SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

SWIM-H2020 SM Regional Activities 14

Presented by:

MOHAMMD SUTARI, MEHSIP RESIDENT EXPERT-JORDAN

SWIM and Horizon 2020 SM REG-14: Refugee Emergency: Fast track project Design of wastewater

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AERATION & MIXING SYSTEMS

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AERATION SYSTEMS

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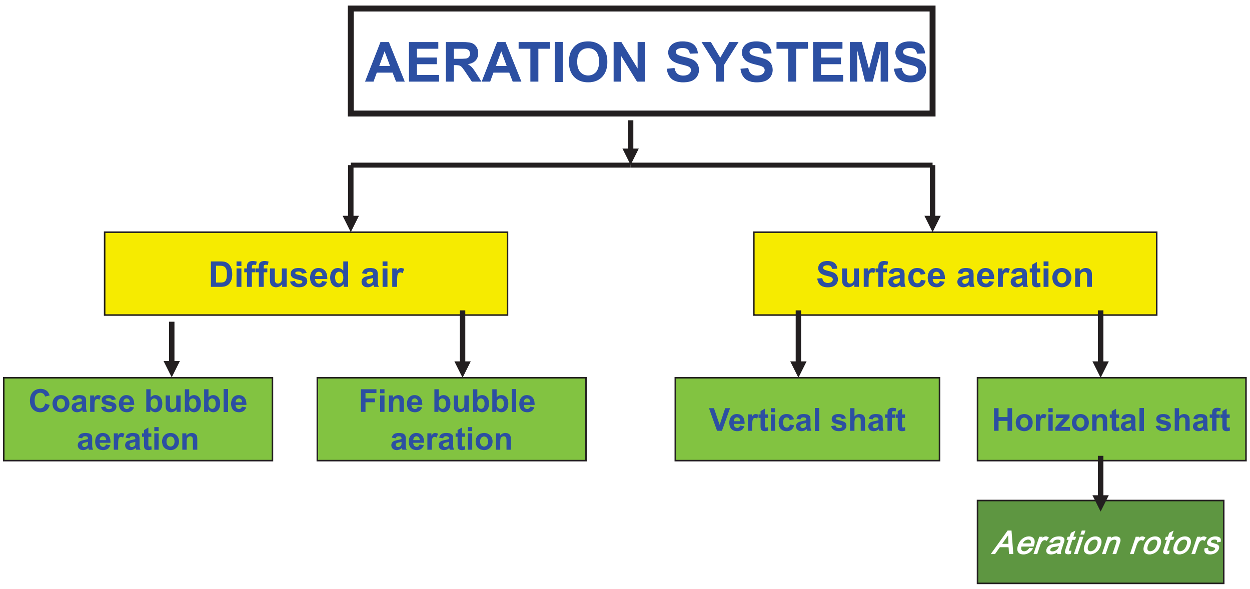
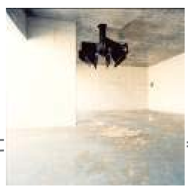
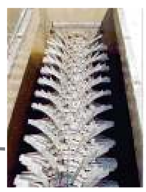
- Objectives
  - Provide oxygen for the biochemical oxidation of carbonaceous and nitrogenous matter.
  - Maintain the biochemical solids in suspension and uniformly mixed within the wastewater.
- Oxygen is provided by
  - Introducing gaseous air.
  - Pure oxygen.
- In order to be useful to the biological matter, gaseous oxygen presents in the air stream must be transferred to dissolved oxygen within the liquid. This transfer can be achieved using mechanical devices and diffusers.
- The aeration process has the highest energy demand, therefore the design must have the flexibility to handle variation in oxygen demand

TYPES OF AERATION SYSTEMS



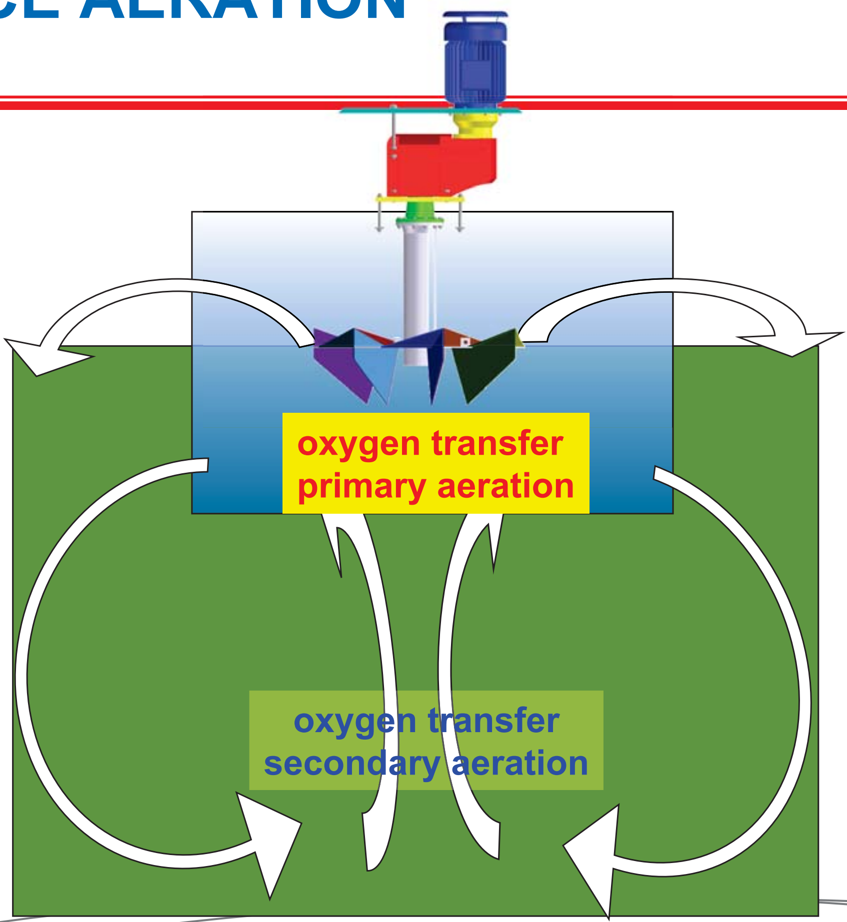


TYPES OF AERATION SYSTEMS

- Diffused Aeration.
  - Diffusion devices located in the aeration tank near the bottom through which air is introduced(through piping) by compressing atmospheric air with blowers.
- Mechanical Aerators.
  - Agitation the wastewater in order to entrain oxygen in the mixed liquor.
- High-Purity Oxygen Aeration
  - Pure oxygen is used as the oxygen source instead of air. It requires sealed reactors.

SURFACE AERATION

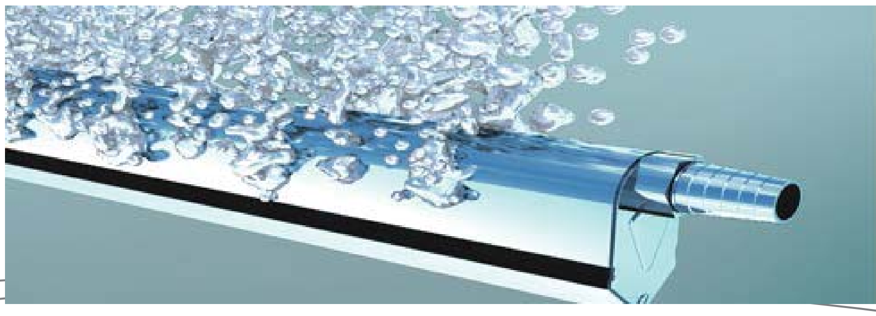


FINE BUBBLE DIFFUSED AERATION SYSTEM

- Fine bubble
  - Typical oxygen transfer efficiency is 6.5% per m of diffuser submergence. A 5 m submergence equals 32.5% OTE in clean water.
  - Consist of membrane or ceramic disks, membrane tubes, mounted on full-floor coverage across the aeration basin bottom.

COARSE BUBBLE DIFFUSED AERATION SYSTEM

- Coarse Bubble
  - Typical oxygen transfer efficiency is 2.6% per m of diffuser submergence. A 5 m submergence equals 13% OTE in clean water.
  - Typically diffusers are mounted along one wall creating spiral roll down the length of the tank.
- The difference between the spiral roll pattern of coarse bubble systems and the mild aeration pattern of fine bubble is that the coarse bubble provides sufficient energy for quick mixing of the tank contents, while the fine-bubble is not able to do this.



ACTUAL OXYGEN REQUIREMENTS AOR CALCULATIONS

ACTUAL & STANDARD OXYGEN REQUIREMENTS (AOR & SOR)

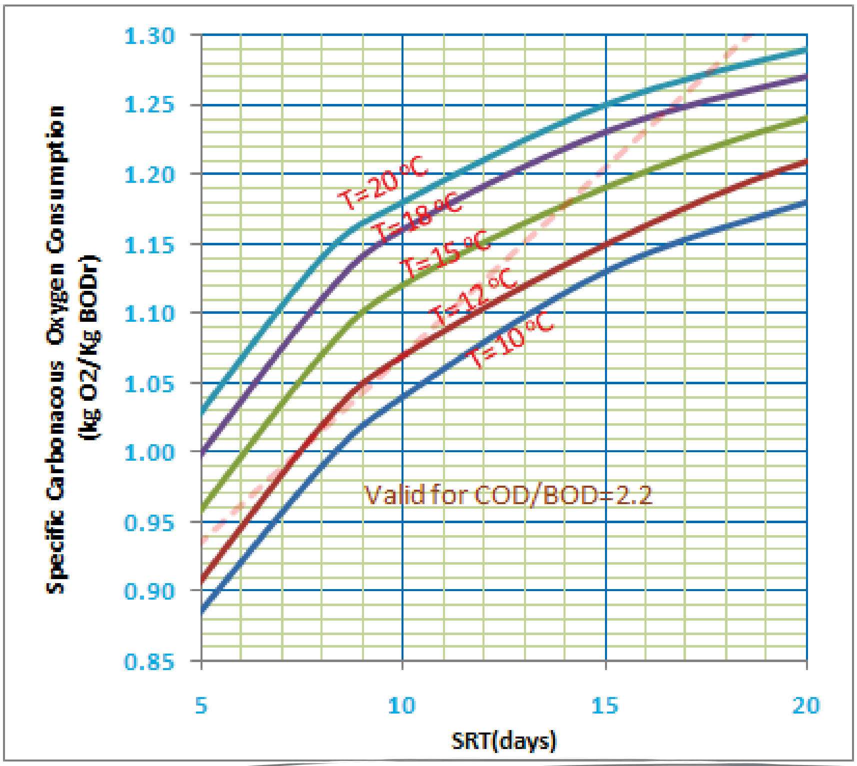
- Oxygen must be provided in biological treatment systems to satisfy various demands.
- This is referred as actual oxygen requirements (AOR). It is expressed as field conditions.
- Each WWTP has its own unique field conditions.
  - Site elevation
  - Temperature
  - DO
  - Diffused submergence
  - Other factors
- Field conditions factors must be used to convert AOR to standard oxygen requirements(SOR)
- SOR is always larger than AOR.
- Confusion and misunderstanding can be minimized for equipment if designs are expressed in SOR values

ACTUAL OXYGEN REQUIREMENTS

- Oxygen is required for:
  - Carbonaceous demands(O2 required to stabilize carbon in the wastewater)
    - Conversion of carbon to new cells(0.5-0.6 kg O_2/kg BOD_5).
    - Endogenous respiration (oxidizing cells, digestion).
  - Nitrogenous demand(O2 required to stabilize nitrogen in the wastewater)
- Carbonaceous Removal
  - Lower limit 0.90 kg O_2 required per kg BOD_5 removed for low SRT plants.
  - Upper limit 1.3 kgO_2 required per kg BOD_5 removed for high SRT plants.

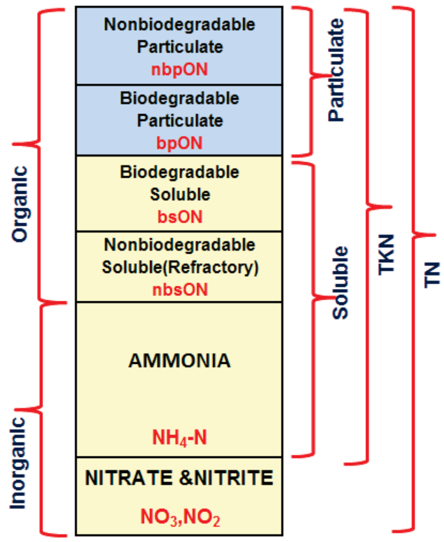
$$Carb\_Oxygen\_required(AOR) = 0.8 + 0.027 \times SRT$$

SPECIFIC OXYGEN CONSUMPTION IN ATV STANDARDS



OXYGEN REQUIREMENTS NITROGENOUS REMOVAL

- Ammonia is oxidized to nitrate.
- Oxygen required for nitrification = 4.25 kg per kg ammonia nitrified.
- Ammonia comprised 60 to 70% of TKN in domestic wastewater.
- The oxygen requirements for nitrification is based on the influent TKN to the activated sludge process. It is wrong to use influent ammonia as the basis of design.
- Ammonia available for nitrification is equal to the influent TKN to aeration tank less the following:
  - Nitrogen used for the carbonaceous removing organisms.
  - Soluble non-biodegradable organic nitrogen(1.5-3% of influent TKN).
  - Residual ammonia.
  - TKN in effluent SS.



Nitrogen Mass Balance

$$NH_4\_N_n(nitrified) = TKN_i - nbsON - NH_4\_N_e - TKN_a$$

OXYGEN REQUIRED ON COD BASIS METCALF & EDDY

- Oxidation of Carbonaceous Material

Oxygen used = bCOD removed-COD of waste sludge

$$R_O = Q \times (S_0 - S) - 1.42 \times P_{X,bio}$$

$$\frac{COD}{VSS} = 1.42$$

ALL bCOD oxidized

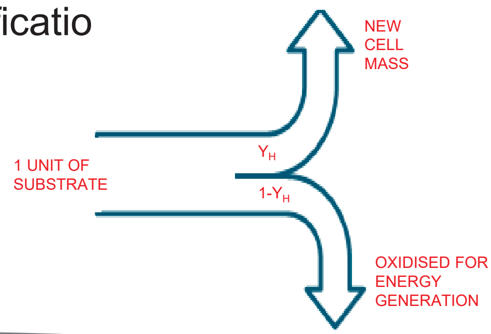
Where:
R_o = oxygen required , kg/d
$P_{x,bio}$ = biomass as VSS waste sludge, kg/d
S_0 = influent bCOD
S = effluent bCOD
Q = influent flow

Bacteria oxidize a portion of the bCOD to provide energy and use a portion of the bCOD for cell growth

- Oxidation of carbonaceous material & Nitrificatio

$$R_O = Q \times (S_0 - S) - 1.42 \times P_{X,bio} + 4.25 \times Q \times NO_x$$

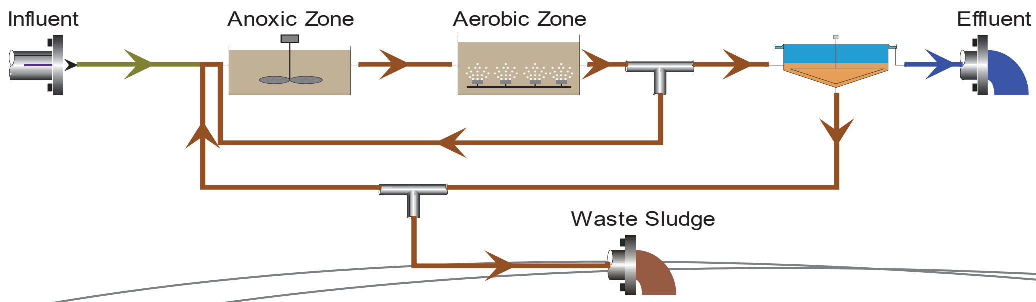
Where:
NO_x = oxidized nitrogen, kg/d



OXYGEN REQUIREMENTS DENITRIFICATION CREDIT

- Denitrification decreases the total process oxygen requirements.
- A portion of the soluble carbonaceous matter oxygen demand is satisfied by nitrate reduction.
- The oxygen credit is 2.86 kg O2 per kg nitrate removed.

Total_Oxygen_Demand = Carb_Oxygen_Demand + Nit_Oxygen_Demand − Denitrification_Credit

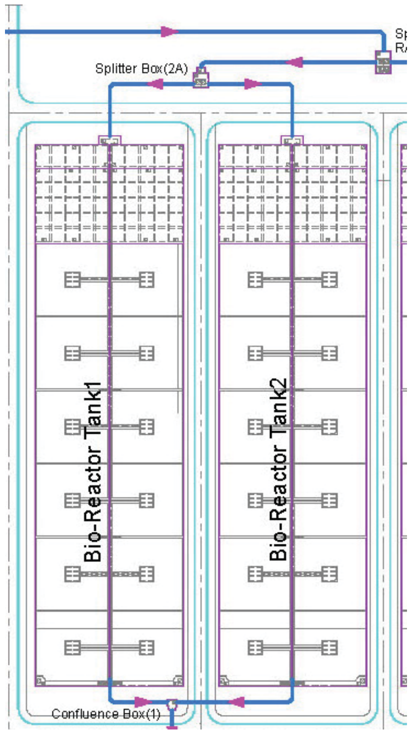


OXYGEN DEMAND VARIATION

- Peak Oxygen demand
  - The maximum daily demand is considered the peak demand for sizing purposes. Therefore oxygen requirements calculations should be based on maximum daily BOD and TKN loads.
- Minimum Oxygen Demand
  - The minimum oxygen demand should be established based on the minimum day BOD and TKN loads.
  - The governing minimum airflow rate is the highest of the followings:
    - Minimum air flow required to meet the minimum daily oxygen demand.
    - Minimum air flow required by the diffuser system.
    - Minimum air flow required to meet the tank mixing requirements.
  - The minimum air flow rate per one 9 inch fine bubble diffuser disk is 0.85 m3/hr. Operation below this airflow may results in fouling and clogging of diffusers.
  - The minimum air for mixing should be based on 27 m3/day per m2 of tank surface area.
  - High DO concentration is expected during periods of low influent loads for at systems that are mixing limited.

TAPERED OXYGEN DEMAND

Oxygen demand will vary across the length of aeration basins (unless designed as complete mix systems). The variation in oxygen demand is clear in plug flow reactors.



COMPONENTS OF OXYGEN DEMAND

- Synthesis during carbonaceous oxidation.
- Endogenous respiration during carbonaceous oxidation.
- Nitrification.

TAPERED OXYGEN DEMAND

- Diffusers layout should be tapered to approximate oxygen demand pattern within the aeration tank using the following procedure:
  - Estimate the total carbonaceous demand from the design SRT.
  - Subdivide the total carbonaceous demand into synthesis and endogenous components:
    - Oxygen for synthesis = 0.5 kg O2/kg BOD removed.
    - Oxygen for endogenous = Total carbonaceous demand - oxygen for synthesis.
  - Nitrification demand is 4.25 kg O2/kg of ammonia available for nitrification.

TAPERED OXYGEN DEMAND

	1st	2nd	3rd
Max. O2 Uptake rate Carbonacous only	125 mg/l.hr		
Max. O2 Uptake rate Nitrifying	175 mg/l.hr		
Carbonacous Synthesis	67%	33%	0%
Carbonacous Endogenous	33%	33%	33%
Nitrification	40%	40%	20%
Denitrification Credit[1]	33%	33%	33%
Total (Approximate)	45%	35%	20%

[1] Occurs in anoxic zone but applied equally across all zones

Flexible design:
- Two speed or variable-frequency drives.
- Variable depth for mechanical aerators.
- Control valves in main aeration pipes.

EXAMPLE FOR ACTUAL OXYGEN REQUIREMENTS CALCULATIONS

Total average and peak oxygen demand

$$OD_{TotAvg} := OD_{CarbAvg} + OD_{NitAvg} - OD_{RedAvg}$$

$$= 7274.0 + 4126.7 - 2602.0$$

$$\boxed{OD_{TotAvg} = 8799}$$ kg/day

$$OD_{TotPeak} := OD_{CarbPeak} + OD_{NitPeak} - OD_{RedPeak}$$

$$= 10147.0 + 5937.0 - 3820.0$$

$$\boxed{OD_{TotPeak} = 12264}$$ kg/day

Actual Oxygen Demand Calculations

STANDARD CONDITIONS

Parameter	Atmospheric Air at Standard Conditions	
	United States	European
Temperature (°C)	20	0
Atmospheric Pressure	1 atm(sea level)	1 atm(sea level)
Relative Humidity	36%	0%
Oxygent Content(g O2/m3)	278	300
Chloride concentration (mg/l)	-	0
Density of air (kg/m3)	1.201	
Oxygen content %	23.20%	

Atmosphere composition

By Weight
23.2% oxygen

By volume
78% nitrogen
21% oxygen

- The density of air varies with temperature and pressure(altitude).
- Air volume, flow rates and density are usually reported at standard conditions.

CLEAN WATER TESTING

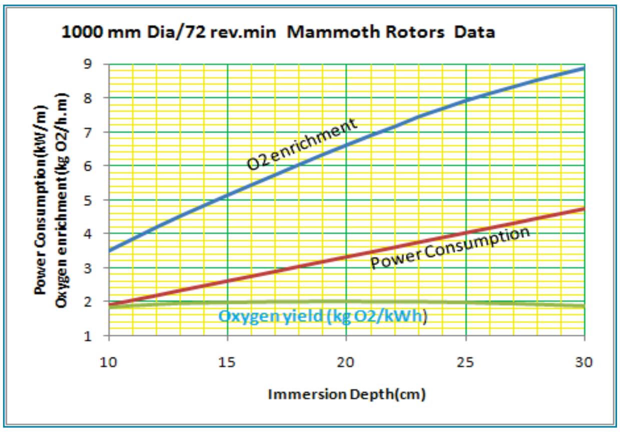
- Oxygen transfer for different devices is conducted in clean water.
- Clean water performance are specified and reported as the Standard Oxygen Transfer Rate(SOTR) or as the Standard Oxygen Transfer Efficiency(SOTE).
- SOTR and SOTE apply to the standard conditions at zero dissolved oxygen concentration.
- The transfer efficiency for mechanical aerators is reported as the standard aeration efficiency(SAE).

$$SAE = \frac{SOTR}{Power\_Input}$$

MECHANICAL AERATION DESIGN

MECHANICAL AERATORS WITH HORIZONTAL AXIS MAMMOTH ROTORS

The circulation power of the mammoth rotors is sufficient for the required mixing up to 3.6 m deep tanks. Additional mixers are required for higher depth tanks.



Technical Data			
Diameter (mm)	Lengths (m)	Power (kW)	Speed (rev/min)
700	1-6	2.2-22	85 & 85/57
1000	3-9	15-45	72& 72/48

$$kW = \frac{Required\_Oxygen(kg/hour)}{Field\_Aeration - Efficiency}$$

Source : Passavant brochures

MINIMUM AIR & ENERGY REQUIRED FOR MIXING

- Aeration tanks must be checked for oxygen transfer and adequate mixing.
- In most aeration systems, the oxygen transfer requirements will govern.
- Mixing may govern at the end of the plug flow tanks
- The size and shape of the aeration tank are very important for good mixing. The depth and width of the aeration tanks for mechanical surface aerators are dependent on aerator size as shown below.

Tanks dimensions vs. Aerators sizes

Aerator size (kW)	Tank dimensions	
	Depth (m)	Width (m)
7.5	3-3.5	9-12
15	3.5-4	10-15
22.5	4-4.5	12-18
30	3.5-5	14-20
37.5	4.5-5.5	14-23
55	4.5-6	15-26
75	4.5-6	18-27

Minimum air & power for adequate mixing

Source	Diffused Aeration m3/1000 m3.min		Mechanical Aerators kW/1000 m3
	Coarse Bubble	Fine Bubble	
Metcalf & Eddy	20-30	10-15	20-40
Average Rule of thumb up to 4000 mg/l MLSS	20		15

AOR/SOR FOR MECHANICAL AERATORS

$$AOTR = SOTR\left(\frac{\beta\Omega C_{SC} - C_L}{9.09}\right)1.024^{(T-20)}\alpha$$

$$\Omega = \frac{P\_ambient}{P\_standard}$$

$$\frac{AOTR}{SOTR} = \frac{AOR}{SOR} = \left(\frac{\beta\Omega C_{SC} - C_L}{9.09}\right)1.024^{(T-20)}\alpha$$

$$\frac{AOTE}{SOTE}$$

Where:
AOTR = actual oxygen transfer rate under field conditions, kg O_2/h
SOTR = standard oxygen transfer rate in tap water at 20 ºC and zero DO, kg O_2/h
AOR = actual oxygen required under field conditions, kg O_2/h
SOR = standard oxygen required in tap water at 20 ºC and zero DO, kg O_2/h
β = oxygen solubility correction factor,0.95.
Ω = altitude correction for oxygen solubility, Pa/Ps.
C_{SC} = standard DO saturation value at given temperature, mg/l.
C_L = minimum DO under operating conditions,mg/l
T = operating design temperature, ºC.
α = oxygen transfer correction factor,0.9
P_ambient = atmospheric pressure at the treatment plant
P_stanadrad = atmospheric pressure at sea level, 10.33 m.

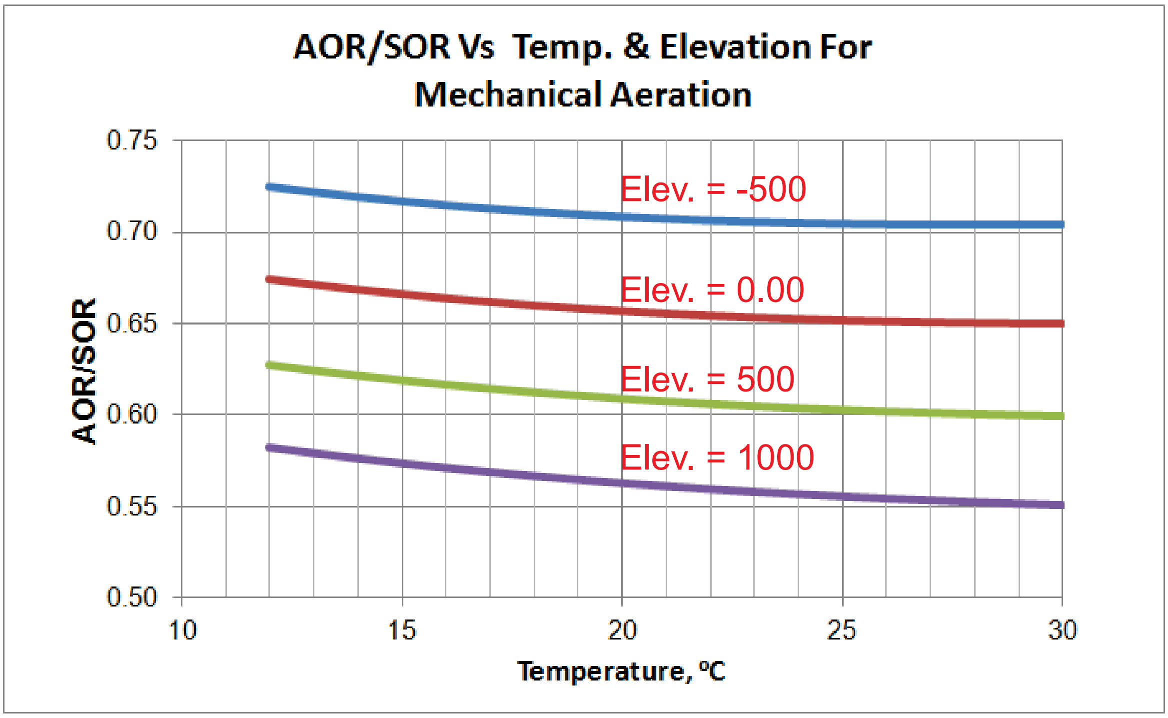
POWER FOR MECHANICAL AERATORS

$$FAE = SAE \times \frac{AOR}{SOR}$$

$$Power = \frac{Actual\_Oxygen\_Demand}{FAE \times 24}$$

FAE = Field aeration efficiency, O2/kw.hr
SAE = standard aeration efficiency, from manufacturer ,kg O2/kw.hr
AOR/SOR = ratio standard to actual transfer efficiency.
Power = power requirements in kw.

AOR/SOR Vs TEMPERATURE & ELEVATION FOR MECHANICAL AERATION



EXAMPLE FOR MECHANICAL AERATION SIZING

Aerators Sizing

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Recalculate correction factors for mechanical aeration

Calculate Altitude Correction, Ω

$$\Omega_{Mechanical} := \frac{P_{Ambient}}{P_{Standardb}}$$

$$= \frac{0.958}{1.0135}$$

$$\boxed{\Omega_{Mechanical} = 0.95}$$

Altitude correction factor for oxygen concentration; approximately equal to PAmbient/PStandard

$$C_{ST.StandardWaterK} = 9.09$$

Calculate Depth Correction, C_{SC}

$$C_{SCMechanical} := 9.87$$

DO saturation at 16 ºC, mg/l

Calculate AOR/SOR Ratio

$$RATIO_{Mechanical} := \left(\frac{\beta \times \Omega_{Mechanical} \times C_{SCMechanical} - C_0}{C_{ST.StandardWaterK}}\right) \times \alpha_{Mechanical} \times \theta^{T_{Wastewater} - 20}$$

$$= \frac{0.95 \times 0.945 \times 9.87 - 2}{9.09} \times 0.9 \times 1.024^{16-20}$$

$$\boxed{RATIO_{Mechanical} = 0.62}$$

Calculate Field Aeration Efficiency

$$FAE := SAE \times RATIO_{Mechanical}$$

$$= 1.8 \times 0.62$$

$$\boxed{FAE = 1.1}$$ kg/kw.hr

Estimate Power Requirements at average conditions

$$P := \frac{OD_{TotAvg}}{FAE \times 24}$$

$$= \frac{8798.7}{1.12 \times 24}$$

$$\boxed{P = 327}$$ Kw

Mechanical Aerators Sizing

AOR/SOR, AOTE/SOTE CALCULATIONS DIFFUSED/MECHANICAL AERATION

FIELD CONDITIONS

- The oxygen transfer rate under actual field operating condition in wastewater is less than that obtained in clean water.
- Factors to be considered in conversion to filed conditions:
  - Operating D.O.
  - Saturation concentration of oxygen.
  - Temperature
  - Pressure(altitude)

APPLICATION OF CORRECTION FACTORS

$$AOTR = SOTR\left(\frac{\beta\tau\Omega C_{SC} - C_L}{C_{SC}}\right)1.024^{(T-20)}\alpha F$$

$$\frac{AOTR}{SOTR} = \left(\frac{\beta\tau\Omega C_{SC} - C_L}{C_{SC}}\right)1.024^{(T-20)}\alpha F$$

$$\frac{AOR}{SOR}$$

$$\frac{AOTE}{SOTE}$$

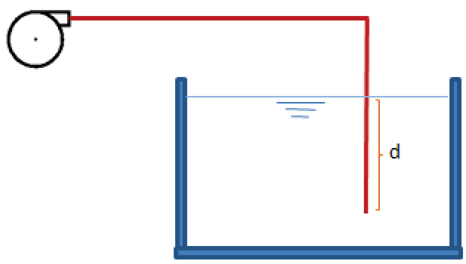
Where:
AOTR = actual oxygen transfer rate under field conditions, kg O_2/h
SOTR = standard oxygen transfer rate in tap water at 20 °C and zero DO, kg O_2/h
β = oxygen solubility correction factor
ζ = temperature correction factor for oxygen solubility.
Ω = altitude correction for oxygen solubility
C_{SC} = standard DO saturation value, corrected for depth of submergence, mg/l.
C_L = minimum DO under operating conditions.
T = operating design temperature, °C.
α = oxygen transfer correction factor.
F = fouling factor, typically 0.65 to 0.9 for diffused aeration. 1 for mechanical aeration.

DEPTH CORRECTION FOR DIFFUSER SUBMERGENCE

$$\frac{AOTR}{SOTR} = \left(\frac{\beta\tau\Omega C_{SC} - C_L}{C_{SC}}\right)1.024^{(T-20)}\alpha F$$

$$C_{SC} = \frac{P_{ambient} + P_{equivalent\_depth}}{P_{ambient}} \times C_S$$

$$P_{equivalent\_depth} = c * d * 0.09817$$

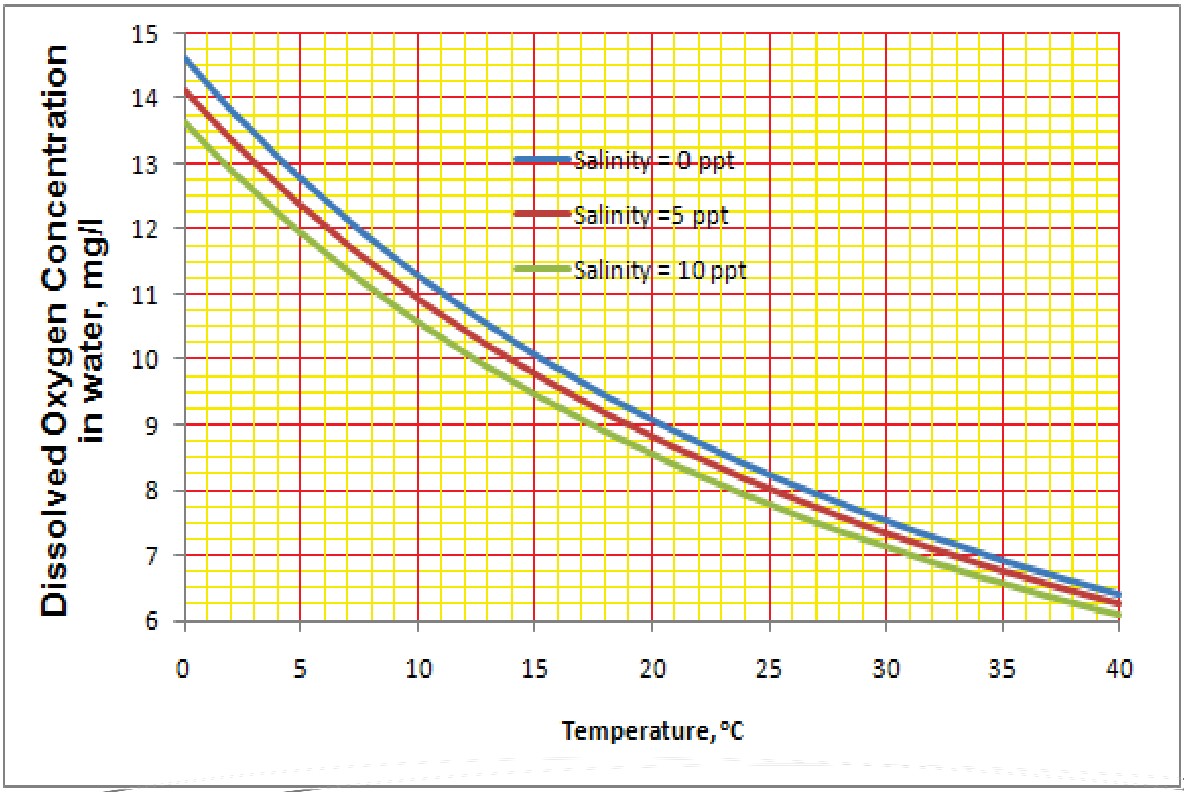


Where:
C_{SC} = Depth corrected standard saturation value, mg/l
$P_{ambient}$ = Atmospheric pressure at the specific site altitude, atm.
$P_{equivalentdepth}$ = Effective pressure at depth of diffuser, atm.
d = Diffuser submergence, m
c = Depth correction factor, 0.33 for fine bubble, 0.25 for coarse bubble.
C_S = Saturation value at standard conditions, mg/l

OXYGEN SATURATION CONCENTRATION AT STANDARD CONDITIONS(C_s)

Temp ^{0}C	Chlorinity mg/l		
	0	5	10
0	14.62	13.73	12.89
1	14.22	13.36	12.55
2	13.83	13.00	12.22
3	13.46	12.66	11.91
4	13.11	12.34	11.61
5	12.77	12.02	11.32
6	12.45	11.73	11.05
7	12.14	11.44	10.78
8	11.84	11.17	10.53
9	11.56	10.91	10.29
10	11.29	10.66	10.06
11	11.03	10.42	9.84
12	10.78	10.18	9.62
13	10.54	9.96	9.41
14	10.31	9.75	9.22
15	10.08	9.54	9.03
16	9.87	9.34	8.84
17	9.67	9.15	8.67
18	9.47	8.97	8.50
19	9.28	8.79	8.33
20	9.09	8.62	8.17
21	8.91	8.46	8.02
22	8.74	8.30	7.87
23	8.58	8.14	7.73
24	8.42	7.99	7.59
25	8.26	7.85	7.46
26	8.11	7.71	7.33
27	7.97	7.58	7.20
28	7.83	7.44	7.08
29	7.69	7.32	6.96
30	7.56	7.19	6.85

OXYGEN SATURATION CONCENTRATION AT STANDARD CONDITIONS(C_s)



EQUATION FOR DISSOLVED OXYGEN SATURATION CONCENTRATION AT STANDARD CONDITIONS(C_s) AS FUNCTION OF TEMPERATURE

$$SDO(T) := \exp\left[\left[-139.34411 + \left(157570.1 \times \frac{K}{T}\right) - \left(66423080 \times \frac{K^2}{T^2}\right) + \left(12438000000 \times \frac{K^3}{T^3}\right) - \left(862194900000 \times \frac{K^4}{T^4}\right) - 0\right]\right]$$

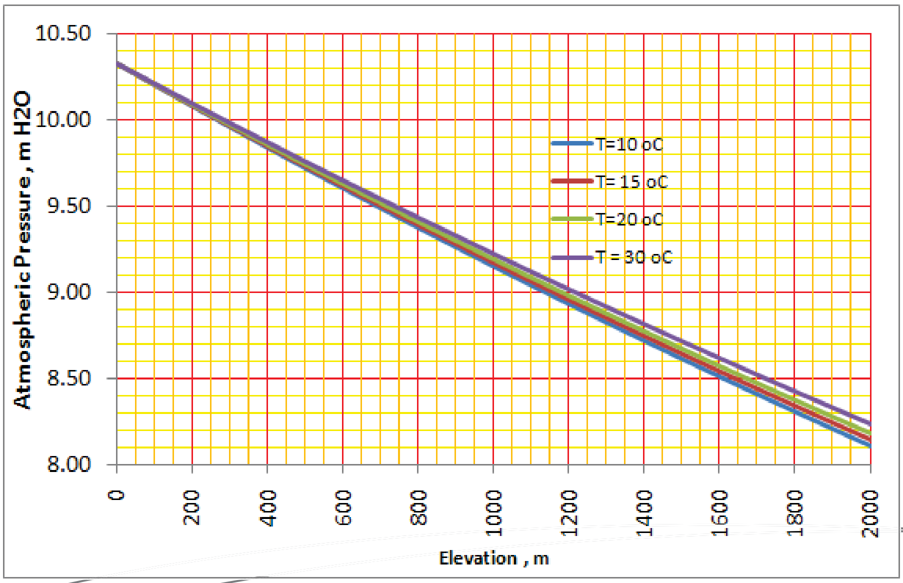
T = Temperature in °K(°C+273.15)

CHANGE IN ATMOSPHERIC PRESSURE WITH ELEVATION

$$P_b = P_a \times e^{\frac{-(Z_b - Z_a)}{(T+273.15)\times 29.25}}$$

$$P_b = 1.01325 \times 10^5 \times e^{-\frac{-Z_b}{(T+273.15)\times 29.25}}$$

Where:
P = pressure, N/m2(Pa)
Z = elevation , m
T = temperature in °C



1 pa = 1 N/m2
1 pa = 1*10^-5 atm
1 pa = 0.1019 mm of water
1 pa = 1 kg/m.s^2

Pressure at sea level = 1 atm
= 10.33 m H2O

Source: Metcalf & Eddy Appendix B, page 1738

CHANGE IN ATMOSPHERIC PRESSURE WITH ELEVATION

$$P_{ambient} = P_{s\tan dard} \times \left[1 - \frac{Elevation}{9144}\right]$$

Where:
P = pressure, N/m2

In some references it is 9450

1 pa = 1 N/m2
1 pa = 1*10^-5 atm
1 pa = 0.1019 mm of water
Pressure at sea level = 1 atm
= 10.33 m H2O

EXAMPLE FOR SATURATION DEPTH CORRECTION

$$C_{SC} = \frac{P_a + (c \times d)}{P_a} \times C_S$$

@ Sea level
Diffuser depth = 4.7 m
Fine bubble diffusers

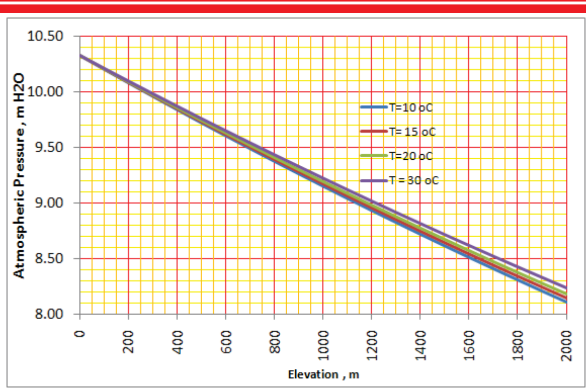
$$C_{SC} = \frac{10.33 + (0.33 \times 4.7)}{10.33} \times 9.09 = 10.45$$

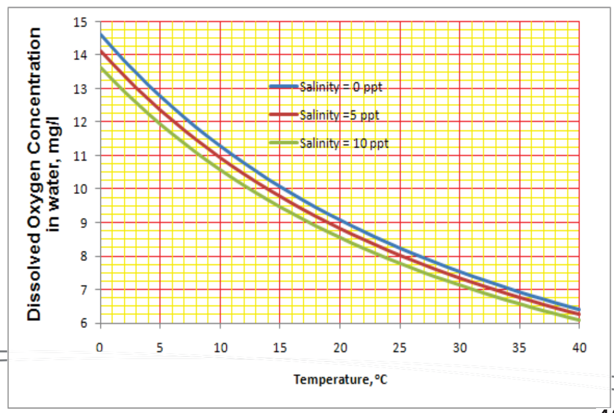
@ 900 m elevation
Diffuser depth = 4.7 m
Fine bubble diffusers

$$C_{SC} = \frac{9.26 + (0.33 \times 4.7)}{9.26} \times 9.09 = 10.61$$

@ 900 m elevation
Diffuser depth = 4.7 m
Coarse bubble diffusers

$$C_{SC} = \frac{9.26 + (0.25 \times 4.7)}{9.26} \times 9.09 = 10.24$$





CORRECTION FACTOR FOR OXYGEN SOLUBILITY, β

$$\frac{AOTR}{SOTR} = \left(\frac{\beta\tau\Omega C_{SC} - C_L}{C_{SC}}\right) 1.024^{(T-20)} \alpha F$$

- The correction factor β is used to correct the test system oxygen transfer rate for differences in oxygen solubility due to constituents in wastewater such as salts and particulates.

$$\beta = \frac{C_S(wastewater)}{C_S(clean\_water)}$$

- The value for β depends upon wastewater characteristics and is independent of the type of aeration.
- The value of β varies from 0.7 to 0.98. Value of 0.95 is used for municipal wastewater.

OXYGEN TRANSFER CORRECTION FACTOR α CORRECTION FACTOR

- The overall mass transfer coefficient under field conditions varies from that for clean water. A correction factor α is used to estimate the mass transfer in actual system.

$$\alpha = \frac{K_L a(wastewater)}{K_L a(clean\_water)}$$

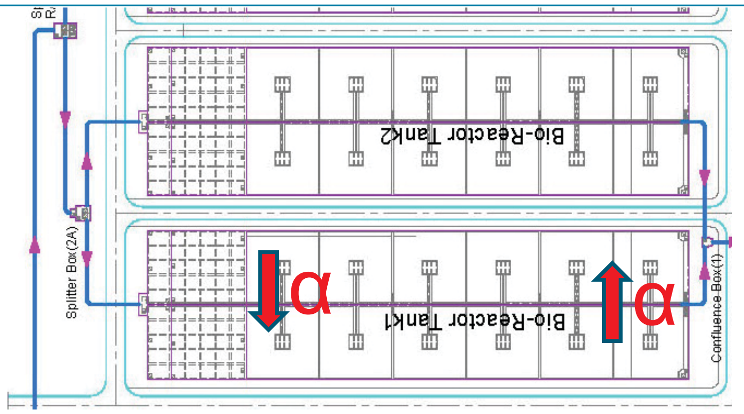
- Values of α vary with wastewater characteristics, aeration device, organic loading, basin geometry, mixing intensity, SRT, & MLSS.
- The value for α increases with the presence of anoxic zone for denitrification.
- The α value is also a function of MLSS concentration, decreasing at higher MLSS levels such as in membrane bioreactors (MBRs) and aerobic digesters
- Manufactures should be consulted during design for selection of α.

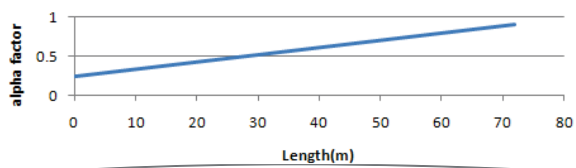
Type of Aeration	α Value	Notes
Mechanical Aerators	0.85	
Coarse-bubble diffusers	0.85	
Fine -bubble diffusers	0.4-0.45	non-nitrifying systems
	0.55-0.65	nitrifying only systems
	0.65-0.75	nitrifying/denitriying systems

$$\frac{AOTR}{SOTR} = \left(\frac{\beta\tau\Omega C_{SC} - C_L}{C_{SC}}\right) 1.024^{(T-20)} \alpha F$$

ALPHA(α) IN PLUG FLOW TANKS

In plug flow type tanks with fine bubble aeration, alpha is generally lower at the inlet or influent and rise to the outlet or effluent end. Designers should be aware of the possibility of significant alpha gradient in long narrow tanks.





ALTITUDE CORRECTION FOR C_S, Ω

- C_S must be corrected for the altitude of the site of the wastewater treatment plant. Ω

$$\Omega = \frac{P\_ambient}{P\_standard}$$

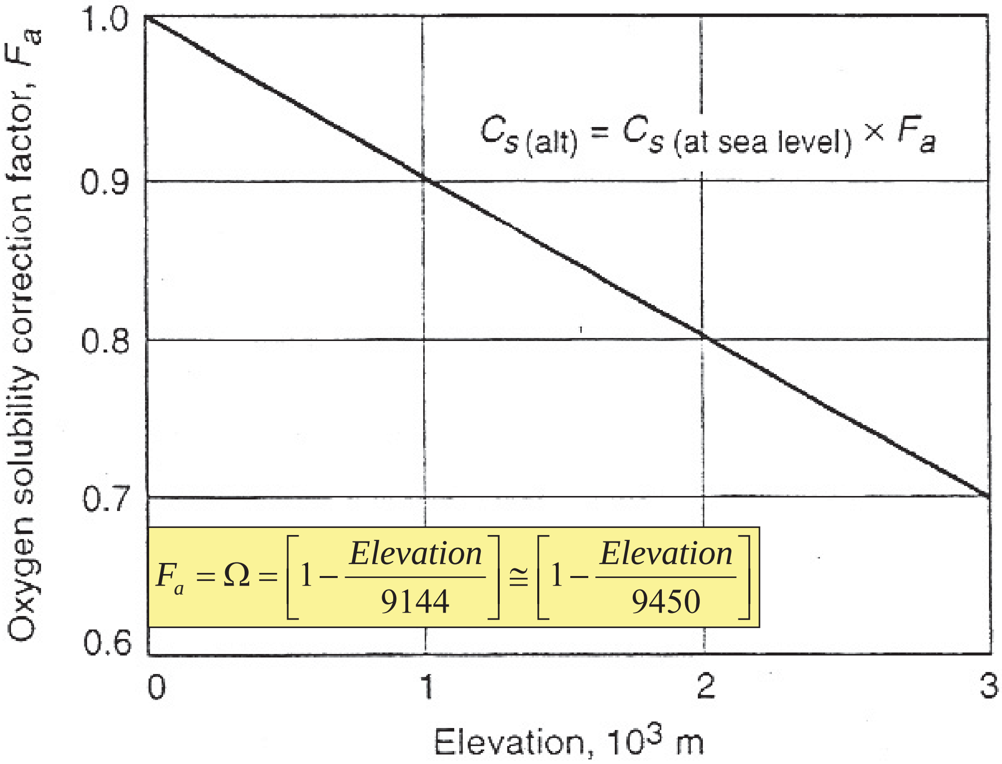
- If the diffuser submergence is greater than 6 m, the correction is as follows:

$$\Omega = \frac{P\_ambient + c \times d - P_{vapor}}{P\_standard + c \times d - P_{vapor}}$$

Where:
P_ambient = atmospheric pressure at the treatment plant
P_stanadrad = atmospheric pressure at sea level, 10.33 m.
c = depth correction factor %.
d = diffuser submergence,m
P_{vapor} = vapor pressure at wastewater temperature

$$\frac{AOTR}{SOTR} = \left(\frac{\beta\tau\Omega C_{SC} - C_L}{C_{SC}}\right)1.024^{(T-20)}\alpha F$$

METCALF & EDDY DO CORRECTION FACTOR VERSUS ELEVATION



VAPOR PRESSURE

$$P_{Vapor}(T) = (0.00000007 \times T^4 + 0.00000313 \times T^3 + 0.00020431 \times T^2 + 0.0065748 \times T + 0.08865719) \times 0.068046$$

Where:
P_{vapor} = vapor pressure, atm, bar
T = temperature °C.

Temperature	Vapor Pressure	
°C	atm	m H2O
10	0.012	1.256
11	0.013	1.342
12	0.014	1.433
13	0.015	1.529
14	0.016	1.631
15	0.017	1.739
16	0.018	1.853
17	0.019	1.974
18	0.020	2.101
19	0.022	2.235
20	0.023	2.377
21	0.024	2.527
22	0.026	2.685
23	0.028	2.852
24	0.029	3.028
25	0.031	3.213
26	0.033	3.408
27	0.035	3.613
28	0.037	3.829
29	0.039	4.057
30	0.042	4.296

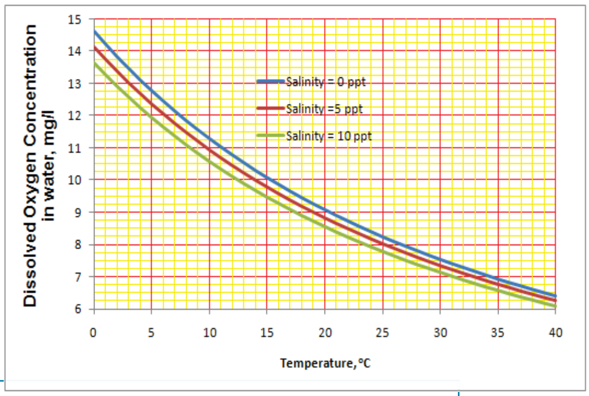
TEMPERATURE CORRECTION

- $K_L a$ and Cs vary with temperature.
- Correction factors are expressed as θ=1.024 and τ

$$\frac{AOTR}{SOTR} = \left(\frac{\beta\tau\Omega C_{SC} - C_L}{C_{SC}} \right) 1.024^{(T-20)} \alpha F$$

$$\theta^{T-20} = \frac{K_L a @ T}{K_L a @ 20}$$

$$\tau = \frac{C_{ST}}{C_{S20}}$$



Where:
T = process temperature °C.
θ = 1.024
C_{ST} = C_S,DO saturation value at process temperature, obtained from oxygen saturation concentration at standard conditions graph or table.
C_{S20} =DO saturation value at standard temperature of 20 °C.

DISSOLVED OXYGEN(DO) CORRECTION

$$\frac{AOTR}{SOTR} = \left(\frac{\beta\tau\Omega C_{SC} - C_L}{C_{SC}} \right) 1.024^{(T-20)} \alpha F$$

- SOTE is based on zero dissolved oxygen concentration in the aeration zone.
- The minimum DO for aeration zone is 2 mg/l.
- DO concentration in the aeration zone decreases the driving force for oxygen transfer to occur and accordingly decreasing the field OTE.

$$Driving\_force\_correction = \frac{C^*_{SC} - C_L}{C_{SC}}$$

Where:
C_{SC} = standard DO concentration value corrected for depth of submergence, mg/l
C_L = minimum DO under operating conditions.
C^*_{SC} = standard DO saturation value corrected for pressure, temperature, and wastewater characteristics,
$C^*_{SC} = C_{SC}\beta\zeta\Omega$

ACTUAL OXYGEN DEMAND CONVERSION TO STANDADR AIR

$$SOTE_{Diffuser} = SOTE_{DiffuserUnit} \times Submergence$$

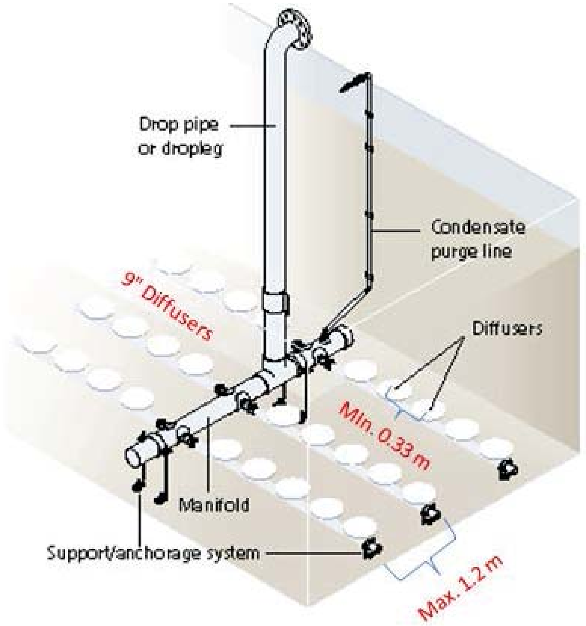
$$FOTE = SOTE \times \frac{AOTE}{SOTE}$$

$$S\tan dard\_Air = \frac{Actual\_Oxygen\_Demand}{FOTE \times \%O_2 \times \rho_{Air}}$$

Where:
SOTE = standard oxygen transfere efficiency, from manufacturer.
Submergence = diffuser submergence.
FOTE = field oxygen transfer efficiency.
$\% O_2$ = percentage of oxygen by weight in air at standard conditions, 0.232
ρ_{Air} = density of air at standard conditions, 1.21 kg/m3.

DIFFUSED AERATION DESIGN

DIFFUSERS SPACINGS & COVERAGE



$$\%\_Coverage = \frac{Area\_Diffusers}{Floor\_Area\_of\_Tank}$$

The maximum spacing between laterals is 1.2 m, larger spacing between laterals and holders can result in spiral flow being created that increase the upward velocity which then reduces the oxygen transfer efficiency.

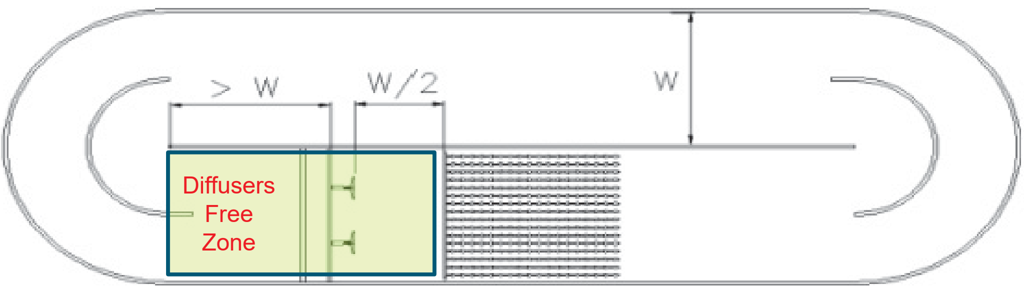
The minimum spacing between 9" diffusers is 0.33m(center to center).

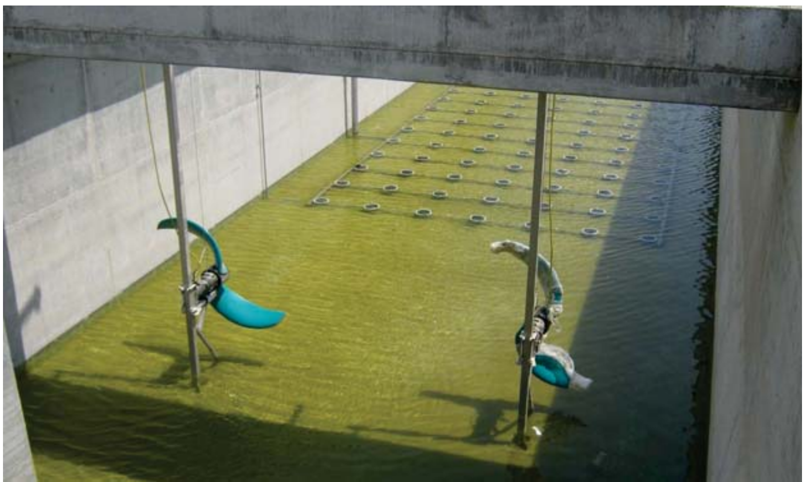
Optimal % coverage is 10%- 12.5%

Min. % coverage is 2.5%
Max % coverage is 25%

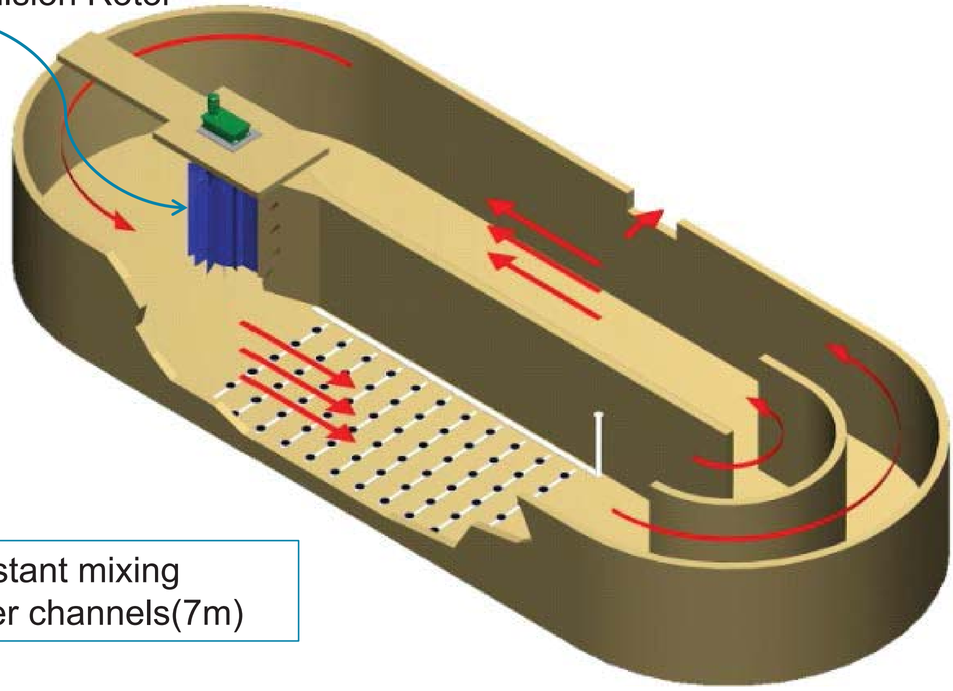
Area of 9" diffuser is 0.038 m2.

DIFFUSERS FREE ZONE FOR SUBMERSIBLE MIXERS





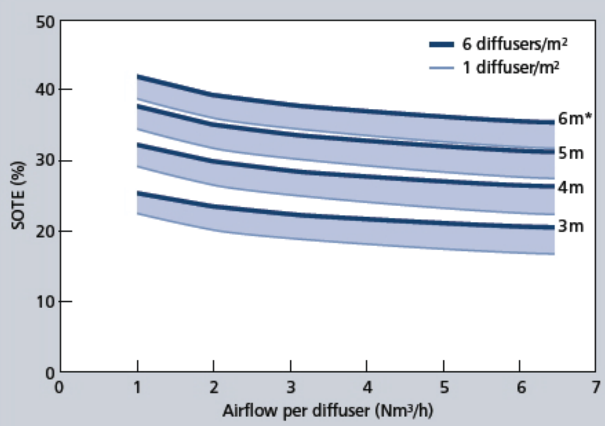
FLOW PROPULSION ROTORS



Deliver constant mixing
Allow deeper channels(7m)

%SOTE FOR SANITAIRE FINE BUBBLE MEMBRANE SILVER SERIES II DIFFUSERS

Performance curves
Silver Series II



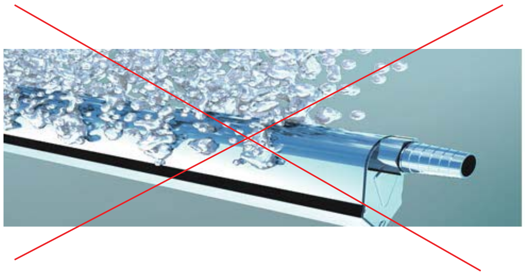
*Submergence

Technical data	
Disc material	Specially blended high-grade EPDM
Diameter	178 or 229 mm (7 or 9 in)
Airflow range per disc	0.8–7 Nm^3/h (0.5–4.5 scfm)
Standard oxygen transfer efficiency (SOTE)	Approx. 6.5% per m submergence (2% per ft)
Standard aeration efficiency (SAE)	2.5–6 kg O_2 /kWh (4–10 lb O_2 /hph)

Sanitaire Silver Series II LP
This 9" low-pressure version of the Sanitaire Silver Series II membrane features a modified slit pattern to handle airflow up to 17Nm^3/h (11 scfm) with minimal pressure loss. It is an excellent choice for sludge and other heavy-duty applications.

DIFFUSED AERATION FOR AEROBIC SLUDGE DIGESTION

- Fine Bubble diffusers are not good for solid contents exceeding 3%.
- Coarse bubble diffusers with a good check valve on the diffuser shall be used to prevent backflow when the air is shut off .
- Coarse bubble “chicken feeder” diffuser are not suitable.



Sanitaire Silver Series II LP
This 9" low-pressure version of the Sanitaire Silver Series II membrane features a modified slit pattern to handle airflow up to 17Nm³/h (11 scfm) with minimal pressure loss. It is an excellent choice for sludge and other heavy-duty applications.

LP diffusers provide much larger bubbles diameter at high air flow rates(>10 Nm3/hour) and it has been used in digesters up to 6% solids.

EXAMPLE FOR DIFFUSED AERATION SYSTEM SIZING

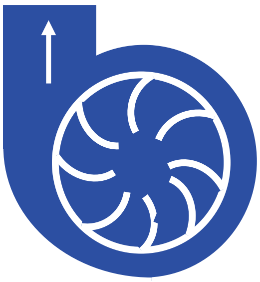
Diffused Aeration System Sizing

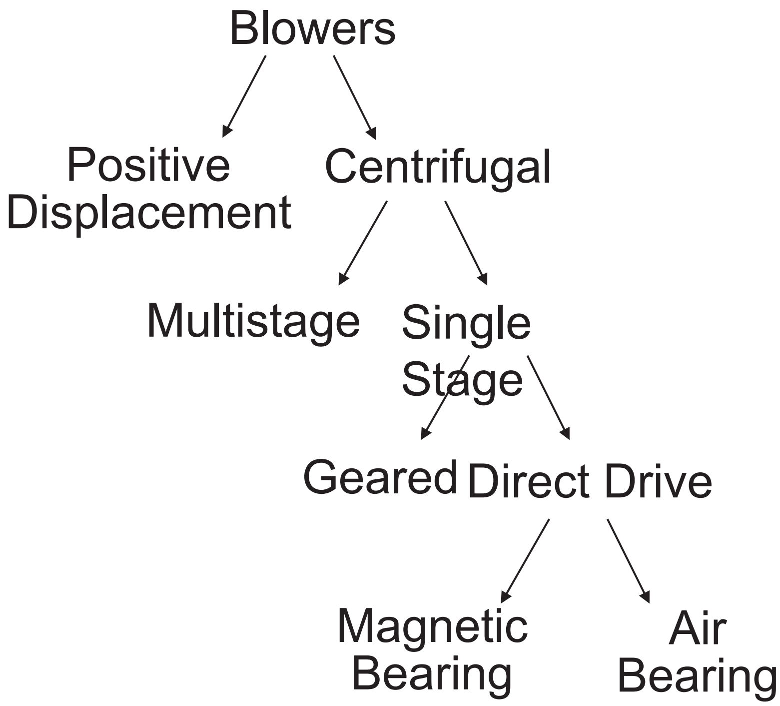
BLOWERS

BLOWERS

- Oxygen demand is met using atmospheric air that is compressed by blowers and discharged via air piping and diffusers.
- Type of blowers
  - Centrifugal
    - Provide variable range of airflow over a narrow range of operating discharge pressure.
  - Positive displacement
    - Provides a constant volume of air over a wide range of operating discharge pressures
- Blowers capacity is based on the air volume required on the warmest summer day.

Blower Technologies for Wastewater Treatment





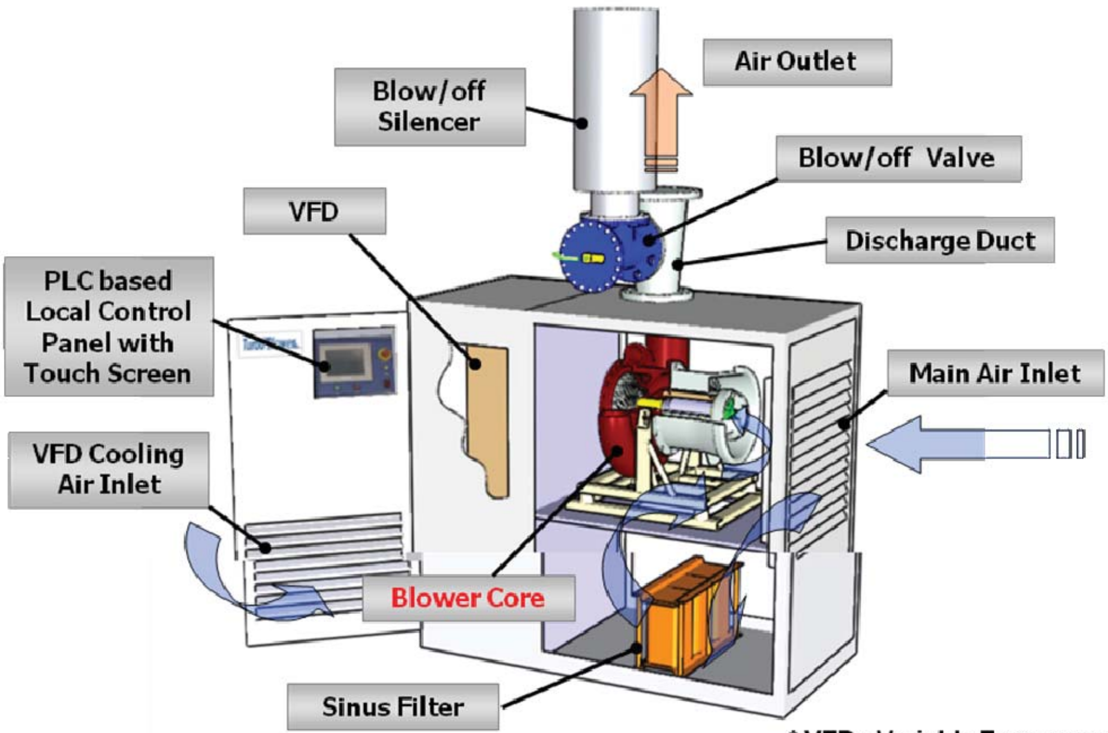
Factors Influencing Blower Selection

- Discharge pressure
  - PD blowers = constant flow, variable pressure
  - Centrifugal blowers = constant pressure, variable flow
    - Inlet guide vanes and outlet diffusers provide wider pressure range
    - Direct drive units operate over wider pressure range
- Capital cost
- Operating cost
- Blower turndown
- Number of units/motor size
- Noise, vibration, maintenance, and footprint

TURBO BLOWERS

- Turbo blowers are packed units with equipment that draw power such as PLC, VFD, and filters.
- Turbo blower will require the same motor size as an integrally geared single-stage centrifugal blower.

TURBO BLOWERS



* VFD : Variable Frequency Driver

DESIGN GUIDELINES FOR BLOWERS

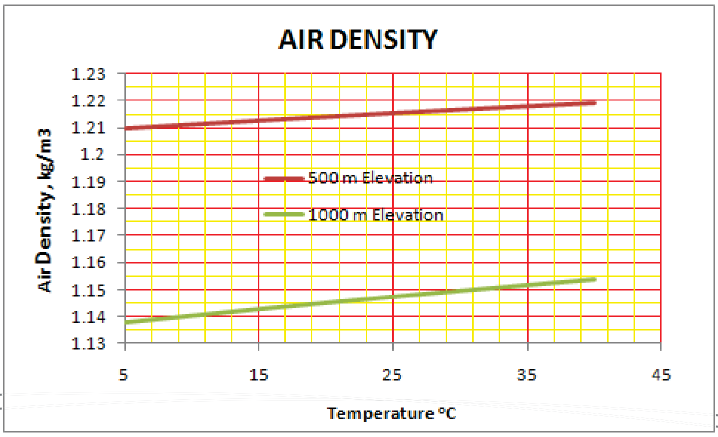
- Inlet air temperature and ambient pressure will affect the density of compressed air. The greater the air density the higher pressure rise across the compressor.
- Motors for centrifugal blowers are sized based on the warm weather air flow rates and the coldest expected winter temperature.
- Air flow rates must be adjusted to actual conditions since the density of air and oxygen content varies with temperature and pressure.

DENSITY OF AIR VERSUS TEMPERATURE

$$\rho_a = \frac{P \times M}{R \times T}$$

Where :
ρ_a = density of air, kg/m3
P = atmospheric pressure, for blower sizing it is the inlet pressure(ambient – inlet losses)(pa, N/m2)
M = mole of air, 28.97 kg/kg-mole.
R = universal gas constant for air, 8314 N.m/kg-mole.K
T = temperature in K(Kelvin) (273.15+°C)

$$\rho_{a,20} = \frac{101325 \times 28.97}{8314 \times (273.15 + 20)} = 1.204\_kg/m3$$



CONVERSION OF STANDARD AIR TO ACTUAL AIR AT FIELD CONDITIONS WITH RH CORRECTION

$$Actual_{AIR} = S\tan dard_{AIR} \times \frac{P_S - (Rh_s \times PV_s)}{P_b - (Rha \times PVa)} \times \frac{T_f}{T_s} \times \frac{P_b}{P_a}$$

Where:
P_s = standard pressure, atm
P_b = ambient atmospheric pressure, atm
P_a = inlet pressure at the blower, atm
Rh_s = standard relative humidity, %
Rh_a = actual relative humidity, %
Pv_s = saturated vapor pressure of water at standard temperature, 0.023068 atm
Pv_a = saturated vapor pressure of water at ambient temperature, atm
T_s = standard temperature, (1.8x 20+32)+460= 528°R
T_f = ambient temperature, °R, (1.8x T(°C)+32)+460

$$P_{Vapor}(T) = (0.00000007 \times T^4 + 0.00000313 \times T^3 + 0.00020431 \times T^2 + 0.0065748 \times T + 0.08865719) \times 0.068046\_atm$$

Whrere:
P_{Vapor} = vapor pressure , atm
T = design wastewater temperature in °C.

CONVERSION OF STANDARD AIR TO ACTUAL AIR AT FIELD CONDITIONS W/O RH CORRECTION

- ❑ Air flow rates must be adjusted to actual conditions since the density of air, and thus the oxygen content, varies with temperature and pressure.
- ❑ As ambient temperature increase and pressures decrease, the oxygen content of the air decreases.

$$Actual_{AIR} = S\tan dard_{AIR} \times \frac{P_S}{P_b} \times \frac{T_f}{T_s}$$

Where:
P_s = standard pressure, 1 atm
P_b = atmospheric pressure at field elevation and temperature, atm
T_s = standard temperature, 68 + 460 = 528°R
T_a = ambient temperature, °R

BLOWER MOTOR SIZING

$$P_w = \frac{w \times R \times T_a}{29.7 \times n \times e}\left[\left(\frac{P_d}{P_a}\right)^n - 1\right]$$

$$w = Q_{Actual\_Air} \times \rho_{Air}$$

Where:
P_w = power requirement, kW
w = weight of flow of air, kg/s
R = engineering gas constant, for air,8.314 kJ/k mole K
T_a = absolute inlet temperature in kelvin, K,(^{o}C+273.15)
P_a = absolute inlet pressure, atm
P_d = absolute discharge pressure, atm.
n = 0.283/e for centrifugal blowers.
= 0.283 for positive displacement blowers
e = efficiency
0.7 for positive displacement and multistage centrifugal.
0.7-0.8 for single stage centrifugal
Q_{Actual_Air} = Required actual air in m3/s
ρ_{Air} = density of air at max summer temperature, kg/m3

CORRECTION BLOWER MOTOR SIZE FOR COLD TEMPERATURE

- Single stage and multi-stage centrifugal blowers motor size shall be corrected for the coldest expected temperature.
- Positive displacement blowers don't require correction for cold temperature since the discharge pressure remains constant with varying inlet conditions. The term wT in power equation is constant.

$$kW_{Winter} = kW_{Summer} \times \frac{T_{Summer}}{T_{Winter}}$$

Where T is absolute temperature in degrees Rankine.
(1.8xT ^{0}C+32)+460

STEPS FOR BLOWERS SIZING

1. Calculate the required standard air based on maximum expected summer temperature, and minimum expected winter temperature(minimum required for centrifugal designs only)

2. Convert standard air to actual air under summer conditions.

$$Actual_{AIR} = S\tan dard_{AIR} \times \frac{P_S}{P_b} \times \frac{(T_f + 273.15)}{(T_s + 273.15)}$$

3. Size the volume of blower based on actual air at warmest conditions.

4. Motor size formula for positive displacement, integrally geared single stage centrifugal, and multi-stage centrifugal blowers.

$$P_w = \frac{w \times R \times T_a}{29.7 \times n \times e}\left[\left(\frac{P_d}{P_a}\right)^n - 1\right]$$

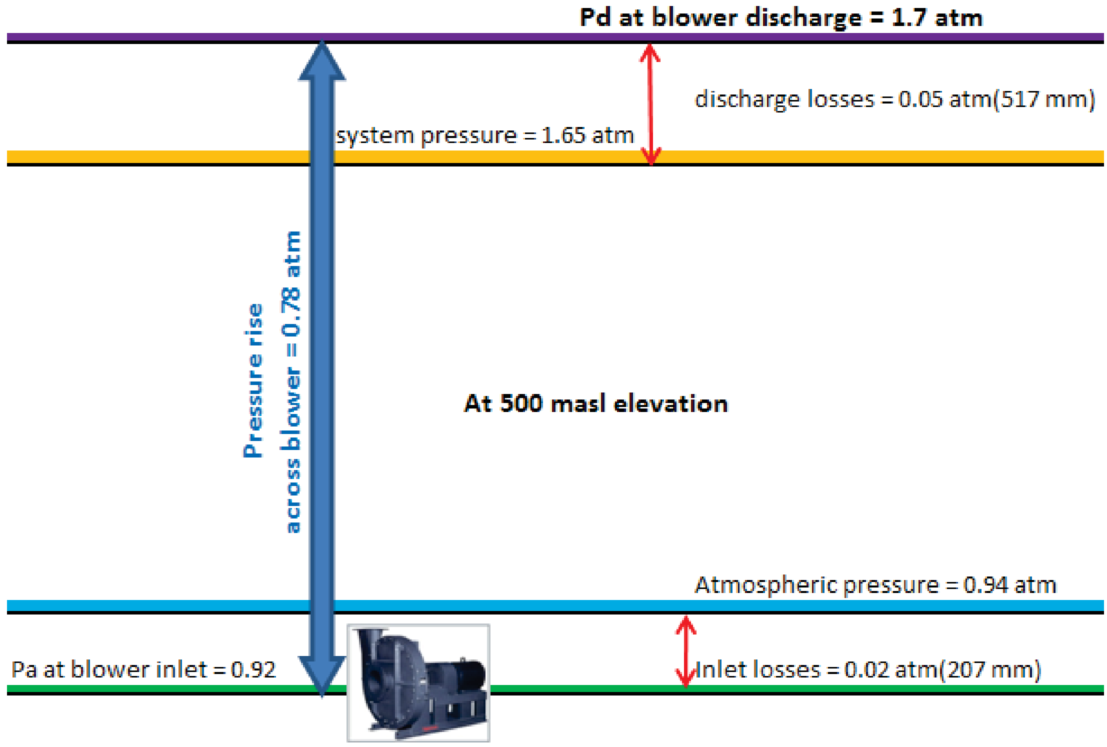
5. Motor size for integrally geared single-stage and multi stage centrifugal blowers shall be determined based on the coldest expected temperature with the following equation.

$$kW_{W\,int\,er} = kW_{Summer} \times \frac{T_{Summer}}{T_{W\,int\,er}}$$

6. Positive displacement blowers requires no correction for cold temperature since the discharge pressure remains constant with varying inlet conditions.

7. In general , a turbo blower will require the same motor size as a integrally geared single-stage centrifugal blower.

PRESSURE CHART FOR BLOWERS



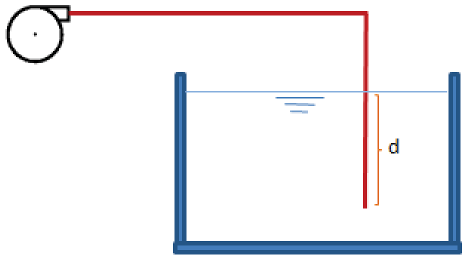
BLOWER DISCHARGE PRESSURE

Blower Discharge Pressure= Pressure @ Inlet +
Discharge Losses +
Static Pressure

Pressure @ Inlet = Ambient Pressure- Inlet Losses(filters & Silencers)

Static Pressure is pressure above diffuser

Static Pressure = γ_w x Submergence



Inlet Losses = 0.02 bar

Discharge Losses = 0.05 bar

DESIGN TEMPERATURE FOR BLOWERS

$$P_w = \frac{w \times R \times T_a}{29.7 \times n \times e}\left[\left(\frac{P_d}{P_a}\right)^n - 1\right]$$

$$w = Q_{Actual\_Air} \times \rho_{Air}$$

- Blower capacity must be based on the air volume required on the warmest expected summer day.
  - In summer hot air has lower density and lower oxygen content, therefore more air is needed.
  - In winter, colder air is denser with more oxygen, therefore less air is needed.
- Motors for centrifugal blowers must be sized based on the warm weather air flow rate and the coldest expected winter temperature.
- The motor correction is not required for rotary positive blowers.

COMPRESSED AIR VOLUME

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

Where:
P1 = inlet pressure, atm
P2 = discharge pressure at particular point, atm
V1= inlet air flow rate, m3/minute
V2 = compressed air flow rate, m3/minute
T1 = max summer inlet temperature, °C
T2 = temperature in air mains. °C

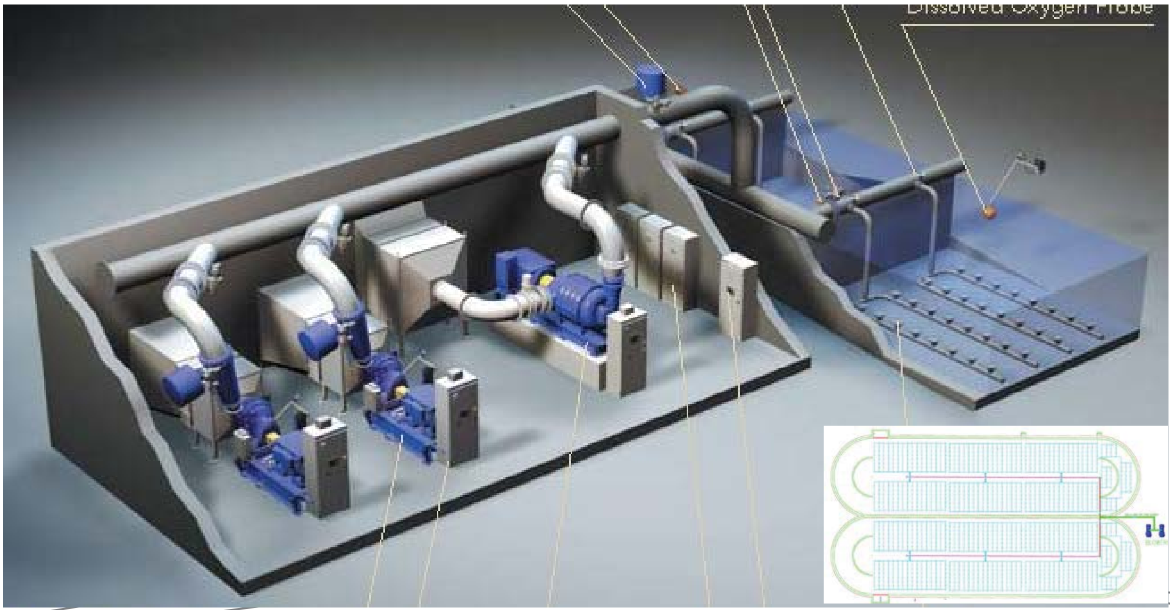
EXAMPLE BLOWERS POWER

Blowers Design

AIR PIPING DESIGN

AIR PIPING DESIGN

- Pipes from blower to the aeration tanks shall be Schedule 10 stainless steel. Pipes on the tank bottom shall be PVC.
- Air piping should be sized for maximum air flow rates, maximum summer temperature.
- Heal loss in the air piping should be 10% of the head loss in across the diffusers.



HEAD LOSS IN AIR PIPING

$$h_L = f \times \frac{L}{D} \times h_i$$

$$f = \frac{0.029 * D^{0.027}}{Q^{0.148}}$$

$$h_i = \frac{\rho v^2}{2g}$$

Typical pipe velocities In Aeration Header Pipes

Pipe Diameter (mm)	Velocity	
	m/minute	(m/s)
25-75	360-540	6-9
100-250	540-900	9-15
300-600	800-1200	13.3-20
750-1500	1100-2000	18.3-33

Where:
h_L = friction loss, mm of water
f = friction factor for steel pipes
L = pipe length, m.
D = pipe diameter,m
h_i = velocity head of air, mm of water.
Q = air flow, m3/min, under prevailing pressure and temperature conditions.
ρ = Density of air 1.205 kg/m^3

1 kgf/m2 = 1 mm of water pressure
= 9.8 pa.

HEAD LOSS IN AIR PIPING

$$h_L = 9.82 \times 10^{-8} \times \frac{f \times L \times T \times Q^2}{P \times D}$$

$$T = T_0 \times \left[\frac{P}{P_0}\right]^{0.283}$$

Where:
hL = friction loss, mm of water.
P = air discharge pressure, atm,
T = temperature in pipe, K,(°C+273.15)
T_0 = ambient air temperature, maximum summer air temperature, K,(°C+273.15)
P_0 = ambient barometric pressure, atm.

Losses in fittings can be computed as a fraction of velocity head using headless coefficient K values

Device	Headloss mm
Air filter	13-76
Silencer	
Centrifugal blower	13-38
Positve displacement blower	152-216
Check valve	20-203

APPENDIX

WATER COLUMN PRESSURE

$$Pressure = \frac{F}{area}$$

A water column will apply a certain force on the water below due to the gravity acting on it. That force depends on the mass of the water column and on the acceleration due to gravity.

$$F = m \times g$$

The mass depends on the volume and on the density of the water

$$F = volume \times density \times g$$

$$F = height \times area \times density \times g$$

$$Pressure = \frac{height \times area \times density \times g}{area} = height \times density \times g$$

$$Pressure = height \times 1000.342$$ In kgf/m2

$$Pressure = height \times 9.81$$ In kPa

$$Pressure = height \times 0.096817$$ In atm

$$Pressure = height \times 0.0981$$ In bar

PRESSURE UNITS CONVERSION

Unit	atm,std	bar	kgf/m2	kPa	Pa	millibar	mm Hg	mm H2O
atm, std	1	0.986923	0.000097	0.009869	0.00001	0.000987	0.001316	0.000097
bar	1.01325	1	0.000098	0.01	0.00001	0.001	0.001333	0.000098
kgf/m2	10332.275	10197.162	1	101.97162	0.101972	10.197162	13.595101	1
kPa	101.325	100	0.009807	1	0.001	0.1	0.133322	0.009807
Pa	101325	100000	9.80665	1000	1	100	133.3224	9.80665
millibar	1013.25	1000	0.009807	10	0.01	1	1.333224	0.098067
mm Hg	759.99982	750.06151	0.073556	7.500615	0.007501	0.750062	1	0.073556
mm H2O	10332.275	10197.162	1	101.97162	0.101972	10.197162	13.595101	1

Multiply column unit by the conversion factor to get the row unit

1 bar = 1x100 kPa   1 bar = 1x0.986923 atm

SWIM-H2020 SM

For further information

Website

www.swim-h2020.eu   E: info@swim-h2020.eu

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