FS-BIO-001

TECHNOLOGY FACT SHEETS
FOR EFFLUENT TREATMENT PLANTS
ON TEXTILE INDUSTRY

ACTIVATED SLUDGE

SERIES: SECONDARY TREATMENTS

TITLE	**ACTIVATED SLUDGE (FS-BIO-001)**
Last update	September 2014
Last review	

UNIVERSIDADE DA CORUÑA

INDITEX

ACTIVATED SLUDGE (FS-BIO-001)

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Last update	Date	Done by:	Update main topics

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1.- DESCRIPTION

Secondary treatment of wastewater requires the implementation of a biological reactor and, as a rule, the corresponding secondary clarifier. In the bioreactor controlled growth of a biomass or biocenosis is promoted, being primarily composed by bacterial culture with the aim of biodegradation or oxidation of contaminants. The final solid - liquid separation is conducted in the secondary clarifier, obtaining the secondary effluent, which will be discharged to the receiving environment.

In the reactors, biocenosis can develop in two ways: 1) as suspended biomass within the liquid (for example activated sludge process in its various forms), or 2) as biomass attached to a carrier or a reactor filler (the so-called biofilm process, for example, biological filters, bio-discs, underwater beds, etc.).

Reactors, or biological processes, employing aerobic biomass in suspension, have traditionally been known as activated sludge processes. These have been categorized, according to the mass loading design in three groups: low load activated sludge (extended aeration, oxidation ditches, etc.), medium load (or conventional) and high loading.

The aim of this document is to standardize the design of secondary treatment based on activated sludge process. The standard design includes the biological reactor and secondary clarifier.

All activated sludge process is a system comprising tank bioreactor with aeration equipment and secondary settling tank. Both tanks connected through the sludge return (Figure 1).

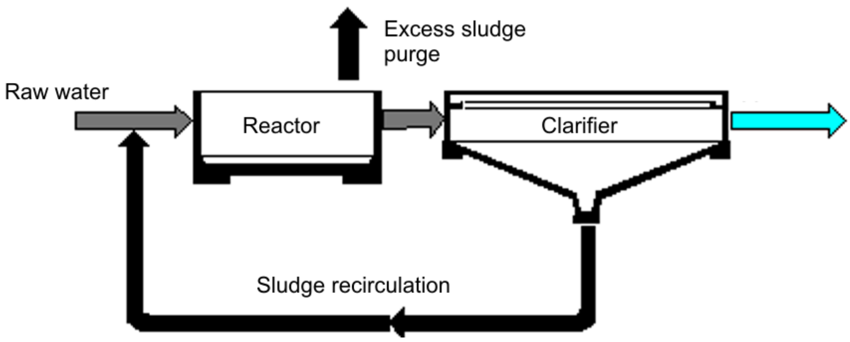


Figure 1.- Outlines the basic elements of an activated sludge process.

2.- DESIGN

2.1.- Basic parameters of the biological reactor

- **Food to microorganism (F/M) ratio:** is the organic matter mass (as kg of BOD_5) fed for 1 day in the reactor per kg of biomass present:

$$F/M = \frac{F_{av} \cdot L_0}{V \cdot X} \qquad Ec.\ 1$$

Where:

F_{av} = average daily inflow (m^3/d)
L_0 = average daily concentration BOD_5 influent to reactor (kg/m^3)
X = concentration of suspended solids in the mixed liquor (kg $MLSS/m^3$)
F/M = food to microorganism ratio (kg BOD_5/kg MLSS/d) or (d^{-1})

- **Organic load:** kg of organic matter (as BOD_5) fed for 1 day per reactor per cubic meter of reactor:

$$CV = \frac{F_{av} \cdot L_0}{V} \qquad Ec.\ 2$$

Where:

CV = organic load (kg BOD_5/m^3 reactor/d)

- **Cellular retention time (or sludge age):** corresponds to the residence time of the biomass in the reactor. It is expressed in days, being the parameter that selects the type of bacterial culture to develop:

$$CRT = \frac{V\ X}{P_{sl}} \qquad Ec.\ 3$$

Where:

CRT = cellular retention time (days)

P_{sl} = excess sludge production (kg/d)

- **Hydraulic retention time:**

$$HRT = \frac{V}{F_{av}} \qquad Ec.\ 4$$

Where:

HRT = hydraulic retention time (hours)

2.2.- Other key variables that affect the operation of the biological reactor

- **Oxygen requirements:** oxygen depends on organic matter consumption, endogenous respiration demand and total nitrification of TKN oxidation.

- **Sludge production:** due to cell growth (positive term in the balance sheet), the decay of a fraction of biomass (negative term in the balance sheet) and non-biological solids accumulation by factors such as adsorption, entrapment, etc.

  In any case, the specific sludge production, $\mathbf{P_f^a}$, will not be less than 0.8 kg SS / kg BOD_5 eliminated.

- **Sludge recirculation rate:** is the ratio between the sludge recirculation volumetric flow, Q_R, and treatment volumetric inflow:

$$\frac{F_R}{F} = R = \frac{X}{X_R - X} \qquad Ec.\ 5$$

  In any case, the capacity of the sludge recirculation system will not be less than 200% of the daily average total inflow**.**

  Another design criterion is established: X_R concentration is 6000 mg SS / L (= 6 kg/m^3).

2.3.- General bioreactor design criteria

Table 1.- Design values for activated sludge reactor.

Parameter	Low F/M	Moderate F/M	High F/M
F/M (kg BOD_5/kg MLSS/d)	0.070	0.15 for a 92% reduction in BOD_5 0.50 for a 88% reduction in BOD_5	> 0.50 and ≤ 1.0 (70% removal)
X (mg/L)	≤ 3.000	≤ 3.000	≤ 3.000
X_R (mg/L)	≤ 6.000	≤ 6.000	≤ 8.000

2.4.- Reactor volume

The reactor volume, *V*, is obtained from the F/M ratio design. Solving Eq. 1:

$$V = \frac{F_{av} \cdot L_0}{F/M \cdot X}$$

2.5.- Removal efficiency

The performance of an activated sludge process is obtained by (Eckenfelder, 1980):

$$L_f = \frac{L_0}{1+\frac{K}{CM}} + f_{CM} \cdot SS_{ef} \qquad \text{Ec. 6}$$

Where:

L_f = Clarified effluent BOD_5 (discharge limit)
K = kinetic coefficient at the design temperature ($days^{-1}$)
f_{CM} = BOD fraction provided by the SS in the clarified effluent (depending on the F/M ratio)
SS_{ef} = SS concentration in clarified effluent

In textile industry wastewater with dyes, the kinetic coefficient *K* will vary between 2-6 d^{-1} at a temperature range of 10-22 °C (Eckenfelder and Grau, 1992). As for f_{CM} be obtained from the following table:

Table 2.- f_{CM} values depending on the F/M ratio.

f_{CM}	*F/M ratio* (d^{-1})
0.8 $F/M^{1/2}$	≤ 0.5
= 0.58	> 0.5

3.- SECONDARY CLARIFICATION

The optimal secondary clarifiers design is essential for the proper operation and performance of the biological process. If the solids are not retained by the settler: 1) contribute to the BOD arise in the effluent, and 2) modify the sludge age in the biological reactor. The secondary clarifier, while clarifying water should achieve some sludge thickening in order to optimize recirculation.

A secondary clarifier is primarily divided into two zones: one at the top, which is often called clarified water area, and one in the deep end, called thickening or sludge concentration zone.

3.1.- Design variables

- **Surface hydraulic loading rate:** is based on the real flow rate circulating through the unit (outflow). Thus, the sludge recirculation flow rate, which also enters the clarification unit, is not taken into account because it is removed by the bottom of the settler, and thus does not influence the surface hydraulic loading rate.

$$HLR = \frac{F}{A_{HLR}} \qquad \text{Ec. 7}$$

Where:

HLR = surface hydraulic loading rate (m/h)
Q = outflow (m^3/h)
A_{HLR} = horizontal clarification surface (m^2)

- **Solids loading rate:** defines required surface for suitable sludge thickening in the bottom of the unit (compression zone).

$$SLR = \frac{(F + Fr)\ X}{A_{SLR}} \qquad Ec.8$$

Where:

SLR = solids loading rate (kg $SS/m^2/h$)
F = outflow (m^3/h)
Fr = sludge recirculation flow rate (m^3/h)
X = MLSS concentration in the bioreactor (kg/m^3)
A_{SLR} = horizontal surface for compressing sludge (m^2)

- **Hydraulic retention time**:

$$HRT = \frac{V}{F} = \frac{A \cdot H}{F} \quad \text{Ec. 9}$$

Where:
HRT = hydraulic retention time (hours)
H = water depth side-wall (m)
V = useful volume for clarification (m^3)
A = horizontal surface of clarifier (m^2) (if $A_{HLR} > A_{SLR}$; A_{HLR}; else A_{SLR})

- **Weir overflow rate:** corresponds to the effluent flow rate per linear meter of weir outlet.

$$WOR = \frac{F}{W_L} \quad Ec. 10$$

Where:
WOR = Weir overflow rate (m^3/h/m)
W_L = weir length (m)

3.2.- General design criteria

Table 3.- Design values for activated sludge secondary clarifier.

Parameter	Low F/M ratio	Moderate and High F/M ratio
HLR (m/h)	Q_{ave} ≤ 0.4 $Q_{máx}$ ≤ 0.8	Q_{ave} ≤ 0.5 $Q_{máx}$ ≤ 1.0
SLR (kg SS/m^2/h)	Q_{ave} ≤ 3.0 $Q_{máx}$ ≤ 6.0	Q_{ave} ≤ 3.0 $Q_{máx}$ ≤ 6.0
WOR (m^3/h/m)	$Q_{máx}$ ≤ 10	$Q_{máx}$ ≤ 10
Xr (mg/L)	6.000	6.000
H (m)	≥ 3.50 m (see section 3.2.1 below)	≥ 3.50 m (see section 3.2.1 below)

In any case, it will be checked for the maximum flow where HRT will not be less than 3 hours.

3.2.1.- Geometrical characteristics

To define the geometric features it should differentiate between settlers "with" and "without" bottom scrapers.

Clarifiers with scrapers

The secondary clarifiers with bottom scrapers may be circular or rectangular. Table 4 shows the water height versus diameter for circular clarifiers.

Table 4.- Diameter of a secondary clarifier according to the water depth side-wall.

Diameter (m)	Water depth side-wall (m)
< 12	3.50
12 to 21	4.00
21 to 30	> 4.00

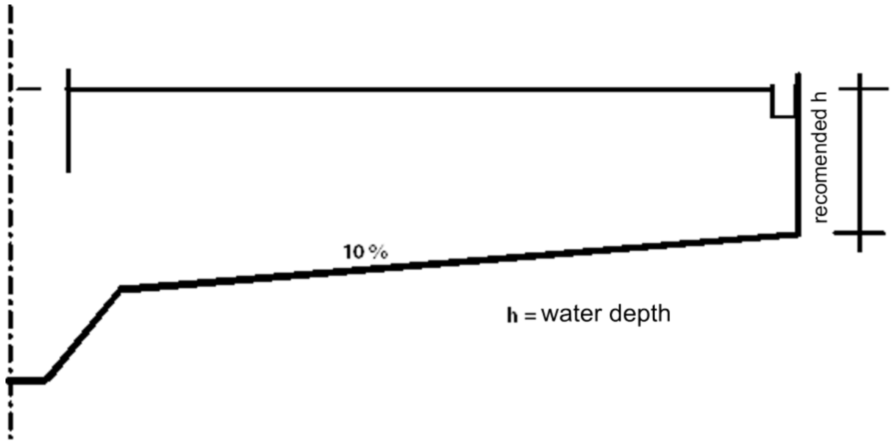


Figure 2.- Secondary clarifier with scraper scheme.

In rectangular clarifiers a length/width ration greater than 3 but less than 6 is usually observed.

The bottom slope so as to facilitate the sludge carryover to the sludge sump will be:

- o Circular: **10%**
- o Rectangular: **1%**

The residence time of the sludge in the sump should be less than 3 hours.

In circular clarifiers the diameter of the central baffle is 1/5 to 1/6 of the diameter of the unit itself. The height will be 1/3 of the maximum depth.

Clarifiers without scrapers (truncated cone)

Clarifiers with truncated cone shape, also called vertical flow clarifiers. For technical and constructive reasons, the diameter will not be greater than 5 m.

The slope of the conical wall area responds to an angle greater than or equal to 60 ° (see figure below).

For these vertical flow clarifiers, the effective horizontal surface is set at the midpoint of the height between the the unit water entry (that is, out of the central baffle) and the elevation of the free water level (see figure below).

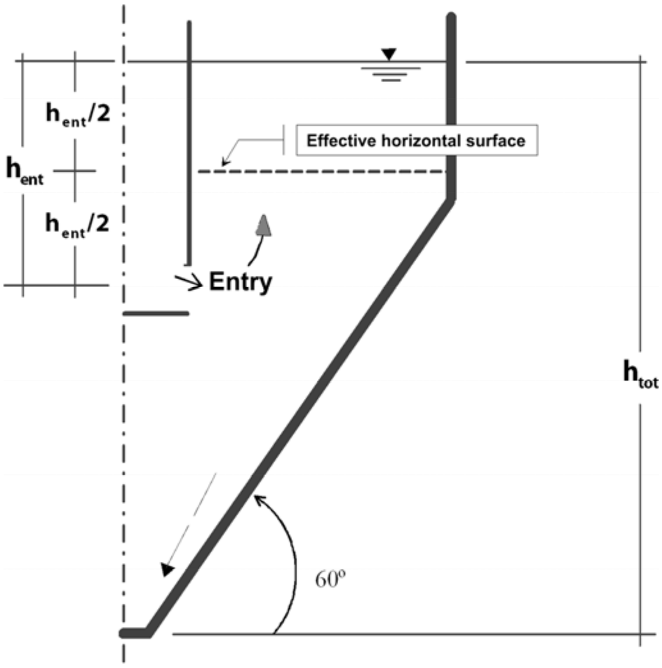


Figure 3.- Schematic of a vertical flow secondary clarifier.

4.- EXAMPLES OF REQUIRED SURFACE

4.1.- Area required for activated sludge bioreactor low F/M

The table 5 shows the surface demand for a low F/M activated sludge biological reactor in different textile mill sizes expressed in terms of the average treatment flow. It has been considered to have placed a flow and concentration homogenization tank prior to secondary treatment.

The general hypotheses are:

- BOD_5 concentration homogenized = 300 mg/L
- MLSS concentration = 3.000 mg/L

The main design criterion is that F/M ratio shall not exceed 0.070 kg BOD_5/kg MLSS/d.

The required area depends on the height of water adopted for the mixed liquor in the reactor. Since the aeration system determines the optimum depth, for this exercise we adopt the following water levels:

- Aeration turbine = 3 m
- Aeration diffusers = 5 m

Thus, the following results were obtained:

Table 5.-Required area for low F/M active sludge reactor depending on the volumetric inflow to be treated.

		water depth (m)	
		3	5
Q	Volume	Area	Area
(m^3/d)	(m^3)	(m^2)	(m^2)
20	28.6	10	6
200	285.7	95	57
1000	1428.6	476	286
2000	2857.1	952	571

4.2.- Required area for secondary clarification

To estimate the necessary settling area, the following design criteria are applied:

HLR at F_{av} = 0.4 m/h
SLR at F_{av} = 3.0 kg SS/m^2/h
Water depth = 4.00 m
Xr = 6.000 mg/L
R = 1

The results are presented in the following table:

Table 6.- Required area for secondary clarification of low F/M activated sludge process ratio as a function of the inflow to be treated.

F	Area
(m^3/d)	(m^2)
20	2.1
200	21
1000	104
2000	208

Finally, the minimum necessary area for the "secondary treatment" is obtained by adding the reactor surface and the surface of the clarifier. The results are presented in the following table:

Table 7.- Estimating total space requirements for secondary treatment (reactor + clarifier).

	Reactor water depth (m)	
	3	**5**
F	**Total area**	**Total area**
(m^3/d)	**(m^2)**	**(m^2)**
20	12	8
200	116	78
1000	580	390
2000	1161	780

5.- PROCESS OPERATION TROUBLESHOOTING

5.1 Changes in the inflow and the characteristics of the wastewater

A common problem is the increased inflow resulting in a shorter aeration of the activated sludge or in a loss of the final clarification due to hydraulic overload. To address this problem, we can regulate the flow recirculation and sludge disposal, maintaining the optimum amount of solids in the aeration tank. Changes in the characteristics of the raw wastewaters may be caused by isolated or seasonal discharges.

5.2.- Changes in temperature

Temperature influences the performance of the activated sludge system. The effects are significant when the temperature change is greater than 6 ° C.

5.3.- Changes in the sampling program

Data on system performance can be greatly affected by changes in the sampling program. When the results vary widely from day to day, the following aspects should be checked: sampling locations, sampling hour and laboratory procedures.

5.4. - Sludge bulking

The bulking is the term applied to the situation where the mixed liquor solids tend to show a very slow sedimentation and they are compacted only to a certain degree. Normally, the interstitial fluid going through the solids is crystalline, with high quality, but the settling time is not sufficient for a complete removal of solids in the secondary clarifier. To prevent sludge bulking, it is necessary to carefully control the following issues:

a) Suitable CRT or sludge age: bulking effect can usually be corrected by decreasing the sludge age.
b) Dissolved oxygen level: it prevents that low dissolved oxygen levels occur.

5.5.- Insufficient aeration capacity

If the secondary effluent is turbid, with a yellowish color, it is a symptom of poor aeration. Aeration time has to be increased. If you cannot increase the concentration of dissolved oxygen, this may be due to three reasons:

a) There is an aeration system malfunction, so it is necessary to find and fix the fault.
b) The aeration system is undersized. In such case, making an improvement in the treatment plant is required.
c) The habit of keeping an excessive amount of sludge in the reactor has been acquired. In that case, it can be corrected by reducing the sludge return, or increasing the wasted sludge.

A quick and easy way to check if the wastewater is treated well is to fill a clear container (Imhoff cone or cylinder) with secondary clarifier effluent and observe their appearance (figure below).

Figure 4.- Yellowish secondary clarified effluent.

5.6.- Filamentous growth

The occurrence of filamentous growth may be caused by an unsuitable age of the sludge, or by an imbalance of nutrients, such as lack or abundance of nitrogen, phosphorus or carbon. If allowed to stabilize, filamentous growth will pose a difficult problem to solve. It can be controlled by maintaining an appropriate sludge age and in special cases, supplying the lack of nutrients.

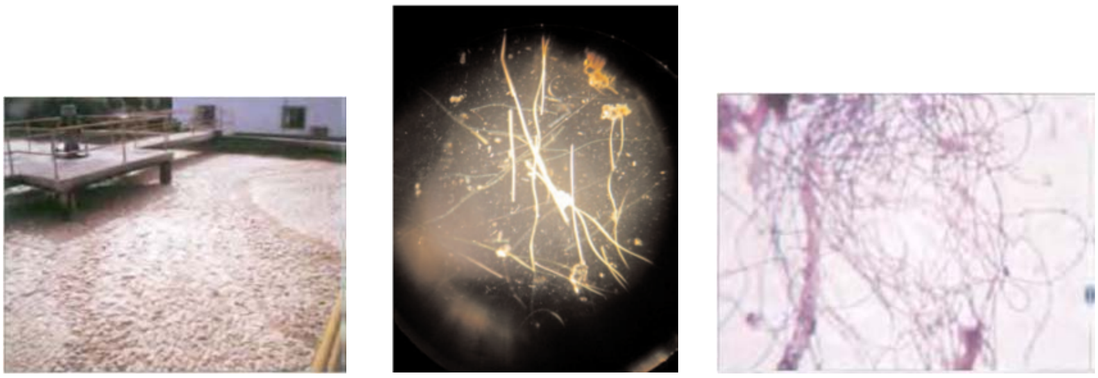


Figure 5.- Filamentous growth (left). Center and right: examples of filamentous growth observed at microscopy.

5.7.- Septic sludge

Any type of sludge can become septic if left too long in places like channels or wells. Septic sludge rises slowly and is likely to cause foul odors. Furthermore, it can disrupt the aeration tank, even in small quantities. In the secondary clarifier, the sludge can become septic due to four causes:

a) Sludge recirculation is too slow: the solids are maintained too much time in the final clarifier, allowing them to become septic.
b) Scrapers clarifier mechanism is stopped, so that the sludge is not transferred to the sludge pit.
c) Drain pipes for wasted sludge are clogged.
d) The sludge recirculation pump is stopped, or the valve is closed.

5.8.- Toxic compounds

Toxicity causes inhibition or death of the active microorganisms, causing disturbances in the system and in the effluent. The operator has little control over its causes.

We must immediately stop the sludge disposal, and all available solids must be returned to the aeration tank. The toxic compounds such as heavy metals, acids, insecticides and pesticides should never be discharged into the sewer system without proper control.

5.9.- Flotation sludge due to gasification

Do not confuse the rise of the sludge by gasification with bulking. In gasification, sludge settles satisfactorily, but once sedimented, it arises to the surface in the form of spots or pea-sized small particles. Generally, it is accompanied by a fine brown foam, which appears on the surface of the aeration tank and secondary clarifier.

If you have sludge on the surface of the settler and the origin is not known, there is a simple way to check whether it is gasification or not. When V30 determination is being made, do not throw the tested sample and leave it during a few hours. If, after some time, part of the mud rises and bubbles appear, then it can be ensured that there is a problem of gasification. This problem can be resolved by increasing the sludge recirculation flow (to remove the solids from the settler quickly) and reducing aeration.

Figure 6.- Floated sludge after several hours of testing V30.

5.10.- Foam formation

In some treatment plants foaming in the aeration tank has been a problem. Several theories have been proposed to explain this phenomenon, such as the presence of detergents, polysaccharides and excessive aeration. But it is normal that white foams occur in a reactor start up due to the non-degradation of detergents. Furtherly, when biomass will be generated in the reactor these foams will disappear.

To control foams:

a) A higher concentration of suspended solids in the mixed liquor must be maintained.
b) During periods of low inflow, air supply should be reduced, in order to maintain the level of dissolved oxygen.

Most installations are equipped to spray water along the aeration tank to remove foams.

Figure 7. - Biological reactor with foams. Left: during startup. Right: after a period of stable performance.

6.- CONTROL PARAMETERS AND STRATEGIES

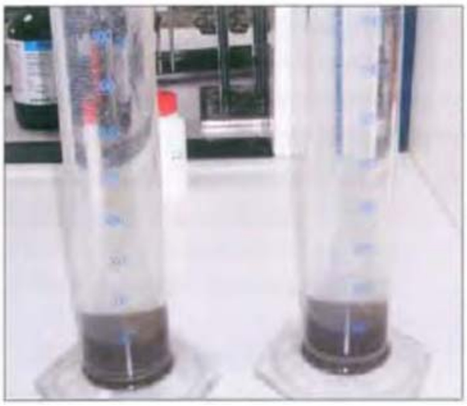
6.1.- Control of microorganisms levels

The efficiency of an activated sludge process depends on the amount of microorganisms (MLSS) existing in the system and its conditions. The V30 is a parameter that indicates whether the biological process operates properly. The recommended determination frequency is every 2 days and for its realization; a 1L Imhoff cone or cylinder and a glass rod are needed.

V30 determination steps:

1. Take a sample of aerated tank mixed liquor while aeration is operating.
2. Pour the mixed liquor in the Imhoff cone, shake slowly with the rod and leave the sludge to settle for 30 minutes.
3. After this time, read V30 level in milliliters of settled sludge per sample liter (mL/L).
4. It is advisable not to empty the cone until the next day to check if the mud rises. If so, this indicates that there is excessive aeration.

(a)



(b)

(c)

(d)

Figure 8. (a) Float mud. (b) Small value of V30. (c) The correct value of V30 (left) and high (right.). (d) High V30.

Interpretation of results:

V30 < 250: means there is little sludge in the reactor. Therefore, sludge purge should be lowered.

V30 between 250 and 650: indicates that the operation is correct.

V30 > 650: means that there is a lot of sludge in the reactor or the sludge does not settle properly. In this case, the sludge purge should be increased.

6.2.- Aeration control

A certain level of dissolved oxygen (DO) should be maintained in the aeration tank. When MLSS concentration and activity increase more airflow is required.

To measure DO concentration a luminescent probe type is used. DO ranges between 0.5 and 2 mg/L are acceptable.

6.3.- Daily checks in the reactor and in the settler

The tasks to control and perform are:

- The appearance of the compartments of aeration and final settling.
- Proper operation and lubrication of the aeration unit.
- Correct operation of the sludge recirculation pipeline system.
- Hosing the walls of the aeration tank and the final compartment.
- Brushing weirs.
- Remove grease and other floating materials such as rubber and plastic pieces.

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ANNEX 1

GRAPHIC DESCRIPTION OF UNIT PROCESSES

Figure 1
Activated sludge reactor in the textile industry.

Figure 2
Activated sludge reactor. Industrial ETP at Bergondo (Spain).

Figure 3
Activated sludge reactor. Industrial ETP at Bergondo (Spain).

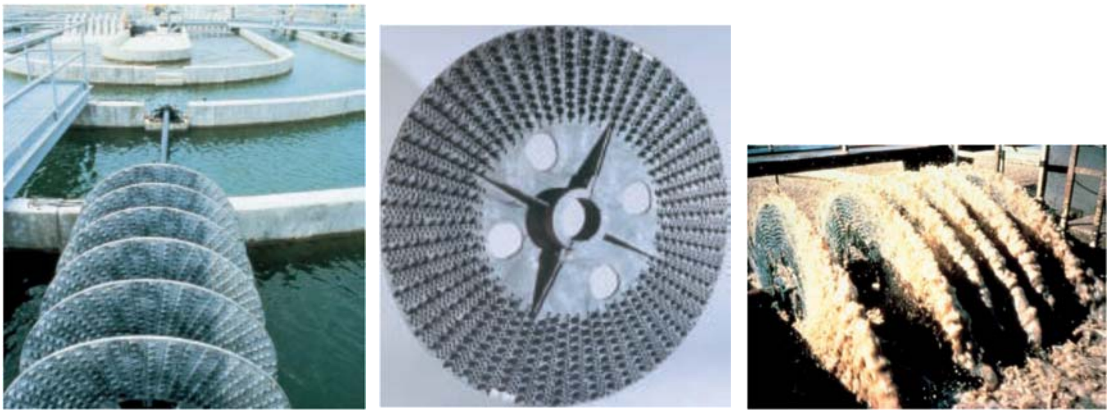

Figure 4
The Orbal process aeration disc. The discs are manufactured of a moulded thermoplastic compounds immune to the effects of wastewater. The discs are 135 cm in diameter (Reproduced from Siemens brochure, 2006).

Figure 5
Activated sludge reactor (oxidation ditch technology). Municipal WWTP at Canduas (Spain) .

Figure 6
Aeration through fine bubble diffusers. Activated sludge reactor (oxidation ditch technology). Municipal WWTP at Sada (Spain).

Figure 7
Removable fine bubble diffusers. Activated sludge reactor (oxidation ditch technology). Municipal WWTP at Carral (Spain).