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Study of dysfunction into activated sludge basins in sewage treatment plant of the City of Khouribga (Morocco)

Y. Salama[1*], O. Salama[2], M. Chennaoui[3], M. Mountadar[4]

[1]*Department of Biology, Polydisciplinary Faculty of Khouribga, University Sultan Moulay Slimane, Khouribga, Morocco.*
[2]*Laboratory of RMI, Faculty of Sciences and Technologies, Hassan 1st University, Settat, Morocco.*
[3]*Laboratory of Life Science and Earth (SVT), Regional Centers for the Professions of Education and Training (CRMEF), El Jadida, Morocco.*
[4]*Department of Chemistry, Faculty of Science, University Chouaïb Doukkali, El Jadida, Morocco.*

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salama.youssef@gmail.com
Phone: +212671264345

Abstract

The wastewater treatment and reuse plant of the city of Khouribga (WWTP) carry out a biological treatment of urban waste water in the city. The activated sludge treatment process is the process adopted at the Khouribga WWTP. This treatment is carried out at two aeration basins. Although the purifying performance of the WWTP and the reliability of this process are proven, several types of biological dysfunctions of the aeration basins can appear. The results of the biological treatment obtained showed that the elimination yield of the physicochemical parameters was 92; 98.4; 96.5 and 97.1 respectively for COD, BOD_5, TSS and turbidity. Generally, the main dysfunction noted in the aeration basin of the WWTP is the proliferation of filamentous bacteria associated with poor settling. This swelling problem leads to poor settling of the mud following an increase in the volume occupied by it. Significant filamentary development severely limits the hydraulic capacity of the clarifier and can cause sludge to leave the natural environment.

1. Introduction

The world is currently suffering from environmental pollution. This pollution is generally due to the increase in human activities in all sectors and it causes damage to human health and alters the ecological balance. For this reason, all countries have made efforts to resolve this problem, especially scarcity and deterioration of the qualities of water due to the diversity of sources of water pollution. The difficulty of managing this pollution by developing countries requires projects with large budgets to solve this problem [1, 2]. Most of these countries have installed wastewater treatment plants, but the management of these stations is different depending on the type of activity in each country [3, 4].

Morocco in recent years has experienced exponential development in various sectors; demographic, economic and tourist which results in an increase in the demand for water as well in agriculture as in industry, and in the domestic food and, on the other hand, the increase in polluting loads which obviously contain substances with harmful effects and pathogenic microorganisms; the volumes of wastewater discharged would reach 900 Mm^3 per year by 2020. 48% of this water is discharged into rivers and the natural environment, the rest is discharged into the sea without any prior treatment [5].

In this context, many treatment plants have been built. The first achievement of ONEE dates back to 2003 and was carried out in the city of Mrirt, currently there are more than a hundred of which 77% are natural lagoons, 15% use d " other techniques (aerated lagoons, bacterial filters ...) and 8% of activated sludge with the aim of reaching 60% of treated wastewater by 2020 [5].

The present study firstly characterizes the urban discharges from the city of Khouribga, then conducts a physico-chemical analysis by determining certain major and global parameters, indicators of the state of pollution by wastewater. A comparative analysis of the theoretical data used for the dimensioning of treatment plants and those actually observed and finally to identify the treatment techniques to be adopted by referring to the characteristics of the wastewater and the local context.

The wastewater treatment and reuse station of the city of Khouribga (WWTP) carry out a biological treatment of urban waste water in the city. The activated sludge treatment process is the process adopted at the Khouribga WWTP. This treatment is carried out at two aeration basins.

2. Material and Methods

1.1. Present context and situation

The city of Khouribga, populated in the twenties thanks to the discovery of phosphate deposits, is located in the center of the kingdom, 120 km southeast of the great Casablanca and is part of the Chaouia Ourdigha region (Figure 1). The area of the city is around 25 km^2 at an altitude of 800 m, with a semi-arid climate, and an average rainfall of 350 mm (Table 1). The city of Khouribga is known for its mining activity considered to be the most important phosphate production zone in the world. Socio-economically, it is a city that presents several points of resemblance to a large category of Moroccan cities.

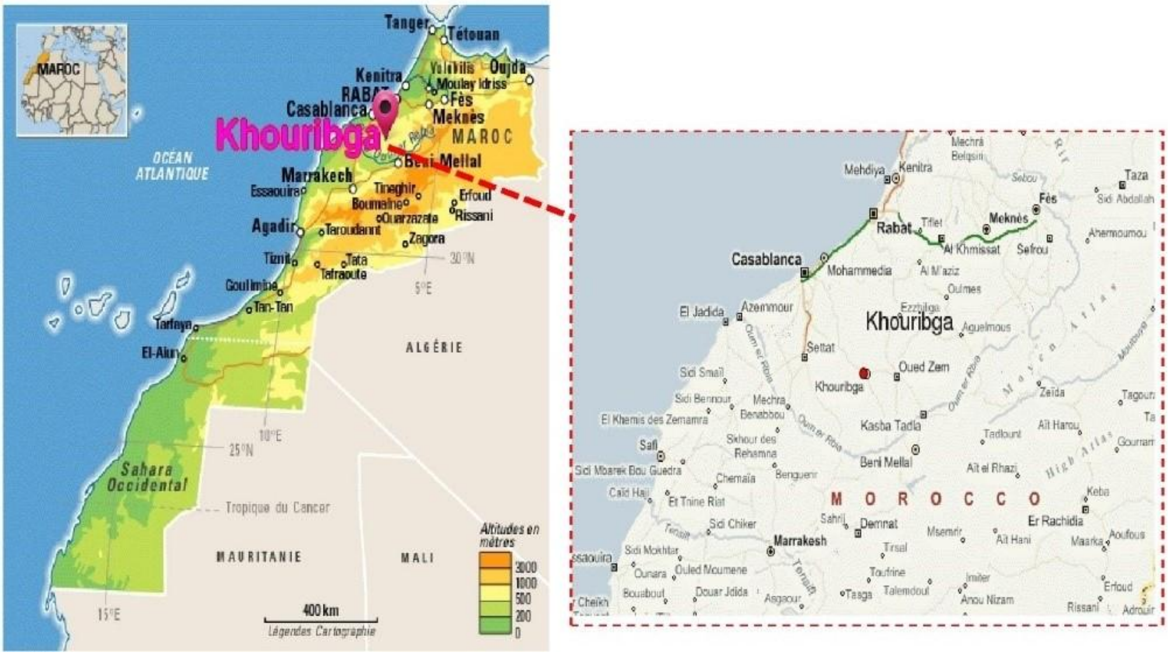

Figure 1*:* Geographical location of the city of Khouribga. Since its creation the population of the city is in constant evolution, it currently has more than 172,000 inhabitants (High Commission for Planning of Morocco (HCP)) distributed in 36 districts (Municipality of Khouribga).

Table 1: Demographic data of the city Khouribga [6, 7].

	1994	2004	2006	2013	2014
Nombre d'habitants	152 090	166 397	172 000	210 000	542 125

Khouribga is among the most populated regions of the Kingdom with the density of 117 inhabitants per km^2 compared to a national average of around 44 inhabitants per km^2.

The study area climate is subhumid to semi-arid, influenced by the Atlantic Ocean, with temperate winters and fairly hot summers; average temperatures vary between 11°C and 25°C; average annual precipitation records values of 350 mm [8].

2.2. Geographical location of the WWTP in Khouribga City

The treatment plant is located about 3 km south of the city of Khouribga, on the road to Foqra.
The WWTP was installed by the Office Chérifiens de Phosphate (OCP) to serve almost 226,000 inhabitants with a maximum capacity of 5 million m^3/year. The station has been operational since 2010 (Figure 2).

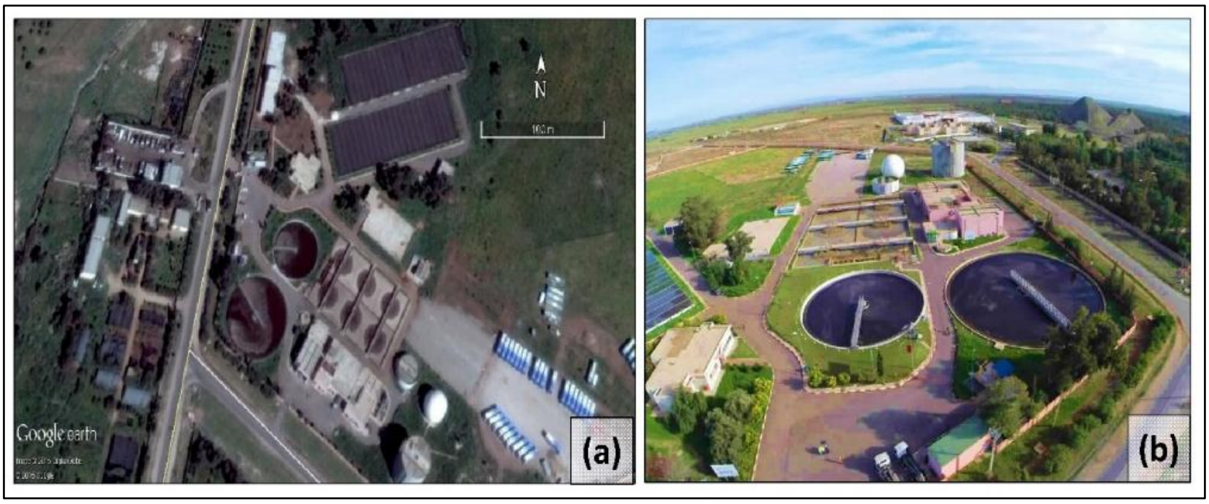

Figure 2*:* Satellite view (a) and panoramic photo (b) of the WWTP in Khouribga City.

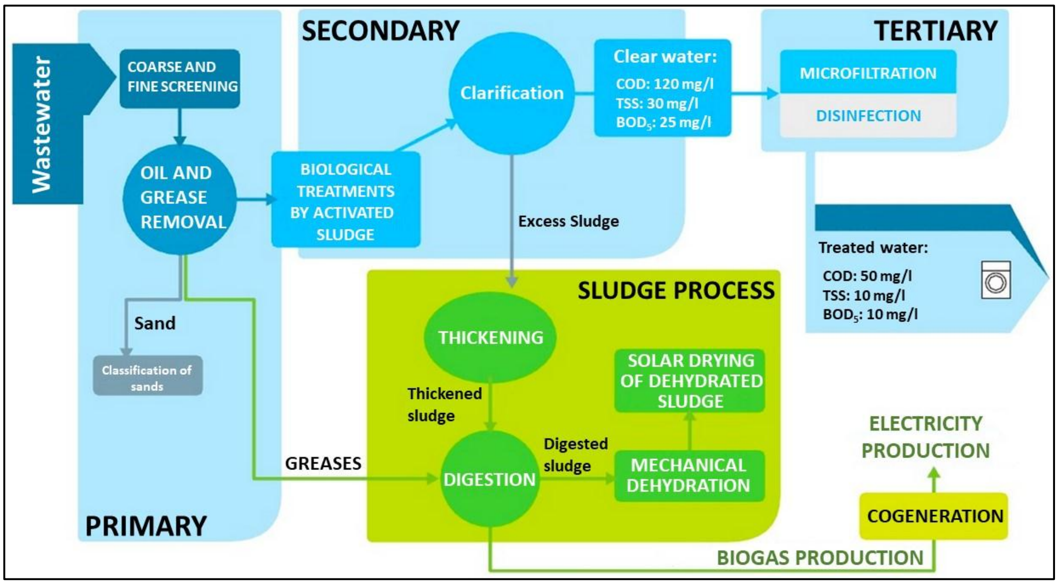

Figure 3*:* Diagram of the WWTP in Khouribga City.

The treatment plant in the city of Khouribga uses the medium-load activated sludge technique. Designed for the treatment of urban wastewater in the city of Khouribga, it has two treatment channels; one of wastewater treatment, the other for sludge treatment, and ventilation and deodorization system (Fig.3).

2.3. Operation and purification process of WWTP in Khouribga City

At the end of the pretreatment, the effluents feed a distribution structure located at the head of the biological basins. The distribution between the two aeration tanks is made by weir. At the end of the distribution, each recirculation feeds a line (Figure 4).

The aeration basin used for biological treatment is divided into two parts to ensure two isolable rows. It is therefore possible to isolate an aeration basin by installing a cofferdam at its supply spillway. This possibility makes it possible to adjust the supply configuration of the basins to operating constraints. In biological basins, biological treatment consists of eliminating organic impurities by the action of a free purifying biomass. It takes place entirely in the biological basin thanks to a specific population of bacteria which degrades pollution in the presence of oxygen. This mechanism generates bacterial growth which allows a renewal and a continuous development of bacteria.
Each biological basin is equipped with 3 aerators and 6 agitators. This equipment ensures the transfer of oxygen from the atmosphere to the effluent and biomass while maintaining a homogeneous mixture in the basins. With an aerated effluent, bacteria find favorable conditions for their development (they have oxygen and a carbon substrate).
In the basins, the following biological reactions take place:

- Degradation of the organic substrate: Bacteria use the available organic materials as a substrate. Under the action of enzymes and in the presence of oxygen, the reaction provides energy and by-products in the form of carbon dioxide, water and ammonia.

- Cell synthesis: The energy produced by the degradation of the substrate allows bacteria to grow and multiply, this is called cell synthesis. However, it is necessary to regulate the quantity of bacteria present in the basins. Also, the extraction of sludge allows maintaining a constant biomass.

Figure 4*:* Photo of the biological basin of the treatment plant in the city of Khouribga.

Satisfying the demand for O_2, without supplying it in excess, is essential for the quality of the treatment, but also for the economic aspect. Over-oxygenated sludge has a deflocculated appearance (problem of starting TSS in purified water). However, a lack of oxygen is harmful to the degradation of the substrate. The operation of aerating turbines is therefore subject to an oxygen concentration setpoint measured in biological basins. This measurement is carried out in each basin by an oxygen sensor. The process used is that of activated medium load sludge.
At the level of the clarifier, the separation of the treated water from the biomass. Its essential role is to separate the bacterial flock from the water, by gravitation. The effectiveness of the water / sludge separation depends on the settle ability of the sludge and the capacity of the structure to attenuate large variations in hydraulic loads.
The clarification works are equipped as follows (Figure 5):

- A conical bottom clarifier identical to a classic radial scraper bridge of 34 meters;

- Another cylindrical type clarifier with flat bottom and the scraper bridge is 1 radius + 1/3 radius design. It is a scraped-sucked bridge. This choice is conditioned by the large diameter of the structure (44.0 m in diameter in the mirror, for a water height of 3.5 m) and the need to effectively control the extraction of decanted sludge so as to limit their residence time in the structure.

The sludge recirculation and extraction are carried out using two sludge wells (one per clarifier) which are fed from the central barrel of the clarifiers. Each sludge pit is equipped with:

- Two pumps (including one installed as backup) for the recirculation of sludge withdrawn to the aeration basins.
- Two pumps (one of which is installed as backup) for extracting excess sludge towards the stabilization basins.

The volumes of recirculated sludge are counted as a function of time and the operating regime of the recirculation pumps. The volumes of sludge extracted are recorded by electromagnetic flowmeters. On leaving the clarifiers, the treated water is sent to tertiary treatment. The recirculation of the sludge collected in the clarifiers aims to:

- Maintain a constant concentration of biomass in the aeration basins to ensure optimum purification performance;
- Limit the residence time of the sludge to protect against any anaerobic condition likely to degrade the performance of the clarifier;
- Maintain an optimum sludge blanket in the clarifiers, on the one hand, to thicken the sludge before its extraction and recirculation and, on the other hand, to prevent any sludge leaking towards the discharge.

Taking into account the concentrations in the basins and the concentrations reached at the outlet of the clarifiers, the recirculation rate may reach 2,300 m^3/h. On each sludge well associated with a clarifier, recirculation is ensured by 2 submerged pumps (of which 1 as back-up installed). The two recirculation pipes supply the distribution structure located upstream from the aeration basins. In addition, the sludge extraction is carried out by two submersible centrifugal pumps (one of which is back-up). The extracted sludge is transported to the biological sludge thickener.

Figure 5: Photo of the clarifier of the treatment plant in the city of Khouribga.

2.3. Physico-Chemical Parameters

Samples of wastewater were collected from a domestic wastewater discharge channel of Khouribga City in Morocco and stored at 4 °C. The withdrawals were made on site. The analysis of different physical

and chemical parameters (pH, temperature, Electrical conductivity/Salinity, Turbidity, TSS, COD, BOD_5) was achieved according to the AFNOR standards (2001) [9]. Dilution -20°C incubation and $K_2CrO_4^-$ boiling methods were used respectively for BOD_5 and COD determination [9, 10].
Sludge Volume Index (SVI) is an extremely useful parameter to measure in a wastewater treatment process. In simple terms, SVI is the result of a mathematical calculation. It takes into account the 30-minute settle ability test results and the activated sludge mixed liquor suspended solids (MLSS) test result to come up with a number (or index) that describes the ability of the sludge to settle and compact. SVI gives a more accurate picture of the sludge settling characteristics than settle ability [11-13]. The formula for SVI is written:

$$\text{SVI (mL/g)} = \frac{\text{Settled Sludge Volume (mL/L)}}{\text{Mixed Liquor Suspended Solids (g/L)}} \times 1{,}000$$

For an activated sludge station: ratio between the weight of BOD_5 eliminated daily in the aeration tank and the weight of microorganisms (MVS) contained in this tank.

Cm = Q. So / Xt.V

with:

- Qo: daily flow,
- So: concentration of substrate,
- Xt: concentration of volatile matter in suspension of the biomass,
- V: volume of the reactor.

2.4. Microscopic examination

2.4.1. Microscopic examination without Gram stain

This preparation, called "dry state," makes it possible to determine different morphological parameters of the filamentous bacteria and the flocs: average number and length of the filaments, average surface and "roughness" of the flocs. The fresh state also makes it possible to determine the different morphological parameters of flocs and filamentous microorganisms. 15 µL of sludge is placed on a glass slide and covered with a coverslip. We observe at a magnification of 100 X [9, 14].

2.4.2. Microscopic examination with Gram stain

The Gram stain procedure is a differential staining procedure that involves multiple steps. It was developed by Danish microbiologist Hans Christian Gram in 1884 as an effective method to distinguish between bacteria with different types of cell walls, and even today it remains one of the most frequently used staining techniques. Gram Staining

First, crystal violet, a primary stain, is applied to a heat-fixed smear, giving all of the cells a purple color. Next, Gram's iodine, a mordant, is added. A mordant is a substance used to set or stabilize stains or dyes; in this case, Gram's iodine acts like a trapping agent that complexes with the crystal violet, making the crystal violet–iodine complex clump and stay contained in thick layers of peptidoglycan in the cell walls. Next, a decolorizing agent is added, usually ethanol or acetone/ethanol solution. Cells that have thick peptidoglycan layers in their cell walls are much less affected by the decolorizing agent; they generally retain the crystal violet dye and remain purple.

However, the decolorizing agent more easily washes the dye out of cells with thinner peptidoglycan layers, making them again colorless. Finally, a secondary counterstain, usually safranin, is added. This stains the decolorized cells pink and is less noticeable in the cells that still contain the crystal violet dye [9, 14].

3. Results and discussion

The analysis of the different parameters allows the monitoring of the operation of the Khouribga WWTP and more specifically the secondary treatment which constitutes the heart of the purification of wastewater. The effectiveness of the treatment is suggested by the degree of agreement of the parameters with the optimal standards which present the discharge or irrigation standards required by Moroccan laws 10-95 on water [15-17].

3.1. Physicochemical characterization of raw wastewater from WWTP

The detailed results of the physico-chemical analyses are illustrated in the Table 2:

Table 2: Values and ranges of variation of the physicochemical parameters of raw wastewater (at the entrance to the WWTP).

		T °C	pH	EC	Salinity	TSS	Turbidity	COD	BOD_5
				µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L
Variation Range	Min.	24.50	6.36	1046	832	310	297	415	386
	Max.	29.60	7.90	2404	2138	385	494	952	633
Average		27.65	7.26	1979.65	1121.5	229.22	262.29	680.57	513.12

3.1.1. Color of raw wastewater

The coloration of the wastewater observed at each sampling at the level of the collector shows that it is a domestic pollution since the waters are gray color (Figure 6). These gray waters are the waters of baths, showers, sinks, washing machines. Sewage or gray water refers to the by-products of digestion such as feces and urine. Sewage originating from different sources will have a different color. Some sewage will be brown, some green, gray or red. This depends on what the sewage contains.
Sewage from homes will mostly be brown, red from slaughter houses, blue or gray from laundries. When all of these sewage mix black sewage is formed.

Figure 6: Color of raw wastewater from WWTP in the city of Khouribga, Morocco.

3.1.2. Odor of raw wastewater

The odor of raw wastewater collected at the sampling point is very strong. It is mainly due to the presence of certain substances produced by the anaerobic decomposition of organic matter: hydrogen sulfide, indole, scatole, mercaptans and other volatile substances. The odor is very strong due to the release of gases such as hydrogen sulfide or ammonia compounds caused by anaerobic decomposition.

3.1.3. Temperature

The variations in the temperature of the WWTP have important effects, as they influence the development of colonies of microorganisms. The raw wastewater temperature is between 24.50 °C and 29.60°C as the minimum and maximum extreme values and 27.65°C as the average value. The recorded wastewater temperature values are close to 30°C. These values are slightly below 35°C, considered as an indicative limit value for discharge into the receiving environment and for water intended for irrigation [16].

3.1.4. Potential of Hydrogen (pH)

The pH is an indicator of pollution par excellence, it varies following the nature of the basic effluents (cooking, washing of resin: NaOH, NaS_2) or acid (dioxide, washing of resin: H_2S_4). The biological pH range is between 6.5 and 8. The recorded pH values vary between 6.36 and 7.90. The measured pH values are acceptable for direct and indirect rejection since these values vary between 6.50 and 8.50 [16].

3.1.5. Electrical conductivity

The electrical conductivity is probably one of the simplest and most important parameters for controlling the quality of wastewater. It reflects the degree of overall mineralization; it informs us of the salinity rate [18, 19]. The recorded electrical conductivity values are between 1046 µS/cm and 2404 µS/cm with 1979.65 µS/cm as the average value. The conductivity values recorded at the effluent level exceed 2000 µS/cm, considered as the limit value for direct discharge into the receiving environment [16].

3.1.6. Total Suspended Solid (TSS)

In general, suspended solids are involved in the composition of water by its ion exchange or absorption effect both on trace chemical elements and on microorganisms [6]. Suspended matter represents all of the mineral and organic particles contained in wastewater [20, 21]. The concentrations of suspended solids in raw wastewater vary between 310 mg/L and 385 mg/L with an average of 229.22 mg/L. The content of suspended matter is higher than the acceptable limit for discharge into the receiving environment which is 50 mg/L [16].

3.1.7. Chemical Oxygen Demand (COD)

The COD makes it possible to assess the concentration of organic or mineral matter, dissolved or suspended in water, through the amount of oxygen necessary for their total chemical oxidation [10]. COD values for raw wastewater vary between 415 mg/L and 952 mg/L with an average of 680.57 mg/L. The average value of the recorded COD are very much higher than 500 mg/L, considered as the limit value for direct discharge [16].

3.1.8. Biochemical Oxygen Demand (BOD_5)

The BOD_5 is an expression to indicate the quantity of oxygen which is used for the decomposition of organic matter decomposable by biochemical processes [22]. The values obtained for BOD_5 at the level of raw wastewater vary between 386 mg/L and 633 mg/L with an average of 513.12 mg/L.

The results of the global pollution parameters reports are presented in the Table 3:

Table 3: Reports of global parameters of raw wastewater pollution from WWTP.

Parameters	**BOD_5/COD**	**TSS/BOD_5**
Average	0.75	0.44

The BOD_5/COD ratio is important for the definition of the effluent treatment chain. Indeed, a clear value of the BOD_5/COD ratio implies the presence of a large proportion of biodegradable materials and makes it possible to envisage a biological treatment [6, 23]. Conversely, a low value of this ratio indicates that a large part of the organic matter is not biodegradable and, in this case, it is better to consider a physico-chemical treatment.

For a BOD_5/COD ratio greater than 0.4, the biodegradability of wastewater is high, and therefore the biological process is most suitable for the treatment of these effluents. However, at rates below 0.30, physico-chemical processes are generally more effective than biological treatments. With regard to the raw wastewater withdrawn, the BOD_5/COD ratio is high with an average value of 0.75, which confirms that the wastewater is heavily loaded with organic matter [23-25].

3.2 .Capacity Assessment and treatment performance of the WWTP

3.2.1. Evolution of temperature

The temperature has a major influence on the rate of biodegradation of wastewater in the aeration tank. The higher the temperature, the faster the biodegradation process. On the other hand, the temperature of the sludge or effluent is a sensitive factor which has various repercussions on treatment and generates various dysfunctions. The temperature of the wastewater in the two biological basins of the WWTP remains generally low throughout the internship period, between 12 and 15.7°C (Figure 7). It is influenced by the decrease in the temperature of the atmosphere of the city of Khouribga during the month of January 2020. This decrease in temperature causes a decrease in the metabolic activity of microorganisms which induces, in addition, proportionately slower recovery times. So, this parameter represents a limiting factor in the biological treatment during this month [7, 10, 26].

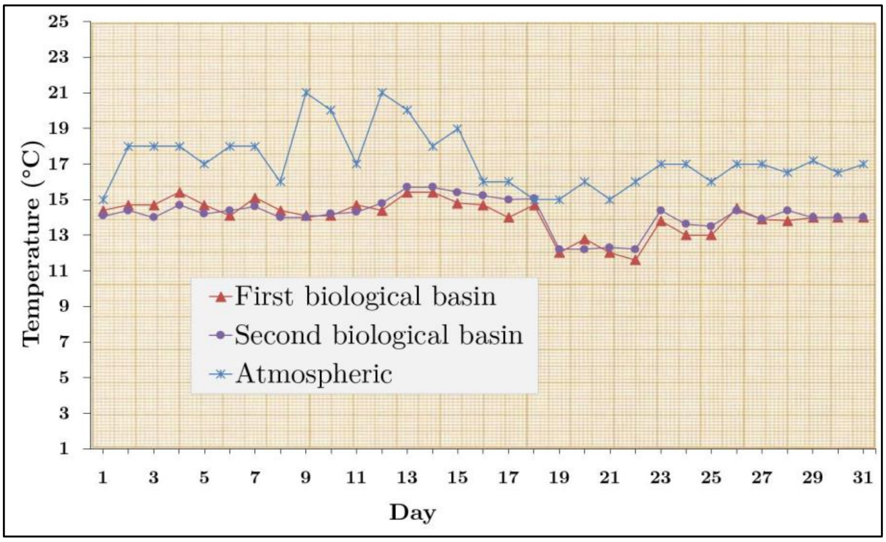

Figure 7: Temperature changes in biological basins of WWTP.

3.2.2. Evolution of pH

The urban wastewater has a high-buffering capacity. The pH values of the wastewater before treatment are between 6.36 and 7.90 with an average of 7.26 which is a characteristic of wastewater, the pH of which is often around 7.5 to 8, the most favorable for bacterial action, for aerobic and anaerobic purification processes. According to Sevrin Reyssac [27], the alkaline pH and the moderate temperature constitute ideal environmental conditions for the proliferation of microorganisms which establish a perfect biological balance, allowing the degradation of organic matter which leads to the decontamination of water [7, 28].

Regarding treated water, the pH is always lower than that recorded at the inlet. The values revolve around neutrality with a tendency towards alkalinity, they vary between 7.19 and 7.82 with an average of 7.53 (Figure 8), respecting the rejection standard delimited between 6.5 and 8.5. According to Gaujoux and Lair [29], this value coincides with the normal pH of seawater and freshwater.

3.2.3. Evolution of electrical conductivity

The hydrogen potential of the water inflow to the WWTP is measured in order to estimate the degree of acidity of the effluent. This factor does not experience any significant variations during the stages of treatment. Its values oscillate around the average which is around 7.53 (Figure 9). Generally, they do not exceed the ordered interval (between 6.5 and 8.5) to promote metabolic activity and certain biological oxidation processes (nitrification) [30, 31]. Other, the value of the conductivity (between raw water, on the one hand, and clarified water and treated water on the other hand) does not register a decrease, which is normal since there is no reduction of soluble ionic compounds during the different treatment stages, this value does not exceed 2467 µS/cm.

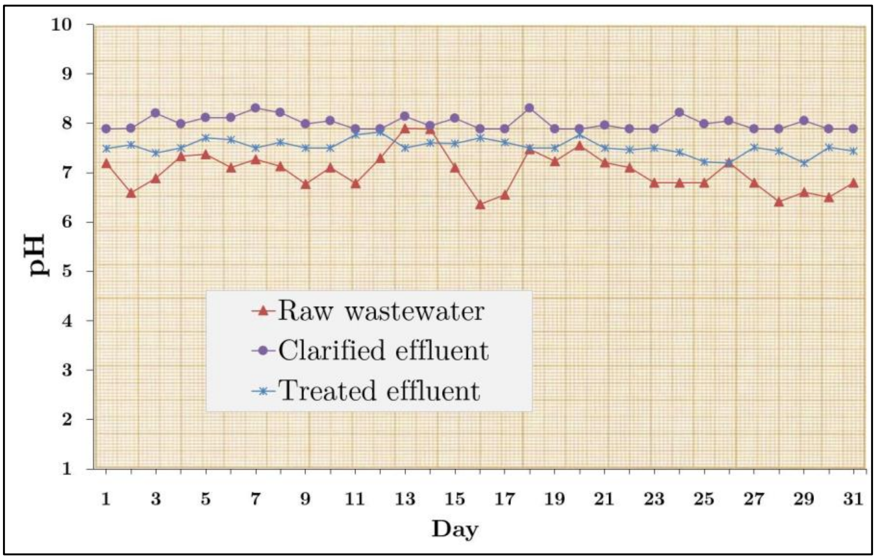

Figure 8: pH changes in WWTP.

The conductivity increases in day 10 is explained by the discharge of residual waste water from industrial units in the sanitation network of the city of Khouribga. While the marked decrease in days 20, 21 and 25 is related to the dilution effect due to the precipitation recorded during this month.

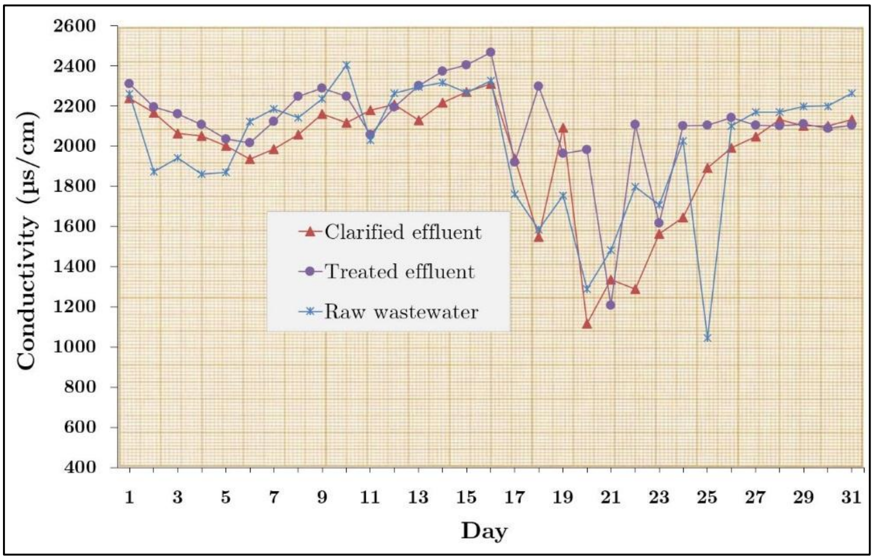

Figure 9: Conductivity (µS/cm) changes in WWTP.

The pH and electrical conductivity in the clarifier allow the appreciation of the metabolic behavior of fixed microorganisms. Their evolution and an indirect measure of the intensity of their activity. The alkalinization of the medium is mainly due to the denitrification process. In fact, the active denitrifying flora participates in increasing the pH of the genesis of hydroxide ions which cause the pH to vary towards values greater than 7 as shown in the following equation [31]:

$$C_{10}H_{19}O_3N + 10\ NO_3^- \rightarrow 5\ N_2 + 10\ CO_2 + 3\ H_2O + NH_3 + 10\ OH^-$$

The decrease in electrical conductivity as a function of biofilm development is due to the use of ionic substances by bacteria during their growth. The evolution of the pH with respect to the conductivity of the medium has a negative correlation (R = - 0.98). It should also be noted that physical or biological treatments have only a small impact on this parameter and that its value varies little between raw water and treated water [31].

3.2.4. Evolution of salinity

We have noticed that the maximum mean value of the raw sewage salinity is 2138 mg/L, and the minimum mean value of 832 mg/L (Figure 10).

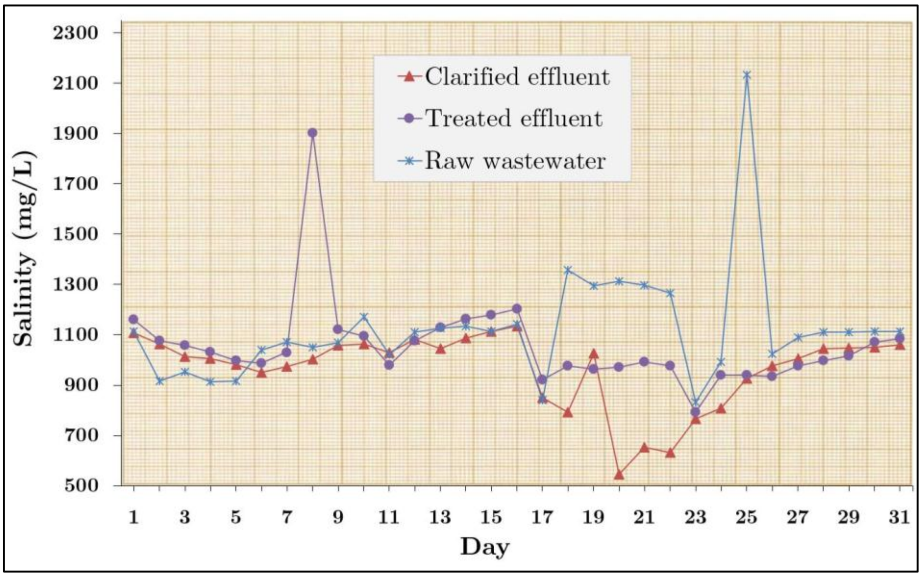

Figure 10: Salinity (mg/L) changes in WWTP.

These values highlight the very significant mineralization of wastewater. The salinity values in the clarified waters vary between 546 mg/L and 1133 mg/L. In addition, the salinity values recorded in the treated water range from 792 mg/L to 1901 mg/L.

3.2.5. Evolution of turbidity

The turbidity is an index of the presence of suspended particles in the wastewater. The figure above shows the evolution of the turbidity of the WWTP wastewater. Figure 11 shows that there is an increasing progressive variation with time of the reduction in the efficiency of the elimination of turbidity in the clarifier and of the treated water at the outlet of the WWTP, it reaches a value of the 98% of the twenty-eight days. This variation is due to the use of organic matter by the microbial flora of the sludge [32, 33].

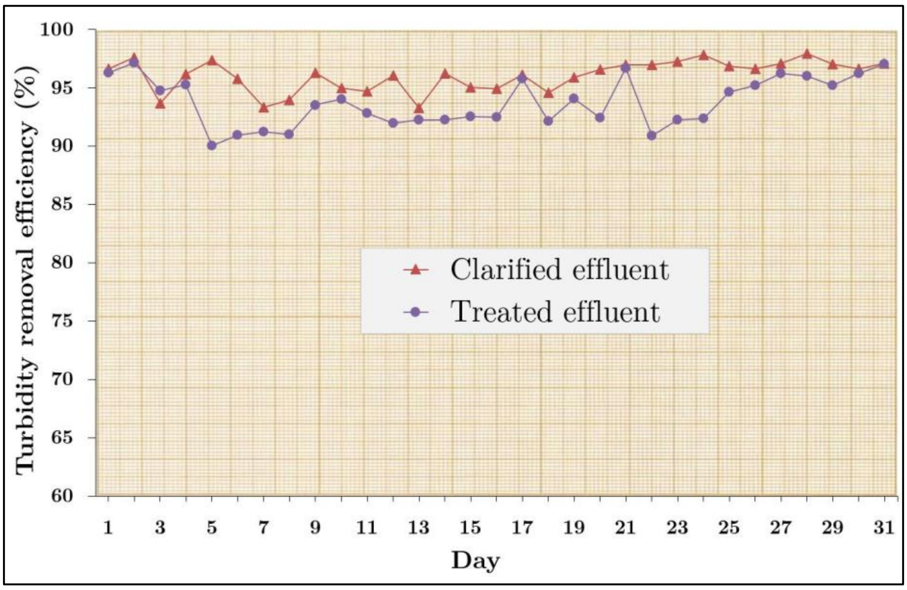

Figure 11: Steady-state Turbidity removal efficiency in WWTP.

3.2.6. Evolution Total suspended solids (TSS)

Total suspended solids represent all of the undissolved mineral and organic particles contained in wastewater. Their effects on the physicochemical characteristics of water are very harmful (modification of water turbidity, reduction of light penetration endangering photosynthesis).

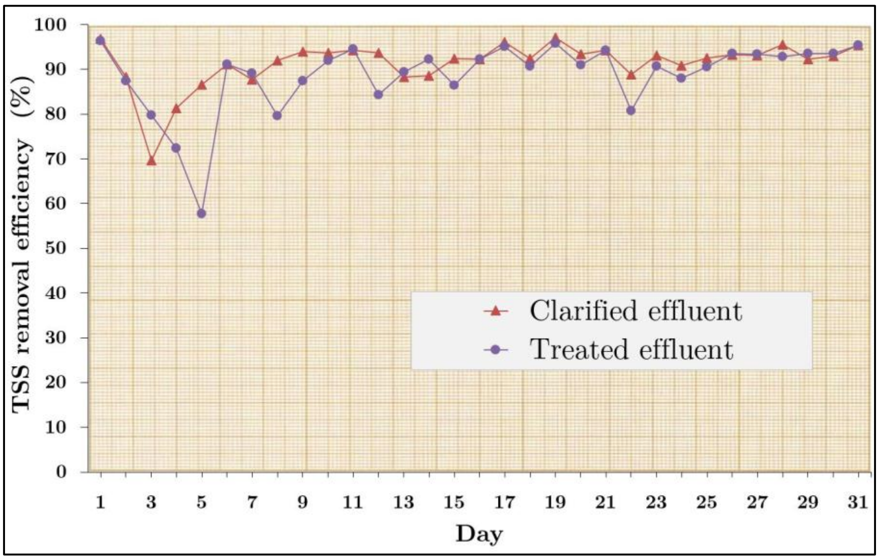

Figure 12: Steady-state TSS removal efficiency in WWTP.

The TSS concentrations vary significantly between the raw wastewater (with an average of 229.22 mg/L) and the treated water (with an average of 23.44 mg/L), and reach a reduction of 96.5% (Figure 12). This decrease is probably due to the phenomenon of adsorption of suspended matter on biological flakes, on the one hand, and, on the other hand, the good sedimentation at the level of the clarifier.

Generally, an increase in TSS directly induced a significant increase in turbidity and therefore a reduction in photosynthetic activity which causes the depletion of the medium in dissolved oxygen. The availability of electrons in organic carbon compounds is one of the most important factors that control the activity of denitrifying heterotrophic bacteria [34]. This author concluded that denitrification has significantly contributed to the degradation of organic matter.

3.2.7. Evolution of CDO

Figure 13 shows the evolution of the COD elimination yield in the WWTP.

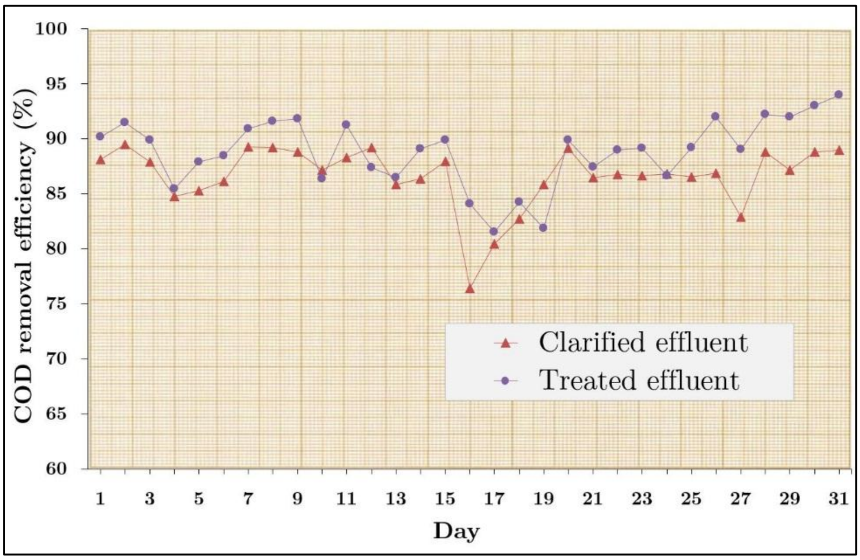

Figure 13: Steady-state CDO removal efficiency in WWTP.

The results show a variation in the COD of raw water and treated water, note that the raw water has a COD which varies between 415 and 952 mg of O_2/L. On the other hand, COD has a significant decrease in treated water with values below the optimal limit which is 120 mg O_2/L, throughout the month. With a reduction rate of 92.18%. The significant concentrations of COD in water entering the station are explained by the presence of a fraction of non-biodegradable organic matter in the treated effluent [35].

3.2.8. Evolution of BOD_5

Figure 14 shows that there is an increasing progressive variation with time of the reduction in the yield of the elimination of BOD_5 in the clarifier and of the treated water at the outlet of the WWTP, it reaches a value of the around 97.9% every twenty-one days. This variation is due to the use of organic matter by the microbial flora of the sludge.

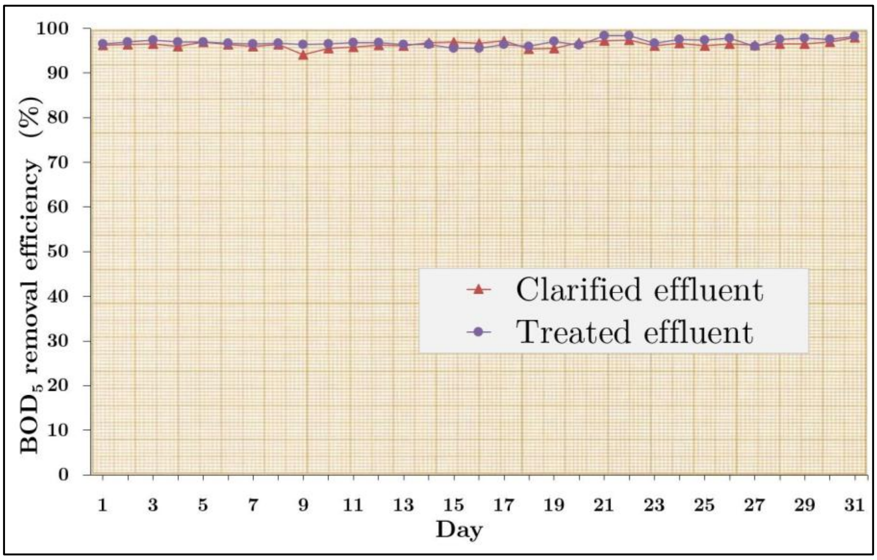

Figure 14: Steady-state BOD_5 removal efficiency in WWTP.

The BOD_5/COD ratio is important for the definition of the effluent treatment chain. Indeed, a clear value of the BOD_5/COD ratio implies the presence of a large proportion of biodegradable materials and makes it possible to envisage a biological treatment. Conversely, a low value of this ratio indicates that a large part of the organic matter is not biodegradable and, in this case, it is preferable to consider a physico-chemical treatment [24].

3.2.9. Evolution of Mass Load (CM)

The average daily flow rate is a key parameter which gives an idea of the quantity of pollutants loads of wastewater at the inlet of the WWTP. The Figure 15, shows that there is a gradual variation in the quantity of wastewater entering the WWTP with a maximum value of around 22,850 m^3/h every twenty-one days. Generally, mass load measurements also showed progressive and proportional variations to the values of average daily flow rate of raw wastewater. A low load operation (less than 0.1 kg BOD_5 per kg of MVS per day) as indicated in the first 5 days, consists of supplying little nutrients to a concentrated purifying ecosystem. While it is the opposite of high load (greater than 1 kg/kg.J), which limits the concentration of bacteria but increases their rate of oxidation;

The results show that the operation adopted by WWTP is a medium load operation which is compromised between the two operating modes (0.2 to 0.5 kg / kg.J).

3.2.10. Evolution of Sludge Volume Index (SVI)

Figure 16, shows the quantity of sludge settled in the two biological basins of the Khouribga WWTP. In general, the results obtained have shown that variations in the sludge index can cause decantation failures and problems with the proliferation of filamentous bacteria.

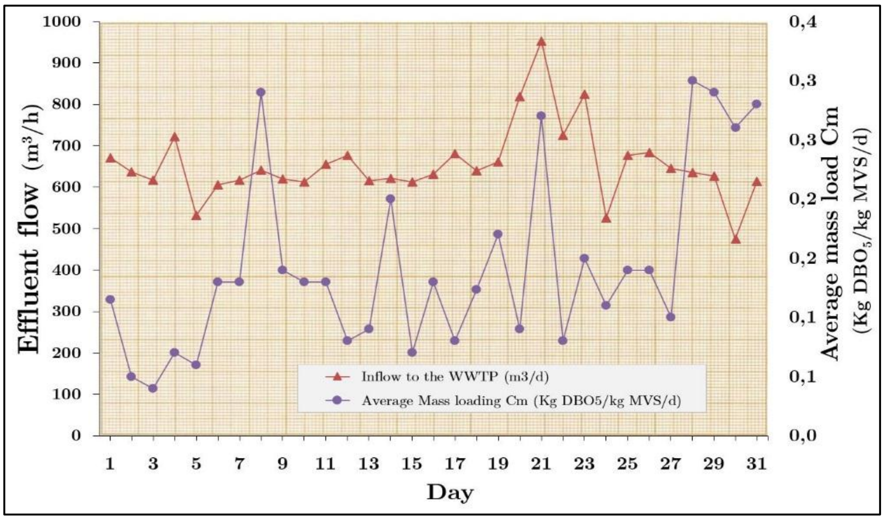

Figure 15: Daily flow and mass load changes in WWTP.

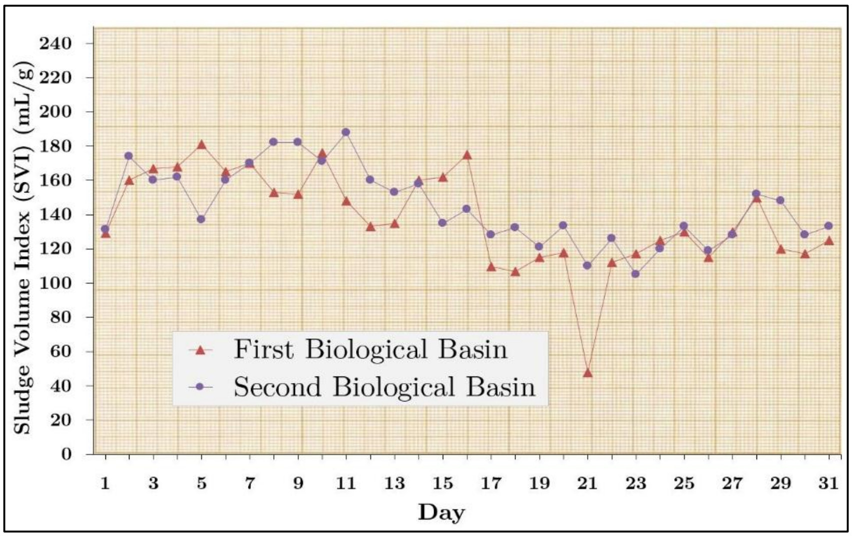

Figure 16: Sludge Volume Index changes in two biological basins of WWTP.

For the first 17 days, the majority of (SVI) values are greater than 150 mL/g, which can be explained by the phenomenon of bulking or the proliferation of filamentous bacteria in biological basins. On the other hand, on the 21st day, a sludge index of 48 mL/g is recorded. This value is less than 50 mL/g, which indicates that we have good settling properties (the flocs are not sufficiently concentrated) [36, 37].

3.2.11. Evolution of sludge dryness

The physical state of a slurry mainly depends on its dryness, which represents the dry matter content. Given the diversity of the sludge produced, it is difficult to know exactly the dryness limit values for each physical state. Any attempt to set limits is arbitrary. Table 4, presents a rough idea of the evolution of the consistency of the mud as a function of the dryness [11].

Table 4: Physical state of the residual sludge according to the dryness.

Dryness (%)	< 10 %	10-25 %	25-50 %	> 50 %
State	Liquid	Pasty	Solid	Granular

The results of the sludge dryness measurement are provided in Figure 17. Drought is measured in the raw wastewater at the entrance to the station and on the samples taken during treatment. From the above results, we note that the dryness of the sludge from waste water from the feed varies between 44 and 70% which leads to the conclusion that the state of the sludge is solid. On the other hand, the values recorded in the samples taken during the treatment process showed a constant variation of the order of 2 to 5%, which shows that the state of the sludge is liquid during the treatment.

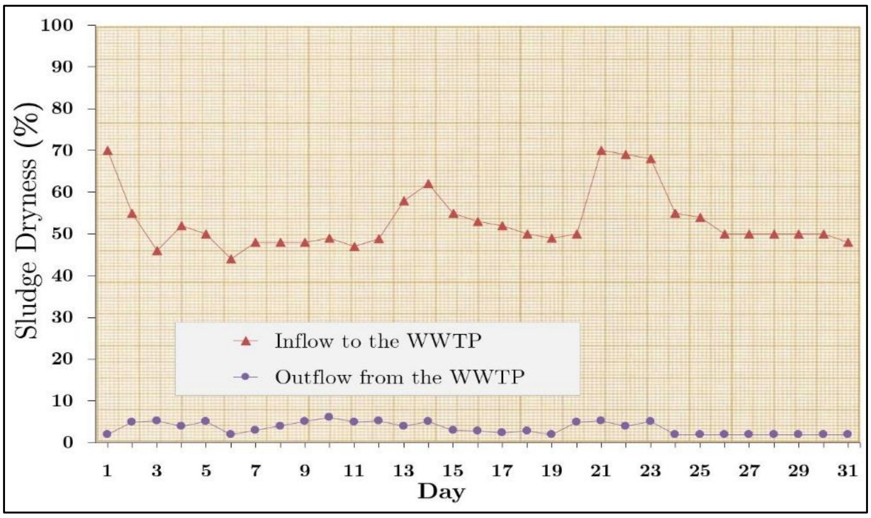

Figure 17: *Rate change of sludge dryness in WWTP*.

3.3. Microbiological aspects of biological basins of the WWTP

Regular basin monitoring made it possible to detect the beginning of the proliferation of filamentous bacteria (Figure 18).

Figure 18: *Biological foam on the surface of the aeration basin in WWTP*.

The means generally implemented for detection further upstream focus on microscopic observation which is tedious and rarely objective. The proliferation of filamentous bacteria in the aeration basin has unfortunate consequences both environmentally and economically speaking. Indeed, once these bacteria are present in large numbers in the basin, they cause decantation defects, foaming and release of sludge into the natural environment [38-41].

3.3.1. Problems caused by filamentous bacteria in WWTP

The main dysfunctions due to filamentous bacteria recorded at the Khouribga WWTP appear in two forms:

- The proliferation: poor decantation of the sludge following an increase in the volume occupied by it;
- Foaming: formation of a thick layer of foam on the surface of the works.

The causes are often of multiple origins (design, operation, composition of the effluent, etc.) and the choice of solutions requires a global analysis: design, operation and operation of the station. Significant filamentary development severely limits the hydraulic capacity of the clarifier and can cause sludge to leave the natural environment [41, 42].

In the WWTP, the proliferation is often associated with:

- A deterioration in the quality of the discharge in the event of loss of episodic or chronic sludge;
- A slightly flaky floc with a large decanted volume during the decantation test, which makes it imperative to dilute the sludge samples.

The foam form very stable floating clusters of light to dark brown color and viscous structure. Their density tends to increase gradually over time. These foams are little unstructured by surface agitation and quickly reform a uniform carpet in the absence of agitation. Gas bubbles promote flotation. These floats constitute an environment favorable to the privileged development of certain filamentous bacteria responsible for foaming. The only way to treat them is to inject a biocide (chlorine, oxygen peroxide ...) to eliminate them or a flocculant to blur their effect. In all cases, the treatment is expensive and risky because it jeopardizes the rest of the purifying biomass present [41, 43].

3.3.2. Possible methods of controlling these filamentous bacteria in WWTP

It is possible to combine different techniques to optimize the effectiveness of the treatment.

3.3.2.1. Preventive actions

Given the complexity of the problems relating to the proliferation and facing the diversity of the technical options that can be used, a pragmatic approach is necessary. It must be based on technical data collected as part of a preliminary study comprises two main phases [44-46]:

- Precise characterization of the problem (diagnosis of swelling, type of filaments, etc.): This characterization makes it possible, for example, to avoid confusion between swelling and other mechanisms (for example denitrification, etc.). In addition, a precise identification of the filament guides the search for the factors triggering its development.

- In-depth study of the station in order to highlight the supposed origins of the phenomenon and possible aggravating factors (design, operating parameters, etc.).

Despite the inevitable delays that they cause, these examinations are the guarantees of the long-term effectiveness of the curative technique chosen. This choice must also take into account the acuteness of the phenomenon and its permanent or occasional nature.

3.3.2.2. Curative actions

In general, the deterioration of the Sludge Volume Index (SVI) is only exceptionally brutal and experience has shown that many stations suffer from permanent latent growth. Acute manifestations are in fact only an amplification of the phenomenon linked to the sudden variation of one of the operating parameters of the station (defective settings ...). In any case, after having solved the acute problem, it will be advisable to modify the settings or to set up other techniques which are less restrictive from the operational and economic points of view [46].

3.4. Parameters influencing the operation of aeration basins

The activated sludge process can be influenced by several factors. We must create optimal operating conditions in order to obtain the most efficient wastewater treatment possible.

3.4.1. Biological problems

3.4.1.1. Inhibition by filamentous bacteria

Filamentous bacteria, like flocculent bacteria contribute to the wastewater treatment process. However, massive growth of filamentous microorganisms leads to deterioration of the settling and dewatering

properties of the sludge. A cluster of filaments is created and the migration of sludge particles to the bottom of the basin is seriously hampered. In other words, the filaments can cause poor sludge sedimentation [46].
The population size of filamentous microorganisms in an activated sludge system can vary widely and is often reflected in the filament index (= FI). This index starts from 0 (= almost total absence of filaments) and ends at 5 (very large excess of filaments). The difference in the quantity of filaments between 2 successive FI levels corresponds roughly to a factor of 10. The use of the filament index induces a certain experience and interpretation of researchers/operator [46].

3.4.1.2. Foam inhibition
The foams are cellular acotyledonous plants, with single or compound stems, with branched roots and composed of a single series of elongated cells, with leaves inserted horizontally and arranged in spirals [47]. The foam form very stable floating clusters of light to dark brown color and viscous structure. Their density tends to increase gradually over time. These foams are little unstructured by surface agitation and quickly reform a uniform carpet in the absence of agitation. Gas bubbles promote flotation. These floats constitute an environment favorable to the privileged development of some filamentous bacteria responsible for foaming [48].
The appearance of a small amount of foam in a treatment plant is quite normal, even when the system is operating normally. However, if this foam is in abundance on the surface of the aeration and clarification tanks, this is not normal.
This extreme foaming can be explained by several factors:

- Presence of high concentrations of detergents and fats
- pH too high or too low
- Absence of oxygen
- Absence of nutrients
- Sludge too old.

In some extreme cases, the foam can represent up to 1/3 of the total biomass, with concentrations of dry matter up to 100 g/L or heights of over a meter. The operating parameters (mass load) and operation of the station are then greatly degraded by this situation (reduction in oxygen transfer) [48].

3.5 .Mechanical problems
3.5.1. Aeration problems
Oxygen is essential to oxidize organic matter and ammonium thanks to the biomass present. The absence of oxygen immediately influences the efficiency of abatement. Oxygen must be supplied in dissolved form, hence the term dissolved oxygen (DO). A minimum DO concentration between 1 and 2mg O_2/L should be stored in the aeration basin.
The supply of O_2 can be carried out using surface aerators (brings the water into contact with the surrounding air), a fine bubble aeration (injection of small air bubbles in the water) or a submerged aerator. Sometimes pure oxygen is used to purify a wastewater treatment plant.
Aeration operation consists of 2 basic processes:

- Physical process: oxygen is in the water and then transported to the sludge flakes (diffusion and turbulence)**;**
- Biochemical process: before oxygen can be used by organic cells, O_2 molecules must be diffused through the cell membrane.

Obviously, the transfer of oxygen into a biological system is influenced by many factors: composition of the waste water, temperature, type of aeration, characteristics of the sludge and configuration of the reactor. Oxygen deficiency in a wastewater treatment plant can be caused by biochemical as well as physical factors (malfunction of the aeration system). The main biochemical factors inducing a deficit in OD and consequently a malfunction of the biological reactor are:

- Organic overload: loads greater than the maximum load;
- Excess fat, oil or other surfactants in the bioreactor;
- Too much sludge concentration: negative impact on the oxygen transfer rate and increased endogenous respiration;
- Large clusters of filamentous sludge (Nocardia);
- The problems of the aeration system;

Prolonged lack of oxygen can lead to:

- The reduction in the removal efficiency;
- The formation of a filamentous biomass, therefore less good decanting;
- The odor nuisance, due to the formation of volatile acids and H_2S under anaerobic conditions;
- The complete cessation of nitrification reactions (= NH_4^+-N oxidation) and therefore no more nitrogen removal.

Too high oxygen concentrations do not directly influence the abatement efficiency, but DO concentrations> 5 mg O_2/L should be avoided, as:

- Waste of energy.
- Smaller flakes (= poor decantation/ turbid effluent).
- Possibly the cause of filament formation.

3.5.2. Malfunction of agitators

A dysfunction of the agitators (breakdown, insufficient specific power) can induce the formation of deposits at the bottom of the structure and create anaerobic zones favorable to the development of populations of filamentous bacteria (less aeration, septicity) [4, 49].

When it is put in place during construction, a poor position of the agitator within the basin (angle, positioning / wall, immersion height, etc.) or the presence of an obstacle (lateral guides of the oversized diffuser rackets, transverse canals ...) in front of it will strongly penalize its efficiency and can create hydraulic movements contrary to those sought (spiral flow). In addition, visual observation of bubbles rising (in air blowing) makes it possible to apprehend the existence of spiral flow between the agitator and the first racket of diffusers [4, 49].

The observation of a surface countercurrent in front of the agitator, aeration and agitation in motion, or the continuous presence of stable foam at certain points in the basin suggests a hydraulic malfunction. Likewise, the arrival of air bubbles in the sweeping area of the blades indicates poor implantation of the device [4, 49].

Conclusion

At the end of this work, which focused on the study of the dysfunctions of the biological basins of the wastewater treatment and reuse plant in the city of Khouribga, we were able to meet the objectives previously outlined. Indeed, in spite of the thoughtful and carefully applied measures for this WWTP to fulfill its mission in the standards, some dysfunctions relating to the optimization of the purification process have been noted and remain to be improved.

The main dysfunction noted in the WWTP aeration tanks is the proliferation of filamentous bacteria associated with poor settling. The causes are very often of multiple origins: either the composition of waste water: (Richness in carbohydrates [sugars, alcohols, ...], nutrient deficiencies [N, P], suspended matter, or dissolved oxygen. In fact, work on the relationships between the state of aeration of the sludge and the profusion demonstrate the negative effects of under-aeration of the sludge, since deficiencies in dissolved oxygen are an aggravating factor, whatever the mass load.

This problem of proliferation results in poor settling sludge following an increase in the volume occupied by it. Significant filamentary development severely limits the hydraulic capacity of the clarifier and can cause mud to leave the natural environment. The foams are also a likely biological problem at the level of activated sludge treatment plants. The foam form clusters of very stable floats of light brown to dark

color and viscous structure. Their density tends to increase gradually over time. These foams are little unstructured by surface agitation and quickly reform a uniform carpet in the absence of agitation. Gas bubbles promote flotation. These floats constitute an environment favorable to the privileged development of some filamentous bacteria responsible for foaming.
Furthermore, the low temperature seems to limit the biological treatment during the month of January 2020. Nevertheless the studied parameters [conductivity, pH, salinity, BOD_5/COD ratio, mass load] display optimal values for a better qualitative yield. The significant reduction in suspended solids, the COD value and the BOD_5 value of treated water is proof of this.

References

1. Y. Salama, M. Chennaoui, M. Mountadar, M. Rihani, O. Assobhei, The physicochemical and bacteriological quality and environmental risks of raw sewage rejected in the coast of the city of el Jadida (Morocco), *Carpath. J. Earth. Env.*, 8(2) (2013) 39-48.
2. S. Youssef, C. Mohammed, E.A. Mohammed, M. Mohammed, R. Mohammed, A. Omar, Evaluation of the qualitative and quantitative of parasitic load and Environmental Risks of Raw Sewage Rejected on the Coast of the City of El Jadida (Morocco), *J. Mater. Environ. Sci.*, 7(2016)1614-23
3. J. Schwartzbrod, S. Banas, Parasite contamination of liquid sludge from urban wastewater treatment plants, *Water Sci. Technol.*, (2003) 163-166. https://doi.org/10.2166/wst.2003.0189
4. F.R. Spellman, Handbook of Water and Wastewater Treatment Plant Operations, Third Edition, Taylor & Francis, ISBN: 9781466553378 (2013).
5. O. Assobhei, M. Mountadar, A. Aajjane, J. Amine, K. Chedad, S. Etahiri, E.M. Kabil, M. Rafrafi, M. Rihani, L.A. Semlali, Production et gestion des boues des stations d'épuration des eaux usées et des déchets organiques biodégradables au Maroc. Délivrable 1 du Projet MOROCOMP (LIFE 05 TCY/MA/000141) http://www.uest.gr/morocomp, (2006).
6. ONEP, Approche de la typologie des eaux usées urbaines au Maroc, Office National de l'Eau potable, Rabat -Maroc, (2005).
7. Y. Salama, M. Chennaoui, A. Sylla, M. Mountadar, M. Rihani, O. Assobhei, Review of Wastewater Treatment and Reuse in the Morocco: Aspects and Perspectives, *Int. J. Environ. Pollut.*, 2(1) (2014) 9-25.
8. ABHBC, Etude d'évaluation des eaux de surface de la zone d'action de l'agence du bassin hydraulique du Bouregreg et de la Chaouia, Agence du Bassin Hydraulique du Bouregreg et de la Chaouia, (2004).
9. AFNOR, (L'Association française de normalisation). Recueil de normes françaises des eaux : méthodes d'essais, Paris-La Défense, (2001).
10. J. Rodier, B. Legube, N. Merlet, L'analyse de l'eau - 10e éd. - Eaux naturelles, eaux résiduaires, eau de mer: Eaux naturelles, eaux résiduaires, eau de mer, Dunod, ISBN : 9782100754120 (2016).
11. G. Mininni, E. Mauro, B. Piccioli, G. Colarullo, F. Brandolini, P. Giacomelli, Production and characteristics of sewage sludge in Italy, *Water. Sci. Technol.*, 79(4) (2019) 619-626. https://doi.org/10.2166/wst.2019.064
12. C. Leal, A.V. del Río, D.P. Mesquita, A.L. Amaral, P.M. Castro, E.C. Ferreira, Sludge volume index and suspended solids estimation of mature aerobic granular sludge by quantitative image analysis and chemometric tools, *Sep. Purif. Technol.*, 234 (2020) 116049. https://doi.org/10.1016/j.seppur.2019.116049
13. M.B. Khan, H. Nisar, C.A. Ng, P.K. Lo, Estimation of sludge volume index (SVI) using bright field activated sludge images, 2016 IEEE International Instrumentation and Measurement Technology Conference Proceedings, IEEE, ISBN: 1467392200 (2016).
14. S. Sharma, J. Acharya, M.R. Banjara, P. Ghimire, A. Singh, Comparison of acridine orange fluorescent microscopy and gram stain light microscopy for the rapid detection of bacteria in cerebrospinal fluid, *BMC Res. Notes*, 13(1) (2020) 1-5.

15. P. Drechsel, C.A. Scott, L. Raschid-Sally, M. Redwood, A. Bahri, L'irrigation avec des eaux usées et la santé, Presses de l'Universite du Quebec, ISBN : 9782760531611 (2011).
16. S.E.E.E, (Secrétariat d'Etat Chargé de l'Eau et de l'Environnement) Recueil des lois relatives à la protection de l'environnement, Royaume du Maroc, Département de de l'Environnement, (2010).
17. O.M.S, Caracterisation des dangers liés à la présence de pathogènes dans les aliments et dans l'eau: Directives, Organisation mondiale de la Santé, ISBN : 9789242541694 (2004).
18. S. El Kettani, E.M. Azzouzi, Prévalence des helminthes au sein d'une population rurale utilisant les eaux usées à des fins agricoles à Settat (Maroc), *Environ. Risque Sante*, 16(4) (2006) 245-251. https://doi:10.1684/san.2007.0046
19. Y. Salama, M. Mountadar, M. Rihani, O. Assobhei, Evaluation physicochimique et bactériologique des eaux usées brutes de la ville d'El Jadida (Maroc), *ScienceLib Editions Mersenne*, 4 (2012) 1-13.
20. T.A. Larsen, K.M. Udert, J. Lienert, Source Separation and Decentralization for Wastewater Management, IWA Publishing, ISBN: 9781843393481 (2013).
21. A.J. Komakech, N.E. Banadda, J.R. Kinobe, L. Kasisira, C. Sundberg, G. Gebresenbet, B. Vinnerås, Characterization of municipal waste in Kampala, Uganda, *J Air Waste Manag. Assoc.*, 64(3) (2014) 340-348. https://doi.org/10.1080/10962247.2013.861373
22. Y. El Guamri, D. Belghyti, Etude de la qualité physico-chimique des eaux usées brutes de la commune urbaine de Saknia, rejetées dans le lac Fouarat (Kénitra, Maroc), *J. Afr. Sci. Environ.*, 1 (2006) 53-60.
23. S. Youssef, Aide-mémoire de traitement biologique des eaux usées de l'ingénieur «Première Édition», Les Editions du Net, ISBN : 9782312022406 (2014).
24. O.B. Smith, P. Moustier, CIRAD, I.D.R. Centre, Développement durable de l'agriculture urbaine en Afrique francophone: enjeux, concepts et méthode, Centre de coopération internationale en recherche agronomique pour le développement, ISBN: 9782876145511 (2004).
25. A.N. Bdour, M.R. Hamdi, Z. Tarawneh, Perspectives on sustainable wastewater treatment technologies and reuse options in the urban areas of the Mediterranean region, *Desalination*, 237(1) (2009) 162-174. https://doi.org/10.1061/40927(243)565
26. D.A. Ratkowsky, J. Olley, T. McMeekin, A. Ball, Relationship between temperature and growth rate of bacterial cultures, *Am. Soc. Microbiol. J.*, 149(1) (1982) 1-5.
27. J. Sevrin-Reyssac, D. Proulx, Les eaux usées, source de biomasse, *Biofutur*, 1995(143) (1995) 15-23. https://doi.org/10.1016/0294-3506(95)80197-9
28. S. Youssef, Traitement Biologique des Eaux Usées au Maroc «Développement d'un bioréacteur à biomasse fixée immergée pour le traitement des eaux usées domestiques», Éditions Universitaires Europeennes, ISBN : 9783841672087 (2015).
29. G. Didier, La pollution des milieux aquatiques : aide-mémoire (2ème éd.), Tec & Doc Lavoisier, ISBN : 9782743000219 (1999).
30. M. Šimek, J. Cooper, The influence of soil pH on denitrification: progress towards the understanding of this interaction over the last 50 years, *Eur. J. Soil Sci.*, 53(3) (2002) 345-354. https://doi.org/10.1046/j.1365-2389.2002.00461.x
31. R. Barnard, P.W. Leadley, B.A. Hungate, Global change, nitrification, and denitrification: a review, *Global Biogeochem. Cy.*, 19(1) (2005) 1-13. https://doi.org/10.1029/2004GB002282
32. H. Rasmussen, J.H. Bruus, K. Keiding, P.H. Nielsen, Observations on dewaterability and physical, chemical and microbiological changes in anaerobically stored activated sludge from a nutrient removal plant, *Water Res.*, 28(2) (1994) 417-425. https://doi.org/10.1016/0043-1354(94)90279-8
33. B.-M. Wilén, J.L. Nielsen, K. Keiding, P.H. Nielsen, Influence of microbial activity on the stability of activated sludge flocs, *Colloids and Surfaces B: Biointerfaces*, 18(2) (2000) 145-156. https://doi.org/10.1016/S0927-7765(99)00138-1

34. H. Bothe, S. Ferguson, W.E. Newton, Biology of the Nitrogen Cycle, Elsevier Science, ISBN: 9780080471334 (2006).
35. G. Crini, P.M. Badot, Traitement et épuration des eaux industrielles polluées: procédés membranaires, bioadsorption et oxydation chimique, Presses universitaires de Franche-Comté, ISBN : 9782848671970 (2007).
36. W.W. Eckenfelder, J.G. Cleary, Activated Sludge Technologies for Treating Industrial Wastewaters, Destech Publications Incorporated, ISBN: 9781605950198 (2013).
37. G. El Kadiri Boutchich, S. Tahiri, M. Mahi, D. Gallart-Mateu, M. de la Guardia, A. Aarfane, E. Lhadi, M. El Krati, Characterization of activated sludge from domestic sewage treatment plants and their management using composting and co-composting in aerobic silos, *J. Mater. Environ. Sci.*, 6(8) (2015) 2206-2220.
38. R. Bowker, Biological odour control by diffusion into activated sludge basins, *Water Sci. Technol.*, 41(6) (2000) 127-132. https://doi.org/10.2166/wst.2000.0101
39. Y. Liu, L. Yuan, S. Huang, D. Huang, B. Liu, Integrated design of monitoring, analysis and maintenance for filamentous sludge bulking in wastewater treatment, *Measurement*,155 (2020) 107548. https://doi.org/10.1016/j.measurement.2020.107548
40. A.T. Mielczarek, C. Kragelund, P.S. Eriksen, P.H. Nielsen, Population dynamics of filamentous bacteria in Danish wastewater treatment plants with nutrient removal, *Water Res.*, 46(12) (2012) 3781-3795. https://doi.org/10.1016/j.watres.2012.04.009
41. G. Gaval, J.-J. Pernelle, Impact of the repetition of oxygen deficiencies on the filamentous bacteria proliferation in activated sludge, *Water Res.*, 37(9) (2003) 1991-2000. https://doi.org/10.1016/S0043-1354(02)00421-9
42. T. El Moussaoui, A. Kessraoui, N. Ouazzani, M. Seffen, L. Mandi, Synthetic urban wastewater treatment by an activated sludge reactor: Evolution of bacterial biomass and purifying efficiency, *J. Mater. Environ. Sci.*, 9(3) (2018) 817-827.
43. N. Deepnarain, M. Nasr, S. Kumari, T.A. Stenström, P. Reddy, K. Pillay, F. Bux, Artificial intelligence and multivariate statistics for comprehensive assessment of filamentous bacteria in wastewater treatment plants experiencing sludge bulking, *Environ. Technol. Inno.*, (2020) 100853. https://doi.org/10.1016/j.eti.2020.100853
44. Y.F. Tsang, S. Sin, H. Chua, Nocardia foaming control in activated sludge process treating domestic wastewater, *Bioresour. Technol.*, 99(9) (2008) 3381-3388. https://doi.org/10.1016/j.biortech.2007.08.012
45. D. Jenkins, M.G. Richard, G.T. Daigger, Manual on the Causes and Control of Activated Sludge Bulking, Foaming and Other Solids Separation Problems, IWA Publishing, ISBN: 9781843390466 (2003).
46. N.K. Shammas, L.K. Wang, N.C. Pereira, Y.T. Hung, Biological Treatment Processes, Humana Press, ISBN: 9781603271561 (2009).
47. W.P. Schimper, Recherches anatomiques et morphologiques sur les mousses: thèse de botanique presentée à la faculté des sciences de Strasbourg, Impr. de G. Silbermann, ISBN : B001BRSP1W (1848).
48. J.-P. Canler, Dysfonctionnements biologiques des stations d'épuration: origines et solutions, Document technique FNDAE, (2005).
49. J. Vymazal, Wastewater Treatment, Plant Dynamics and Management in Constructed and Natural Wetlands, Springer Netherlands, ISBN: 9781402082351 (2008).