI	110	82	47

Figure 9. Velocity profiles derived from flow-pattern tests in three center-feed circular clarifiers.

that all three plants had relatively steady flow rates during test times. Transient peak flows at any of the sites may have seriously degraded effluent quality, especially at Albuquerque. The depth utilized for forward flow must, by physical necessity, be inversely related to the velocities of horizontal throughflow. Higher velocity is associated with higher levels of turbulence, which is in turn suspected as a prime mover of solids toward the weirs. Table 6 presents a set of velocity calculations based on the three velocity profiles of Figure 9.

Increased Solids Transport Induced by Amplitude Variation of Flow—By any reasonable estimate, horizontal clarifier flows are turbulent, not laminar. Thus, we are confronted with eddies which move particles upward while horizontal transport is occurring. By use of some simplifying assumptions, including a uniform eddy viscosity and reasonable values of particle settling velocity, a diffusion model can be solved to provide a factor by which increased

TABLE 6. CALCULATED MEAN FORWARD FLUID VELOCITIES AT MID-RADIUS FROM THREE CENTER-FEED CIRCULAR CLARIFIERS

Site	% Depth Utilized	Tank Radius (m)	Mean Forward Velocity at Mid-Radius* (m/sec)
Albuquerque	70	20 57	0.00323
Stamford	45	19 81	0 00436
Morganton	25	12 19	0 00489

*Based on total overflow plus one half underflow rate

transport of solids within the clarifier, resulting from amplitude variations of plant flow, can be predicted:

$$T_R = \frac{1}{T} \sum_{i=1}^{n} \left\{ \left(\frac{\bar{u}}{\bar{v}} \right)^3 \Delta T \right\}_i$$

where T_R = solids transport relative to that expected in steady flow

T = total period of measured values

$\bar{u}$ = Spatial average instantaneous forward velocity in some cross-section (say at mid-radius)

$\bar{v}$ = time average of all $\bar{u}$ values.

A simple example of an evaluation of this equation is presented in Table 7 This evaluation indicates that a plant flow variation of ± 10% would result in an increase in solids transport in the clarifier of 5%. Application of the same equation to normal, dry weather diurnal flow variations in five small Texas cities resulted in predicted increased solids transport of 46 to 123%. This turbulent diffusion model predicts flow-induced solids transport in secondary clarifiers, but does not determine amounts of solids escaping the clarifier. If it is assumed that effluent solids are proportional to the solids transported, then flow variability could have significant impact on clarifier performance.

TABLE 7 HYPOTHETICAL FLOW VARIATIONS EVALUATED FOR INCREASE IN EFFLUENT TSS

$\bar{u}$	$\bar{u}/\bar{v}$	$(\bar{u}/\bar{v})^3$
1 8	0 9	0 729
2 0	1 0	1 000
2 2	1 1	1 331
	Average	1 05

At Holly Hill, an attempt was made to explain improvements in effluent TSS performance, which apparently resulted from attempting to equalize flows by using the channel ahead of the aeration basin. These improvements are listed in the preliminary data compilation, Table 8.

At moderate flows, illustrated in Figure 10, the amplitude equation predicts only 9.6% improvement in TSS performance where all flow variations have been removed. It was apparent that yet another phenomenon was operating, as shown by the consistently better performance of both the test and control clarifiers when the small storage channel is in use.

Frequency of Flow Variation—The turbulent diffusion model predicts higher concentrations of transportable solids above the blanket at higher velocities of horizontal flow. Three representative solids profiles may be similar to those shown in Figure 11, which correspond to increasing velocity and turbulence levels.

Turbulence is quickly generated by higher velocity, but is very slow to die off as velocity decreases. Theoretical

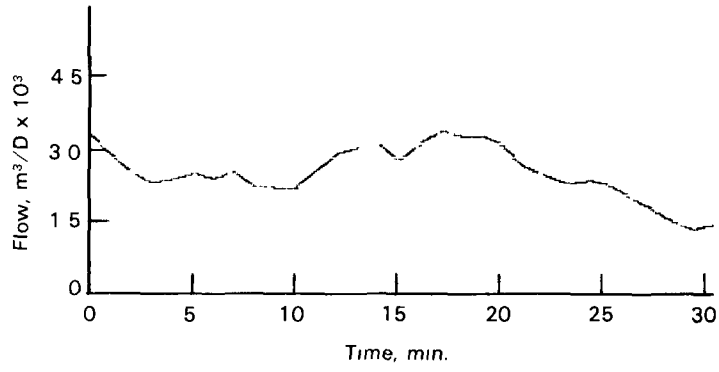


Figure 10. Measured discharge rate from the Holly Hill clarifier during a 30-minute period.

TABLE 8 EFFLUENT TSS AVERAGES IN TEST AND CONTROL CLARIFIERS (HOLLY HILL) AT FLOWS EQUAL TO OR LESS THAN DESIGN RATES OF 1.2 MGD

Number of Days in Sample	Test Condition*	Test (South) Clarifier Effluent TSS (mg/l)	Control (North) Clarifier Effluent TSS (mg/l)
25	First trial of new reaction baffles, 1000 gallon storage not in use. March 12—June 1, 1979	25.6	25 2
23	First trial of new reaction baffles, 1000 gallon storage in use March 12—June 1, 1979	15 5	20 7
20	Second baffle revision, 1000 gallon storage not in use June 1—August 18, 1979	16 0	19 6
13	Second baffle revision, 1000 gallon storage in use June 1—August 18, 1979	11 5	17.2

*Storage was utilized on a week-on, week-off basis to separate hydraulic improvement phenomena from the possible effects of long-term process changes.

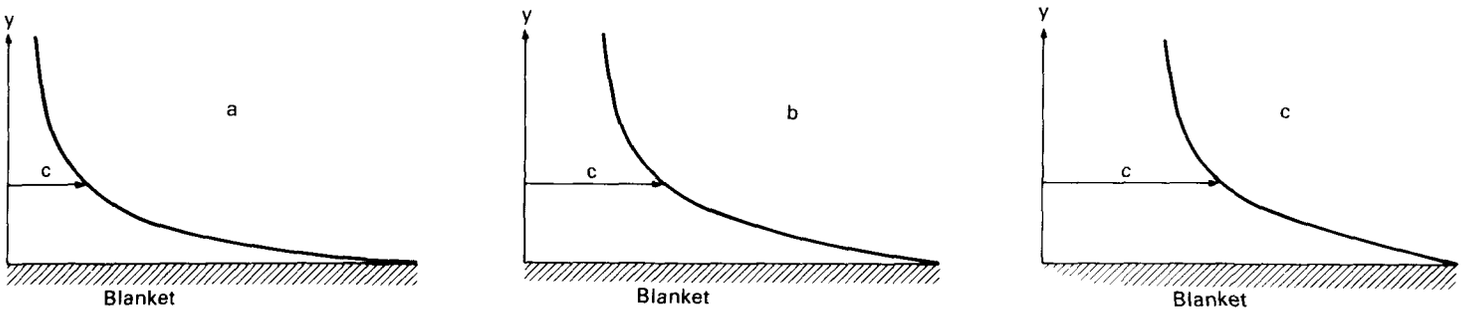


Figure 11. Concentration profile at a) low horizontal velocity, b) moderate horizontal velocity, c) high horizontal velocity.

analysis has shown that die-off time is on the order of the retention time of the basin, or longer.

Since the decrease in turbulence is so much slower than its onset, it can be seen that rapid changes in flow rate will result in concentrations of suspended and transportable solids which are much nearer high velocity values than average velocity values. As a first approximation, transport varies as the frequency of flow rate changes. This estimate helps to explain the discrepancy in modest predicted improvement versus actual significant improvement in effluent TSS at Holly Hill by use of a small equalization basin. This phenomenon, as well as several other observations and calculations mentioned in this article, will be further verified during research planned for 1980.

This study was completed by Robert Crosby of Crosby, Young and Associates, under the direction of Jon Bender of Urban Systems Management Section, Municipal Environmental Research Laboratory, U.S. EPA. All requests for additional information should be directed to Crosby, Young and Associates, 1201 E. 15th Street, Plano, Texas 75074.

Symposium Announcement: Health Risks Associated with Land Application of Municipal Sludges

An international symposium on "Evaluation of Health Risks Associated with Feeding and/or Land Application of Municipal Sludges" will be held in Tampa, Florida, on April 29-May 1, 1980. This symposium is sponsored jointly by EPA's Office of Research & Development and the Institute of Food and Agricultural Sciences of the University of Florida. The program will feature invited papers delivered by authorities in the field. These speakers will cover major aspects of health significance as they relate to sludge application to land. Two sessions will be devoted to contributed papers based on original research. Major findings of a number of research projects dealing with land application of sludge will also be discussed. Information concerning presentation of papers, registration and accommodations can be obtained form E. M. Hoffmann, 1059 McCarty Hall, University of Florida, Gainesville, Florida 32611.

Seminar Series Ends—Wastewater Treatment Facialities for Small Communities

The last two in the series of Technology Transfer Municipal Design Seminars on Wastewater Treatment Facilities for Small Communities were held November 5-7, in Orlando, Florida and December 4-6, 1979 in Philadelphia, Pennsylvania.

Completion of these seminars brings to an end almost three years' work and 22 seminar presentations by the Technology Transfer Environmental Control Systems Staff and the seminar speakers. The series, which began in March 1977, has been continually updated to include the latest design information and research results for handling waste from individual residences and small communities, as well as changes in federal legislation (P.L. 95-217). Over 4,000 engineers and pollution control officials attended these seminars.

EPA Plans International Seminar on Control Technology for Nutrients in Municipal Wastewater Effluents

The Municipal Environmental Research Laboratory will sponsor a seminar to disseminate information by worldwide experts in the field of full-scale municipal nutrient control systems. This seminar is scheduled to be held September 9-11, 1980, in San Diego, California at the Hotel del Coronado.

In the past ten years, nutrient control technology has advanced from the pilot plant and prototype stage to hundreds of full-scale installations. The purpose of this seminar is to review the design, operating, and economic characteristics of successful full-scale systems. The material presented will benefit environmental personnel involved in designing second generation systems to meet stringent water quality requirements.

Case histories will be presented by over 20 invited speakers from the United States, Canada, Japan, Sweden, Austria, Australia, England, and South Africa. A wide range of nutrient control approaches will be discussed, including chemical-physical, biochemical, chemical supplementation, batch process, and land application. The seminar will be divided into three one-day sessions: phosphorus control, nitrogen control, and combined phosphorus and nitrogen control. A block of rooms has been reserved for conference attendees; no registration fee is required. To obtain more information about the seminar, contact:

Norm Kulujian
USEPA
Cincinnati, OH 45268
Telephone (513) 684-7394

New Capsule Report on Acoustic Monitoring

There are as many as 500,000 earthen diked areas in the United States containing hazardous wastes which if spilled or leaked to the environment could have long-lasting impact. EPA's Office of Research and Development has long been aware of the potential hazard posed by these earthen impoundments and the need for an inexpensive and simple technique to monitor their stability. Under this impetus, a system—acoustic emission monitoring—was developed through the Industrial Environmental Research Laboratory in Cincinnati. This system is based on the phenomenon that soils emit sounds under stress and, when properly amplified and quantified, can be a valuable guide in evaluating the stability of the hazardous waste dams.

A new Technology Transfer Capsule Report, "Acoustic Monitoring to Determine the Integrity of Hazardous Waste Dams," describes the theory, installation and costs of this system.

To order the report, check box #2024 and return the order form at the back of this Newsletter.

Earthen dams containing hazardous wastes are potential danger to the environment.

New Seminar Publication on Forest Products

"Pollution Control in the Forest Products Industry" is a compilation of the presentations of seminars held in Portland, Oregon and Dallas, Texas. This publication deals with both air and water pollution control problems in the forest products industry and briefly reviews the Clean Air and Clean Water Acts as they apply to this industry. Examples of the kinds of research and technologies being applied by the industry to meet its air and water pollution control responsibilities are described. Several case studies are also included in the report. To order a copy of this Seminar Publication, check box #3010 and return the form at the back of this Newsletter.

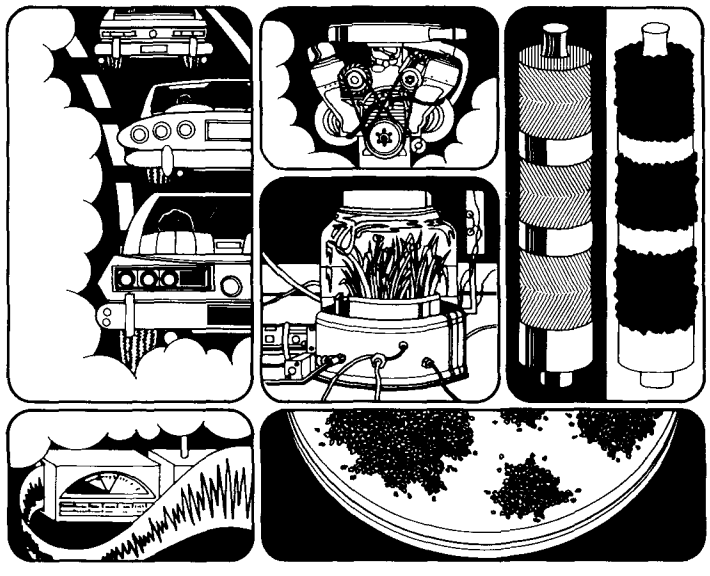
New TT Publication on Diesel Emissions Research

Because of the fuel efficiency of diesel engines, the number of diesel-powered passenger cars on U.S. roadways is expected to increase substantially during the next decade. Concern about the human health implications of this change has prompted EPA's Office of Research and Development (ORD) to launch a major research effort to assess the potential human health impacts from diesel emissions.

The Center for Environmental Research Information (CERI), in cooperation with ORD's Mobile Sources Research Committee, has recently generated a new publication describing this research effort. The report, entitled "The Diesel Emissions Research Program," highlights the work that is being done by seven ORD components to determine the health effects of diesel emissions. Research includes: human population studies, animal and cellular studies, chemical characterization of diesel particles, pollutant monitoring, control technology development and pollutant level and human population exposure estimations.

In addition, the report explains how the information generated from this research will be used to assess the public health risk associated with increased use of the diesel engine. The estimated risk along with other important factors then will be used by EPA to determine whether additional regulation is required for diesel emissions.

A copy of this report can be ordered by checking box #9004 and returning the order form at the back of this Newsletter.



Potential health effects by diesel emissions is currently being researched.

1979 Bibliography of Small Wastewater Flows

"The 1979 Bibliography of Small Wastewater Flows," compiled by the U.S. EPA National Small Wastewater Flows Clearinghouse has been published and is now available.

The Clearinghouse is administered by the West Virginia University Energy Research Center, under a grant funded by EPA's Center for Environmental Research Information (Office of Research and Development) under the authority of and as provided for by the 1977 Clean Water Act. Included in the bibliography are indexes by accession number and title, toxonomy index, an author index, a state index and a glossary of descriptive words. Information is included on the following topics:

- septic tanks and subsurface disposal systems;
- other on-site systems, including dual systems;
- cluster systems serving a small number of households or commercial users, with average annual dry weather flows of under 25,000 gallons per day;
- six-inch and smaller gravity sewers carrying partially or fully treated wastewater or carrying raw wastewater as part of limited conveyance systems which serve clusters of households and small commercial establishments;
- pressure and vacuum sewers;
- the above and other alternative sewers that are specifically exempted from the collector sewer interceptor designations and that are not the subject of EPA collection system policy; and
- other treatment or conveyance works that employ alternative technologies and that serve communities with populations of 3,500 or less or the sparsely populated areas of larger communities.

Copies of the 1979 *Bibliography of Small Wastewater Flows,* at a cost of $7 per copy (including postage and handling), are available from:

West Virginia Bookstore
Mountain Lair
West Virginia University
Morgantown, WV 26506

Seminar Announcement: Water and Wastes Management in the Arctic Environment

Two Technology Transfer seminars on "Water and Wastes Management in the Arctic Environment" will be held in March. The Center for Environmental Research Information (CERI), in association with the Environmental Research Laboratory at Corvallis, Oregon, is sponsoring the series to be held March 27-28 in Anchorage, Alaska, and March 31-April 1 in Seattle, Washington.

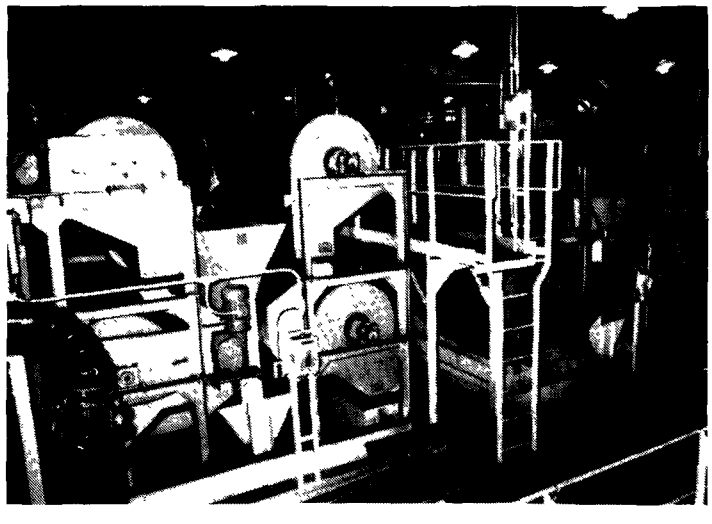
The seminar series is intended for consulting engineers, municipal and industrial design engineers, and federal, state and local officials who are involved in planning, construction and operation of utility facilities in an arctic-type environment.

These seminars are based on a new Process Design Manual, "Cold Climate Utilities Delivery," which was prepared by a group of U.S. and Canadian experts who have extensive field experience in this area. Presentations will include: planning for design and construction of cold region facilities; water supply systems—storage and treatment; drinking water distribution and wastewater collection; wastewater treatment and disposal; thermal consideration for design and construction; energy considerations in design of utilities; solid waste management; and design of central facilities and water conservation.

For additional information on this seminar series, contact Dr. J. E. Smith, Jr., USEPA—CERI, Cincinnati, Ohio 45268, (513) 684-7394.

New Capsule Report: Physical Coal Cleaning Demonstration at Homer City, Pennsylvania

The Center for Environmental Research Information recently published a Technology Transfer Capsule Report entitled, "First Progress Report: Physical Coal Cleaning Demonstration at Homer City, Pennsylvania." Under the 1977 Clean Air Act, as amended, specific standards have been established to limit sulfur dioxide (SO_2) emissions from large stationary sources, such as coal-burning boilers. In addition, new sources may emit only a limited percentage of the sulfur and other pollutants present in the raw coal. This cleaning process allows the use of raw coals with a pyritic to organic sulfur content of 2:1 to 4:1, by removing enough pyrite sulfur to permit the cleaned coal to be burned while still meeting the SO_2 standards. An advantage of this process is that other SO_2 emission control devices are rarely needed. This publication describes the theory, the current testing program at Homer City and other applications of the PCC process, such as its use in combination with flue gas desulfurization to minimize costs. To order this publication, check (#2023) and return the order form at the back of this Newsletter.



Magnetic separators used in the physical coal-cleaning method.

Seminar Series Ends

Approximately 1500 engineers, municipal officials, government engineers, and other interested individuals attended the series of ten seminars held in 1979 dealing with EPA's new Innovative and Alternative (I/A) Technology Program. The "Innovative and Alternative Technology Assessment Manual," EPA-430/9-78-009, MCD-53, a draft of which was handed out at the seminars, is currently under revision. To obtain a copy of the final edition, write:

U.S. Environmental Protection Agency
WH-547
401 M Street, S.W.
Washington, DC 20460

ERRATA SHEET

Sulfur Oxides Control Technology Series: Flue Gas Desulfurization

Wellman-Lord Process

EPA 625/8-79-001 (February 1979)

The second paragraph on page 5 reads (in part) "All equations are in the un-ionized form to simplify the presentation." However, throughout the report, the equations are shown in the ionized form The following corrections are required to change the chemical reactions to the un-ionized form

Page No.	*From*		*To*	
8	$Na_2SO_3^{=} + SO_2 + H_2O \longrightarrow 2NaHSO_3^{-}$	(1)	$Na_2SO_3 + SO_2 + H_2O \longrightarrow 2NaHSO_3$	(1)
8	$Na_2CO_3^{=} + SO_2 \longrightarrow Na_2SO_3^{=} + CO_2$	(2)	$Na_2CO_3 + SO_2 \longrightarrow Na_2SO_3 + CO_2$	(2)
8,15	$Na_2SO_3^{=} + \frac{1}{2}O_2 \longrightarrow Na_2SO_4^{=}$	(3)	$Na_2SO_3 + \frac{1}{2}O_2 \longrightarrow Na_2SO_4$	(3)
12	$6NaHSO_3^{-} \xrightarrow{\Delta} 2Na_2SO_4^{=} + Na_2S_2O_3^{=} + 2SO_2 + 3H_2O$	(5)	$6NaHSO_3 \xrightarrow{\Delta} 2Na_2SO_4 + Na_2S_2O_3 + 2SO_2 + 3H_2O$	(5)
12	$2NaHSO_3^{-} + 2Na_2SO_3^{=} \xrightarrow{\Delta} 2Na_2SO_4^{=} + Na_2S_2O_3^{=} + H_2O$	(6)	$2NaHSO_3 + 2Na_2SO_3 \xrightarrow{\Delta} 2Na_2SO_4 + Na_2S_2O_3 + H_2O$	(6)
15	$2Na_3SO_3^{=} + SO_3 + H_2O \longrightarrow Na_2SO_4^{=} + 2Na_2HSO_3^{-}$	(7)	$2Na_2SO_3 + SO_3 + H_2O \longrightarrow Na_2SO_4 + 2Na_2HSO_3$	(7)

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