Wastewater treatment plant analytic control through expeditious analysis methods

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Summary: The existence of an high number of Wastewater Treatment Plants (WWTP) of reduced size, without permanent operating technicians, makes it essential the existence of rapid and expeditious methods that allow a technician the evaluation of the correct WWTP functioning. The parameters to evaluate range from the assessment of the efficiency of each treatment organ to the verification of its dimensioning variables.

Keywords: WWTP, control, operation, expeditious methods, analysis

1. Introduction

There are many WWTP in Portugal, with its vast majority being classified, adjusted to the demographic characteristics, as small and medium dimension, serving up to 2000 and 30000 inhabitants, respectively. Being WWTP onerous infrastructures which have as function the effluent depuration, it becomes necessary to control its functioning through periodic monitoring of several parameters in the several stages of which the treatment process consists of.

The present work thus consists in establishing swift methods for operational control of a WWTP employing the activated sludge, of small and medium dimension, where it is not considered the existence of in house laboratories, nor permanent teams of specialized technicians.

2. National wastewater treatment

Currently, Portugal has a processing level of 81% of wastewater drainage and level of treatment of 79%, (Baptista, 2014), having had big improvements over the last two decades. The wastewater drainage and treatment services are divided into retail systems and bulk systems. Retail WWTP systems correspond to more than 60% of Portuguese WWTPs, and are generally low/medium sized facilities, mainly managed by municipalized systems, either directly through municipia, either through municipalized companies. On the other end of the spectrum, bulk WWTP systems are essentially managed through multi-municipal companies, serving at least 2 municipia. Table 1 displays values of several factors that characterize Portuguese drainage and wastewater treatment network.

Currently the novel strategy “PENSAAR 2020” is in effect for the water supply and wastewater sanitation. Formerly, the PEAASAR II plan was in effect, which had as main goal to provide wastewater drainage and treatment services to 90% of the population. That goal is currently not achieved yet. The wastewater drainage and treatment services are regulated by ERSAR, *Entidade Reguladora dos Serviços de Águas e Resíduos.*

Table 1 – Drainage and wastewater treatment network – Data referring to 2012 (ERSAR, 2013).

Pupulation served (inhab.)	8×10^6	Submarine outfall	25
Yearly wastewater produced* (m^3)	1009×10^6	Management entities	283
Yearly wastewater treated (m^3)	824×10^6	Expenditure by management entities (€)	840×10^6
Collectors (km)	53087	Management entities revenue (€)	782×10^6
Lift Stations	4677	Average rate (€/m^3)	0.5215
Collective septic tanks	1732	Specialized workers**	6677
Wastewater treatment plants	2536	Yearly energy consumption (kWh)	340×10^6

Overall, the agreement is that big advances were made regarding wastewater drainage and treatment, mainly through infrastructure creation and improvement. This way, there are many WWTP, with its majority (63%) having retail system management, corresponding to small and medium sized facilities, making it extremely useful to assess its performance *in situ*.

3. Activated sludge treatment process

WWTPs have as goal the treatment of effluent wastewaters, as well as the treatment of the resulting sludge from the wastewater treatment process. The final treated effluent should respect the pre-established limit discharge values for a given WWTP, and the resulting sludge should be able to be placed at their final destination.

As the effluent enters the treatment plant, its subject to up to four treatment phases regarding the liquid phase: preliminary, primary, secondary (or biological) and tertiary. The maximum treatment level to apply depends on how demanding the receiving medium is and on the characteristics of the effluent wastewater.

Preliminary Treatment

The inflow enters the WWTP at the structure denominated headworks, followed by the preliminary treatment, a physical process aimed at the removal of coarse solids, grease, oils and grit. This step prepares the effluent for the following phases, guaranteeing the correct functioning of the equipment through which it will pass subsequently, avoiding for instance process outages due to clogging/obstructions and the formation of excessive foams. The screenings (coarse solids), grit and grease removed in this step are subsequently routed to the adequate final destination. The inflow is routed primarily to the screening in which the large coarse solids are removed through the use of a screen chamber, rotary drum screen or sieve. Before this step there can be a grinder so that the solids with larger sizes are reduced to small sizes (between 6 and 10 mm).

The sand removal is made through a grit gravity or dynamic chamber. In the gravity grit chamber, a constant and low draining speed of about 0.3 m/s is maintained, promoting the sand sedimentation and the dragging of organic material (Levy, 2000).

For the removal of oils and lipids, degreasers are used, and can be mechanical or static. This treatment step aims to avoid the subsequent formation of surface films that would difficult the development of responsible microorganisms for the biological treatment. However, the main function of the degreaser is not to compromise the quality of the final flow withdrawn effluent. This step is specially important in treatment plants that do not comprise a primary sedimentation tank. (WEF, 2009).

The grit/sand, oil and lipid removal can be performed at the same treatment organ, and is designated grit chamber/degreaser.

Primary treatment

The primary treatment goal is the clarification the effluent, by removing granular solids (about 90% (Levy, 1991)), skimming, BOD_5 and BOD, and the result of this step is non-stabilized primary sludge (with solid concentrations generally from 3 a 5%, which are modified to 5 to 10% after the thickening process). The primary treatment can be performed through a primary thickener, for which there are in this stage, removal efficiencies equal or above 50% for TSS and 20% for BOD_5.

There are two sedimentation tank types, one is denominated gravity sedimentation tank or Dortmund sedimentation tank, in which the particles with larger size, settle due to gravity effect, and it's characterized by steep sloped bottom walls. These tanks do not require scraping equipment due to gravity action cleaning the walls. The other type of sedimentation tank is characterized by the weak slope of the bottom walls (ranging from 6 to 8º), and thus requires a bottom mechanical scraper to route the sludge to the sludge collection well where they will be subsequently treated (Levy, 1991).

Secondary treatment

The secondary treatment is generally a biological process in which organic matter is consumed by microorganisms. In this work the treatment by suspended growth on the variant of activated sludge, is covered, consisting of an aeration tank where organic matter is digested by microorganisms, forming flocks.

The activated sludge treatment is usually comprised by the aeration tank (reactor) and the secondary sedimentation tank, and this process is denominated activated sludge extended aeration process (Figure 1). In this treatment process diagram, there is no primary treatment, and the wastewater at the exit of the preliminary treatment flow continuously to the aeration tank, where aerobiosis ideal conditions are created for microorganism growth, through existing aeration mechanisms within the tank, equally responsible for maintaining the matter in suspension, thus forming the activated sludge (flocks comprised by microorganisms in the aeration tank), also designated by mixed liquor.

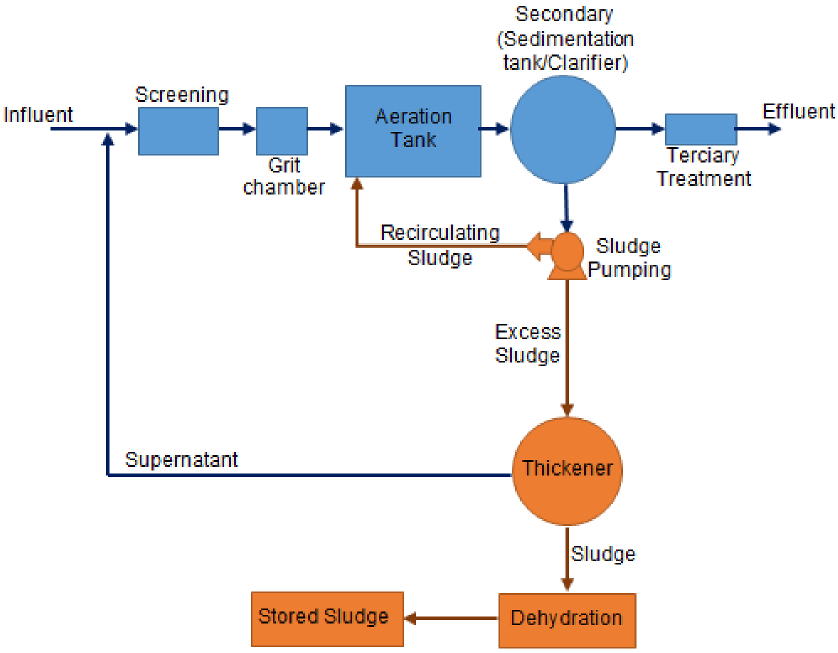

Figure 1 – Diagram representing the processing steps in the activated sludge extended aeration process.

Subsequently, the wastewater is routed to the secondary sedimentation tank (clarifier), where the Total Suspended Solids (TSS) sediment, forming stabilized sludge, due to the high time-window at the aeration tank (20 to 30 days). The resulting sludge is then routed to the recirculating sludge well, in which a part of it returns to the aeration tank, pumped by an elevation station, so that there is always the needed amount of microorganisms to degrade the organic matter. When the aeration tank has excess sludge, it's routed to the sludge treatment.

At the upper part of the secondary sedimentation tank lays the clarified effluent with low BOD_5 values, and this effluent can be the final effluent to discharge or it can still go through a tertiary treatment, depending on the receptor medium requirements.

Another variant of the activated sludge treatment process is denominated conventional treatment. This treatment differs from the described above, essentially on the time the effluent is at the aeration tank, being of much low duration (5 to 15 days), from which non-stabilized sludge results, which require subsequent stabilization. Another difference it's the fact that there is a primary sedimentation tank (primary treatment) before the flow of the effluent to the aeration tank.

Tertiary treatment

The tertiary treatment is a complement to the secondary treatment and not always is applied, depending on the demand of the receptor medium of the treated effluent, and on if it is destined to reuse. This treatment phase has as goal to improve the effluent quality through the removal of TSS, microorganisms, nitrogen, and phosphorous. Some examples of tertiary treatments are: Ultraviolet (UV) irradiation disinfection, chlorine or ozone, removal of nitrogen and phosphorous, maturation ponds, micro-filtration, etc.

Sludge treatment

From the treatment steps previously described, big quantities of sludge are created, which must be submitted to appropriate treatments so that they have the adequate characteristics to be deposited at a final destination. In figure 2, the diagram of the sludge treatment process diagram at a WWTP is shown.

The sludge proceeding from activated sludge extended aeration treatment is stabilized when it exits the secondary sedimentation tank (clarifier), whereas in the conventional activated sludge treatment, all the produced sludge requires stabilization.

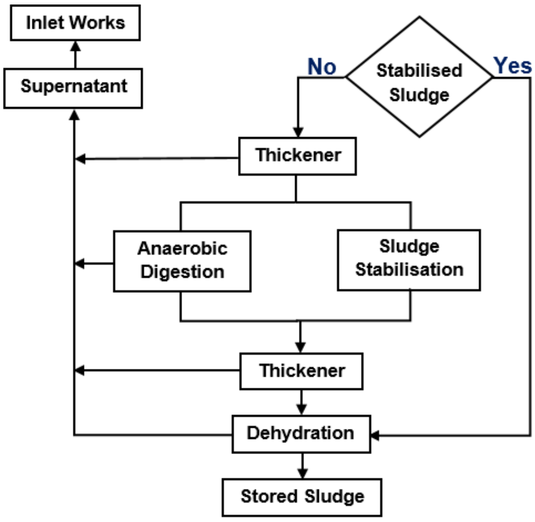

Figure 2 – WWTP sludge treatment diagram

The main purpose of the sludge thickening is the reduction of the sludge water content, be it primary sludge or secondary sludge. At small/medium sized WWTPs the originating sludge from the several treatment stages is mixed and routed to a gravity thickener, which concentrates the sludge through gravity and removes some of its humidity.

The sludge stabilization after thickening has as main function to decrease the putrefaction level as well as decrease the presence of pathogenic microorganisms and their associated odours. This treatment phase materializes in aerobic or anaerobic digesters.

Dehydration it's the process of reduction of the sludge water content, decreasing its total volume. It usually corresponds to one of the following processes: drying beds, filtering bags, belt-filter press, filter press or centrifuge (Levy, 2000). In all dehydration processes, the originating run-offs must be routed to the WWTP head. Finally, the sludge is stored in silos or containers, for subsequently being sent to the final destination.

4. WWTP Control

For the monitoring of the operation of a WWTP, determination of several parameters in strategic points is required. Household wastewater usually shows as relatively constant composition, since the type of waste rejected in the collector network is identical. In Portugal, household wastewater typically presents the characteristics shown in table 2.

Table 2 – Average values of some parameters in Portugal's wastewater, measured in laboratory

Parameter	Units	Average Value	Parameter	Units	Average Value
Total Suspension Solids (TSS)	mg/l	253	pH	-	7,5
Biochemical Oxygen Demand (BOD_5^{20})	mg/l O_2	165	Total Nitrogen	mg/l N	50
Chemical Oxygen Demand (BOD)	mg/l O_3	465	Total Phosphorous	mg/l P	9

In the WWTP headworks, a flow meter must be present so that the monitoring of the affluent flow is possible. Moreover, several affluent parameters must be determined so that they can be subsequently compared with the ones obtained at other points of the WWTP, as a way of assessing the treatment efficiency.

Screening

At the screening the quantity of collected screenings must be controlled, which depends on the characteristics of the affluent wastewater and on the implemented system (the larger the spacing between bars in the screening chamber, the smaller the amount of collected screenings). To assess the quantity of collected screenings, these can be weighted, placing them in a bucket and using a digital dynamometer, figure 3. Alternatively, one can count the number of filled containers during a certain time-interval and thus estimate the volume of collected screenings, as the container volume is known. Another parameter to control on the screening chambers is the fluid draining speed, making use of a portable meter, so it can be compared with the projected speed.

Figure 3 – digital dynamometer (KERN, 2015)

Grit chamber

At the grit chamber it's required to measure the quantity of removed sand/grains, as on average the sand/grains affluent to a WWTP is around 37 l/1000 m^3. A rapid way to evaluate its functioning is by weighting them with a digital dynamometer.

In this treatment organ, the flow speed must be low, allowing for sedimentation, reason for which the control of this parameter is important.

Figure 4 – Ultrasonic Flow Meter (Mitchell Instrument Company Inc.®, 2014).

Measuring the flow area.and using a portable flowmeter, figure 4, the flow speed is calculated.

Grease removal

To evaluate the performance of the degreaser, pick two wastewater samples, one prior and another after this treatment organ, and determine the grease quantity in both samples, using a portable oil and grease meter, figure 5, so that by comparison one can determine the removal efficiency of that contaminant. Usually the degreaser efficiency is around 30 to 40%, having better efficiencies of 50 to 70% when it's a degreaser with oxygen insufflation.

Figure 5 – Portable meter of oils and grease *(PETRO Industry News, 2015).*

Primary sedimentation tank

In the primary sedimentation tank measurements must be made to the temperature, pH, BOD$_5$, BOD, TSS, turbidity and the sludge level.

For a correct functioning of this treatment organ, the percentage decrease for TSS should be around 40% and around 25% to 33% to BOD$_5$ (Spellman, 2014). The liquid after primary treatment should be also more clarified in comparison with the initial affluent.

For the measurement of the TSS and turbidity values one can use the same device, a portable TSS meter, figure 6. There are also measurement devices that only determine the turbidity level, figure 7, and others that allow simultaneously reading of some of the parameters that are referred next, figure 8.


Figure 6 – Portable TSS meter (Hach, 2015).


Figure 7 – Portable Turbidity meter (Hach, 2015).


Figure 8 – Portable multi-parameter meter with probe, for measurement of pH, turbidity, temperature, dissolved oxygen, etc. (HANNA Instruments, s.d.).

The determination of the sludge level is important so that excess sludge does not build-up, and consequently rises to the surface. This parameter can be measured through a probe or using the *Sludge Judge* equipment, figure 9.

For the measurement of the remaining parameters it's necessary the collection of samples with the aid of a sample collector, figure 10 .The temperature and pH are measured with a portable device, figure 11. The pH must be near the value found at the initial affluent. The temperature influences the hydraulic retention time (HRT) required for the sedimentation. The lower the temperature, the higher the required hydraulic retention time, and vice-versa. (e.g., the required HRT for a 10 ºC affluent is 1.38 times higher compared with a 20ºC affluent) (Metcalf & Eddy, 2003).


Figure 9 – Section-based sludge sampler, Sludge Judge *(Hach, 2015)*.


Figure 10 – Sample collector.


Figure 11 – Portable pH and temperature meter.

The determination of the BOD value is made through the use of a portable photometer, figure 12, and cuvette tests, figure 13, which are easy to use and include simple usage instructions in its package.

Although the parameter BOD_5 can't be measured *in situ*, it is related with BOD it can be estimated (e.g., the BOD_5/BOD ratio in household wastewater is around 0.5 to 0.6 at the affluent and around 0.2 at the final affluent (Davies, 2005). For other locations on the WWTP, like the primary sedimentation tank, the ratio is calculated with the lab tests previously made).

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Figure 12 – Portable photometer.

Figura 3 Figure 13 – Cuvette test box (BOD example).

Figure 14 – Portable DO meter.

Aeration tank

The aeration tank surface should look homogeneous, and showing stirring signs (caused by air injection). The surface foam colour must have a brownish tone, indicating that the sludge has good settling characteristics. (Ragsdale and Associates Training Specialists).

In this treatment phase, the measurement of the dissolved oxygen (DO) is required, and must be equal or greater to 2 mg/l (WEF, 2009), favourable conditions for the development of essential microorganisms in the aerobic biological treatment process. This parameter is determined through a portable DO meter, figure 14.

Besides the dissolved oxygen, the measurements of temperature, pH, TSS, Volatile Suspended Solids (VSS) e the Sludge Volume Index (SVI) or Mohlman Index (Levy, 1991). It's also important to consider the sludge colour, which must be brown (soil colour), not too clear, nor too dark.

The temperature influences significantly the microorganism growth speed, approximately doubling it per each 10ºC of temperature increase, between 15 and 36ºC. The temperature rise leads also to the decrease in sludge production and to the increase on the consumed oxygen, which impairs the sludge sedimentation. The characteristics of the sludge sedimentation and the aeration capacity usually worsen with the temperature increase. The pH must have an approximately neutral value between 6.5 and 7.5, so that there is good microorganism growth and consequently there's reduction of BOD$_5$ (WEF, 2009).

The Sludge Volume Index (SVI), is an indicator of the quality of activated sludge sedimentation, and represents the volume (measured in ml) occupied by 1 gram of activated sludge, which corresponds to the relationship between the volume of settled sludge after 30 minutes on a Imhoff cone, figure 15, and the concentration of suspended solids in the used sample. The bigger the SVI value, the lower will be the sludge sedimentation capability. For SVI values above 120 ml/g, it's considered that the sludge have weak sedimentation capability. For values under 80 ml/g it's considered that the sedimentation capability is good, and very good for values around 50 ml/g (Gray, 2004).

Figure 15 – Imhoff Cone.

The Mixed Liquor Suspended Solids (MLSS) concentration in the biological reactor/aeration tank must be between 2000 mg/l and 4000 mg/l (Metcalf & Eddy, 2003).

Secondary Sedimentation Tank (Clarifier)

In the secondary sedimentation tank, one must verify that there isn't much sludge at the surface, and if on the final duct the liquid is clarified (in many cases that will be the final effluent, as there is no tertiary treatment). The values of BOD, TSS, phosphorous, nitrogen, and turbidity levels must also be measured. The values of phosphorous and nitrogen can be determined through cuvette tests similar to the performed for BOD parameter.

In table 3, the reduction percentages of some parameters in several stages of the treatment process on the liquid phase at a WWTP are shown.

Table 3 – Percentage reduction of some parameters in several stages of the treatment process on the liquid phase at a WWTP (Levy, 2000) *and* (Marecos do Monte & Albuquerque, 2010).

Parameter	Parameter decrease (%)			
	Primary Treatment	**Secondary Treatment**	**Tertiary Treatment**	**Final Effluent (Global)**
BOD_5	30	63	5	98
TSS	40	55	4	99
Turbidity	12	74	14	99
Nitrogen	5	52	1	58
Phosphorous	16	28	54	98

Sludge recirculating well

In the sludge recirculating well, temperature, pH and the level of sludge sedimentation measurements must be taken, in order to evaluate the quality of the sludge that will be reintroduced in the treatment process at the aeration tank.

Outlet

At the outlet stage, the same values measured at the inlet, should be measured, i.e. temperature, pH, grease, nitrogen, phosphorous, BOD, BOD_5, TSS and turbidity level, so that from both groups of measurements one can derive the WWTP efficiency. The turbidity level must be null and the temperature must be the closest possible to the one of the receiving water line, so that it doesn't have negative impact on its existing fauna and flora.

The emission limit values in Portugal for the several parameters subject to control are defined at Decree-law no. 152/97 and Decree-Law no. 236/98.

Sludge treatment

The treatment stage on the solid phase/sludge treatment is performed in closed circuit. Nevertheless there are some parameters that can be controlled.

It's possible to determine the volume of the sludge sent to the sludge treatment process, as well as the volume of treated sludge, that will be subsequently sent to the final destination. Both volumes are different, since at the thickener and at the dehydration, the resulting run-offs are routed to the WWTP entrance, resuming the treatment at its starting point.

Figure 16 – Portable moisture meter.

The digester goal is to stabilize the sludge, which is considered stabilized if it has a black colour, does not release unpleasant odours and does not bubble.

After dehydration, which main goal is to significantly reduce the sludge moisture content, one can make a simple test, recurring to a portable device, figure 16, to determine if the existing moisture percentage after dehydration is within the values associated to the process used at the WWTP being evaluated.

5. Conclusion

Over the last years, portable field measurement devices have been developed, allowing in a near immediate measurements of the concentration value of several important parameters, to evaluate the correct functioning of a WWTP, thus avoiding the waiting time that laboratory tests require. These instruments can be easily operated, allowing technicians with poor knowledge in chemistry to obtain correct values.

This equipment, when taken by a field team to a WWTP, allows them to get an overview of the treatment plant, simplifying the suggestion on a quick manner of intervention measures for the improvement of the WWTP functioning and performance.

References

Baptista, J. F. (2014). Uma abordagem regulatória integrada (ARIT-ERSAR) para os serviços de águas e resíduos. ERSAR.

Davies, P. S. (2005). *The Biological Basis of Wastewater Treatment.* Strathkelvin Instruments Ltd.

ERSAR. (2013). Conheça os serviços de águas e resíduos em Portugal.

Gray, N. (2004). *Biology of Wastewater Treatment - second edition.* Irlanda: Imperial College Press.

Hach. (2015). Obtido em March de 2015, de http://www.hach.com/

HANNA Instruments. (s.d.). Obtido em July de 2015, de http://www.hannacom.pt/

KERN. (2015). (KERN & SOHN GmbH) Obtido em setembro de 2015, de http://www.kern-sohn.com

Levy, J. (1991). *Manual de saneamento básico - Tomo VI, Exploração de Sistemas.* Lisboa: DGRN.

Levy, J. (2000). Aspectos determinantes na concepção de estações de tratamento de águas residuais. *IV encontro anual MGI.*

Marecos do Monte, H., & Albuquerque, A. (2010). Reutilização de águas residuais. *Série Guias Técnicos 14*. ISEL e ERSAR.

Metcalf & Eddy. (2003). *Wastewater Engineering Treatment and Reuse, 4thEd.* Seatle: McGraw Hill.

Mitchell Instrument Company Inc.®. (2014). Obtido em setembro de 2015, de http://www.mitchellinstrument.com/

PETRO Industry News. (2015). Obtido de http://www.petro-online.com/

Ragsdale and Associates Training Specialists, L. (s.d.). *Chapter 8: Activated Sludge.*

Spellman, F. (2014). *Handbook of Water and Wastewater Treatment Plant Operations (3rd Edition).* Taylor & Francis.

WEF. (2009). *Design of Municicial Wastewater Treatment Plant* (Vol. 2: Liquid Treatment Processes). WEF Press.