Case study for the evaluation of the fine bubble diffused aeration system efficiency in an activated sludge process of a municipal plant

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The company DAM – Depuración de Aguas del Mediterráneo reached an agreement with SURCIS to carry out a study of one of the WWTPs it is currently operating in order to evaluate the condition and efficiency of the aeration system of the activated sluge process (ASP) and validate the procedure used by Surcis for this purpose.

In this study, Surcis used the results of respirometry tests performed in DAM laboratories with a BM-Advance series respirometer.

1. Respirometry system used in the study

The BM Respirometry technology is based on an exclusive system, based on the modified LFS + LSS respirometry principles, developed by Surcis S.L., which is included in a series of different BM respirometer models. This technology allows that, in the previous test settings, and even during its perfomance, it ia possible to adapt it to different conditions of pH, Temperature, Oxygen and sample / sludge ratio. It also allow the possibility of introducing certain data that can participate in the automatic calculations of fundamental parameters.

OUR & Cyclic OUR operation modes	
Parameter	Description
OUR	Oxygen uptake rate (mg O_2/L)
SOUR	Specific OUR (mg O_2/g VSS/h) SOUR = OUR / MLVSS
R operation mode	
Rs	Dynamic exogenous uptake rate (mg/L/h)
Rsp	Specific Rs (mg O_2/g VSS/h) Rsp = Rs / MLVSS
bCOD	Biodegradable COD (mg/L)
rbCOD	Readily biodegradable COD (mg/L) – using truly soluble sample -
U	COD uptake rate (mg COD/L/h)
q	Specific U (mg COD / mg VSS/d)

Table 1. Parameters automatically measured in a BM respirometry system

Figure 1. BM-Advance Pro multipurpose respirometry system

2. Parameters used in the study

Parameter	Description
Auxiliary parameters	
$SOUR_{end}$ (mg/g/h)	Specific oxygen uptake rate of the sludge under endogenous phase
K_d (d^{-1})	Endogenous decay rate
CO (mg/L)	Consumed oxygen in the organic standard (sodium acetate)
$Y_{H.O2}$ (O_2/DQO)	Heterotrophic yield coefficient
$Y_{H.obs}$ (SSV/DQO)	Observed yield coefficient
bCOD (mg/L)	Biodegradable COD fraction
Key parameters	
AOR (kg O_2/d)	Total actual oxygen requirement
AOR_C (kg O_2/d)	Actual oxygen requirement for organic matter removal
AOR_N (kg O_2/d)	Actual oxygen requirement for nitrification
AOR_{DN} (kg O_2/d)	Actual oxygen requirement for denitrification
SOTE (%)	Estándar oxygen transfer effieciency
SOR (kg O_2/d)	Standard oxygen requirement
AOR/SOR	AOR/SOR ratio
OTE_f (%)	Oxygen transfer efficiency in process
Q_{O2ref} (kg O_2/d)	Reference oxygen flow
$Q_{aire.ref}$ (Nm^3/h)	Reference air flow
OTE_{ref} (%)	Reference oxygen transfer efficiency

Table 2. Parameters calculated from respirometry and from ASP data

3. ASP data

Type / Parameter	Description	Value (average)
Type of ASP system	Extended aeration	-
Type of diffusers	Fine bubble diffusers membrane	-
h	Diffusers depth	4.235 m
Aeration system age	Diffusers age	> 8 years
Diffusers cleaning	Last cleaning	4 months ago
T	Temperature	20 ºC
Q	Influent flow	3.145 m^3/d
SRT	Sludge retention time (Sludge age)	20 d
Q_{air}	Air flow	5.800 Nm^3/h
Q_{O2}	Oxygen flow	39.672 kg O_2/d
Q_{air}/difusor	Air flow / diffuser	3.7 Nm^3/h
DO	Dissolved oxygen in aerobic reactor	0.7 mg/L
BOD	BOD5 influent	366 mg/L
COD	COD influent	1.055 mg/L
BOD/COD	BOD5 / COD ratio	0.34
COD_{ef}	COD effluent	35 mg/L
CODe	COD removed	1020 mg/L
TKN_{in}	TKN influent	101 mg N/L
TKN_{ef}	TKN effluent	5 mg N/L
TKN_e	NTK removed	96 mg N/L
NO_3-N_e	Nitrate removed	95 mg N-NO_3/L

Table 3. Data from the ASP

4. Basic principle of the procedure

The procedure for this study is follows the basic principle of comparing the actual oxygen requirement with the flow rate of oxygen being supplied, giving way to parameters that will be evaluated against reference values.

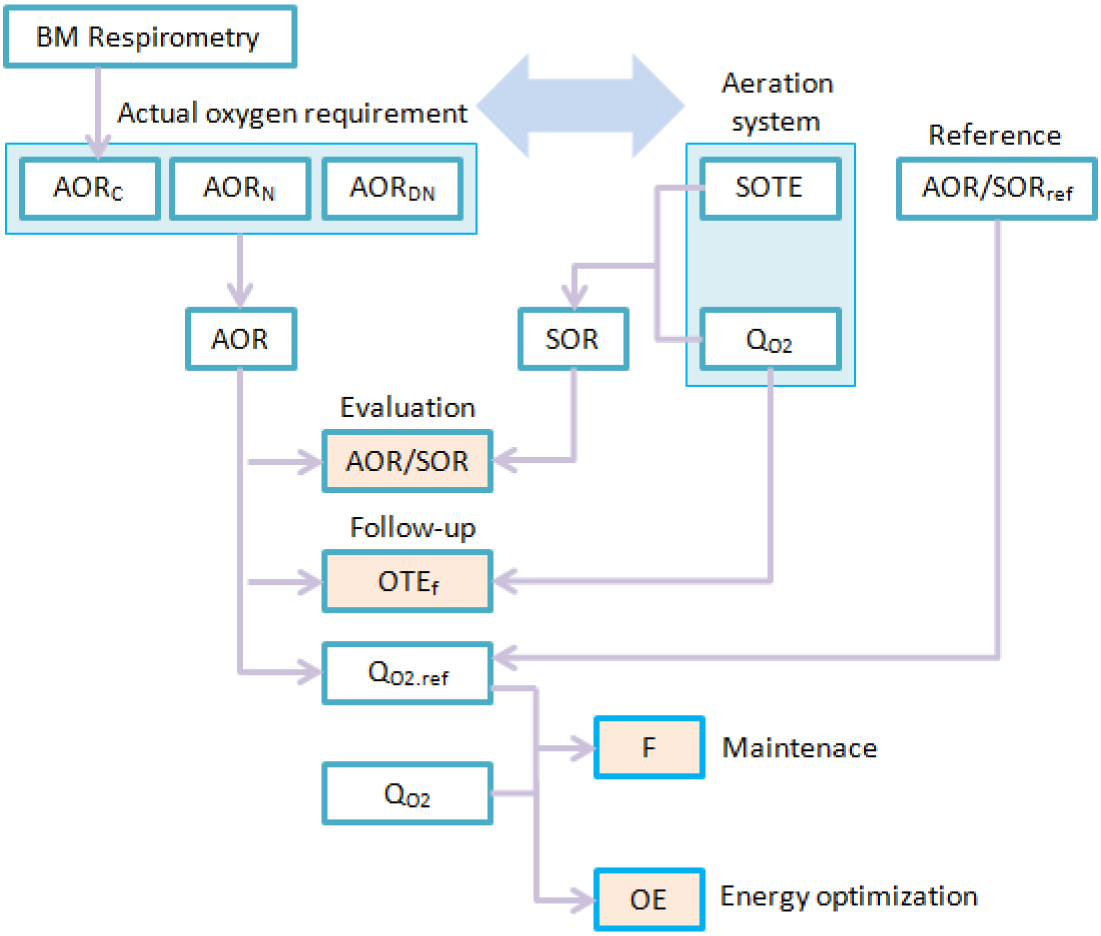


Figure 2. Diagram of the procedure

5. Aauxiliary parameters

Auxiliary parameters are to be understood as a series of basic parameters that are needed to complement the calculation of the key parameters.

The main source of these parameters is in the respirometry tests carried out for this purpose.

5.1. Specific OUR: $SOUR_{end}$

The $SOUR_{end}$ is ontained from an OUR test carried out with sludge colected from the end of the ASP (effluent sludge) and passde to endogenous phase, where there is not any presence of substrate.

By entering the value of the MLVSS concentration in the test settings board, the BM respirometer automatically calculates this parameter by dividing the OUR value by the MLVSS concentration.

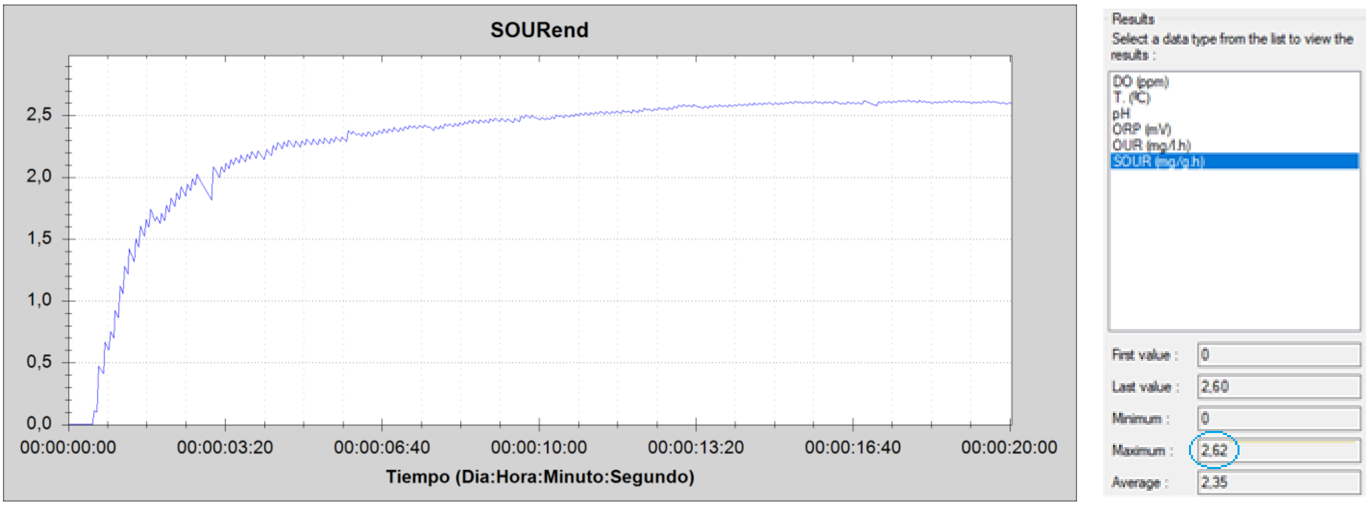


Figure 3. OUR respirogram and result

SOUR = 2.62 mg / gSSV.h = 0,06 kg / kg SSV.d

5.2. Endogenous decay coefficient: K_d

This coefficient takes into account the loss of cell mass due to the oxidation of internal energy storage products for the maintenance of the cell in the endogenous respiration phase.

K_d = SOURend / 1,42 = 0,06 / 1,42 = 0,04 (d^{-1})

5.3. Heterotrophic yield coefficient: Y_H

This coefficient represents the part of the biodegradable COD that is used in the reproduction of heterotrophic biomass.

It is calculated from the consumed oxygen (CO) value automatically obtained from a R respirometry test using a standar sample (sodium acetate) of known COD (COD_{ac} = 300 mg/L)

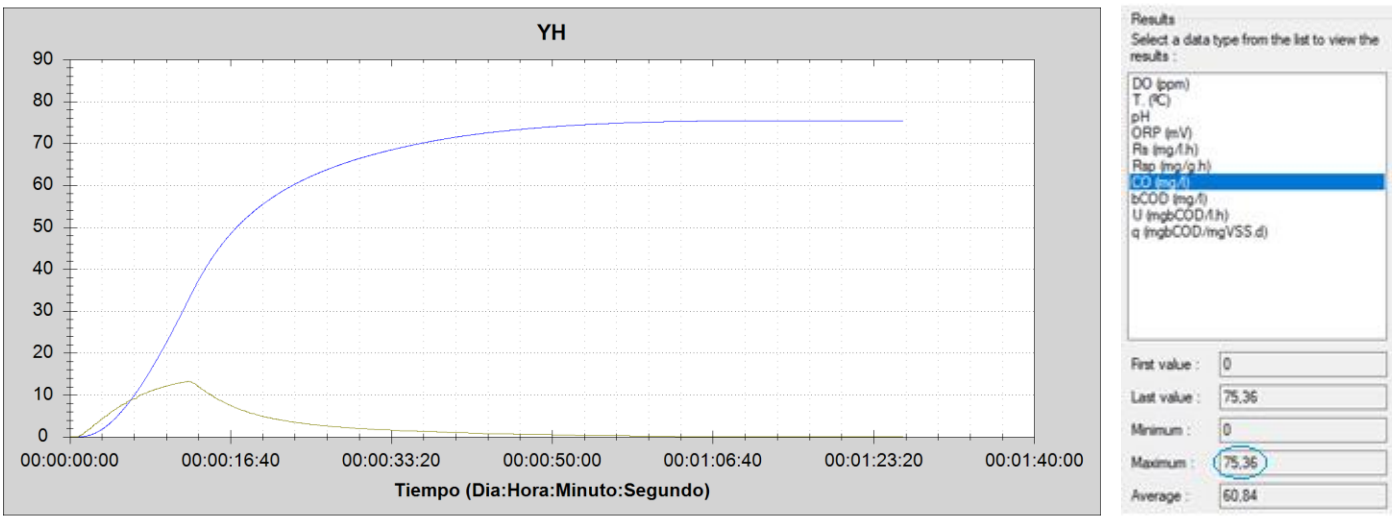


Figure 4. Rs and OC respirograms and result

$Y_{H.O2}$ = 1 – CO / COD_{ac} = 1 – 75 / 300 = 0,75 (O_2/COD)

5.4. Observed heterotrophic yield coefficient: Y_{obs}

This coefficient represents the ratio of net biomass accumulation (observed biomass yield, Yobs) to the amount of excess sludge. It is related to the K_d and sludge age (SRT), thus accounting for bacterial cell lysis (death) and predation.

$Y_{obs} = (Y_{H.O2}/1.42) / (1 + K_d * SRT) = (0.75/1.42) / (1 + 0.04 * 20) \approx 0,3$ (VSS/COD)

5.5. Biodegradable COD: bCOD

bCOD is one of the essential parameters in the calculation of the oxygen requirements of the process. From a BM respirometer test, the percentage of bCOD in the total COD will be determined. Thus, to obtain the corresponding actual bCOD in the influent, this percentage will be applied to the influent COD data provided by the plant operator.

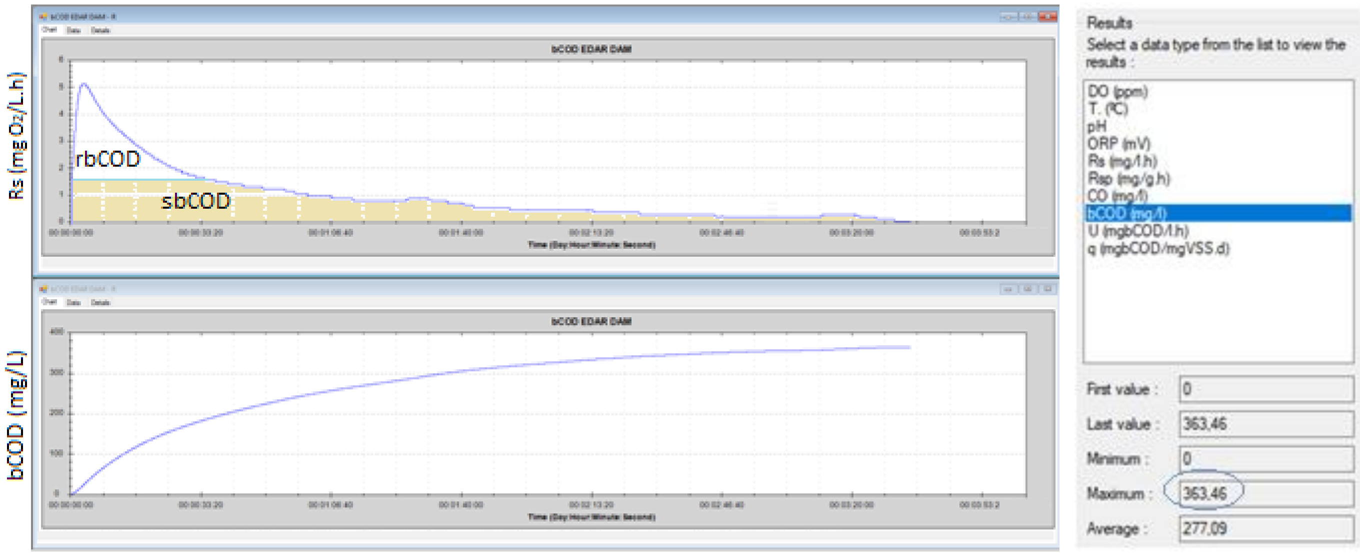


Figure 5. Rs & bCOD respirograms and bCOD result

bCOD sample = 363 mg/L

COD sample = 372 mg/L (data provided by the plant)

bCOD sample / COD sample = 363 / 372 = 0.97

influent bCOD = 0,97 * COD data = 0,97 * 1055 = 1023 mg/L

<u>Analysis of the COD fractions</u>

As It is observed in the Rs respirogram there is a significant part of slowly biodegradable COD (sbCOD) with very slow removal rate (Rs very close to the horizontal base-line).

Considering the COD removed, the bCOD value can also be considered as the bCOD removed (bCODe) in the ASP.

Important note

Since the BOD5 and COD data provided by the plant are 366 mg/L and 1055 mg/L respectively, when compared to bCOD of 1023 mg/L, it is evident that BOD5 does not detect a significant part of the bCOD.

5.6. Sludge production: P_X

This parameter represents the net biomass growth.

$P_X = Y_{obs} * Q * bCOD_e / 1000 = 0.3 * 3145 * 1023 / 1000 = 965$ kg O_2/d

6. Key parameters

6.1. Actual oxygen requirement: AOR

The actual oxygen requirement is the oxygen demand from the actual loading entering in the ASP.
The AOR involves three partial requirements:

- AOR_C: Oxygen requirement for organic matter.
- AOR_{CN} : Oxygen requirement for nitrification.
- AOR_{DN} : Oxygen requirement for denitrification.

The oxygen requirement by denitrification (AOR_{DN}), taking place under anoxic conditions, is presented as a credit to the overall oxygen requirement.

$AOR_C = Q * DQOb_e / 1000 - 1.42 * P_X = 3145 * 1023/1000 – 1.42 * 965 = 3217 – 1370 = 1847$ kg O_2/d

$AOR_N = 4{,}57 * Q * TKNe / 1000 = 4.57 * 3145 * 96 / 1000 = 1379$ kg O_2/d

Where 4.57: mg O_2 to remove 1 mg of NH_4-N

$AOR_{DN} = 2.28 * Q *. N\text{-}NO_3 / 1000 = 2.28 * 3145 * 95 / 1000 = 681$ kg O_2/d

Where 2.28: mg O_2 to remove 1 mg of NO_3-N

$AOR = AOR_C + AOR_N - AOR_N = 1847 + 1379 – 681 = 2545$ kg O_2/d

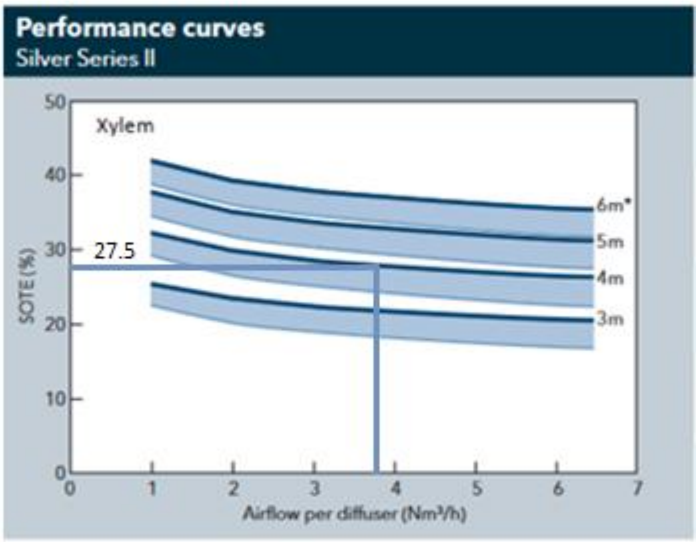
6.2. Standard oxygen transfer efficiency: SOTE

SOTE is the efficiency of oxygen transfer to the process under standard conditions (20 ºC, 1 atmosphere and 0 mg/L oxygen) at full capacity and in clean water.

The manufacturer provides a graph of the SOTE value based on the average flow rate per diffuser and diffuser depth in the biological reactor.

So, from the data of the diffusers depth (h = 4.235 m), the air flow/diffuser (Nm3/h) and the correponding curve, the value of SOTE is then determined (see Fig. 6)

SOTE = 27.5 %



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)

*Submergence

Figura 6. SOTE curves

This result of 27.5 % fits perfectly with the estimated value that can be calculated by multiplying 6.5 by the depth of the diffusers.

6.3. Standard oxygen requirement: SOR

The SOR is related to the amount of oxygen that must be transferred to meet the AOR after adjusting the biological reactor conditions. It is for this reason that it is normally used in conjunction with the AOR with the AOR/SOR ratio. With this, it is one of the parameters used to assess the oxygen sufficiency for the process and also to compare different aeration systems.

SOR = Q_{O2} * SOTE / 100 = 39672 * 27.5 / 100 = 10910 kg O_2/d

6.4. AOR/SOR ratio

The AOR/SOR ratio can be used as a primary evaluation parameter.
In fact, many manufacturers propose this ratio for calculating oxygen flow rate on design pruposes.
This ratio does nothing more than adhere to the basic principle of relating the average oxygen requirement to the oxygen flow rate being supplied. For this reason, the AOR/SOR can be taken as a first assessment parameter to start the procedure for the evaluation and follow up of the aeration system.

The AOR/SOR ratio usually has a normal range between 0.3 and 0.5.

For fine bubble aeration systems, the usual reference value of AOR/SOR is 0.33 (CED Engineering, Harlan H. Bengtson - 2017, Sanitaire, University of Idaho, Environmental Engineering, CVE - 2021, others).
This value of 0.33 will be taken as the basis for the calculation of other benchmarks.

AOR/SOR = 2545 / 10910 = 0,23

6.5. Reference oxygen flow: $Q_{O2.ref}$

The reference flow rate (QO2.ref) corresponds to the estimated flow rate that would be needed, for the same AOR requirement, after an effective maintenance of the diffusers (cleaning or replacement)

$Q_{O2.ref}$ = AOR / (0.33 * SOTE) = 2545 / (0.33 * 27.5/100) = 28044 kg O_2/d

6.6. Oxygen transfer efficiency : OTE_f

The oxygen transfer efficiency of the overall system drives the amount of air that is needed to meet the oxygen demand, so that lower efficiencies mean that more air (and more energy) is required to meet the oxygen requirements of the system.

The OTE of the process is one of the most important parameters in aeration systems. The higher the OTE_f, the less air must be supplied to a reactor to ensure the amount needed in the process.

Determination of OTE_f allows plants to evaluate the long-term operating costs of their aeration systems and to confirm that sufficient capacity is available to meet the oxygen requirement of the process input load. As such, it is a parameter that can be considered critical for monitoring the aeration system.

With the current performance and process conditions, the dynamic way to calculate the OTE_f is by the ratio between the oxygen requirement (AOR) of the inlet load and the current flow rate of oxygen (Q_{O2}) being supplied (Ferrell, P.E., BCEE, CEM, LEED Green Assoc.- 2010; Viktor Larsson - 2011, among others).

OTE_f = 100 * AOR / Q_{O2} = 100 * 2545 / 39672 = 6.41 %

6.7. Reference oxygen transfer efficiency: $OTE_{f.ref}$

$OTE_{f.ref}$ = 100 * AOR / $Q_{O2.ref}$ = 100 * 2545 / 28044 = 9.1 %

6.8. Estimated fouling factor: F

Factor F assesses the current condition of the diffusers in terms of fouling or/and aging.

The estimated F factor can be calculated from the ratio of the current OTE to the reference OTE.

F = OTE / OTE_{ref} = 6.41 / 9.1 ≈ 0.7

The usual normal range of F-factor is between 0.7 and 0.9.

The F-factor in fine pore diffusers decreases with time due to aging, fouling, inorganic fouling or changes as a result of wastewater quality, sludge characteristics and operating conditions.

When the F-value is below 0.7, it indicates that there is reduced oxygen transfer, which may be due to fouling and/or aging of the diffuser membranes and, therefore, a re-cleaning or membranes replacement may be considered. In any case, it is recommended that the F-factor should be counted in conjunction with other system assessment data.

6.9. Estimated energy optimization: EO (%)

EO represents the estimated energy optimization that an effective maintenance of a fine bubble aeration system by cleaning or membrane replacement (in case the diffusers are old enough to be replaced) can bring about.

OE = 100 * (Q_{O2} – $Q_{O2.ref}$) / Q_{O2} = (39672 – 28044) / 39672 = 29 %

7. Summary of results

Parameter	Value	Comment / Assessment
AOR	2.545 kg O_2/d	-
SOR	10.910 kg O_2/d	-
AOR/SOR	0,23	Below the normal reference value (0.33) = Aeration deficiency
SOTE	27,5 %	-
$Q_{O2.ref}$	28.044 kg O_2/d	Well below the current flow rate (39672 kg O_2/d)
OTE_f	6,3 %	Below the reference value (9.1 %) = Low aeration performance
$OTE_{f.ref}$	9.1 %	-
F	0,7	At the lower limit of the normal range
OE	29 %	Significant optimization

Table 4. Summary of results

8. Conclusions

1. From the BOD/COD ratio (0.34) provided by the plant and bCOD result, it can be deduced that BOD is not able to detect a significant percentage of the bCOD which, in all likelihood, is about the sbCOD. Therefore, an estimated calculation of the AOR from the BOD (instead of bCOD) could lead to a value significantly lower than the real one.

2. The AOR/SOR ratio together with the OTE_f, being well below their reference values, gives a primary assessment of clear deficiency and poor performance of the aeration system.

3. The F-factor of 0,7, even if in the low normal range, when computed together with AOR/SOR and OTEf values, must be assessed as critical. Therefore, taking into account that the diffusers have more than 8 years of operation, it can be deduced that they are responsible for the deficiency of oxygen transfer.

4. Although the cleaning of diffusers was done approximately four months ago, the aeration is still demonstrating a well low performance and the change of membranes can be an important energy optimization (OE ≈ 29%) for the same AOR.

SURCIS

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