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Evaluation of Blower and Diffuser Requirement in the Aeration System

Sanjay Kumar
Department of Mechanical Engineering
IEC College of Engineering & technology
Greater Noida, India

Ijlal Ahmad Rizvi
Assistant Professor, Department of Mechanical Engineering
IEC College of Engineering & technology
Greater Noida, India

***Abstract*: - Most of energy that is used for running the waste water treatment goes to biological treatment unit. 70-75 percent of energy used by the waste water treatment plant is spend to run the blower to deliver the air for aeration of waste water. The energy needed by the blower depends upon the efficiency of the aeration system. The more will be the efficiency of the aeration system, lessor energy will be required by the aeration system. So it is very crucial to design the whole aeration system i.e. from blower to diffuser including piping. This research paper focuses on the need of blower and the number of diffuser required because these two are the most important part of the aeration system.**

Keywords: Waste water treatment plant, Aeration system, Blower size calculations, Number of diffuser, AOTE, Oxygen requirement, SOTE, TDS Activated sludge.

INTRODUCTION

Waste water generated by the people living in metropolitan cities as well as in small cities has been a major problem and increasing industrialization aggravates this problem. So it is very necessary to handle this waste water very delicately to make our earth green and clean.

Now a days to eradicate waste water problem the developed nations are using and developing are going forward to use the waste water treatment plants. Commissioning cost of the plant is not a problem but the running cost of the plant is great cause of concern for the industries as well as for the government also.

So for a researcher is worth focusing on minimize the cost of running of the plant. Mostly the cost of running spend in the aeration system for biological treatment of the waste water. The location of the plant plays a significant role in minimizing the cost of operation of the aeration system. So we can say that the designing of aeration system is very important [4].

It is very necessary to be familiar about the few terms to understand about the most important terms:

SOLIDS IN WATER

Solids in the water are of the two types which can be classified according to their size and shape, chemical properties and size distribution. Theses solids can also be classified as organic, inorganic and immiscible liquids. The biological degradation of solids results in objectionable by products. So solids removal from water is of great importance.

TURBIDITY

The turbidity of water is the measure of ability of light passing through it. Its ability measured against a turbidity index. The water having turbidity index five allows no passage of light, while index one shows little or no turbidity.

COLOR

The pure water is colorless but foreign substances can often tint water. These foreign substances are vegetation, soils, municipal and industrial waste and aquatic organisms. Water color is measured by standard color solution or colored glass disc.

TASTE AND ODOR

Minerals, metals, salt from soil and end products of biological reaction decides the taste and odor of water. The taste and odor has little impact on safety. Potassium permanganate, chlorine and other oxidants are used to remove taste and odor by oxidation

TEMPERATURE

The temperature of water is very important for aquatic life because temperature of water affects the solubility of oxygen in the water. The temperature of waste water is also very significant for industrial purposes because the cold water needs more chemicals for efficient coagulation and flocculation.

TOTAL DISSOLVED SOLIDS

Dissolve solids can be present in the form of organic, inorganic matter in water. The dissolve solids occurs in water by the contact with substances in soil, on surfaces and in the atmosphere. Decayed vegetation, organic chemicals and gases are the major sources of organic dissolve solids. These sources causes the physiological effects and color, taste and odor problems. The dissolve solids can be separated from water by filtration, evaporation, electro dialysis, reverse osmosis and ion exchange.

ALKALINITY

Alkalinity is the measure of water’s ability that how much it can neutralize the acids. In other words we can say that it is the buffering capacity of water. Bicarbonate, carbonate and hydroxyl ions are responsible for the alkalinity of the water. Carbon dioxide from the different sources is also responsible for alkalinity of the water. High alkaline water can be bitter in taste but has no serious effect on human health.

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HARDNESS

Minerals of calcium and magnesium present in the water are responsible for hardness, so hardness indicates the concentration of these minerals in water. Deposits is the major problem in hot water due to these minerals in pipeline. Hard water also have many advantages i.e. it helps tooth and bone growth.

FLUORIDES

Little fluoride ions in potable water is good for dental health. Fluoride ions in large quantity can be toxic for human. The surface water has fluoride ions in appreciable quantity.

METAL

Metals in water may harm the human health even in little quantity. It can be divided into two categories i.e. toxic and non-toxic. These metals be present in natural water due to dissolution from natural deposits and discharges of industrial wastes.

ORGANICS

Color, taste and odor is affected by the organic matter present in water. Halogenated compound be formed in the water undergoing chlorine disinfection due to the presence of organic matter. Organic matter present in water affects the solubility of oxygen that interferes the water treatment process. Presence of organic matter is the most important cause of the BOD increase.

PH

PH is the measure of hydrogen ion concentration in water. In other words it can be said that it is the measure of acidity or alkalinity of water. The biological and chemical reaction are affected by the PH. Water with higher PH level has more chlorine contact time for disinfection**.**

CHLORIDES

Chlorides be there in groundwater naturally. Higher concentration of chloride does not have any effect to human health but it causes salty taste.

DESIGN PROCEDURE OF AERATION SYSTEM

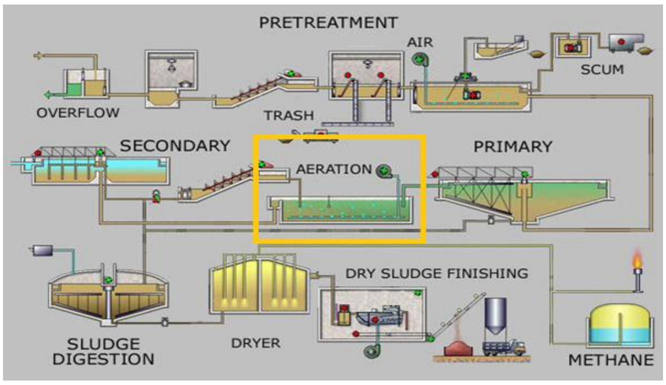
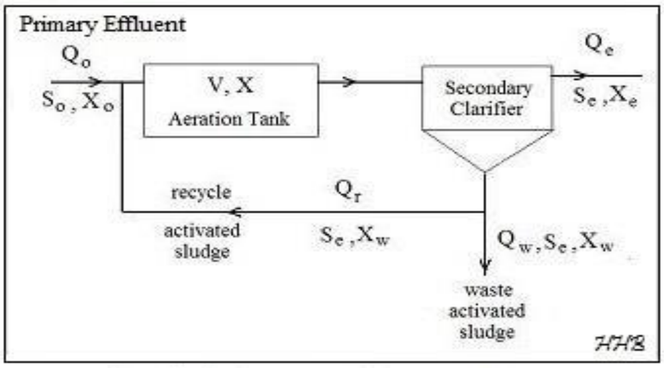


Fig. Different stages of water treatment plant [4]

1. Information required for designing of plant [5]



Activated Sludge Flow Diagram & Parameters

Q is volumetric flow rate in m^3day
S is BOD5 concentration in g/m^3
X is total suspended solids concentration in g/m^3
The subscript o refers to the primary effluent stream.
The subscript e refers to the secondary effluent stream.
The subscript w refers to the waste act. Sludge stream.
The subscript r refers to the recycle act. Sludge stream.

V is the volume of the aeration tank in m^3.
X is the mixed liquor suspended solids concentration in the aeration tank in g/m3.

Waste water properties supplied to the plant
Waste water flow rate, $\mathbf{Q_o}$ in (m^3/d)
Primary Effluent BOD_5, $\mathbf{S_o}$ in (g/m^3)
Aeration Tank MLSS, **X** in (g/m^3)
Percentage volatile MLSS, in **% Vol**

Waste/recycle activated sludge properties
Sludge SS concentration $\mathbf{X_w}$ in (g/m^3)
Secondary Effluent TSS, $\mathbf{X_e}$ in (g/m^3)

2. Aeration tank sizing calculations

Activated Sludge Design Parameters - Typical Values

Activated Sludge Process	Volumetric Loading kg BOD/day/m^3	F:M Ratio kg BOD/day/kg MLVSS	Hydr. Retention Time hours
Conventional Act. Sludge	0.3 - 0.7	0.2 - 0.5	4 - 8
Extended Aeration	0.1 - 0.3	0.05 - 0.15	18 - 36

SIZING BASED ON VOLUMETRIC LOADING

Volumetric Loading: VL in g/kg) **(given)**
Design Aeration Tank Volume = Qo* So /(VL*1000)
Values of other Design Parameters
Aeration Tank Hydraulic Retention Time = 24*V/Q_o hr
Aeration Tank F:M Ratio = (Qo *So)/(**%** Vol.*X* V) kg BOD_5/day/kg MLVSS

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Sizing based on hydraulic retention time [6]
Hydraulic Loading: HRT = 24*V/Q_o hr **(given)**
Aeration Tank Volume = Qo*HRT/24
Values of other Design Parameters
Aeration Tank Volumetric Loading = (Qo *So)/(V*1000) kg BOD5/day/m^3
Aeration Tank F:M Ratio = (Qo *So)/(%Vol*X*V) kg BOD5/day/kg MLVSS

Sizing based on F:M ratio
F:M Ratio: F:M in kg BOD_5/day/kg MLVSS **(given)**
Aeration Tank Volume = (Qo* So)/(%Vol*X* F:M Ratio)
Values of other Design Parameters
Aeration Tank Volumetric Loading = (Qo* So)/(V*1000) kg BOD_5/day/m^3
Aeration Tank Hydraulic Retention Time = V*24/ Qo* hr

3. Aeration tank operation calculations

ESSENTIAL DATA REQUIRED

Activated Sludge Operational Parameters - Typical Ranges				
Activated Sludge Process	SRT days	MLSS g/m^3	F:M kg BOD/d/kg MLVSS	Q_r/Q_o %
Conventional Act. Sludge	5 - 10	1500 - 4000	0.2 - 0.5	50 - 100
Extended Aeration	20 - 40	2000 - 6000	0.05 - 0.15	75 - 150

Aeration Tank Volume, V in m^3 **(given)**
Target Sludge Retention Time in SRT days **(given)**

Activated sludge operational parameters calculation
Recycle Act. Sludge Rate, Qr = Qo-X/(Xw-X) m^3/d
Waste Act. Sludge Rate, Qw = (V*X/SRT-Qo*Xe)/Xw m^3/d
Aer. Tank F:M Ratio, F:M = (Qo*So)/(%VOL*X*V) kg BOD/day/kg MLVSS
Note: In Calculating Qw, the effluent flow rate, Qe is taken to be equal to the influent flow rate, Qo, based on the assumption that liquid streams separated from the waste activated sludge are sent back into the wastewater stream.

4. Oxygen requirements/blower sizing calculations
Note: To aid in setting the design WW flow rate for these calculations, it is recommended that the maximum, minimum and average WW flow rates be identified and that the oxygen requirement rates be calculated for each.

ESSENTIAL DATA REQUIRED
Permitted Secondary effluent BOD, BODe in g/m^3
Permitted Secondary effluent TSS, TSSe in g/m^3
% volatile solids in effluent TSS in % Vol
Sludge Retention Time, SRT in days
Synthesis Yield Coefficient, Y in kg VSS/kg BOD_5
Endogenous Decay Coefficient (at 20oC), kd_{20} in kg VSS/d/kg VSS
Std. O2 transfer Efficiency, SOTE in % (from diffuser mfr or vendor)
Press.drop across diffuser, ΔP_{diff} in bar (from diffuser mfr or vendor)
Depth of Diffuser, d_{diff} in m (from installation or plans)
Design ambient air Temperature, Ta in °C
Influent TKN, TKNo in g/m^3
Effluent NH4-N Concentration, Ne in g/m^3
Design Barometric Press., Patm in bar (ambient pressure at site)
Design wastewater Temperature Tw in °C
Ratio of BOD5/BODu, f in ratio
Blower efficiency, h in %
Ratio of oxygen transfer rate in wastewater to that in clean water, a in ratio
Ratio of D.O. saturation in wastewater to that in clean water at same T & P, B in ratio
D.O. saturation concentration for clean water at waste water temp. & 1 atm, Cs in g/m^3
D.O conc. to be maintained for WW treatment operation, CL in g/m^3
Diffuser fouling factor, F = 0.8
Pressure drop at blower inlet, ΔPin = in bar (due to filter, silencer, etc.)

Standard pressure and temperature for Sm^3/m calculation (per ASME & CAGI) - changeable by user			
Standard Pressure, P_S	1.014 bar	Standard Temperature, T_S	20 °C

Constants and conversion factors used in the calculations					
Temp. coeff for k_d θ	1.024		Saturation D.O. in water at 20°C & 1 atm, C_{ss}	9.17	g/m^3
Ideal Gas Law Constant, R	8.3145	kN-m/kgmole-K	Molecular weight of air	28.97	
Specific Weight of water, γ_{H2O}	9.807	kN/m^3	Molecular weight of oxygen	32	
Conversion Factor, C_{f1}	1000	g/kg	Atmospheric Press. at sea level, P_{std}	1.014	bar
Conversion Factor, C_{f2}	60	min/hr or sec/min	Oxygen mole fraction in air	0.209	
CbCOD (BOD_{ult}) equivalent of VSS:	1.42	kg COD/kg VSS	Conversion Factor, C_{f3}	24	hr/day
O_2 equivalent of NH_3-N:	4.57	kg O_2/kg NH_3-N	Conversion Factor, C_{f4}	100	kPa/bar

Oxygen requirement/blower specifications (BOD Removal Only)

AIR REQUIREMENT/BLOWER DESIGN CALCULATIONS

Effluent Soluble BOD, Se = BODe-(f*cbCOD*%VOL*TSSe) g/m^3
Endog. Decay Coeff. (at 20°C), k_{d20} = k_{d20}*(θ^(Tw-20) kg VSS/d/kg VSS
Observed Yield (with recycle), Y_{obs} =Y/(1+ k_{d20}*SRT) kg VSS/kg BOD_5
Required O2 flow rate = Qo/C_{f1})*(So-Se)((1/f-cbCOD*Y_{obs})/C_{f3}) kg/hr

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Act. O2 transfer Efficiency, AOTE* =SOTE*α*F*(((B*(P_D/P_{std})*C_5)-C_L)/C_{55})* θ^(Tw-20) %
Pressure at Mid Depth, P_D = P_{atm}+(γ_{H2O}*(d_{diff}/2)/C_{f4} bar
Standard Air Density, ρ_{air} = Mole. Wt .of air*(P_s*100)/(R(T_s+273.15)) kg/m^3
(from Ideal Gas Law)
Design Air Flow Rate, SCMM = (Req.O_2 flow rate/AOTE)*Mol. Wt. of air/(O_2 mole frction in air*Mol. Wt. of O_2* ρ_{air}* C_{f2}) m_{std}^3/min
Design Air Flow Rate, ACMM = SCMM*(P_{std}/P_{B2})*(Ta+273.15)/(Ts+273.15) m^3/min (at delivery point)
Blower outlet pressure, P_{B2} = P_{atm}+ΔP_{diff} +(γ_{H2O}* d_{diff} / C_{f4}) bar

5. Computation of actual oxygen transfer efficiency and diffuser requirements - diffuser aeration systems [5]
Constants (from literature and computed) used in AOTE computations.

constants		
Standard O_2 solubility (DO.std)	9.08	mg/L, DO solubility in clean water at 20 °C and at 1 ATM ambient atmospheric pressure
Process temperature correction factor, (theta)	1.024	unit less
Atmospheric temperature lapse coefficient (B.atm)	0.0065	K/m, used with normal atmospheric pressure computation
Universal gas constant (R.univ)	0.082057	(m^3-ATM)/(k mol-K)
Mass-based gas constant for air (R.M)	286.9	J/(kg-K), used with normal atmospheric pressure computation
Standard meteorological temperature (T.met)	288	K, used with normal atmospheric pressure computation
Gravitational acceleration (g)	9.806	m/s^2, used with normal atmospheric pressure computation
Standard process temperature (T.std)	20	°C, base T for process computation and for use of standard cubic meter
Standard atmospheric pressure (P.std)	1	ATM (much more convenient than kPa), normal ambient pressure at sea level
Specific weight of water (SW.w)	9.789	kN/m^3, taken at 20 °C and considered constant with process temperature
Standard atmospheric O_2 content (Y.O2.std)	0.209	(mol_{O2}/mol_{air})
Molecular mass of O_2 (MW.O2)	32	kg/kmol
Molar specific volume of ideal gas at STP (SV.stp)	24.0427	m^3/kmol; SV.air =ROUND(R.univ*(T.std+273)/P.std, 4)
Conversion from ATM to kPa (kpa.atm)	101.325	kPa/ATM
The a.DO - d.DO coefficients fit a third-order polynomial to the data presented at right from the USGS database		
a.DO	-0.00007021	
b.DO	0.007635	
c.DO	-0.4004	
d.DO	14.59	
DO.sat.T = a.DO*T.des^3 + b.DO*T.des^2 + c.DO*T.des + d.DO		

Input data required for site-specific conditions

Parameter	value	description
Maximum actual oxygen transfer rate (AOTR.max), kg_{O2}/day	10000	design maximum mass of O_2 needed per day (exactly equal to the oxygen utilization rate, OUR) - use this to determine the number of diffusers necessary
non-maximum AOTR to be investigated(AOTR), kg_{O2}/day	5000	Use this to investigate air delivery for min, average and other special cases once the number of diffusers is set
Elevation of process site (H.site), m	3000	site elevation above mean sea level
Diffuser submergence (D.sub), m	7	depth of centerline of diffuser below air/liquid interface
Diffuser transfer rate ratio (alpha), dimensionless	0.95	ratio of K_La in process water to K_La in clean water at standard temperature
Oxygen solubility ratio (beta), dimensionless	0.9	ratio of DO_{sat} in process to DO_{sat} in clean water at standard temperature
Diffuser fouling factor (F.foul), dimensionless	0.8	ratio of K_La for fouled diffuser to K_La for clean diffuser
Process temperature (T.des), °C	25	process temperature for computation of necessary gas flow requirement
Design process O_2 level (DO), mg/L	1	oxygen concentration level to be maintained in process mixed liquor
If high-purity O_2 is used, enter the purity	0.95	mol_{O2}/mol_{gas}

Computed parameter values for site-specific conditions
The saturation value of DO at a specified T.des is given by:
DO.sat.T = a.DO*T.des^3 + b.DO*T.des^2 + c.DO*T.des + d.DO
DO.sat.T = a.DO*T.des^3 + b.DO*T.des^2 + c.DO*T.des + d.DO mg/L
P.H = P.std*(1-B.atm*H.site/T.std)^(g/R.M+B.atm) atm
P.mid = P.H+(SW.w*D.sub/2)/P.std.kPa atm
P.disch = P.H+SW.w*D.sub/P.std.kPa atm
DO.sat.T.H=DO.sat.T*P.H/P.std mg/L

Calculation for the number of diffuser required
Calculation of actual (Field) oxygen transfer efficiency (AOTE) requires manufacturers' value of standard oxygen transfer efficiency (SOTE). By using AOTE the number of diffusers necessary at the design maximum case is computed. For these computations manufacturers' data correlating with gas flow per diffusers are necessary for the computation of AOTE and number of diffusers required.

q	SOTE
m^3/(min-diff)	%
0.071	44.4
0.129	42.3
0.183	40.5
0.238	39.3
0.296	38.58
0.354	38.22

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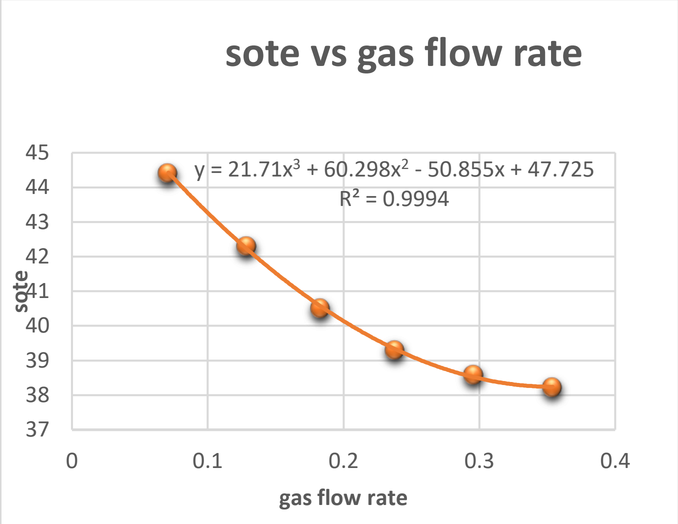
The following graph and equation is obtained by using excel with the help of manufacturers' data of sote and gas flow rate for a particular diffuser.

The number of diffusers necessary to deliver air at the maximum OUR is determined by simultaneously solving following set of equation yielding $Y_{o2.avg}$, $C_{sat.avg}$ and AOTE.



$Y_{o2.avg} = Y_{o2.std} * (1+(1-AOTE/100)/(1- Y_{o2.std} * AOTE/100))$
$C_{sat.avg} = C_{sat.T.H} * (P_{D/2} Y_{o2.avg} / (P_H * Y_{o2.std}))$
$AOTE = SOTE*((\beta C_{sat.avg} - C_{MLSS}) / C_{sat.avg}) * \theta^{(Tdes-Tstd)} * \alpha * F$

The corresponding oxygen application rate is determined using the following equation.
OAR=AOTE*100/AOTE

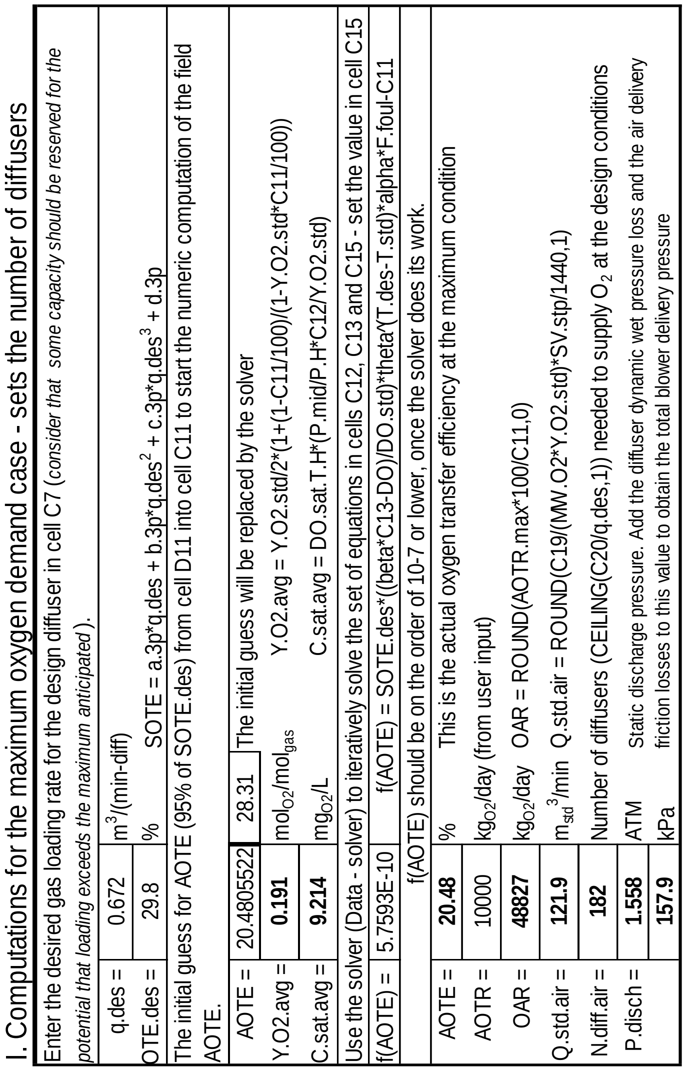
The total air delivery rate is computed from the following equation.
$Q_{std.air} = OAR*V_{air.spec} / (MW_{o2} * Y_{o2.std})$

The number of diffusers necessary is computed from the following relation.
$N_{diff} = Q_{std.air} / q_{diff}$

Once the number of diffusers is known for non maximum OUR the air deliver per diffuser is computed by simultaneous solution of the following two equation with the three from the above.
$q_{diff} = AOTR*R_{univ}*(T_{std}+273)/((AOTE/100)* N_{diff} * MW_{o2} * Y_{o2.std} * P_{std})$
$SOTE = a_{sote} * q_{diff} + b_{sote} * q_{diff}^2 + c_{sote} * q_{diff}^3 + d_{sote}$
(The values of coefficients of this equation will be equal to the coefficients of the equation obtained from the graph by using excel tool.)

We can solve the simultaneous system of equation by using the excel solver tool by using established relation between sote and gas flow rate and can compute the number of diffusers for maximum oxygen demand case and required gas delivery for non max oxygen delivery case.

The images of excel sheet is provided as below.



I. Computations for the maximum oxygen demand case - sets the number of diffusers

Enter the desired gas loading rate for the design diffuser in cell C7 (*consider that some capacity should be reserved for the potential that loading exceeds the maximum anticipated*).			
q.des =	0.672	m³/(min-diff)	
OTE.des =	29.8	%	SOTE = a.3p*q.des + b.3p*q.des² + c.3p*q.des³ + d.3p
The initial guess for AOTE (95% of SOTE.des) from cell D11 into cell C11 to start the numeric computation of the field AOTE.			
AOTE =	20.4805522	28.31	The initial guess will be replaced by the solver
Y.O2.avg =	**0.191**	mol$_{O2}$/mol$_{gas}$	Y.O2.avg = Y.O2.std/2*(1+(1-C11/100)/(1-Y.O2.std*C11/100))
C.sat.avg =	**9.214**	mg$_{O2}$/L	C.sat.avg = DO.sat.T.H*(P.mid/P.H*C12/Y.O2.std)
Use the solver (Data - solver) to iteratively solve the set of equations in cells C12, C13 and C15 - set the value in cell C15			
f(AOTE) =	5.7593E-10		f(AOTE) = SOTE.des*((beta*C13-DO)/DO.std)*theta^(T.des-T.std)*alpha*F.foul-C11
			f(AOTE) should be on the order of 10-7 or lower, once the solver does its work.
AOTE =	**20.48**	%	This is the actual oxygen transfer efficiency at the maximum condition
AOTR =	10000	kg$_{O2}$/day (from user input)	
OAR =	**48827**	kg$_{O2}$/day	OAR = ROUND(AOTR.max*100/C11,0)
Q.std.air =	**121.9**	m$_{std}$³/min	Q.std.air = ROUND(C19/(MW.O2*Y.O2.std)*SV.stp/1440,1)
N.diff.air =	**182**	Number of diffusers (CEILING(C20/q.des,1)) needed to supply O_2 at the design conditions	
P.disch =	**1.558**	ATM	Static discharge pressure. Add the diffuser dynamic wet pressure loss and the air delivery friction losses to this value to obtain the total blower delivery pressure
	157.9	kPa	

CONCLUSION

The goal of this research paper is to understand the necessity and design of the aeration system. In this research paper we have learned about parameters affecting the operation and design procedure of aeration system. So we can summarize that this research paper dealt with aeration tank sizing, aeration tank operations, activated sludge operational parameters, oxygen requirements, blower sizing, air requirement, computation of actual oxygen transfer efficiency and number of diffuser required.

II. Computations for a non-max oxygen demand case - computes required gas delivery

AOTR =	5000	kg_{O2}/day, non-max oxygen requirement (from user input)	
Enter the final AOTE value from Cell C17 (**copy and paste as value**) in cell C30 to begin the iterative solution.			
AOTE =	22.3108647	The initial guess for the non-max case AOTE will be replaced by the solver	
Cells C32 - C35 and C37 contain a set of five equations solved simultaneously to obtain the non-max case solution			
q =	**0.307**	m^3/(diff-min)	q = AOTR*R.univ*(T.std+273)/(C30/100*N.diff.air*1440*MW.O2*Y.O2.std*P
SOTE =	**32.8**	%	SOTE = c.3p*C32^3 +b.3p*C32^2+a.3p*C32+d.3p
Y.O2.avg =	**0.1897**	mol_{O2}/mol_{gas}	Y.O2.avg = Y.O2.std/2*(1+(1-C30/100)/(1-Y.O2.std*C30/100))
C.sat.avg =	**9.134**	mg_{O2}/L	C.sat.avg = DO.sat.T.H*P.mid/P.H*C34/Y.O2.std
set C37 to zero by changing C30.			
f(AOTE) =	5.463E-11		f(AOTE) = C33*(beta*C35-DO)/DO.std*theta^(T.des-T.std)*alpha*F.foul-C30
f(AOTE) should be on the order of 10^{-7} or lower, once the solver does its work.			
AOTE =	**22.31**	%	This is the AOTE (ROUND(C30,2)) at the non-maximum condition
Q.std.air =	**55.9**	m_{std}^3/min	Q.std.air = ROUND(N.diff.air*C32,1)
P.disch =	**1.558**	ATM	Static discharge pressure. Add the diffuser dynamic wet pressure loss and the air delivery
	157.9	kPa	friction losses to this value to obtain the total blower delivery pressure

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