BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 68 (72), Numărul 2, 2022
Secţia
CONSTRUCŢII. ARHITECTURĂ
DOI: 10.2478/bipca-2022-0015

MONITORING OF WASTEWATER PARAMETERS IN TREATMENT PLANTS: CASE STUDY – WWTP OF IASI CITY

BY

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Received: April 4, 2022
Accepted for publication: April 29, 2022

Abstract. This article briefly presents how to monitor a technological process in a municipal WWTP, in order to better understand the treatment processes. Monitoring the parameters of wastewater in a treatment plant, involves monitoring the quality of wastewater through measuring and control equipment, sampling wastewater as accurately and as many points as possible, the ideal case being after each technological object or treatment step and analysis of wastewater samples as accurately as possible, also the ideal case being compliance with well-defined methodologies. Following the monitoring of wastewater parameters, data and study results are obtained that can be used to evaluate the technological process, make graphs and tables or to optimize technological processes. The research methodology consists in the presentation of the way of monitoring the wastewater parameters with the measuring and control equipment, the presentation of the sampling method and the analysis method, after which the obtained data will be presented graphically and tabularly.

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Keywords: Wastewater parameters, pollutants, WWTP, technological process, sampling.

1. Introduction

For the environment sector, the energy sector or any other engineering field, the monitoring of the technological processes specific to each specialized domain is necessary and indispensable in the current conditions both at national and global level.

The advantages that such activity can bring can be human in nature, by creating an optimal number of jobs, and optimizing all energy and economic factors, by operating in optimal conditions the process equipment so that the energy consumption and the efficiency of these equipments do not increase the production costs.

In the water field, the concern of researchers for the improvement of technological processes has been and continues to be constant, their aim being the increase of efficiency and an improvement of water quality.

In 1977, Bayer proposed a nonlinear method of identifying an optimal treatment solution. Afterwards (Pingry & Shaftel, 1979) proposed a heuristic model for optimizing the wastewater management. (Cocklin, 1989) demonstrated the need to understand optimization models (de Melo and Câmara, 1993), the research continuing today with the evolution of this field.

The monitoring of WWTPs under operational conditions aims to accumulate enough information in order to choose the best decision (data acquisition), to improve operation or finding the optimal operational area, improving operating costs and, last but not least, providing a sound environmental protection.

In many ways, the data acquisition may be the same for several technological purposes, but normally the data for operational decisions exceed the number of allowed values and often less accurate data may be sufficient for optimal decisions (Kroiss and Svardal, 1999).

The numerous combinations of processes that take place in WWTPs, applied to different wastewater types and the requirements of ever-increasing efficiency, make it necessary to focus on the most common wastewater treatment processes.

Mechanical treatment processes consist of removing floating solids by means of screens, the removal of grease and sand together or separately and the removal of solid suspensions by sedimentation (Rojanschi & Ognean, 1989).

Biological treatment processes, whether we are talking about the removal of carbon, nutrients or refractory substances consist in neutralizing pollutants through microorganisms cultures (Robescu, 2015), which is a process depending on the environmental and working conditions that can be of several types.

A process monitoring can only be considered a success if the data collected as a result of the activity is correct, because wrong data is leading to wrong decisions, wrong results, low yields and high operating costs.

The research in this article is carried out in the Iași City WWTP, and due to the sheer size of the facility, but also due to the processes complexity, the research was focused only on the plant's wastewater process line.

2. Research Methodology

2.1. SCADA monitoring

The SCADA system in the Iași WWTP is composed of 15 operational blocks, which in turn each contain one or more operational sub-blocks.

Each object of the plant is transposed into the SCADA system, and all installations, technological equipment and measuring and control equipment are also transposed into SCADA.

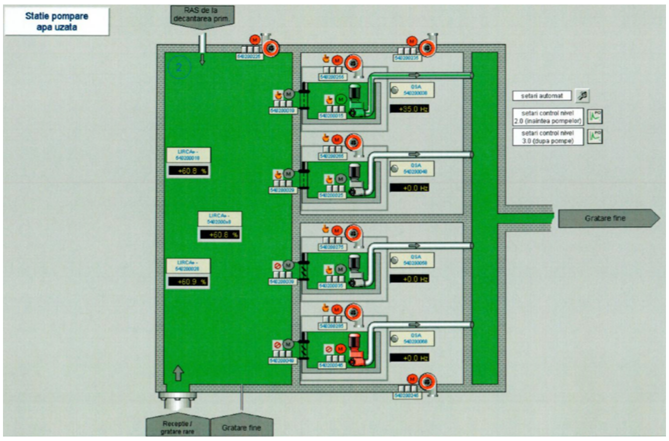

Fig. 1 – SCADA monitoring - wastewater pumping station.

All equipment signals, which contain information about the operation of the plant and processes inside can be viewed in the form of graphs.

Process keys, PIDs or hydromechanical equipment can all be operated via the SCADA software interface.

2.2. Sampling

Wastewater sampling is done manually or automatically, depending on requirements and needs.

When sampling is manual, all factors that may influence the results obtained after analyzing the water samples are taken into account. Thus, the sampling containers are well rinsed before the samples are collected. And an attempt is also made to collect the samples without agitation.

Fig. 2 – Automatic sampler.

In the case of automatic samplers all factors that can hinder the tests results are eliminated.

2.3. Samples testing

The testing of wastewater samples is performed according to well-defined test methods and in accordance with all legal requirements.

Used test methods are all compliant to a corresponding standard: for phosphorus (P) standard SR EN ISO 6878:2005 applies; for COD, standard SR SR 6060:1996 applies; for NH_4, standard SR ISO 7150-1:2001 applies; for TSS determination it's the standard SR EN 872:2005 that is applied; for pH, it's the standard SR EN ISO 10523:2012 is applied; and for dry filterable residue at 105°C it's the standard STAS 9187-84.

This study does not include all test methods and all the process parameters analyzed in the technological process within the Iași WWTP.

2.4. Process data analytical procedure

The process data analysis means the computing of the hydraulic retention time (HRT), by means of the following formula:

$$HRT = \frac{V}{Q} \tag{1}$$

where: V is the volume expressed in m^3, Q is the wastewater inflow, in m^3/day, and the result is to be expressed in minutes.

The equation of the surface overflow rate is:

$$SOR = \frac{Q}{A} \tag{2}$$

where: Q is the wastewater inflow, in m^3/day, A is the area, in m^2, and the result is expressed in m^3/m^2.day.

The weir loading rate (WLR) is calculated with the next formula:

$$WLR=\frac{Q}{L} \tag{3}$$

where: Q is already described above, with the same measurement unit, L is the weir's length and the result is expressed in m^3/m.day.

The settling velocity (sv) is given by the ratio between the clarifier's nominal height and the hydraulic retention time, the result being expressed in m/min.

The sludge volume index (SVI) is to be computed with this formula:

$$SVI=\frac{sv_{30}}{MLSS} \tag{4}$$

where: sv_{30} is the amount of the sludge settled after a 30 minutes period, expressed in ml/l, MLSS is the sludge concentration in bioreactor, expressed în mg/l, and the test results will be expressed in cm^3/g.

The sedimentation test (SV) is achieved by readings on the marked cylinder at 30 minutes and 60 minutes intervals for biological treatment and at 2 hours interval for the mechanical treatment.

The RAS flow (Q_{Re}) is computed with the next formula:

$$Q_{Re}=\frac{MLSS}{S_R\text{-}MLSS}\times Q_i \tag{5}$$

or

$$Q_{Re}=\frac{R_e\times Q_i}{100} \tag{6}$$

where: MLSS is the sludge concentration in bioreactor, expressed in mg/l, S_R is RAS concentration, in mg/l, Q_i is the inflow of bioreactor, in m^3/day, R_e is the recirculation rate, expressed in percentage, the result being given in m^3/day.

The recirculation rate factor (R_e) is to be calculated with the next formulas:

$$R_e=\frac{Q_{Re}}{Q_i}\times 100 \tag{7}$$

or

$$R_e = \frac{MLSS}{S_R\text{-}MLSS} \times 100 \tag{8}$$

where: MLSS, S_R, Q_{Re} and Q_i were described above, the result being expressed in percentage.

The food/microorganism ratio (F/M) is to be computed with:

$$F/M = \frac{BOD \times Q}{MLSS \times V} \tag{9}$$

where: Q is the inflow of bioreactor, in m^3/day, BOD is the biochemical oxygen demand, expressed in mg/l, MLSS and V are described above, and the result is to be expressed in kg BOD.day/kg MLSS.

This parameter is sometimes named the volumetric organic load (VOL), and is expressed in kg BOD/kg SS.day.

The mass organic load (MOL) is computed with this formula:

$$MOL = \frac{BOD \times Q}{V} \tag{10}$$

where: BOD, Q and V were described above, and the results is given in kg BOD/m^3 clarifier.day.

The sludge age (SRT) is calculated with formula:

$$SRT = \frac{MLSS \times V}{S_W \times Q_w} \tag{11}$$

where: S_W is the WAS sludge concentration expressed in mg/l, Q_W is the flow of sludge wasted from the process, expressed in m^3/day, MLSS and V are described above, and the measurement units for SRT are days.

The excess flow (Q_W) can be determined in several ways, by example by maintaining a target concentration for the sludge within bioreactor. The calculation formula being:

$$Q_W = \frac{kg\ MLSS\ wasted \times 1000}{S_W} \tag{12}$$

where: S_w was described above, and result is expressed in m^3/day.

The wasted sludge production (SS kg wasted) is computed by means of the formula below

$$kg\ SS_{wasted} = S_w \times Q_w \tag{13}$$

where: S_w și Q_w were determined above, and the measurement unit is kg SS/day.
Obtained data are presented as a table and a graph.

2.5. Case study-The Iasi WWTP

As a case study, the Iași WWTP is presented (Fig. 3) and the plant includes a mechanical treatment equipped with coarse screen, pumping stations, grit and grease removal equipment, primary clarifiers and a biological treatment provided with activated sludge bioreactors, secondary clarifiers and a phosphorus chemical precipitation stage.

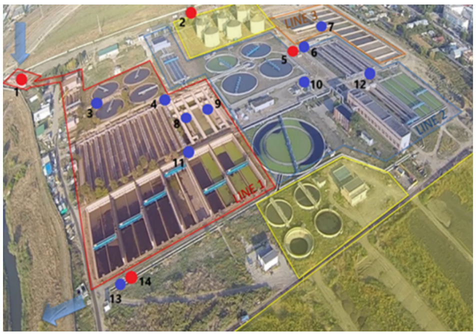

Fig. 3 – The study area - Iași WWTP.

From a hydraulic point of view, the Iași WWTP can treat in the mechanic and biological stages, in dry weather conditions, an amount of 2200l/s wastewater and 4033l/s during precipitation/wet weather. Apart this, in the plant HRT is 88 minutes, respectively 120 minutes for primary clarifiers, the SRT in bioreactors is 8.7 days, the sludge daily production is 0.972 kg SS kg BOD.d, the excess sludge production is 35830 kg SS/d, the SVI reaches 110 cm^3/g, MLSS is 3700 mg/l, S_R is 8640 mg/l, R_e is between 63% and 150%, R_i is up to 295% of average wastewater inflow, and the DO concentration is between 1 mgO_2/l and 3 mgO_2/l. The analysis of the process was carried out over a period of 5 days, the process flows being presented in Table 1.

Table 1
Iași WWTP, flows

Day	Q_i (m^3/d)		Q_e (m^3/d)	Q_{Re} (m^3/d)		Q_W (m^3/d)		Q_{RI} (m^3/d)	
	L1	L3		L1	L3	L1	L3	L1	L3
1	*59962*	*61662*	*121624*	*57442*	*90806*	*4335*	*2505*	*86400*	*209693*
2	*48044*	*67976*	*116020*	*56991*	*91929*	*5200*	*2332*		
3	*54199*	*66866*	*121065*	*53776*	*92275*	*4413*	*2592*		
4	*47855*	*69733*	*117588*	*57000*	*92275*	*4921*	*1728*		
5	*43030*	*74991*	*118021*	*57600*	*92880*	*4869*	*2332*		

Regarding the pollutant loads inside Iași WWTP, this facility was sized for a load of 537 mg/l COD, 293 mg/l BOD, 341 mg/l TSS, 43.9 mg/l NTK and 8.8 mg/l TP, at a compliance rate of 93%. The loads related to the studied period are presented in Table 2.

Table 2
Iași WWTP, loads in wastewater

Day	TSS (mg/l)			BOD (mg/l)			COD (mg/l)		
	Inf.	TM	Efl.	Inf.	TM	Efl.	Inf.	TM	Efl.
1	*318*	*188*	*7*	*280*	*190*	*11*	*467*	*312*	*31*
2	*148*	*89*	*9*	*135*	*92*	*9*	*240*	*161*	*28*
3	*539*	*332*	*11*	*240*	*163*	*10*	*412*	*276*	*31*
4	*490*	*294*	*10*	*192*	*131*	*8*	*372*	*249*	*28*
5	*130*	*78*	*13*	*150*	*102*	*9*	*312*	*209*	*30*
Day	NH_4 (mg/l)			NO_3 (mg/l)			NO_2 (mg/l)		
	Inf.	TM	Efl.	Inf.	TM	Efl.	Inf.	TM	Efl.
1	*30,38*	*37,89*	*0,292*	*1,6*	*1,77*	*19,8*	*0,14*	*0,162*	*0,051*
2	*28,94*	*35,88*	*0,063*	*2,57*	*2,83*	*24,02*	*0,191*	*0,221*	*0,031*
3	*30,19*	*37,43*	*0,061*	*2,62*	*2,88*	*22,81*	*0,056*	*0,065*	*0,033*
4	*37,73*	*46,78*	*0,077*	*3,14*	*3,45*	*27,28*	*0,094*	*0,109*	*0,055*
5	*33,85*	*41,97*	*0,211*	*2,52*	*2,77*	*27,73*	*0,189*	*0,219*	*0,048*
Day	N_T (mg/l)			P_T (mg/l)			pH (unit. pH)		
	Inf.	TM	Efl.	Inf.	TM	Efl.	Inf.	TM	Efl.
1	*31,09*	*38,26*	*5,08*	*2,79*	*3,4*	*0,55*	*7,5*	*7,6*	*7,5*
2	*37,2*	*45,75*	*6,25*	*2,87*	*3,47*	*0,31*	*7,7*	*7,8*	*7,6*
3	*29,08*	*35,76*	*5,54*	*3,12*	*3,77*	*0,78*	*7,5*	*7,6*	*7,5*
4	*34,49*	*42,41*	*6,57*	*3,48*	*4,21*	*0,87*	*7,7*	*7,7*	*7,7*
5	*34,03*	*41,85*	*6,83*	*3,2*	*3,87*	*1,03*	*7,6*	*7,7*	*7,8*

The sludge concentration in the biological stage, in RAS and WAS, the results of sedimentation tests and those for the SVI during the studied period are shown in Table 3.

Table 3
MLSS, sv, S_R, S_W and SVI in Iași WWTP

Day	MLSS (mg/l)		S_R+S_W (mg/l)		SVI (cm^3/g)		sv_{30} (ml/l)		sv_{60} (ml/l)	
	L1	L3	L1	L3	L1	L3	L1	L3	L1	L3
1	*4430*	*4210*	*6290*	*7550*	*169*	*163*	*750*	*690*	*500*	*490*
2	*4550*	*4850*	*4910*	*7320*	*173*	*179*	*790*	*870*	*680*	*710*
3	*3240*	*3600*	*5970*	*6710*	*201*	*222*	*650*	*600*	*600*	*560*
4	*4180*	*5020*	*6490*	*6750*	*143*	*139*	*600*	*700*	*450*	*500*
5	*3050*	*3900*	*5460*	*6640*	*144*	*149*	*440*	*580*	*370*	*420*

3. Results and discussions

The purpose of activity carried out in the WWTP is the process control and monitoring, in order to avoid the pollution in the emissary, and another goal is the decrease of energy costs (Samira S. Farhani *et all*, 2017).

The analysis of process data starts after data collection, and the larger and more varied the amount of data is, the easier the results and decision-making processes are.

Thus, the database obtained from laboratory tests, sedimentation tests, process sensors, recorded flows and environmental factors form the technical basis for the applied process operations.

The mechanical treatment processes, although firstly not considered of special importance, ensure the necessary contribution of organic load and nutrients needed for the development of the processes within the biological stage, that is, the very important C:N:P ratio is.

(EPA, 1997), (Perju & Mănescu, 2011), (C.A.L. Negulescu, 2004), (Robescu, 2015) recommend that this ratio should be 100:5:1, in order for the WWTP process to take place in optimal conditions.

One of the most important components of the mechanical treatment stage, if not the most important, is the primary clarifier, where the main analyzed parameters are the hydraulic retention time, the surface overflow rate, the weir loading rate, the settling velocity, the two hours sedimentation test in Imhoff cone and the amount of sludge produced.

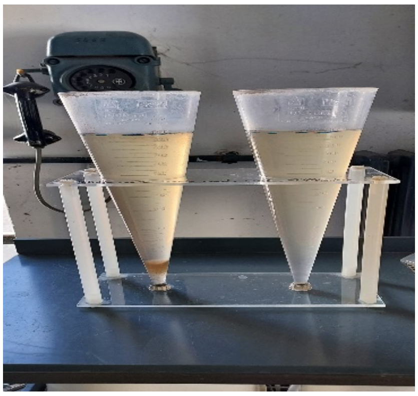

Fig. 4 – The two hours sedimentation test.

The hydraulic retention time is given by the ratio between the clarifier's volume and its wastewater inflow. Related to this (Qasim & Zhu, 2018) recommend values of 1.5-3.5 h for it.

The surface overflow rate is given by the ratio between the inflow and the clarifier's surface area, and the settling velocity is given by the height of the wastewater in clarifier divided to the hydraulic retention time (Qasim and Zhu, 2018).

The two-hour sedimentation test (Fig. 4) is performed in order to observe the amount of suspension that is not retained by the mechanical stage and is found in the primary clarifier's effluent, thus monitoring the loads' reduction efficiency.

Hence, the recommended value for the sedimentation test after two hours is 0.1 mgSS/l (Chen, et. all, 2020), (Zhu, 2018).

The amount of sludge produced in the primary clarifiers is computed by multiplying the amount of sludge retained in clarifiers with the inflow (Negulescu, 2004), the sludge flow to be pumped being correlated with the sludge specific weight and moisture (Qasim and Zhu, 2018).

The analysis of the biological processes is the most important part of the treatment processes and one of the most important parameters we can recall is the 30 minutes sedimentation test (Fig.5), the determination of the sludge concentration inside the bioreactor and the concentration of recirculated sludge, sludge age, F/M ratio or the oxygen transfer rate.

Fig. 5 – The 30 minutes sedimentation test.

During the analyzed period (Fig. 6), the HRT recorded in the primary clarifiers L_1 was between 144 and 175 min, while in L_2 it was between 199 and 250 min, the SOR was in L_1 27.63 and 33.6 m^3/m^2.day, and in L_2 between 19.28 and 24.28 m^3/m^2.day.

The WLR value was in the range 260.31-316.58 m^3/m^2.day in L_1 and in the range 181.65-238.59 m^3/m^2.day in L_2.

The settling velocity v_s was higher in the primary clarifiers L_1, with values in the range 0.019-0.023 m/min and in the range 0.013-0.017 m/min in the primary clarifiers L_2.

The primary sludge production was in the range 3899.53-13841.26 kg SS/day for L_1 and in the range 2237.56-11219.19 kg SS/day in L_2, and the primary sludge flow varied between 77.37-81.63 m^3/day in L_1 and 44.40-222.60 m^3/day in L_2.

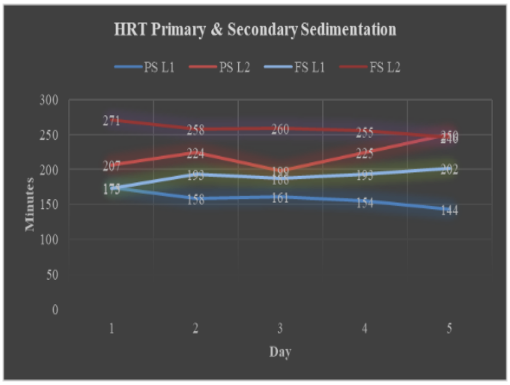

Fig. 6 – HRT: primary and secondary clarifiers.

In the biological stage the Mohlman index în L_1 varied in the range of 144-201 cm^3/g and in the range 139-222 cm^3/g în L_2, the external recirculation rate was in the range 96-134 % in L_1 and in the range 124-147 % in L_2, and the internal recirculation rate was in the range 73,56-85,86 % in L_1 and in the range 124,9-137,53 % in L_2.

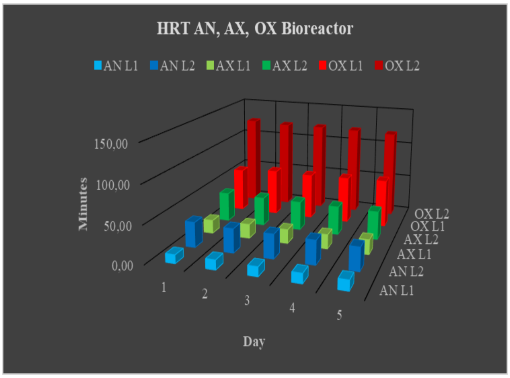

Fig. 7 – HRT: Bioreactors.

The recorded F/M ratio (Fig. 8) in L_1 was in the range 0,083-0,233 kg BOD.day/kg MLSS and in the range 0,029-0,068 kg BOD.day/kg MLSS in L_2, the VOL (Fig. 8) was in the range 0,375-0,973 kg BOD/m^3 clarifier.day in L_1 and in range of 0,141-0,264 kg BOD/m^3 clarifier.day, and the MOL factor was in the range of 3,68-5,12 m^3 ww/m^3 clarifier.day in L_1 and in the range of 1,39-1,69 m^3 ww/m^3 clarifier.day.

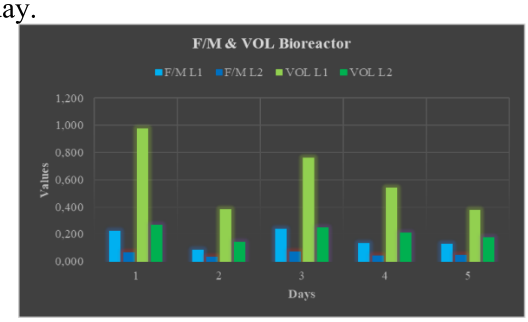

Fig. 8 – Factors F/M and VOL, biological stage

$HRT_{anaerob}$ (Fig. 7) had values in the range of 11-13 minute in L_1 and 30-33 minutes in L_2, HRT_{anox} had values in the range of 17-19 minute in L_1 and 38-40 minutes in L_2, HRT_{oxic} had values in the range of 58-64 minutes in L_1 and 118-123 minutes in L_2, and SRT in L_1 had values in the range of 2-9 days, in L_2 being in the range of 9-19 days.

The evacuated sludge production in L_1 was in the range of 25532-31937 kg SS, and for L_2 this was in the range 15490-58561 kgSS. The computed Q_w was in the range 0-2026,5 m^3/day in L_1 and in the range 0-8675,7 m^3/day in L_2.

In secondary clarifiers HRT was in the range of 173-202 minutes in L_1 and in the range of 246-271 minutes in L_2, SOR was in the range of 28,57-33,33 m^3/m^2.day in L_1, and in the range of 20,87-22,98 m^3/m^2.day in L_2, WLR was in the range of 207,13-241,66 m^3/m.day in L_1, and in the range of 147,88-162,82 m^3/m.day in L_2, and the settling velocity was in the range of 0,0198-0,0231 m/min in L_1 and in the range of 0,0148-0,0162 m/min in L_2.

4. Conclusion

By analyzing results obtained from the calculations of technological parameters, gathered laboratory data and SCADA values we can see the multitude of data needed to choose an optimal solution, each parameter being closely correlated with at least two or three other parameters.

The settling velocity is influenced by factors like the retention time, temperature, hydraulic load, etc. The sludge production, if we refer to primary clarifiers, is influenced by the retention time and the wastewater inflow.

The primary sludge flow is also influenced by the sludge production, and the sludge specific gravity and moisture content.

In the biological stage, the sludge concentration is influenced by the recirculation rate and flow, the concentration of recirculated sludge, but also the amount of excess sludge.

The Mohlman index gives us information about the sludge sedimentability in the secondary clarifiers, the technical literature recommending values between 80 and 120 cm^3/g, this parameter being also influenced by the recirculation rate and flow.

The recirculated sludge flow is influenced by the concentration of recirculated sludge and the concentration of sludge in the bioreactor, which also indicates the recirculation rate.

The sludge age is influenced by the amount of sludge removed and the concentration of recirculated sludge and the sludge concentration in the bioreactor.

The retention times, whether we refer to the anaerobic, anoxic, oxic zone or the entire zone, are influenced by the inflow and recirculated flow.

This parameter is one of the most important parameters, because microorganisms in bioreactors need to grow and develop at full capacity and just like humans, even if they are single-celled organisms and multiply by division, they have a life cycle.

For example, autotrophic microorganisms, specific to oxic zones, have a lifespan of 12 hours, and heterotrophic microorganisms, specific to anoxic zones, have a lifespan of 3 hours.

This means that the growth and development rate of heterotrophic microorganisms is 4 times faster than that of autotrophic microorganisms, which requires, for the A^2/O process scheme used in Iași WWTP, a $HRT_{anaerob}$ of 0.5-1.5 hours, 1- 3 hours as regards HRT_{anox}, 4-8 hours as regards HRT_{oxic} and a total HRT of 6-12 hours.

Factors like the F/M ratio, VOL, MOL, indicate the process area in which the WWTP operates, conventional aeration, extended aeration, etc., all these parameters being in turn influenced by other parameters, for example increasing the sludge age will reduce the F/M ratio and vice versa.

As a final conclusion, operating a WWTP in the absence of sound process calculations, with erroneous SCADA data or insufficient laboratory data can increase operating costs and facilitate a faulty management of all processes within a WWTP.

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MONITORIZAREA PARAMETRILOR APEI UZATE ÎN STAȚIILE DE EPURARE: STUDIU DE CAZ – SEAU A ORAȘULUI IAȘI

În treapta mecanică de epurare, parametrii apei uzate ce trebuie monitorizați sunt: testul de sedimentabilitate în conul Imhoff, cantitatea de plutitori reținută de grătare, cantitatea de nisip și pietriş evacuată, cantitatea de nămol evacuată din decantoare, raportul C:N:P, debitul de apă uzată, raportul F/M, timpul de retenție hidraulic, încărcarea hidraulică și poluanții ce trebuie monitorizați conform normelor legislative, cum ar fi CCO, CBO, N_T, P_T etc. În treapta biologică de epurare, parametrii apei uzate ce trebuie monitorizați sunt: debitul apei uzate, a oxigenului și a nămolului, SVI, HRT, SRT, R, I_H, I_{OB}, I_{ON}, producția de nămol etc.

Stația de epurare a orașului Iași are o capacitate hidraulică de 4,03 m^3/s în condiții cu precipitații și 2,2 m^3/s în condiții fără precipitații, debitul mediu fiind de aproximativ 1,1 m^3/s.