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Best Management Practices in Wastewater Treatment in Italian Country: the Territorial Approach of the Autonomous Province of Trento

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ABSTRACT

The paper deals with an innovative strategy and methodology to globally improve the wastewater treatment and management in a whole water basin district, where a large network of 73 treatment plants, mostly small and decentralized, are operating. The network of wastewater treatment plants (WWTPs) was analysed to outline the current state of the wastewater treatment and management. These detailed analyses were used by the competent authority to identify the critical aspects and assess the call for tender regarding the wastewater treatment and management. The call is focused on two main concepts: (1) scientific approach and technological innovation for trouble-shooting and WWTPs upgrading; (2) periodical verification and validation of the results achieved, according to protocols proposed by the tenderers. Therefore, the response of the tenderers was mainly based on the alternate cycles processes to improve the secondary effluent quality in terms of nitrogen and phosphorus content, reduce the waste activated sludge production and consumptions of electric energy. Additionally, locals adoption of waste sludge ozonization will contribute to achieve the global results in the whole water basin district.

Keywords: Territorial wastewater treatment and management, Large network of small WWTPs, Alternate cycles process

1.0 INTRODUCTION

According to the European Water Framework Directive (WFD - 2000/60/CE), the protection of the environmental quality of aquifers and surface water and the promotion of sustainable water use should be reached by planning usage and treatment at water basin (and water basin district) levels. As far as concern the wastewater treatment in mountain water basin district, the low population density and its irregular distribution call for the unitary management of networks of plants, often composed by many small decentralized and a number of larger centralized systems (APAT, 2005). In these cases, the Best Management Practices (BMPs) are approaches based on the known science and should be followed to achieve the required environmental quality standards. Best Management Practices (BMP) is a term used to describe a type of water pollution control. Historically the term has referred to auxiliary

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pollution controls in the fields of industrial and municipal wastewater control. These practices include the maintenance procedures, the documented plans that are designed to effectively reduce or prevent discharge of pollutants into receiving waters and the establishing treatment procedures for waste streams. In the water basin district of the Autonomous Province of Trento (APT) the BMPs have recently been followed to set the guidelines to manage a network of 73 wastewater treatment plants (WWTPs), mainly small and decentralized. Major aim of the APT was to achieve a general territorial improvement of the wastewater treatment, as required by the WFD, by local actions classified for priority. This paper shows and discusses: (1) the WWTPs network, (2) the guidelines and the required BMPs to achieve well defined objectives for the wastewater treatment in the water basin district of the APT; (3) the state-of-the-art consolidated technologies and practices proposed to follow the guidelines and achieve the objectives within a clear timetable.

2.0 CURRENT WASTEWATER TREATMENT IN THE APT WATER BASIN DISTRICT

The APT water basin district is located in northern Italy and is large about 6200 km^2, basically in the Alps and Pre-Alps areas. It can be divided in three main water basins (East, Central and West). The sewage treatment is currently implemented in a network of 73 wastewater treatment plants (WWTPs) with different treatment capacities. Specifically, 10 WWTPs have a design treatment capacity (PE_d) lower than 400 PE. Indeed, the 63 WWTPs, analysed in this paper, are characterized by a treatment capacity from 400 PE_d to 120,000 PE_d (Figure 1). While the whole flow schemes of the single plants are very different, the 63 activated sludge reactors use mainly two biological processes: 27% a multi-zone conventional predenitritication-nitrification (DN), while 65% total oxidation systems (TO) (Figure 1). Among the larger WWTPs, with treatment capacity higher than 10 000 PE, the number of TO systems is not negligible and comparable to the most common DN scheme. In addition, the membrane bioreactor (MBR) process characterizes two plants, the first with a design capacity of 4000 PE and the second (3100 PE_d) coupled with a TO process for a total capacity of 6800 PE_d. Finally, in 2007 four WWTPs (from 5,000 to 26,500 PE_d) were upgraded by shifting from the TO to the intermittent aeration automatically controlled by the alternate cycles (AC) process (Battistoni et al., 2003) (Figure 1). Of course, the evaluation of the under or over-loading condition, (ratio between the real and the design treatment capacities PE_r/PE_d (%)), is a key aspect to have an actual overview of the whole network of the WWTPs. Particularly, about 54% of the plants are characterized by a PEr lower than 6,000 PE (21% with a real treatment capacity under 2,000 PE and 33% between 2,000 and 6,000 PE, respectively). Considering the PE_r/PE_d ratio, it is shown that the potential residual treatment capacity of the whole WWTP network is significant (Table 1). In fact, only 10 plants are over-loaded with respect to the design values. As far as concerned the influent characteristics, one should take into account that: (1) in the WWTPs fed by a combined sewer system (C) also industrial effluents are discharged (mainly produced by wineries, agroindustry and slaughterhouses); (2) the majority of the plants are fed by separated sewer system (S) and are subject to strong seasonal fluctuations mainly related to the touristic fluxes. As a consequence of this very heterogeneous scenario, the concentrations of the main conventional pollutants are summarized in Table 1: COD from about 370 mgL^{-1} to 730 mgL^{-1};

TN from 37 mgL^{-1} to 55 mgL^{-1} and TP from 3 mgL^{-1} to 8 mgL^{-1}. However, a common feature to the whole network could be observed regarding the ratio COD/TN always higher than 10, that let one suppose high potential for removal of total nitrogen. The analysis of real and design specific reaction volume (Vspec) calculated on COD basis (105 gCOD per day discharged pro capita), (Table 2) points out that the design Vspec was in the range 100-150 $LPEd^{-1}$, theoretically adequate to ensure the complete COD and ammonia oxidation within total oxidation processes. However this value could be not always sufficient in DN processes. In addition, the nitrogen loading rate (NLR) is lower than 0.1 $kgTNm^{-3}d^{-1}$ for all the under-loaded activated sludge reactors. Notwithstanding these supportable loading conditions (if temperature is not considered), the removal of total nitrogen is not high for the large incidence of WWTPs adopting the TO process, without denitrification zone (Table 2).The low quality standard of the effluent concerning the total nitrogen is shown in Table 3. This is due mainly to the high incidence of the TO process. On the other hand, the evaluation of the specific reactor volume (see Figure 2) let one estimate the potential of the WWTPs network to drastically decrease the total nitrogen in the effluent adopting a nitrification and denitrification, which should be able to cope also with the high loading fluctuations. On the other hand, the effluent TP concentrations (between 0.9 and mgL^{-1} and 1.6 mgL^{-1}) point out a general good quality standard. However, these good performances are achieved mainly (from 58% to 80%) by chemical precipitation, causing a remarkable amount of chemical waste sludge production. Table 4 shows the specific electric consumptions (EE) and the relative incidence of the biological process. The scenario highlights the high waste of energy in the under-loaded WWTPs, mainly adopting TO processes. In fact, the specific data (Table 4) change from 0.435 $kWhPE^{-1}d^{-1}$ (PE_r/PE_d <40%) to 0.141 $kWhPE^{-1}d^{-1}$ (60%<PE_r/PE_d<80%). On the other hand, in the WWTPs with PEr/PEd higher than 60%, the specific EE consumption are almost stable in the range 0.136-0.141 kWhPE-1d-1 (Table 4). Finally, the waste sludge treatment (anaerobic digestion or aerobic stabilization) is carried out locally only in the WWTPs with PE_d higher than 32,000 PE. About 4% of all the plants adopts anaerobic digestion (AD), and 56% relies on the aerobic stabilization (AS). The remaining 40% has only a dewatering unit (DW) (Figure 3). The sludge production of all the plants in the APT was, during the 2008, equal to 9,155 tTSy-1 (with an average TS% of 18.9% and an average TVS/TS% of 70%). Considering the average values for the specific productions ($kgTSPE^{-1}y^{-1}$) (Figure 3) and for the observed yield (Yobs = $kgTVS_{produced}kgCOD_{removed}^{-1}$) one may observe a good agreement with other full scale data (12-14 $kgTSPE^{-1}y^{-1}$ and 0.220-0.250 $kgTVS_{produced}kgCOD_{removed}^{-1}$) (SOIS, 2004), regardless of the treatment applied. As show in Figure 3 the specific production and the Yobs evaluated for the AD, DW and AS processes are respectively 9 $kgTSPE^{-1}y^{-1}$ and 0.191 $kgTVS_{produced}kgCOD_{removed}^{-1}$, 12 $kgTSPE^{-1}y^{-1}$ and 0.259 $kgTVS_{produced}kgCOD_{removed}^{-1}$ and 12 $kgTSPE^{-1}y^{-1}$ and 0.238 $kgTVSp_{roduced}kgCOD_{removed}^{-1}$. However, the standard deviation shows how the sludge production is not stable and reaches sometimes values much higher than the literature data (Figure 3). Similar results as specific production and Yobs are obtained considering a classification on the basis of the biological process applied in the water line. In fact, the plants who adopt the TO and DN, are characterized respectively by 11 $kgTSPE^{-1}y^{-1}$ and 0.236 $kgTVS_{produced}kgCOD_{removed}^{-1}$ and 13 $kgTSPE^{-1}y^{-1}$ and 0.269 $kgTVS_{produced}kgCOD_{removed}^{-1}$.

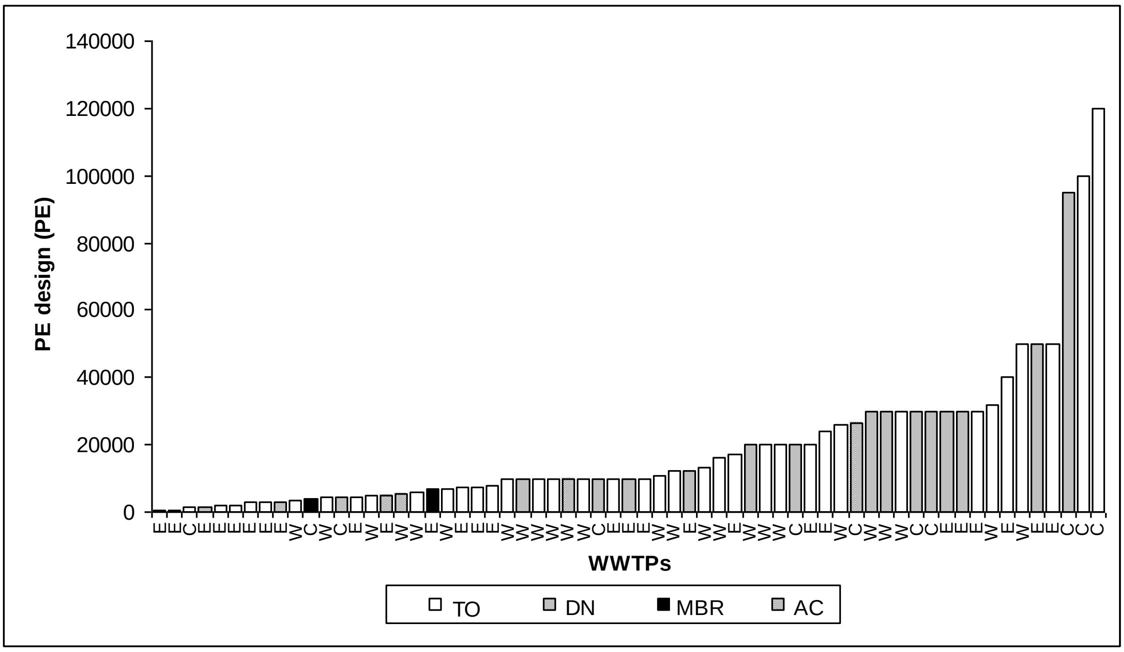

Figure 1 Design capacity (PEd) and territorial distribution of the WWTPs (East watershed (E) - Central watershed (C) – West watershed (W)) and Biological process typologies

Table 1 Real and design treatment capacity ratio and the main influent characterization

WWTP	n %	Sewer	CODin mgL^{-1}	TNin mgL^{-1}	TPin mgL^{-1}	COD/TN
PE_r/PE_d <40%	32	C/S	372	37	3	10
40%<PE_r/PE_d <60%	27	C/S	481	46	5	11
60%<PE_r/PE_d <80%	14	C/S	526	42	6	14
80%<PE_r/PE_d <100%	17	C/S	502	46	5	12
PE_r/PE_d >100%	10	C/S	728	55	8	14

Table 2 Biological reactor: processes distribution on the PE_r basis, specific volumes and nitrogen loading rate

WWTP	Biological Process				V_{spec}		NLR
	MBR	AC	D-N	Total oxidation			
	%	%	%	%	LPE_d^{-1}	LPE_r^{-1}	$kgTNm^{-3}d^{-1}$
PEr/PEd <40%	0	0	40	60	147	742	0.04
40%<PEr/PEd <60%	0	5	24	71	148	300	0.04
60%<PEr/PEd <80%	0	11	22	67	125	186	0.05
80%<PEr/PEd <100%	0	18	27	55	140	161	0.06
PEr/PEd >100%	17	0	0	83	111	120	0.14

Table 3 Average TN and TP effluent and removal performances

WWTP		TNout		TPout	
		mgL^{-1}	E%	mgL^{-1}	E%
PEr/PEd <40%	average	16	57	1.1	58
	st. dev.	8	23	0.6	22
40%<PEr/PEd <60%	average	16	65	1.5	68
	st. dev.	8	11	0.7	17
60%<PEr/PEd <80%	average	16	60	0.9	59
	st. dev.	10	21	0.5	34
80%<PEr/PEd <100%	average	16	62	1.3	64
	st. dev.	6	15	0.6	23
PEr/PEd >100%	average	19	63	1.6	80
	st. dev.	6	17	0.8	6

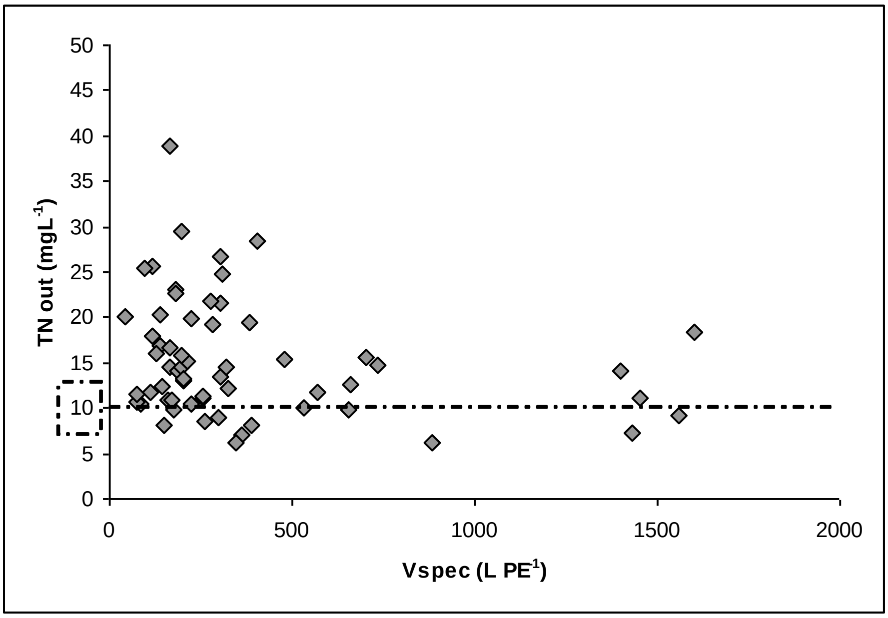

Figure 2 TN effluent linked with the specific biological volume on PE_r basis

Table 4 Specific energy adsorbed consumption and incidence of biological installed power on the total one

WWTP	Energy absorbed EE $kWhPE^{-1}d^{-1}$	Power installed bio/tot %
PEr/PEd <40%	0.435	52
40%<PEr/PEd <60%	0.192	56
60%<PEr/PEd <80%	0.141	52
80%<PEr/PEd <100%	0.141	55
PEr/PEd >100%	0.136	44

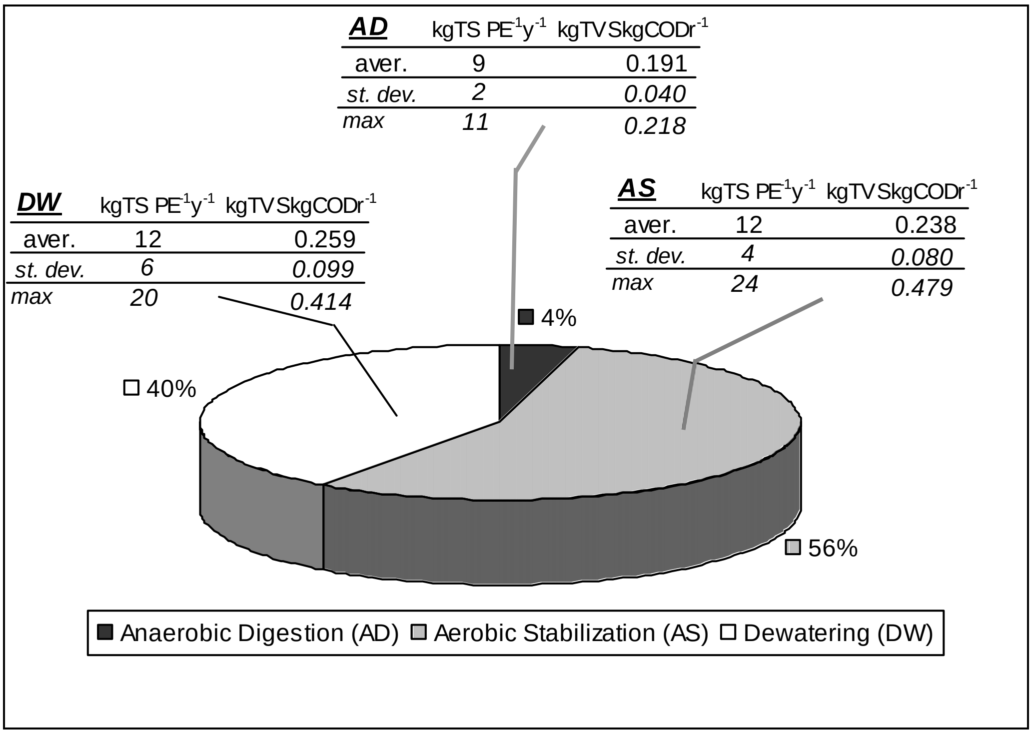

Figure 3 Percentages, specific sludge production and Yobs for each type of sludge treatment process applied

3.0 GUIDELINES AND BEST MANAGEMENT PRACTICES FOR AN INNOVATIVE CONCEPT OF WASTEWATER TREATMENT AND MANAGEMENT

The usual practice to manage networks of WWTPs in Italy is a call for tender with the aim of operation and maintenance. By this way, the contractor (usually the competent authority) calls basically for a service job, far from the BMPs and the improvement of the quality of the service. Indeed, the BMPs define the necessity to control the amount of nitrogen and phosphorus using treatment technologies for point sources, mainly related with the biological way, and to optimize the energy consumption trough the aeration system upgrading and the advanced system to automatically control of the process. On the basis of these concepts, in 2009 the competent authority for the APT published an innovative call for the management, operation and maintenance of the wastewater treatment in the APT water basin district. This is one of the most innovative practice in Italy, since it is focused on two main concepts: (1) scientific approach and technological innovation for trouble-shooting and WWTPs upgrading; (2) periodical verification and validation of the results achieved, according to protocols agreed with the tenderers. In addition, the innovative policy of the contractor consisted in taking active part in the general improvement of the wastewater treatment service and supervising the achievement of the results. As discussed in the previous section, the call for tender was preceded by a detailed analysis of the framework regarding the wastewater treatment in the APT water basin district. This approach was necessary to evaluate the main weaknesses and establish the guidelines of the call for tender, from one side, and the criteria to evaluate and quantify the expected results, from the other side. Furthermore, great importance was given to the technical offer. In fact, the best price had a relative incidence of only 25%, while the rest of the evaluation was related to the technical offer which should have been structured to respond to well defined points shown in Table 5. The call for tender listed also the contents of the required technical reports to include in the offer, as many as the objectives in Table 5 are shown. In particular, the reports from the tenderers should had to contain: the scientific background, the list of priority WWTPs selected for upgrading and the proposed modifications, the expected improvements of the quality of the service and the time to achieve them, the methods for the supervision and the verification of the results achievement.

Table 5 Requirements to be explained in the technical offer

General priority	Objective	Description
Proposal for technical improvement of the wastewater treatment and management	Biological excess sludge reduction	On dry matter basis, without worsening of the quality of the secondary effluent and waste sludge for final disposal
	Reduction of the EE consumptions	By energy-efficient processes and by local energy autoproduction
	Reduction of the total nitrogen discharged in the water bodies	
	Reduction of the total phosphorus discharged in the water bodies	Without use of external chemical reagents
	Automation in sludge treatment lines	
Organization of the service of operation and maintenance	Good skills of the operators	
	Improved general quality standard of the service	
Plan of acquisition of the tools and instrumentations for plant maintenance, operation and process control	Equipments for WWTPs operation and maintenance	
	Instrumentation for process control and automation	
Personnel training	Training subjects	Quality and diversification of the training programs
	Number of hours for training and personnel involved	Attention to the major part of the professionals involved in the management of the WWTPs. The safety issue is not accounted in the hours per training, as it is already provided by the national law on safety in workplace

4.0 THE TECHNICAL PROPOSALS ACCORDING TO THE BEST AVAILABLE TECHNOLOGIES AND BEST MANAGEMENT PRACTICES

According to the current framework of the wastewater treatment in the APT water basin district, the following proposals were considered for the technical improvement of the wastewater treatment and management. The proposals exposed are applied in 23 WWTPs, 37% of the total plants analyzed, with a PE_d from 600 PE to 120,000 PE and a PE_r from 222 PE to 156,000 PE.

4.1 Intermittent Aeration Automatically Controlled to Enhance Total Nitrogen Removal

The application of the alternate cycles (AC_A) process in the water line of 19 plants. According to this process, the intermittent aeration of the continuously fed activated sludge bioreactor is automatically controlled on the basis of dissolved oxygen (DO) and Oxidation Reduction Potential (ORP) on-line signals (Battistoni et al., 1999). The AC_A is already operating in 4 plants of the APT (Figure 1) highlighting the optimization as effluent nitrogen and energy consumptions (Eusebi et al., 2009). The percentages of nitrogen removal for the different forms are related to the length of the aerobic and anoxic phases. The ORP and DO profiles analysis, the set-points and the time length basis are the operative controllers to determine the phase length. These different levels of the automatically control establish the flexibility of the process. A data-processing software was purposely engineered to evaluate the reliability of the device system.

The implementation of intermittent aeration process (Andreottola et al., 2003) (AC_B) in 4 plants regulated by ammonia and dissolved oxygen online signals. The process and the turning on and off the aeration system is controlled on NH_4-N probes located in the biological reactor. The adjustment of the working setting condition of the blowers, during the aerobic phase, is based on the DO recorded values. Applying the AC_A and the AC_B (Table 6) the TN performances expected increase from the actual percentages 57%-65% (Table 3) to 75%-80%.

4.2 Enhanced Phosphorus Bioremoval as Result of The Intermittent Aeration and Soft Fasting/Feasting Conditions

The techniques and technology choices for action are the same that allow the nitrogen reduction in the effluent and concern the implementation of AC in the water line. These approaches determines the development of the PAO and DPAO biomass able to accumulate the organic phosphorus as polyphosphate in predictable percentages of 0.5-1% of P on the dry matter basis. In fact, the establishment of fasting and feasting condition in the dynamic system enhance the polymers accumulation phenomena typical of PAO and DPAO growth (Cıggın et al., 2007). The method determines a reduction of the reagents use to TP precipitation expected around 20% (Table 6).

Table 6 Enhancement proposals and expected performances

Proposals	WWTPs	TN performances %	Reagents Reduction for TP %	Sludge Reduction %	EE reduction %
AC_A	19	75-80	20	8	10
AC_B	4	75-80	20	8	10
AC_SL	4	-	-	25	10
O	2	-	-	35	-

4.3 Automatic Control of A Sludge Conditioning Bioreactor

The purpose of the application of Alternates Cycles process in Sludge Line (AC_SL) of 4 full scale plants defines the goal to minimize excess sludge production by taking advantage of both uncoupling metabolism and cryptic growth. The process is realized by including in the recycle line a conditioning reactor, where an intermittent aeration is carried out on the ORP and DO basis automatically determined by a patented control device (Battistoni et al., 2007) which operates an on-line data processing. The sludge is treated along an appropriate hydraulic retention time and is pumped back to the main activated sludge reactor so as to create the ideal conditions for the energy decoupling of the biomass and reducing the waste production of 25% (Table 6).

The application of the AC in the water line has evidenced in previous full scale applications a contribution to reduce the sludge production. The alternating oxic-anoxic phases produce a partial conditioning of the biomass and the reduction of the sludge growth decrement is expected at about 8% (Table 6) (Nardelli et al., 2009).

The ozonolysis process (O) will be implemented on the water line of 2 full scale plants, so to realize the solubilization a fraction of sludge recycle line by the ozone. The ozone is produced from atmospheric air (80-100 gO_3m^{-3}air) and dosed in the contact reactor. The technology determines an expected sludge reduction of 35% (Table 6) and has as secondary effects the improvements of the settleability sludge behaviour and of the TS% in the sludge dewatering.

4.4 Application of Energy-Saving Technologies and Processes

The goal of the energy saving is a direct consequence of the AC application in the wastewater and in the sludge treatment lines. In fact, the AC technology in the wastewater treatment line allowed for the best exploitation of nitrogen-bound oxygen, involving savings for the aeration of the biology, and the absence of nitrates recycle, involving savings for the sludge pumping. When applied to the sludge treatment line, the EE savings compared to the aerobic stabilization are relevant. Furthermore, the flexibility of the AC control systems allow to cope with the short and long term fluctuations of the inloadings, avoiding overaeration and relative EE waste. The average energy reduction expected in 23 WWTPs is of about 10% (Table 6).

Table 7 Results and comparison between previous and after the proposals application

	TN discharged ty^{-1}	Reagents used for TP ty^{-1}	Sludge Production $tTSy^{-1}$	EE $kWhy^{-1}$
Previous proposals application	947	1456	9155	42,000,000
After proposals application	706	~1316	8035	39,900,000

Finally, the best available technologies application determines in all the autonomous province of Trento a new overview as nitrogen removal performances, reagents use for TP precipitation, sludge production and energy consumption compared with the situation previous the innovative call for tender (Table 7). In fact, the results expected after the proposals application are a reduction of the TN discharged from 947 ty^{-1} to 706 ty^{-1}, a decrement of the reagents used for the TP precipitation of about 100 ty^{-1}, an excess sludge production of about 8000 ty^{-1} compared with the previous 9000 ty^{-1} and a minor energy consumption almost of 5% (Table 7).

5.0 CONCLUSIONS

An innovative strategy and methodology, based on the known science and scientific approach, was applied to plan the general improvement of the wastewater treatment and management in a whole water basin district, where a small of wastewater treatment plants is operating.

The strategy can be resumed according to the following key-steps:

1. Detailed knowledge of the current framework concerning the whole network of treatment systems in the water basin district. This allows to identify and quantify the critical issues and to know the priorities for the actions to be taken.

2. A call for tender where the contractor takes active part in the supervision and achievement of the results. This is based on a scientific approach and technological innovation for trouble-shooting and WWTPs upgrading and a periodical verification and validation of the results achieved, according to protocols proposed by the tenderers.

Further to a call for tender so innovative, the response of the tenderers was high quality and identified the alternate cycles technology as key process to reduce the energy consumptions, the nitrogen discharge and the waste sludge, having even the side effect to enhance the bioP removal.

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