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Integrated process scheme for the combined treatment of liquid wastes and municipal wastewaters: a process analysis

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ABSTRACT

In the following paper, we explored the possibility of integrating the treatment of civil sewage waters with that of liquid wastes, such as landfill leachate, by modifying a typical domestic wastewater process scheme of a real small wastewater treatment plant, located in Southern Italy. In the scheme of the analyzed process, which included the line of treatments for only domestic effluents, a specific line for the treatment of liquid wastes and leachate is added. Liquid wastes are thus pretreated and then simultaneously purified with the municipal wastewaters, in order to fulfill the limits for discharge into superficial water bodies. The process analysis, conducted by performing mass balances on the proposed scheme, has shown that in the case study examined, the treatments carried out (with the removal efficiencies assumed from the literature) are able to produce an effluent, whose concentrations are within the limits of the law dictated by the Italian Legislative Decree n. 152/06 for discharge in surface waters.

Keywords: Leachate; Municipal wastewaters; Process analysis

1. Introduction

The need to process large quantities of liquid wastes produced by different industrial activities as well as the residual liquid effluents coming from the solid waste treatment processes (e.g. anaerobic digestion and landfilling), has made it necessary to explore the possibility of dealing with these liquid wastes together with the domestic wastewater, with a combined treatment. Examples of wastes that can be treated together with municipal wastewater are the landfill leachate, the digestate and the olive oil vegetation waters.

Vegetation waters are an aqueous effluent coming from the olive oil production process. They are difficult to treat since the presence of solids in suspension and mainly due to the high content of polluting

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organic compounds, such as polyphenols, as well as dissolved salts [1]. Moreover, a challenge in their treatment is that vegetation waters are a seasonal waste, since their production is condensed into about three months during the olive harvest.

Leachate, coming from waste degradation in landfill sites [2], has to be processed by means of both biological and physical/chemical treatments, to meet current stringent provisions. This is a difficult challenge, as leachate is a mixture of organic and inorganic pollutants, including humic acids, ammonia nitrogen, heavy metals, xenobiotics, and inorganic salts. Furthermore, chemical and biological composition depends on its age. Young leachates, affected by high BOD_5/COD value (about 0.6), are characterized by a low TKN concentration; older leachates, with a BOD_5/COD about 0.06, show a high TKN concentration with high recalcitrant compound content, that are very difficult to treat [3]. So, medium and older leachates have to be processed with a combination of chemical/physical/biological treatments before discharging into sewage systems or superficial water bodies, in accordance with the stringent Italian Legislative Decree n. 152/06. As a matter of fact, due to low BOD/COD values characterizing medium-old leachate, the biological treatment usually results in low treatment efficiencies.

Anaerobic digestion, also referred to as biogasification, is a versatile technology platform that can serve many purposes in industry. However, together with biogas phase—the noble part of the process—a liquid stream effluent (digestate) is produced, which has to be treated before discharging into sewage system. This liquid digestate is characterized by a very different composition, depending on biological matrix used as feed stream in anaerobic digester. As for example, liquid digestate coming from organic fraction of solid waste (OFSW) digestion is a mixture of nitrogen, phosphorus, organic matter, and heavy metals (e.g. iron, aluminum, zinc, nickel, chromium), that have to be greatly reduced by means of physical and chemical treatments. As a matter of fact, digestate characteristics are not so far from those of a medium leachate, with a higher value of total solid contents and a lower TKN concentration.

Among those listed, leachate is thus the stream definitely more difficult to treat. Within chemical treatments used for leachate, coagulation process is often used as a pre-treatment step [4] for old and stabilized landfill leachate [5]. It is a physical–chemical technique successfully employed prior to biological or other techniques. Different coagulants are used like aluminum sulfate $Al_2(SO_4)_3$, ferric sulphate (Fe_2SO_4), ferric chloride ($FeCl_3$) ,and Poly-Aluminum Chloride (PAC) [6,7]. This technique is very effective in suspended solids and colloids removal. Furthermore, it is necessary in presence of heavy metals, that may precipitate with the addition of a reactant agent, in order to meet provisions [8–10]. If lime (0–10 g/l) is used alone, COD value lowers insufficiently, about 10%. So, the addition of another reactant agent like $FeCl_3$ (20–100 mg) is to be preferred [11], together with a coagulant agent which may facilitate aggregation in clusters, whose dimensions favor the liquid–solid separation process. However, coagulation process, alone, can result in only moderate removals of COD contents: so further treatment steps are necessary [12]. Particularly, Advanced Oxidation Processes [13] such as Fenton appear to be a suitable treatment for such critical wastes, in addition to classical biological treatments. For this purpose, the choice of the right sequence to adopt is crucial in order to achieve the best removal of all contaminants. Deng and Englehardt [14] examined different process schemes: comparing the flowsheets proposed, the most suitable in leachate treatment seems to be the one which provides the following steps in sequence: biological, Fenton, biological. In particular, Fenton treatment is strongly recommended both in leachate and digestate cases. It is an oxidation step, which permits to increase BOD_5/COD ratio until 0.5 value—where biological treatments are admitted—and to remove 60% of initial COD [15–17]. Besides, Gotvajn et al. [18] demonstrated that Fenton can be effective in nitrogen removal (about 6%), too, if used like pre-treatment before coagulation. On the other hand Oller et al. [19] showed that if leachate is characterized by high biodegradable substance concentration, Fenton treatment alone may cause a high chemical consumption. Authors suggested to put first a biological step, where biodegradable species are removed, then a Fenton treatment, which converts non-biodegradables in biodegradables with lower chemicals consumption, followed by a final biological polishing step. This integrated process is recommended in case of leachates or, in general, when wastewaters are characterized by a high biodegradable COD content, with low heavy metal concentrations.

Relying on the above considerations, it is explored the possibility of integrating the treatment of civil sewage waters with that of liquid wastes, such as landfill leachate and vegetation waters, by modifying a typical domestic wastewater process scheme located in Southern Italy (Calitri, AV). In the scheme of the analyzed process, which in its original configuration included the line of treatment for only domestic effluent, a specific line for liquid wastes, particularly for leachate, is added. After a treatment line depending on the waste nature, liquid streams are thus simultaneously purified with the municipal wastewater, in order to fulfill the strict limits for discharge into superficial water bodies. The additional line choice includes a flocculation tank, a biological step and a Fenton treatment.

2. Materials and methods

2.1. Real plant description

In this process, the real wastewater treatment plant (WWTP) of Calitri (AV), located in the Campania Region, Southern Italy, has been considered for the proposed upgrade. The plant is a small WWTP, whose project data are reported in Table 1.

The Calitri WWTP, whose plant layout is shown in Fig. 1, in its initial configuration, was intended to serve the combined domestic and industrial liquid streams coming from the area, but a reduced population and the delocalization of part of the industrial activity, strongly diminished the hydraulic and organic load to be treated, thus requiring a plant revamping. The original water line treatment sequence consisted of the classical chemical–physical pre-treatment, followed by a primary sedimentation tank, an activated sludge oxidation plant with a secondary clarifier and a chlorine disinfection, besides the simple sludge treatment line, composed by sludge conditioning and mechanical dewatering equipment.

In order to revamp the plant, since the property gained all the necessary authorizations to treat different kinds of liquid streams, a novel flowsheet is proposed. This new scheme takes into account for the dimensions of the available basins and it is structured with a treatment sequence which is able to treat high pollutant streams observant of the more and more stringent provisions.

In detail, liquid wastes to be treated together with municipal wastewaters (***WW***) have been distinguished into three categories, besides the leachate:

(a) liquid wastes *highly biodegradable* (***HB***): characterized by a $BOD_5/COD > 0.5$;
(b) liquid wastes *medium biodegradable* (***MB***): characterized by a $0.3 < BOD_5/COD > 0.5$;
(c) liquid wastes *low biodegradable* (***LB***), mainly vegetation waters: characterized by a $BOD_5/COD < 0.3$;
(d) leachate from solid wastes, ***P*** (CER 19.07.03), classified as not dangerous.

3. Results and discussion

By keeping the plant layout reported in Fig. 1, the proposed treatment sequence is the one reported in Figs. 2 and 3, in which besides the original treatment line of domestic WW (30 m^3/d), several specific lines for the treatment of different kind liquid wastes (50 m^3/d in total) and of leachate are added (50 m^3/d). In detail, referring to Figs. 2 and 3 labels, after a preliminary grinding, MB (stream #3) and HB liquid wastes (stream #5) are sent to a clariflocculation by using PAC. Then they are fed together with civil wastewaters (WW, stream #11), to an equalization/denitrification tank. Leachate (P, stream #6), is passed through a coagulation treatment with lime and $FeCl_3$, a primary sedimentation (stream #7), a biological pre-treatment (stream #8) prior to Fenton treatment, where it merges with LB liquid wastes. Afterwards LB and P (stream #9) are conveyed to the pre-denitrification basin. This is the core of the plant, because in its capacity the recycle lines coming from the combined nitrification/oxidation basin (nitrates line, stream #14) and the recycle of activated sludge, coming from the secondary sedimentation tank (aerated mixed liquor recycle, stream #20), together with LB and P (stream #9) are conveyed. The outlet stream from this crucial step (stream #12) undergoes an oxidation and nitrification process (stream #13), before reaching the secondary sedimentation tank (stream #16). Finally, it goes

Table 1
Calitri WWTP—Plant technical data

Characteristic	Value	Units
Sewer kind	separate	–
Equivalent inhabitants	50,000	E.I.
Wastewater daily flowrate (Q_d)	5,184	m^3/d
Average wastewater flowrate on dry basis (Average 24 h) (Q24)	216	m^3/h
Maximum flowrate	648	m^3/h
Organic load expressed ad BOD_5	3,000	kg/d
Specific load	580	mg/l
Total suspended solids	4,500	mg/l

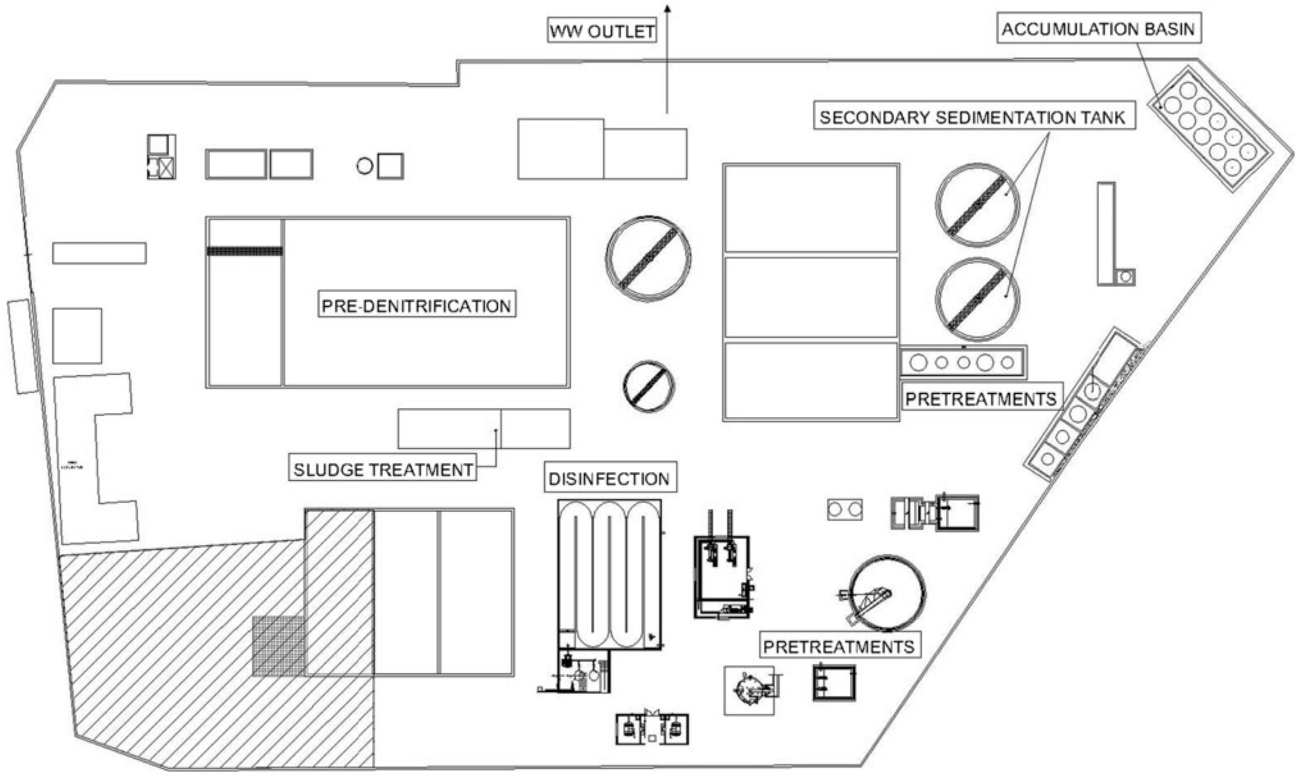

Fig. 1. Calitri wastewater treatment plant.

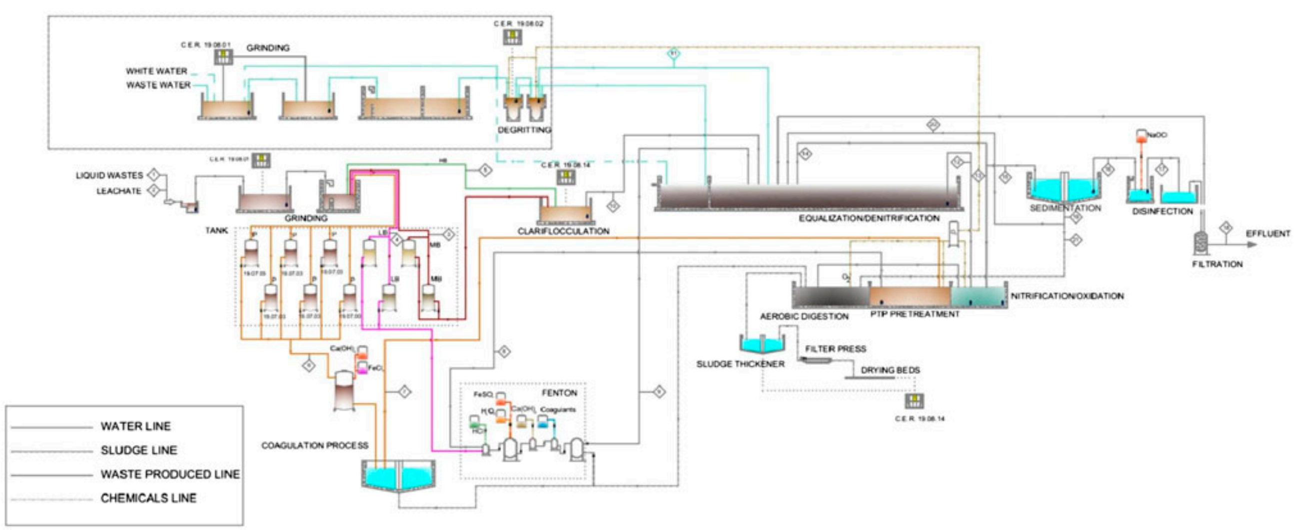

Fig. 2. Sketch of the modified Calitri WWTP plant.

through a disinfection with NaOCl (stream #17) and a filtration process (double step with sand and activated carbon), to reduce the level of suspended solids. At the end, it is discharged (stream #18).

3.1. Simulation results

The process analysis, conducted by performing mass balances on the proposed scheme, is reported in

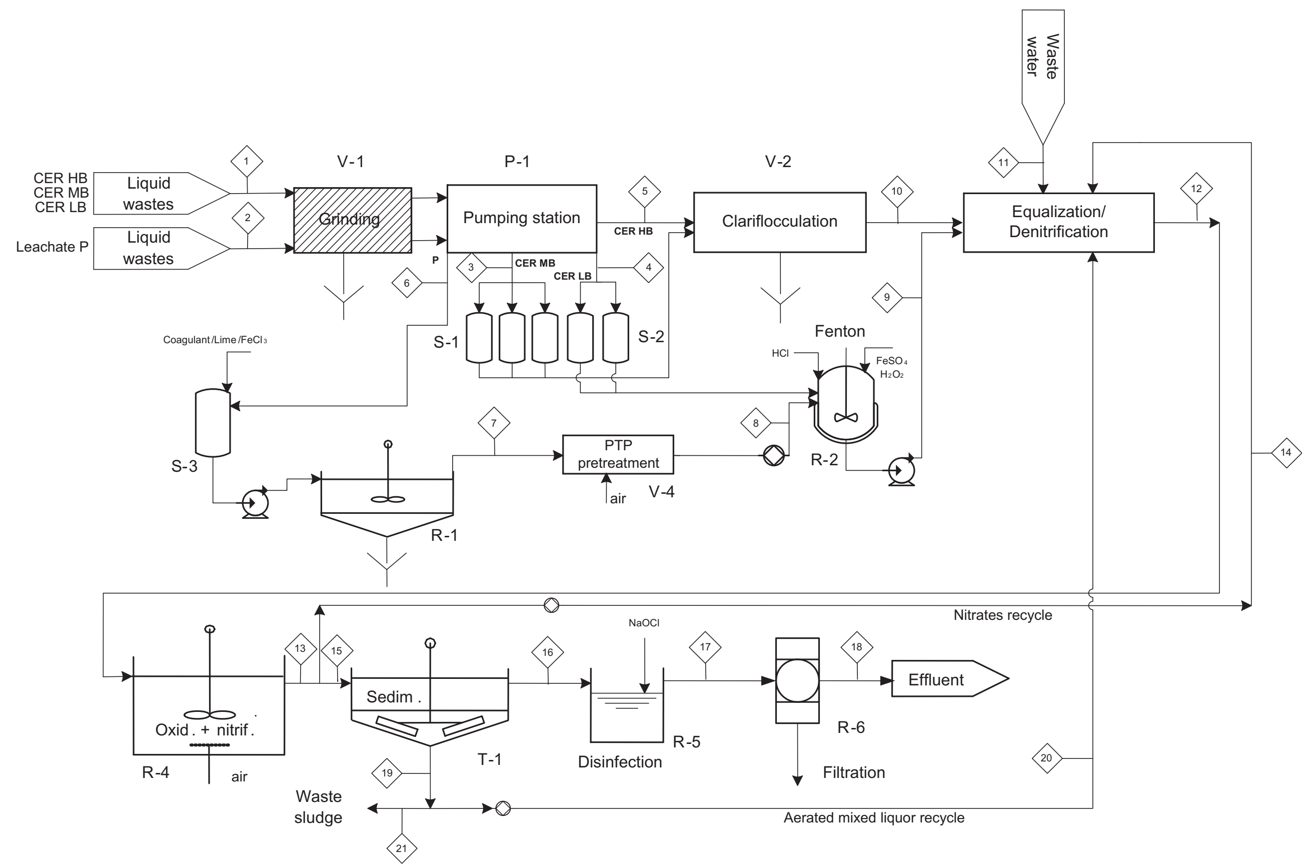

Fig. 3. Block scheme of the proposed process for Calitri WWTP.

Table 2, Figs. 4 and 5. The analysis of the table shows that in the case study examined the treatments carried out (whose removal efficiencies were assumed from the literature) are able to produce an effluent, whose concentrations are within the limits of the law dictated by the Italian Legislative Decree n. 152/ 06, as reported in Table 3. Fig. 4 reports BOD_5 and COD values in each section of the plant, together with their ratio; LB and P streams show the highest initial BOD_5 and COD values. Both are treated with Fenton process, but leachate, in particular, undergoes a coagulation process with lime and $FeCl_3$ to remove suspended solids and colloids. Additionally, the use of ferric chloride contributes to a first abatement of BOD_5 and COD values, even if, to meet provisions limits further treatment are necessary. This is the reason why leachate, together with LB stream, go through a Fenton process, which is able to still reduce BOD_5 and COD until values, that permit further biological treatments. Fenton process is subsequent to coagulation process, to optimize the use of coagulant species like $FeCl_3$. After equalization/denitrification process a further biological treatment (oxidation and nitrification), together with disinfection and filtration step, allows to reach final values of BOD_5 and COD, which both meet Italian Legislative Decree n. 152/ 06, reported in Table 3.

Fig. 5 shows the behavior of nitrogen—in its total and ammoniacal form—and heavy metals along with the treatment line. The streams with the most of nitrogen content are LB and P, while MB and HB show low concentration values. The coagulation step with $FeCl_3$ and the biological treatment progressively reduce nitrogen content in P stream. Anyway a Fenton process is necessary for both P and LB streams: this step reduces nitrogen content, but it is the equalization/denitrification step that hardly lowers nitrogen content. This is followed by an oxidation/nitrification process, which allows to reach nitrogen values that meet Italian provisions.

As for heavy metals, Fig. 5 reports the behavior of the sum of Pb, Ni, Cr and Fe concentration. Leachate stream shows the highest heavy metal content, particularly regarding Fe species. Coagulation step with $FeCl_3$ hardly reduces heavy metal content, then the

Table 2
Main process streams' composition

Parameter	Units	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Q_h	m^3/h	0.63	0.42	1.04	2.08	2.08	2.08	2.50	1.67	1.25	42.61	42.61	32.50	10.11	5.42	5.42	5.42	4.69	3.25	1.44
Q_d	m^3/d	15.00	10.00	25.00	50.00	50.00	50.00	60.00	40.00	30.00	1,022.58	1,022.58	780.00	242.58	130.00	130.00	130.00	112.58	78.00	34.58
BOD_5 load	kg/d	52.50	150.00	62.50	900.00	270.00	81.00	207.90	57.50	13.50	338.21	33.82	33.82	8.02	4.30	4.30	1.72	33.51	23.22	10.29
NO_3^-/NO_2^-	–	0.10	0.10	0.10	0.10	0.10	194.50	129.68	0.09	0.10	0.84	0.84	0.84	0.84	0.68	0.68	0.61	0.17	0.17	0.17
SST	mg/l	3,850.00	16,500.00	2,750.00	19,800.00	3,960.00	7,920.00	3,168.00	1,581.25	200.00	3,679.03	4,000.00	4,000.00	4,000.00	600.00	600.00	60.00	3,400.00	3,400.00	3,400.00
Pb	mg/l	0.00	0.00	0.00	1.00	0.10	0.10	0.05	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Ni	mg/l	0.00	0.00	0.00	2.00	0.20	0.20	0.10	0.00	0.00	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00
Cr	mg/l	0.00	0.00	0.00	1.00	0.10	0.10	0.05	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Fe	mg/l	0.00	0.00	0.00	40.00	4.00	4.00	2.00	0.00	0.00	0.32	0.32	0.32	0.32	0.26	0.26	0.18	0.06	0.06	0.06

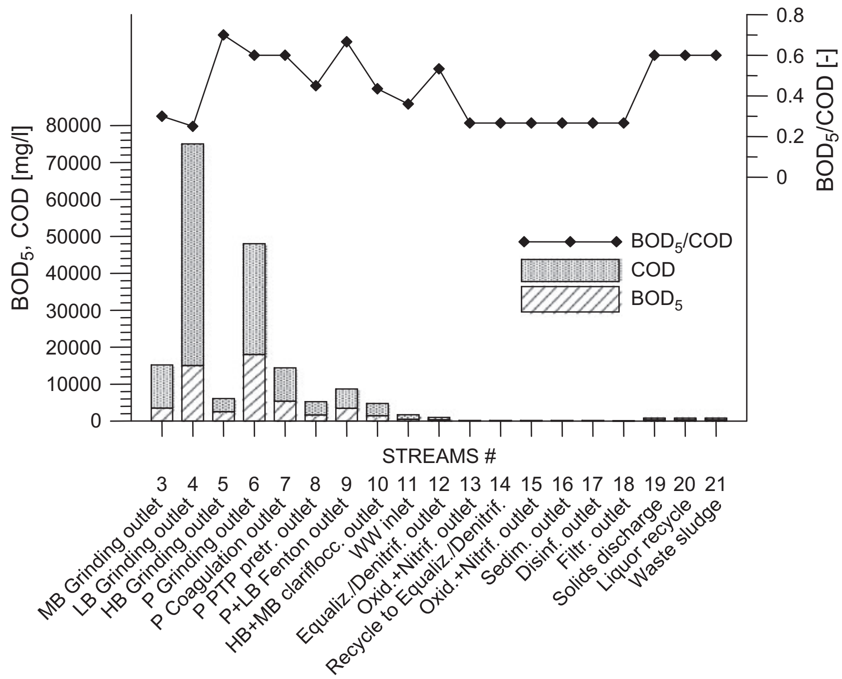

Fig. 4. BOD_5, COD and their ratio along with the treatment line.

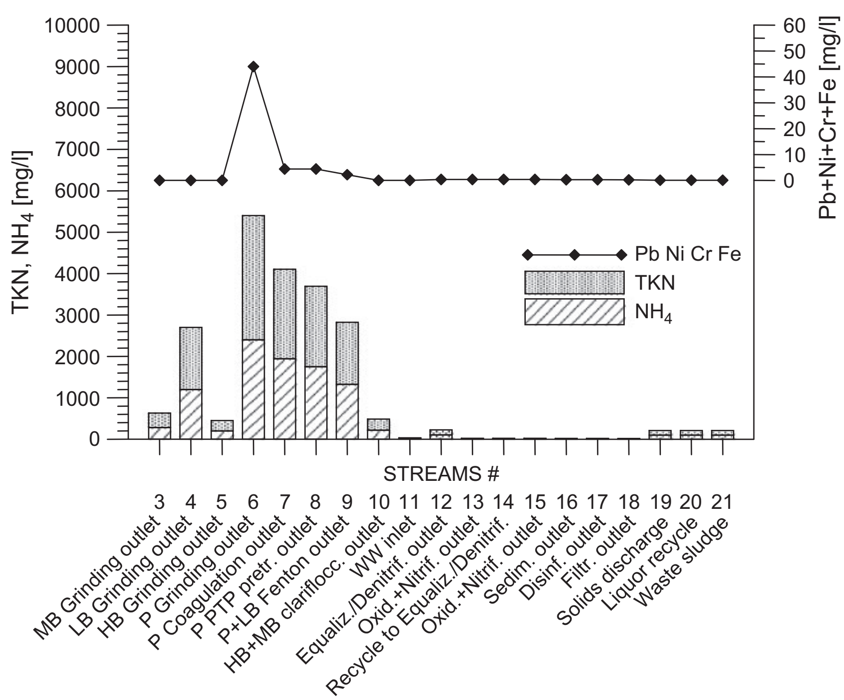

Fig. 5. Nitrogen (Kjeldahl and ammoniacal) and heavy metals along with the treatment line.

Table 3
Effluent composition and emission limits (surface water bodies)

Parameter	Units	Effluent (stream # 18)	Emission limits (according to Italian Legislative Decree n. 152/ 06)
Q_h	m^3/h	5.42	
Q_d	m^3/d	130.00	
BOD_5 load	kg/d	1.72	
BOD_5	mg/l	13.23	<40
COD	mg/l	49.62	<160
BOD_5/COD	–	0.27	
TKN	mg/l	8.44	
NH_4^+	mg/l	7.59	<15
NO_3^-/NO_2^-	–	0.61	<20
SST	mg/l	60.00	<80
Pb	mg/l	0.00	0.2
Ni	mg/l	0.01	2
Cr	mg/l	0.00	2 (0.2 for Cr^{+6})
Fe	mg/l	0.18	2

removal completes with the following Fenton process until values, which meet Italian provisions.

4. Conclusions

An integrated treatment scheme of civil sewage waters and liquid wastes, such as landfill leachate and vegetation waters, by modifying a typical domestic wastewater process scheme of a real WWTP is presented. Liquid wastes are pretreated with a Fenton process that a literature analysis showed to be very effective and then simultaneously purified with the municipal wastewater, in order to fulfill the limits for discharge into superficial waters. The process analysis, conducted by performing mass balances on the proposed scheme, has shown that in the case study examined the treatments carried out are able to produce an effluent, whose concentrations are within the limits of the law dictated by the Italian Legislative Decree n. 152/06. From the analysis, it is clear that the pivotal role played by the Fenton process in increasing the liquid wastes biodegradability in order to treat them in a combined way with wastewaters.

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