

MEMORANDUM

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Attached is an article that addresses oxygen transfer in activated sludge systems by various types of aeration devices.

Total pages = 21

OXYGEN TRANSFER SYSTEMS FOR INDUSTRIAL WASTEWATER TREATMENT

By

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THEORETICAL DEVELOPMENT

The basic model for oxygen transfer in a dispersed gas-liquid system such as activated sludge mixed liquor is,

Mass Rate of Transfer = Transfer Coefficient x Driving Force

or

$$N = K_L A (C_{sat} - C_L) \quad (1)$$

Where,

- N = Mass rate of transfer, mg/hr
- K_L = Liquid film transfer coefficient, L/hr-sq ft
- C_{sat} = Average dissolved oxygen (DO) saturation concentration, mg/L
- C_L = Average mixed liquor DO concentration, mg/L
- A = Area of gas-liquid interface, sq ft

On a concentration basis, Equation (1) can be expressed per unit of aeration basin volume (V) as,

$$N/V = dC/dt = K_L(A/V)(C_{sat} - C_L) = (K_L a)(C_{sat} - C_L) \quad (2)$$

Since the area of the gas-liquid interface can not be measured in mixed liquor, the term " $K_L(A/V)$ " is expressed as " $K_L a$ ". Term " $K_L a$ " is the overall oxygen mass transfer coefficient at temperature T and has units of hr^{-1} . The average oxygen transfer rate (OTR) in the aeration basin at the mixed liquor temperature, T, is,

$$OTR = (K_L a)_T V [(C_{sat})_T - C_L] \quad (3)$$

The OTR varies with the mixed liquor temperature due to changes in $(K_L a)_T$ and $(C_{sat})_T$ and with the local site elevation and water salinity (ie, TDS) due to changes in $(C_{sat})_T$. In order to facilitate comparison of different oxygen transfer devices (as represented by their $K_L a$ values), the operating variables in Equation (3) have been standardized to define the Standard Oxygen Transfer Rate (SOTR). The standard conditions are T = 20°C, $C_L = 0$ mg/L, 1.0 atm barometric pressure and "clean water". Under these conditions, the overall mass transfer coefficient, $(K_L a)_{20}$, is the only variable and Equation (3) expresses the Standard Oxygen Transfer Rate (SOTR) as,

$$\text{SOTR} = (K_L a)_{20} V (C_{\text{sat}})_{20} \quad (4)$$

The SOTR is expressed in units of "lb of O₂ transferred per wire horsepower hour of operation" (lb/wire hp-hr). For diffused aeration systems, the oxygen transfer rate is expressed as the mass transferred per unit mass of oxygen delivered and Equation (4) becomes the Standard Oxygen Transfer Efficiency (SOTE). The SOTE is typically expressed as a percentage or as the "lb of O₂ transferred per diffuser unit per hour of operation" (lb/hr/unit).

The value of $(C_{\text{sat}})_T$ varies with the operating temperature and the "effective depth" of the oxygenation source as illustrated in Figure 1. The value can be determined by Equation (5),

$$(C_{\text{sat}})_T = (C_{\text{sat}})_T^* [(P_b / 59.84) + (O_t/42)] \quad (5)$$

Where,

- $(C_{\text{sat}})_T^*$ = Surface saturation DO for clean water at operating temperature T and TDS and the prevailing site barometric pressure, mg/L
- P_b = Absolute pressure at point of air release, in Hg
- O_t = Oxygen in off-gas leaving the aeration tank, % (v/v)

The value of $(C_{\text{sat}})_T^*$ can be taken from Standard Method's tables for dissolved oxygen saturation which include adjustment for TDS, elevation and temperature.

The effect of diffuser submergence on the saturation value for oxygen is significant. For example, in a deep tank with diffusers located at 25 ft submergence and a 10 percent transfer efficiency, the value of $(C_{\text{sat}})_T$ is 35 percent higher than at sea level. Thus, the SOTE is increased due to both the greater driving force provided by the higher DO saturation value as well as the longer residence time of the bubble's rise through the liquid. Equation (5) can also be applied to mechanical surface aeration devices using " P_b " values equal to 5 to 15 percent of the liquid depth and O_t values of 19 to 20 percent.

APPLICATION OF SOTR TO OPERATING CONDITIONS

The performance of aeration devices, expressed as their SOTR (or SOTE), is available from equipment vendors. The treatment process, however, requires that the carbonaceous and nitrogenous oxygen demands be satisfied at prevailing conditions of mixed liquor temperature and average DO and wastewater characteristics. The SOTR (or SOTE) therefore, must be adjusted to site specific conditions such that the Actual Oxygen Transfer Rate (AOTR) satisfies the treatment process's oxygen demand. The AOTR can be determined by Equation (6).

$$\text{AOTR} = \text{SOTR} [F(\alpha)_{20}(\theta)^{T-20}] [\beta(C_{\text{sat}})_T - C_L] / (C_{\text{sat}})_{20}^* \quad (6)$$

Where,

- AOTR = Actual oxygen transfer rate under field conditions, lb/hr
(C_{sat})_{20*} = Surface DO saturation of clean water at 1.0 atm, mg/L
 β = Ratio of (C_{sat})_T of wastewater to that of clean water
(α)₂₀ = Ratio of ($K_L a$)₂₀ of wastewater to that of clean water
 θ = Temperature correction factor for (α)₂₀
F = Fouling factor (<1.0) for aerator after specified service time.

It is noteworthy in Equation (6), that only the SOTR is controlled by the design engineer's selection of the aeration device. All of the remaining parameters are either site specific (e.g. (C_{sat})_T, C_L and T) or wastewater specific (e.g., β , (α)₂₀, F, and θ). The effects of the wastewater related parameters are discussed below in terms of their application to industrial wastewater treatment.

TEMPERATURE CORRECTION FACTOR, θ

The temperature correction factor, θ , varies from 1.008 to 1.047 and is usually assumed to be 1.024. The actual θ value depends on the specific wastewater characteristics, aeration basin mixing intensity, and the type of aeration device.

The effect of θ on the AOTR can be significant since the α value is established at 20°C and varies exponentially with the mixed liquor temperature. Operating mixed liquor temperatures can be 35°C to >40°C when treating high BOD/COD strength industrial wastewaters particularly when using covered aeration basins. The effect of θ on AOTR is illustrated in Table 1 which shows the ratio of AOTR/SOTR for the range of θ values. Table 1 was developed assuming that $C_L = 2.0$ mg/L, F, barometric pressure, (α)₂₀ and $\beta = 1.0$, TDS = 400 mg/L and a 20 ft diffuser submergence.

The results indicate that at $\theta = 1.024$, the decrease in AOTR caused by the reduction in available "driving force" at the lower (C_{sat})_T values and higher temperatures, is offset by the increase in (α)_T. The resulting AOTR/SOTR ratios remain approximately constant over the broad operating temperature range of 10°C to 40°C. However, if the mixed liquor temperature was 40°C and the actual θ value of the wastewater was 1.008, the AOTR would be only 73 percent of the value that was expected at $\theta = 1.024$. Under this condition, there would be a 27 percent shortfall in oxygenation capacity.

Although θ is usually assumed to be 1.024, there is little consensus regarding the effects of the design and operational variables on the accurate prediction of θ . As such, θ should be estimated from bench-, pilot- or full-scale aeration tests.

TABLE 1
EFFECT OF TEMPERATURE CORRECTION FACTOR, θ , ON AOTR/SOTR^a

Temperature (°C)	$(C_{sat})_T$ (mg/L)	AOTR/SOTR at Indicated θ Value		
		1.008	1.024	1.047
10	11.25	1.24	1.06	0.84
20	9.16	1.05	1.05	1.05
30	7.57	0.90	1.05	1.31
40	6.60	0.82	1.12	1.74

a. Based on $C_L = 2.0$ mg/L, $F=1$, $H=20$ ft and 1.0 atm. ambient.

BETA

Beta is the ratio of C_{sat} of the wastewater to C_{sat} of clean water at a common temperature and is independent of the type of aeration device, aeration basin mixing intensity and tank geometry. Beta values of industrial wastewaters vary from 0.7 to 1.2 with the higher values associated with high dissolved salt concentrations. The AOTR, however, is not particularly sensitive to the value of beta since in Equation (6) it is part of a "compound" expression involving several other parameters.

The value of beta can be reasonably estimated by simple bench-scale, batch aeration tests using a porous stone diffuser and the treated effluent. In the absence of test data, a beta value of 0.9 can be assumed for most industrial wastewaters.

FOULING FACTOR, F

The fouling factor for diffused aeration devices is the ratio of the $K_L a$ of the wastewater, $(K_L a)_{w/w}$, after a "t" period of service to the $(K_L a)_{w/w}$ at $t = 0$. The factor reflects the effect of chemical and biological accumulation on the aeration device, as well as, the physical deterioration of the device or diffuser membrane itself over an extended period of service.

Clogging of the diffuser pores on the air side occurs due to airborne particulates and on the liquid side due to precipitation of metal hydroxides and carbonates. Similarly, the liquid side can be fouled by a biofilm layer which does not directly plug the diffuser pores but overlies the membrane surface. In either case, the clogging effect causes the formation of larger or irregular bubbles and decreased AOTR at the expense of increased operating pressure. Air side clogging is uncommon and can be minimized by proper filtration of the blower intake air supply and use of non-corrosive and non-scaling materials for air header piping. Liquid side clogging, however, is chronic and depends on the wastewater characteristics and several design and operational parameters.

Unfortunately, rigorous evaluation of the F factor has only been recently undertaken. Oxygen transfer efficiencies of ceramic disk (7 inch) diffusers during a 30-month service period are summarized in Figure 2. The diffusers are located in two parallel rectangular 300x30x15 ft (LxWxD) tapered aeration basins at the Tillman Wastewater Reclamation Plant (TWRC) in the San Fernando Valley, CA. The results indicate a 20 percent loss in average SOTE during the 125-day Feb-June 1992 operating period. After the diffusers were acid cleaned and retested (Dec 10, 1993), the average SOTE increased to 13.40 and 10.79 percent in Tank Nos. 6 and 7, respectively. These efficiencies however, remained below their initial (i.e., 'as installed') values. In July 1994, the diffusers in Tank No.6 were replaced and those in Tank No. 7 were cleaned with liquid acid. Cleaning partially restored the average SOTE (16.87 percent) but in Tank No. 7 but it remained less than the average SOTE of the new diffusers 6 (19.63 percent) that were placed in Tank No 6.

Additional test work was conducted at the TWRC during March and April 1998 in Tank Nos. 4 and 5 that were equipped with Aercor ceramic dome diffusers (7-inch). These results indicated a rapid loss of approximately 50 percent in the average SOTE during the 3-month period. The average SOTE in Tank No. 4 decreased from 18.93 percent to 8.97 percent while the SOTE in Tank No. 5 declined from 9.85 percent to 4.66 percent. These losses were attributed to the combined effects of fouling and mechanical 'flooding' of the aeration headers due to frequent power outages at the blower system during the period.

The focus of the above investigations has been on diffuser systems in large municipal treatment facilities that have negligible impact from industrial wastewater loads. However, survey results from three activated sludge plants treating food processing wastewaters are available and are summarized in Table 2. All three plants used the same tube-type fine bubble membrane diffuser and were operated at organic loading rates of approximately 50 lb BOD/d-1000 cu ft.

**TABLE 2
SUMMARY OF DIFFUSER FOULING EFFECTS
FOR FOOD PROCESSING WASTEWATERS**

Plant	Service Time	Diffuser Condition	DWPa	SOTE ^a
No 1	0	New	8.8 in	18.0 %
	13 mth	Cleaned	3.8 in	14.8 %
No 2	0	New	15.3 in	23.0 %
	24 mth	Cleaned	6.3 in	17.5 %
No 3	0	New	11.8 in	21.8 %
	8 mth	Cleaned	---	18.8 %

a. Dynamic wet pressure measured at 1.0 scfm per diffuser

The results indicate that clogging caused a significant loss in SOTE (and thus AOTE) within only 8 to 24 months of operation. Acid gas cleaning of the diffusers failed to restore the SOTE to its "as-new" condition. The resulting loss in SOTE ranged from 14 to 24 percent (i.e. F values of -0.76 to 0.86 should have been used in Equation (6) to calculate the AOTE).

It is unclear whether the failure to recover the as-new SOTE at these facilities was only temporary and due to an inadequate cleaning program or permanent due to severe incrustation or deterioration of the membrane itself. Membrane deterioration is due to the shrinking or swelling of the membrane/pores caused by the gradual loss of volatile materials that are used in the manufacturing process and retained in the membrane. As the air flow "strips" the volatiles, the membrane may lose its original properties and SOTE characteristics which can not be restored.

Effect of Process Characteristics on Fouling

The municipal data base developed for evaluation of the F factor is limited to treatment of relatively low strength wastewaters using a narrow range of SRTs and organic loading rates that are not indicative of industrial wastewater treatment. As such, the data provide only limited insight to the effects that process design and operating parameters might have on the F factor in industrial wastewater treatment applications. Based on review of the available municipal wastewater treatment data, however, the following guidelines are suggested for the effects of diffuser fouling on industrial wastewater treatment:

1. The F factor is site specific and varied from 0.2 to 0.9 at similar aeration service times. This variation is notable considering the relative "uniformity" of treatment characteristics found in large municipal treatment facilities compared to industrial wastewater treatment.
2. Lower unit airflow rates (scfm/sq ft of diffuser membrane) and higher diffuser densities (number per unit tank area) are associated with less clogging and higher F values.
3. The F value appears to increase with increasing SRT. The SOTE at one plant increased from 11.5% at a SRT of 2.4 d to 17.1% at a SRT of 14.0 d after nitrification was established.
4. The F value decreases with increasing organic loading rate (lb BOD/d-1000 cu ft) and increasing SOUR. Loading rates >50 lb BOD/d-1000 cu ft resulted in F values of <0.4 while rates < 25 lb/d-1000 cu ft resulted in F >0.75. These loading rates are low for industrial wastewater treatment practice, and thus, diffuser fouling could be a significant cause of decreased AOTR in these plants.
5. The average F value for the municipal wastewater treatment facilities in the survey that used medium to fine bubble membrane diffusers was <0.6. Since the process operating conditions used for industrial wastewater treatment are more severe

than those for municipal treatment, it should be assumed that the resulting F values for similar diffusers will be no greater than 0.6.

F Factor For Mechanical Aeration Systems

The F factor is also applicable to mechanical surface type aeration systems and jet-type systems although no operational data were available at this time. The loss in AOTR for these systems is due to mechanical deterioration of the aeration device (rather than to fouling of the device) and will require a much longer service time, t , to be evidenced. For example, the SOTR of jet-type aerators is very sensitive to the recycle pumping rate and, thus, wear of the pump impeller will cause a gradual loss in oxygenation capacity. Similarly, the SOTR of mechanical surface aerators depends on the depth and angle of blade submergence. As such, wearing of the blades will cause a loss of AOTR.

The service time required to experience these F effects, however, are probably expressed in years rather than months as for diffused air systems. Nevertheless, some consideration of the F value is warranted in the determination of the AOTR of mechanical oxygenation systems.

ALPHA FACTOR

The alpha factor is the ratio of the overall mass transfer coefficient of the wastewater, $(K_L a)_{w/w}$, to that of clean water, $(K_L a)_{c/w}$, at 20°C. Since the AOTR in Equation (6) is directly proportional to $(\alpha)_{20}$, the accuracy of the selected $(\alpha)_{20}$ value has a significant effect on providing the required oxygenation capacity. Alpha, however, depends on the wastewater characteristics, the specific aeration device, aeration basin geometry and aerator placement, and the power density (hp/MG) in the aeration basin. As such, the "true" alpha value always has a degree of uncertainty which should be realized in the design procedure for the aeration system. The effects of the various design and operational parameters on alpha are discussed in the following subsections.

Illustrative Values of α

Alpha values measured for different aeration systems and for different industrial wastewaters are presented in Table 3 and Table 4, respectively. These data are presented to illustrate typical variations in alpha and should only be used as guidelines to initiate design and equipment selection.

Wastewater Characteristics

Surface active agents or "bulk" pollutants (expressed as BOD or COD) have a marked effect on the AOTR since they affect both the liquid film coefficient (K_L) and the interfacial area (A), and thus the $K_L a$ of the oxygenation system. This effect is reflected by changes in the surfactant concentration and/or the mixing intensity of the aeration basin as illustrated in Figure 3.

TABLE 3
ALPHA VALUES FOR SELECTED INDUSTRIAL WASTEWATERS

Wastewater Type	BOD (mg/L)		Alpha	
	Influent	Effluent	Influent	Effluent
Pulp and Paper	187	50	0.68	0.77
Bleached Paper	250	30	0.83-1.98	0.8-1.0
Pharmaceutical	4500	380	1.75-2.15	0.6-0.8
Synthetic Fiber	5400	590	1.88-3.25	1.0-2.0
Pharmaceutical	3500	299	-----	0.85
Food Processing	2500	200	-----	0.80

TABLE 4
TYPICAL ALPHA VALUES FOR SELECTED AERATOR TYPES

Aerator Type	Alpha	Wastewater Type
Fine bubble	0.4-0.6	Domestic sewage
Brush/Rotor	0.8-1.0	Domestic sewage
Coarse sparger	0.7-0.8	Domestic sewage
Coarse wide band	0.6-0.7	Tap water with surfactant
Static tube	0.6-0.9	High strength industrial
Draft tube	0.7-0.8	Domestic sewage

A surfactant concentrates at the gas-liquid interface and establishes a film that reduces the diffusion of oxygen into the bulk solution. This decreases the mass transfer rate, K_L , until the interface is saturated. The surfactant, however, also increases the interfacial area (A) by allowing smaller bubbles to form. This increases the A/V ratio and may negate the decrease in K_L . High wastewater TDS concentrations (>30,000 mg/L) have similar effects on A/V and result in increased $K_L a$ values. Alpha values of 1.6 to 1.9 have been measured in an organic chemicals wastewater having a TDS of 60,000 mg/L. This wastewater was treated in a chemostat type activated sludge process since the high TDS prevented floc formation and sludge settling.

Power Density

The degree of mixing in the aeration basin depends on the type of aeration device and the power input per unit volume. The effect of mixing intensity is illustrated in Figure No 4 using the two-film model. At very low mixing levels (approaching a stagnant film), there is no effect on alpha since the bulk liquid transport of oxygen exceeds the interfa-

cial resistance. This condition is never encountered in aeration practice. Under moderately turbulent conditions, a maximum suppression of alpha occurs, because the interfacial barrier is controlling the rate of oxygen transfer. At high mixing levels, the interfacial barrier is not established and A/V increases. This effect, combined with bubble entrainment from either a diffused or mechanical aeration system, increases the $K_L a$ and the AOTR.

Design and operation at high power densities also increases the active fraction of the biomass under aeration. The greater active mass fraction increases the substrate removal rate coefficient and the extent of endogenous decay. These characteristics are illustrated in Figure Nos. 5 and 6 using the velocity gradient (G) to quantify the power density. For example, the BOD removal rate coefficient for treatment of wastewater from a bleached Kraft pulp and paper mill that was operated at a F/M of 0.3/day and a power density of 200 hp/MG, was 4.5/day. When the power density was increased to 500 hp/MG, the removal rate coefficient increased to 12/day with no loss of BOD removal efficiency.

The effect of power density on the SOTR is illustrated in Figure No. 7 for a jet aeration system and in Figure No. 8 for fine and coarse bubble diffused aeration systems. These effects on SOTR are also indicative of the effect on the AOTR (or AOTE) since the turbulence level would have similar effects on the $K_L a$ of both the wastewater and the clean water.

Effect of Tank Geometry and Unit Placement

The effects of tank geometry and aerator placement that have been demonstrated for clean water and municipal wastewater treatment are applicable to industrial wastewater treatment. Thus, data developed from existing systems and vendor data and experience are the principal resources for evaluating these effects. The following conclusions have been developed from review of clean water test data collected from a wide range of basin geometries and aerator configurations.

1. The SOTRs of high speed and low speed mechanical aerators are dictated primarily by the surface area of the basin. The maximum SOTR (lb./wire hp-hr) is determined by the pumping capacity of the aerator.
2. The combined AOTR of multiple aerators installed in a large basin cannot achieve the sum of the AOTR of the individual units in proportionally smaller basins. This is due to the inability to reproduce the mixing and recirculation patterns in the multiple unit large basin.
3. The mechanical mixing conditions (rather than the air flow rate) of submerged turbine type aerators in a specific tank geometry control the SOTR of the unit. Increasing the basin depth increases the SOTR even though the power density is less. The SOTR of a submerged turbine aerator can be changed by up to 100 percent based on selection of basin geometry and power density.
4. At diffuser depths <15 ft, basin geometry (excluding depth of diffuser submergence), does not significantly affect the SOTR. At diffuser depths >15 ft, basin

geometry and diffuser placement pattern can affect the SOTR by up to 100 percent.

ESTIMATION OF OVERALL MASS TRANSFER COEFFICIENT, $K_L a$

A comprehensive review of the alternative procedures for measurement of the field oxygen transfer rate and estimation of α has been presented by others. These procedures utilize steady state, non-steady state, continuous flow and batch methods to determine $K_L a$ over a range of actual operating conditions of mixed liquor, wastewater characteristics, aerator type and placement, and tank geometry. These sources of data provide the most representative values of α and should be used for design or upgrading of facilities. The test results, of course, are subject to change if an alternative basin geometry, aeration device, etc. is substituted for those used in the field test condition.

The following data are required for each selected operating period.

- Mixed liquor dissolved oxygen, oxygen utilization rate, and temperature.
- Blower discharge rate, discharge pressure, and discharge air temperature. If the blower discharge temperatures are not known, their values can be estimated based on the blower intake air temperature and the appropriate equations for the thermodynamics of gas compression.
- Performance (i.e., SOTE) curves for installed aeration system.
- Plant elevation, aeration basin volume, and depth of diffuser submergence.

Operating periods should be selected that provide "complete sets" of reliable monitoring data. The duration of the selected period should be at least three times the hydraulic retention time of the aeration basin during the period. The period can extend through a targeted production campaign/cycle, operating condition (e.g. F/M), or other control condition. The duration however, should not be so extended that it causes significant increases in the standard deviations of the operating parameters.

Case Study

Operational data were analyzed using the above procedures to estimate α for expansion of a complete mix activated sludge process. The treatment plant served multiple pharmaceutical factories that were operated on a "campaign basis" of production. Sixteen months of operating records were analyzed to identify periods that represented a range of product wastestreams and were supported by a comprehensive and reliable database. Six operating periods were selected. The selected periods ranged from seven days to 52 days in length. Collectively, the study periods comprised 91 days of the 16-month period of record. The durations of the selected operating periods were approximately 3 to 20 times the average hydraulic retention time of the aeration basins and allowed adequate time to establish 'pseudo steady-state' operating conditions.

The average operating conditions for the aeration basins during each of the selected periods are summarized in Table 5. These data were used to determine the average α_{20} value for each operating period.

**TABLE 5
SUMMARY OF AVERAGE OPERATING CHARACTERISTICS
DURING SELECTED PERIODS**

No	Period		Average Value During Period				COD ton/d	F/M ^a d ⁻¹
	Dates	Duration days	DO mg/L	T °C	OUR mg/L-hr	(Q _{air}) cu m/hr		
<u>1996</u>								
1	29/01-08/02	11	5.19	28.0	20.80	6,856	9.61	0.42
2	09/02-15/02	7	6.31	27.8	24.10	6,621	13.79	0.68
3	16/02-22/02	7	6.92	28.1	23.10	5,991	12.52	0.51
4	22/04-12/06	52	6.77	27.7	14.32	4,110	7.82	0.40
5	06/09-12/09	7	5.67	30.7	20.36	4,168	13.49	0.45
<u>1997</u>								
6	04/04-10/04	7	5.92	27.27	15.35	5,129	11.99	0.33

a. Expressed as mg COD/mg MLVSS-d

The blower air discharge temperature was not routinely measured and was calculated for each operating period assuming adiabatic compression. The SOTE of the installed jet aeration system was estimated from Figure 9 at a 5.5-m depth of jet nozzle submergence. The results of the analysis of α_{20} during the six operating periods are summarized in Table 6.

**TABLE 6
SUMMARY OF α_{20} VALUES DURING 16 MONTH PERIOD OF RECORD**

No	Operating Period		Q _{air} ¹ (std cu m/hr-jet)	SOTE ² (%)	Avg. α_{20}
	Dates	Duration			
<u>1996</u>					
1	29 Jan-8 Feb	11	63.9	35	0.39
2	9-15 Feb.	7	61.8	36	0.64
3	16-22 Feb.	7	55.8	37	0.88
4	22 Apr.-12 June	52	38.3	40	0.67
5	6-12 Sept.	7	38.8	40	0.67
<u>1997</u>					
1	4-10 Apr.	7	47.8	40	0.40

1. Based on number of jets in aeration basin
2. Based on Figure 7 with D=5.5 m

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a. Expressed as mg COD/mg MLVSS-d

The blower air discharge temperature was not routinely measured and was calculated for each operating period assuming adiabatic compression. The SOTE of the installed jet aeration system was estimated from Figure 9 at a 5.5-m depth of jet nozzle submergence. The results of the analysis of α_{20} during the six operating periods are summarized in Table 6.

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1. Based on number of jets in aeration basin
2. Based on Figure 7 with D=5.5 m

The α_{20} value ranged from approximately 0.40 during Period Nos. 1 and 6 to 0.88 during Period No 3. The time-weighted value of α_{20} was 0.64 during the 91-day period of record.

The variation in α_{20} during the operating periods is due to changes in the wastewater characteristics and to the inherent variation in the monitoring data (primarily OUR). During the continuous 25-day period of 29 Jan. through 22 Feb. 1996 (Period Nos. 1, 2, and 3) the wasteload from a specific product campaign gradually decreased from its maximum to zero and the α_{20} progressively increased from 0.39 to 0.88. When the product campaign was restarted in April 1997 (Period No. 7) the α_{20} returned to 0.40.

Based on these results, a α_{20} value of 0.55 and β of 0.95 selected for process analysis and design of the expanded treatment facility.

If field test data are not available bench- or pilot-scale studies should be conducted to determine a "best estimate" of K_La . Guidelines and limitations for such tests are listed below.

1. The actual aeration device, i.e., a replicate diffuser(s), should be used in the largest possible test tank volume.
2. The power density of the test should be as close as possible to that of the full scale system. This is particularly true of tests of jet-type systems.
3. Tests should be conducted at $\sim 20^\circ\text{C}$ and at the projected design operating mixed liquor temperature to estimate the θ value.
4. Similar bench- or pilot-scale tests should be conducted on a wastewater that has a K_La value determined from field tests using a similar aeration device. This will provide a baseline condition to compare the effects of the bench- or pilot-scale test procedure on the known K_La .

EFFECT OF OXYGENATION RATE ON STRIPPING OF VOCs

The rate and method of oxygenation directly affect the amount of volatile organic compounds (VOC) that are stripped from the aeration basin rather than metabolized by the biomass. The amount of a specific VOC (designated as "i"), that is stripped depends on the overall mass transfer rate coefficient, $K_La_{O_2}$, of the aeration system and is expressed by Equation (7).

$$(K_La)_i = j (K_La)_{O_2} \quad (7)$$

Term "j" is the ratio of the liquid phase diffusivities of the VOC compound and oxygen, D_i / D_{O_2} .

For surface aeration devices, the fraction of the influent VOC_i load that is stripped to the air is,

$$f_{\text{air}} = (j (K_L a)_{\text{O}_2} V) / (Q_0 + M + j (K_L a)_{\text{O}_2} V) \quad (8)$$

For a diffused air oxygenation system, the fraction of the influent VOC_i load that is stripped to the air is,

$$f_{\text{air}} = (Q_{\text{air}} (H_C)_i) / (Q_0 + M + Q_{\text{air}} (H_C)_i) \quad (9)$$

Where,

- f_{air} = fraction of influent VOC_i stripped
- Q_0 = influent flow rate, L /sec
- Q_{air} = air flow rate, m^3 /sec
- V = aeration basin volume, m^3
- $(H_C)_i$ = Henry's constant for VOC_i
- M = $(W_i q_m X_v V) / (K_s)_i$
- q_m = biodegradation rate for VOC_i , g COD/g VSS/sec
- X_v = MLVSS, g/L
- $(K_s)_i$ = half saturation constant for biodegradation of VOC_i , g/L
- W_i = weighted cell yield coefficient for VOC_i

The application of Equations (8) and (9) for the stripping of benzene by diffused and mechanical aeration systems is illustrated in Figure No 10.

CONCLUSIONS

The following conclusions can be made regarding the application of the principals of oxygenation and aeration system design that have been developed from municipal wastewater treatment experience to the treatment of industrial wastewater.

1. The operating mixed liquor temperature can significantly affect the AOTR/SOTR ratio by changing alpha and $(C_{\text{sat}})_T$. The alpha effect is quantified by the temperature correction coefficient, θ , which varies from 1.008 to 1.047. Use of the "average" $\theta = 1.024$, however, can result in up to 20 percent error depending on the true θ value and the operating temperature. Bench- or pilot-scale tests should be conducted to develop the applicable θ value, particularly if the design operating mixed liquor temperature is $>30^\circ\text{C}$.
2. Although the value of beta varies from 0.7 to 1.2 for industrial wastewaters, it does not have a significant effect on the calculation of the AOTR. Beta can be easily estimated in the laboratory. In the absence of wastewater specific data, a beta value of 0.9 can be reasonably assumed.

3. Fouling of medium- and fine-bubble diffusers is a chronic problem that causes a decrease in AOTR at the expense of higher operating pressures and power costs. Although F data for industrial wastewater treatment are limited, it can be reasonably concluded that the fouling rate increases with F/M, SOUR and organic loading rate. Therefore, F factors of <0.6 are recommended for application of medium- to fine-bubble diffusers to the treatment of high BOD strength industrial wastewaters when using organic loading rates >50 lb. BOD/d/1000 cu ft. Furthermore, design and operational measures should be provided to assure monitoring of fouling and the application of routine and effective diffuser cleaning procedures.

Owners, operators, and suppliers of oxygenation systems should expect that AOTR performance and acceptance tests will be conducted after a reasonable period of in-situ service (e.g., 6 to 12 months) rather than for the "as-new" condition.

The adverse effects of fouling on medium to fine bubble diffusers dictate that coarse bubble type and mechanical oxygenation alternatives be evaluated in terms of their maintenance requirements, reliability and life-cycle costs.

4. Alpha has a strong effect on the AOTR. Unfortunately, it is dependent on multiple controlled and uncontrolled variables, such as the wastewater characteristics, aeration device, tank geometry, and power density in the aeration basin. As such, it is highly variable. In-situ testing and experience with identical/similar wastewater and aeration systems are the best sources of data for estimating alpha.

In the absence of reliable field test data, bench- or pilot-scale tests should be conducted to develop a "best estimate" of alpha (as well as β and θ). Guidelines and limitations for conducting these tests have been presented.

5. The rate and method of oxygenation directly effect the fraction of the influent VOC load that is stripped from the aeration basin. These VOC and odor emissions can be significant when treating industrial wastewaters. Equations are presented to estimate the fraction of the influent VOC load that is stripped when using diffused or mechanical oxygenation systems.

FIGURE 1. EFFECT OF DEPTH OF SUBMERGENCE ON SOTE OF ALTERNATIVE OXYGENATION SYSTEMS AT MID-POWER DENSITY¹

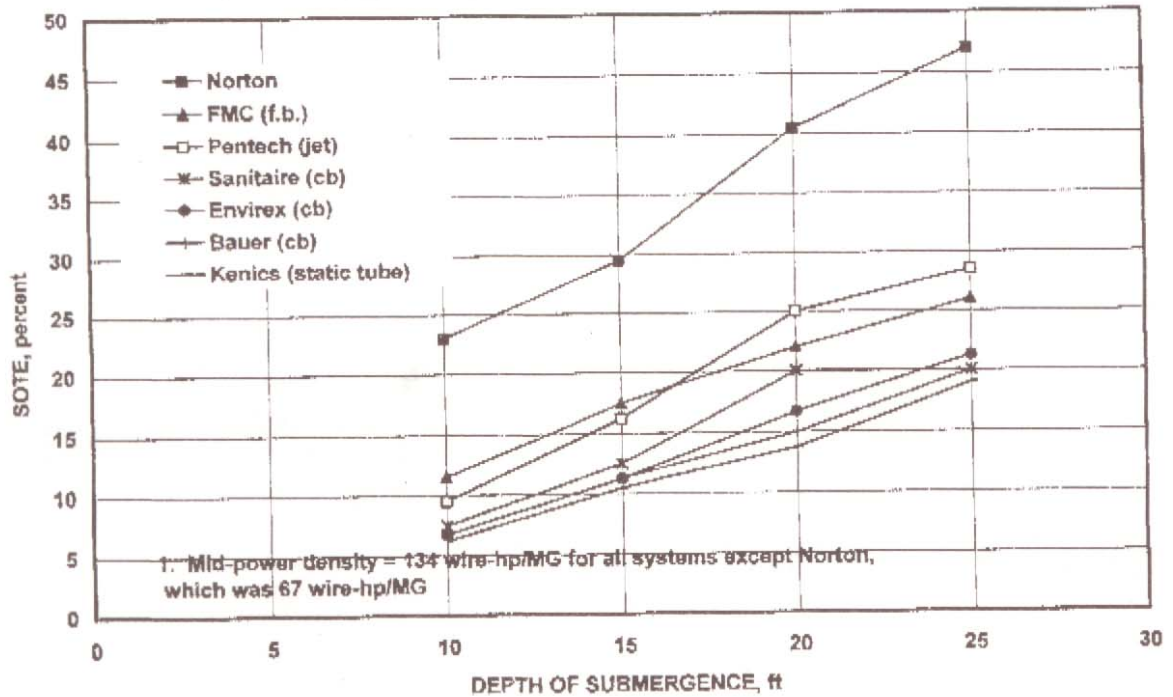
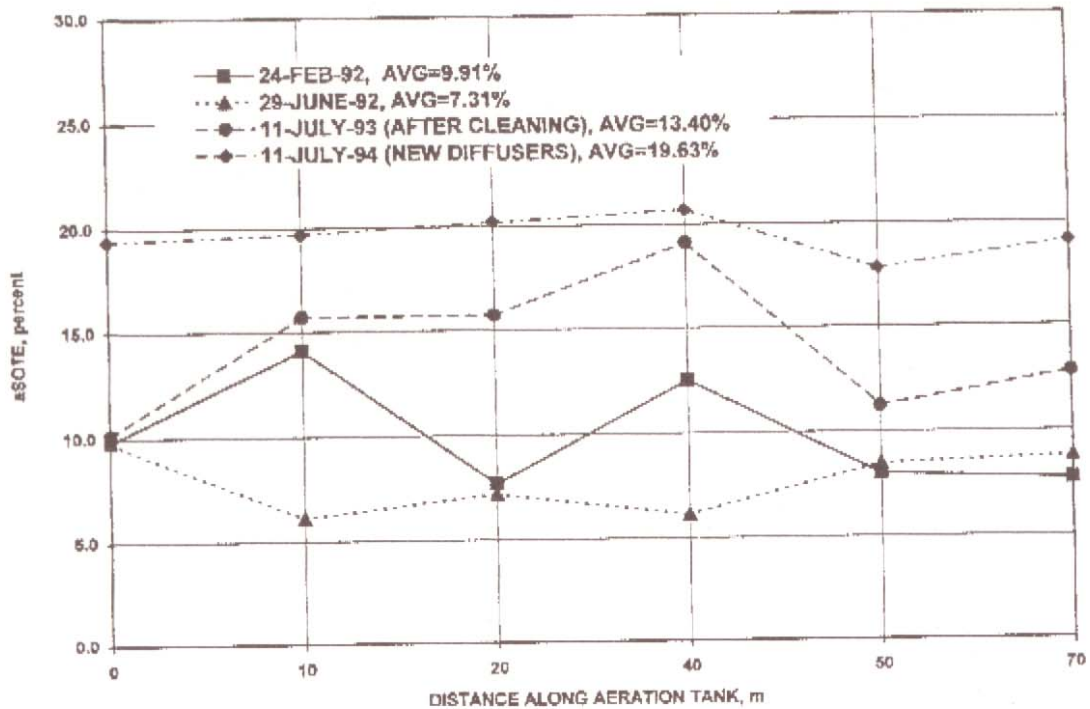


FIGURE 2. CHANGE IN aSOTE WITH TIME OF SERVICE IN AERATION TANK NO. 6 AT TWRP



$$\alpha = \frac{K_{La} \text{ WASTE}}{K_{La} \text{ WATER}}$$

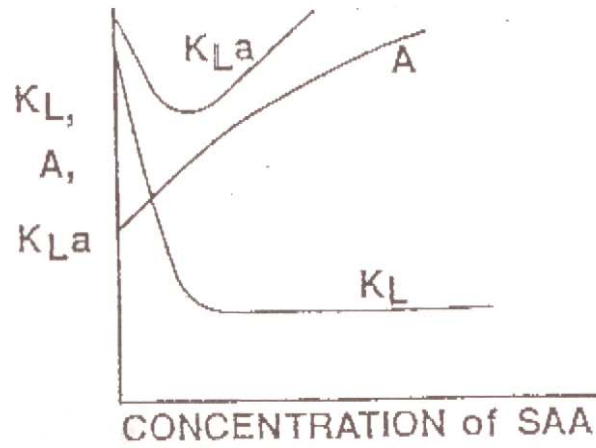


FIGURE 3
Effect of Surfactant on K_{La}

FIGURE 4
Effect of Turbulence on Oxygen Transfer

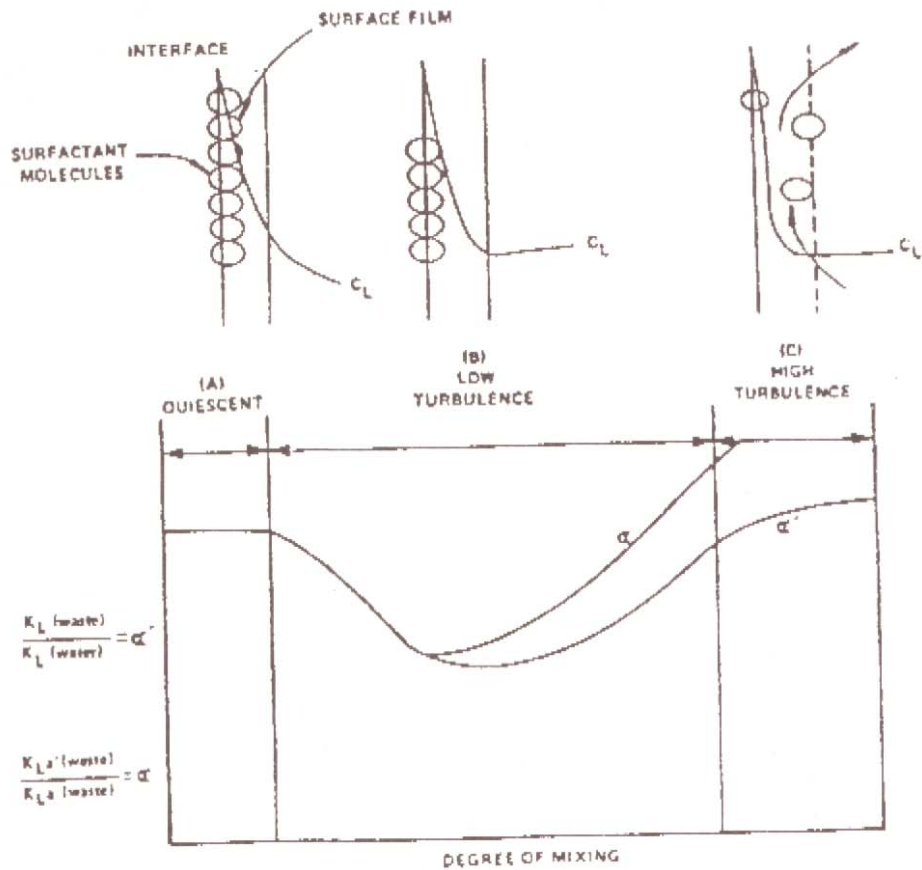


FIGURE 5. RELATIONSHIP BETWEEN AERATION BASIN VELOCITY GRADIENT AND OBSERVED SLUDGE PRODUCTION RATE

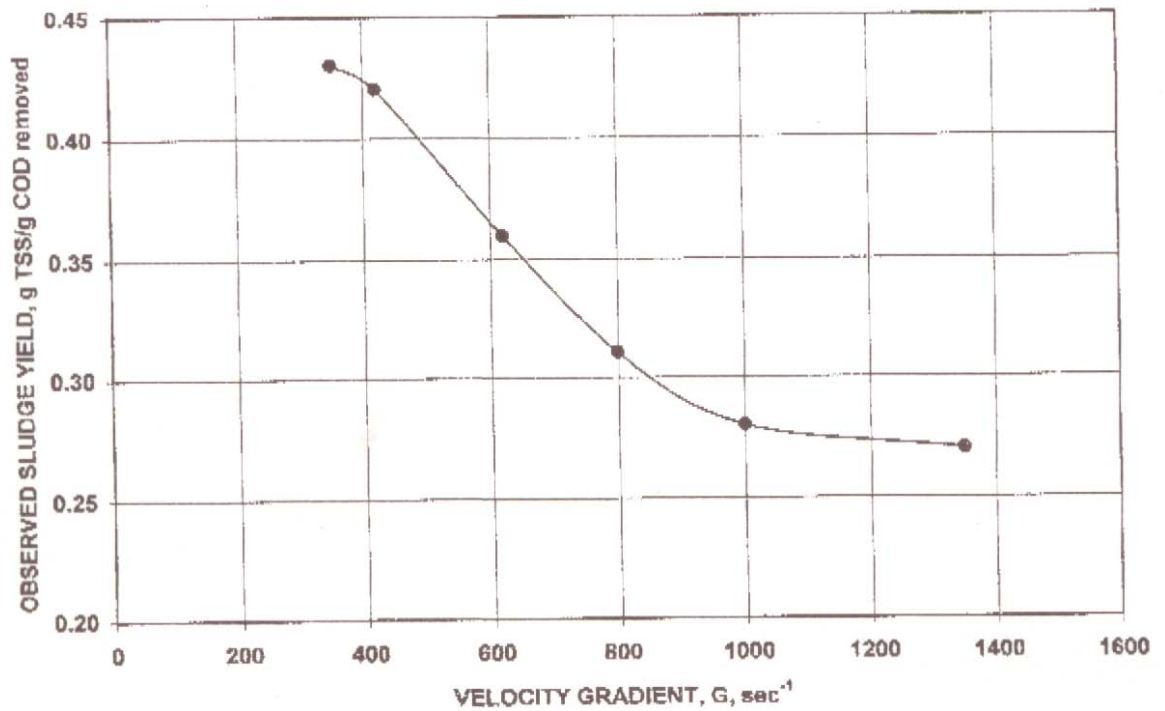


FIGURE 6. RELATIONSHIP BETWEEN ORGANIC REMOVAL RATE COEFFICIENT AND AERATION BASIN VELOCITY GRADIENT



FIGURE 7. EFFECT OF POWER DENSITY ON JET SYSTEM AT ALTERNATIVE DEPTH OF SUBMERGENCE¹

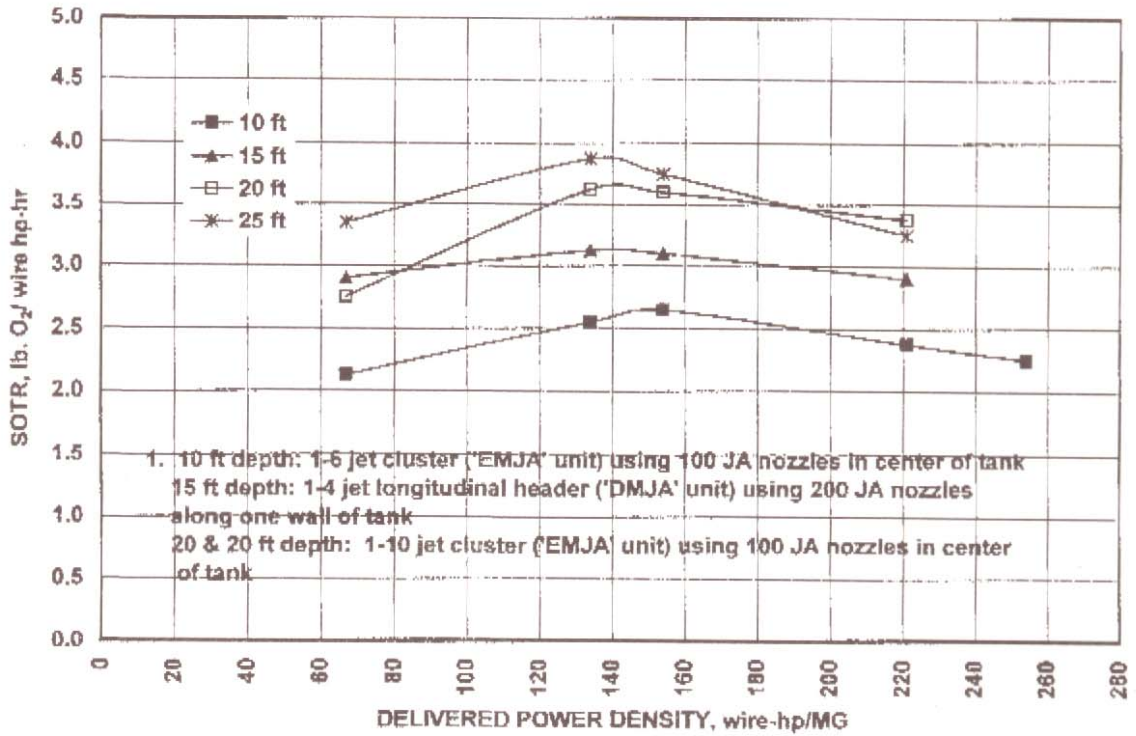


FIGURE 8. EFFECT OF POWER DENSITY ON SOTR OF ALTERNATIVE OXYGENATION SYSTEMS AT 25 FT SUBMERGENCE

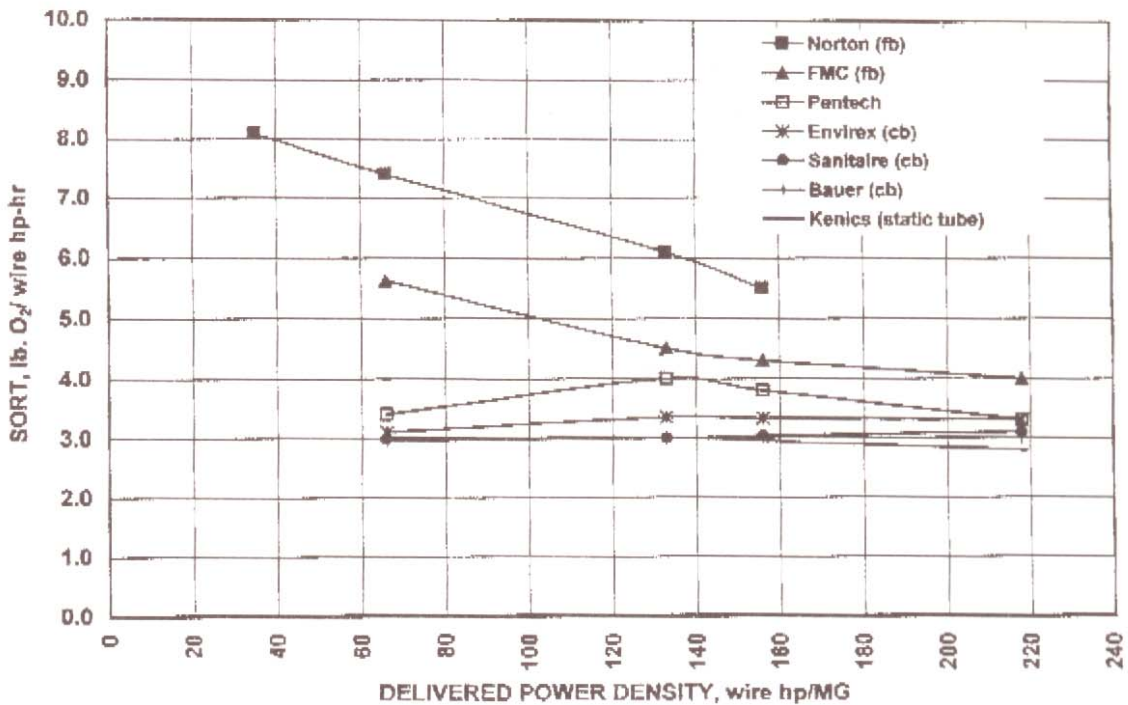


FIGURE 9. SOTE PERFORMANCE FOR JET TYPE OXYGENATION SYSTEM AT ALTERNATIVE OPERATING DEPTHS

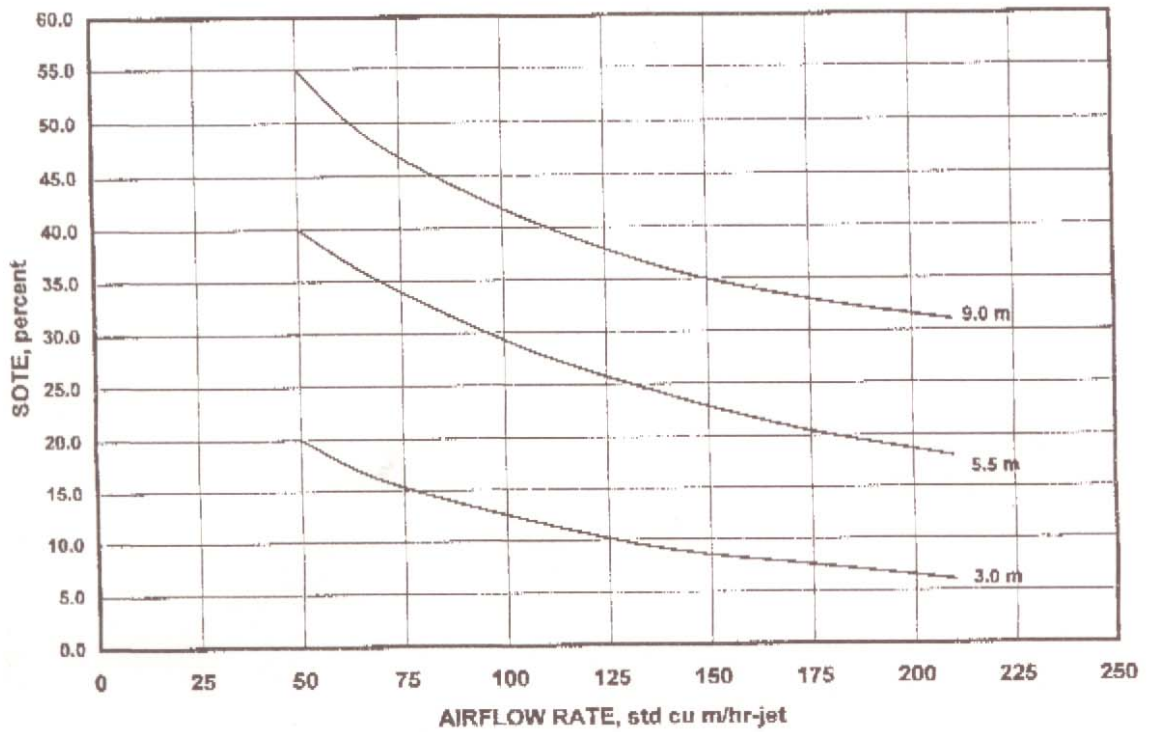


FIGURE 10. EFFECT OF TYPE OF AERATION DEVICE ON STRIPPING OF BENZENE

