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Application of food waste disposers and alternate cycles process in small-decentralized towns: A case study

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A B S T R A C T

The use of food waste disposers (FWDs) can be an interesting option to integrate the management of municipal wastewaters and household organic waste in small towns and decentralized areas. This strategy can be even more environmentally friendly if a suitable treatment process of the resulting sewage is performed in order to control nutrients emission. However, still nowadays, part of the scientific and technical community considers the application of this technology a possible source of problems. In this study, the FWDs were applied, with a market penetration factor of 67%, in a mountain village of 250 inhabitants. Further, the existing wastewater treatment plant (WWTP) was upgraded by applying an automatically controlled alternate cycles process for the management of nutrients removal. With specific reference to the observed results, the impact of the ground food waste on the sewerage system did not show particular solids sedimentation or significant hydraulic overflows. Further, the WWTP was able to face the overloads of 11, 55 and 2 g per capita per day of TSS, COD and TN, respectively. Then, the increase of the readily biodegradable COD (rbCOD/COD from 0.20 to 0.25) and the favourable COD/TN ratio (from 9.9 to 12) led to a specific denitrification rate of some 0.06 kg NO_3-N/(kg MLVSS day). Therefore, not only COD removal, but also the total nitrogen removal increased: the denitrification efficiency reached 85%. That led to a better exploitation of the nitrogen-bound oxygen and a consequent reduction of energy requirements of 39%. The final economic evaluation showed the benefits of the application of this technology with a pay back time of 4–5 years.

1. Introduction

The production of municipal solid waste (MSW) in Europe is estimated to be some 500 kg per capita per year in Western Countries and some 350 kg per capita per year in Central and Eastern Countries (EEA, 2005): as an average, some 30% of this material is organic waste (biowaste). Now, a severe regulation on disposal of waste (Directive 99/31 and Council Decision 19 December 2002 of the European Union) almost forbids the disposal of the organic wastes in landfills, so to reduce the production of leachate and gases responsible for greenhouse effects. Further, the treatment of biowaste to reclaim important elements like carbon, nutrients (N and P), energy and heat is encouraged.

According to this scenario, an interesting option to manage the stream of organic wastes and divert it from landfilling to wastewater treatment facilities is the application of food waste disposers (FWDs) for the treatment of kitchen waste.

This technology is widely applied in USA, Canada, Brazil, Japan and Australia but is less diffused in Europe, where only

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Nomenclature

AUR	ammonia utilization rate
BOD	biological oxygen demand
COD	chemical oxygen demand
DO	dissolved oxygen
FWD	foodwaste disposer
GFW	ground food waste
HPLC	high-performance liquid cromatography
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
NUR	nitrogen utilization rate
OFMSW	organic fraction of municipal solid waste
ORP	oxidation–reduction potential
RAS	recycled activated sludge
rbCOD	readily biodegradable chemical oxygen demand
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
WAS	waste activated sludge
WWTP	wastewaster treatment plant

recently it has been acknowledged that the potentiality of FWDs for the future organic waste management (CECED, 2003; Bolzonella et al., 2003). However, even though a number of studies have been carried out to point out the reliability of this approach, a part of the scientific and technical communities still believe its application to be hazardous. Previous studies clearly showed that this technology caused the addition of little amounts of tap water, while the addition of extra-loadings of pollutants like chemical oxygen demand (COD), biological oxygen demand (BOD), suspended solids, nutrients or greases and oils are sometimes consistent, but can be easily managed in existing properly designed and managed sewerage systems and wastewater treatment plants (WWTPs). Further, this extra-load of organic material can improve the performances of the activated sludge processes as well as the anaerobic digestion process (when present). Taking into account only the last 2 decades, many publications showed the convenience of the application of FWDs and the relative inconsistency of the uncertainties (Nilsson et al., 1990; de Koning and van der Graaf, 1996; Henze, 1997; Sankai et al., 1997; Bressi et al., 1998; Galil and Yaacov, 2001; Rosenwinkel and Wendler, 2001; Bolzonella et al., 2003; Diggleman and Ham, 2003; Marashlian and El-Fadel, 2005). Some of these studies are just theoretical and others are only partially practical-oriented. From an experimental stand point, the most representative experimentation probably concerns the city of New York (Department of Environmental Protection, NY City, 1997). Here, after a 1-year study, it was demonstrated the safe application of the FWDs technology and addressed the decision of the local policy makers.

As far as the possible impacts of the application of the FWD technology is concerned, besides sewerage system and wastewater treatment efficiency, the economical benefits should be considered. In particular, the application of FWDs technology seems to be even more attractive in those districts where the source collection of organic wastes is complicated and expensive, like small and decentralized towns, especially in mountainous or hilly areas.

In order to clarify the benefits to be derived from the application of FWDs in a small and decentralized urban centre, a study was carried out to verify the impacts of the waste on the sewers and the wastewater treatment system in a small village in central Italy. This paper reports the main findings of the study describing as widely as possible the impacts and the feasibility of the technology.

2. Materials and methods

In this study, FWDs were applied in households and a school canteen of a small village served by its own WWTP. Both the sewer system and the treatment facility were constantly monitored to verify and compare the conditions and performances of the systems before and after the application of the FWDs.

2.1. *The area, the village and the installed FWDs*

The experimentation was carried out with the support of a public utility, COSMARI, that manages the collection and treatment of MSW in a district with about 300 000 inhabitants and a surface of 2770 km^2, located in the Macerata province, central Italy. Here, the source collected biowaste is transported to a centralized plant for composting. The overall area, mainly hilly, is characterized by a low density of population (113 inhabitants/km^2) and people mostly live in towns of less than 10 000 inhabitants (75% of the population).

As a consequence, the waste collection and transport are quite expensive and take a long time.

Inside the examined area, a small town, Gagliole, situated 38 km from the composting plant, was selected for the experimentation: 35 families decided to participate in the experimentation involving a domestic population of 95 persons. Also an industrial FWD, for an equivalent treatment capacity of 60 persons, was installed in the canteen of the local school. Therefore the total "penetration market factor" was about 67% of the resident population (Table 1).

Table 1 – Installed and operating FWDs and market penetration factor

	Number of FWDs	Number of persons served	Market penetration factor (%)
Domestic	35	95	41
Industrial	1	60	26
Total	36	155	67

2.2. The sewer system

The 20-year-old sewerage system of the area collects both municipal wastewaters and rainfall runoff and has a typical retention time (dry weather) of 1.5 h. Therefore, according to Bolzonella et al. (2003), the time that the organic wastes stayed into the sewerage pipelines was not long enough to trigger the fermentation processes. Since overflow channels are not present in this system, all the ground waste reached the WWTP. The pipelines, circular and concrete-made, were in good condition, but a sewerage line of 75 m (diameter 350 mm) showed a critical slope (1 mm/m). This was periodically monitored during the experimentation by videotape inspections in order to have the most significant results of the impact on the seweage system.

2.3. The wastewater treatment plant

The WWTP was originally designed with a treatment capacity of 250 population equivalent (PE) and a max flowrate of 6.87 m^3/h. The WWTP had the basic configuration, which is very common in Italy for small plants (Fig. 1): the incoming raw wastewater is pumped to an automatic screen (openings between bars 3 mm) and then to the biological reactor (83 m^3 volume). Activated sludge is then separated in a static rectangular clarifier and returned into the bioreactor, while the treated water is disinfected and finally discharged into a stream. The waste activated sludge (WAS) is spread on drying beds, which are then periodically emptied. Finally, the dried sludge is disposed of in landfills.

With specific reference to the biological process, an extended aeration process was originally applied since limits for nutrients discharge were not stringent for small plants with a treatment capacity lower than 2000 PE. Obviously, this technology was able to perform only carbon removal and ammonia nitrification with low sludge production. The plant was not under remote control and was periodically visited by skilled personnel involving high managing costs.

As the application of the FWDs can provide additional amounts of readily biodegradable chemical oxygen demand (rbCOD), to enhance the biological removal of nutrients (Bolzonella et al., 2003), the continuous aeration was modified to an intermittent process so as to perform an effective nitrogen removal. The control of the aeration was operated according to two strategies: firstly, a simple time controlled system was adopted, then, an automatic control based on on-line signals was applied (Battistoni et al., 2003a, b; Italian Patent NR99A000018, 1999). In this last process, in a continuously fed bioreactor, aerobic and anoxic cycles are performed alternately. The length of the cycles is automatically determined on the basis of the oxidation–reduction potential (ORP) and dissolved oxygen (DO) signals monitored on-line (Wareham et al., 1993; Zipper et al., 1998), which are collected and processed by a patented device. This system determines the alternation of aerobic and anoxic/anaerobic phases that optimize the N and can enhance P removal (Battistoni et al., 2003a, b; Fatone et al., 2005).

2.4. The monitoring and analytical plan

The experimentation was carried out for 275 days: 96 before and 179 days after the installation of the FWDs. During the first 3 months the existing scenario was defined, while in the second part of the study, impacts of the ground food waste (GFW) on sewers and wastewater treatments were analysed.

The chemical–physical characterization of the WWTP influent, effluent and activated sludge was determined twice a week on daily averaged samples: COD, soluble COD (sCOD), NH_4-N, TKN, total phosphorus (TP), total suspended solids (TSS), mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS), pH and total alkalinity were determined according to the American Public Health Association (1985), while the rbCOD was calculated according to Mamais et al. (1993). High-performance liquid chromatograph (HPLC) was used to determine concentrations of anions (NO_2^-, NO_3^{2-}, PO_4^{3-}, Cl^-, SO_4^{2-}, F^-) and cations (Na^+, K^+, Mg^{2+}, Ca^{2+}). Further, the specific rates for nitrogen removal, nitrates utilization rate (NUR), and oxidation, ammonium utilization rate (AUR), were determined by means of batch tests (Kristensen et al., 1992) in order to study the impact of the FWDs on the biological kinetics and, in particular, on the denitrifying capability of the activated sludge.

3. Results and discussion

3.1. Impact of the GFW on the sewers system

The impact of the GFW on the sewer system was evaluated in terms of hydraulic and mass overloads and solids sedimentation into pipes. No significant solids sedimentation is reported to occur if materials like piece of bones, shells, etc. are not introduced into the devices. In fact, according to

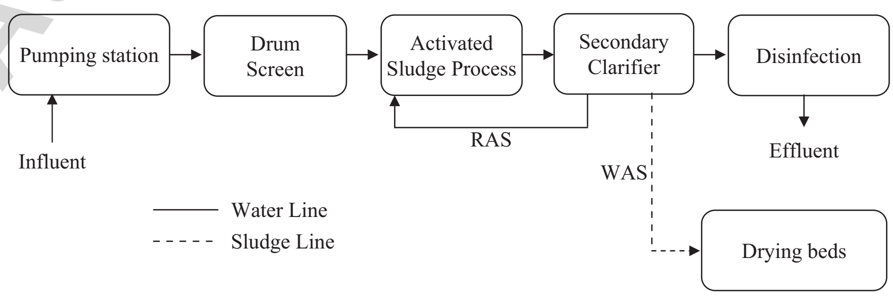

Fig. 1 – Schematic diagram of the WWTP.

Bolzonella et al. (2003), the adoption of FWDs can involve settling of some 16.8% of the GFW into the pipelines. In this study, the direct investigations (i.e., video and photo inspections along the most critical sewerage line and in the access ports) did not show relevant phenomena of solid sedimentation as already concluded by Nilsson et al. (1990).

As for the hydraulic overloads due to the additional tap water needed for the use of the FWDs, literature data reported an increase in the range 1–4.5 l per capita per day; therefore, an additional flowrate of 0.16–0.70 m^3/day was expected. As a result, the range of the incoming flowrate between 48 and 52 m^3/day was always observed in dry weather conditions. Moreover, comparing the typical daily patterns (Fig. 2), no significant changes were brought by the FWDs operation and the flowrate peaks were unexpectedly slightly levelled.

3.2. *Impact of the FWDs on sewers*

As commonly found in small systems, the influent COD, TSS, N and P during the experimentation were quite variable (Figs. 3a–d), consequently the real impact of the GFW is not easy to be distinguished. However, the effect of the waste becomes more evident considering the mass loadings (Table 2).

Increased values were observed both for the TSS, COD and, total nitrogen (TN) contents and for their standard deviations, but not for TP. In particular, a proportional increase of about

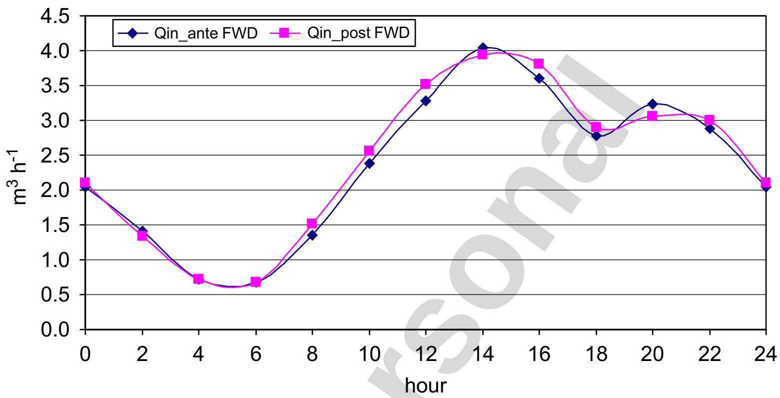

Fig. 2 – Typical daily fluctuations of influent to the WWTP, before and after the FWDs installations.

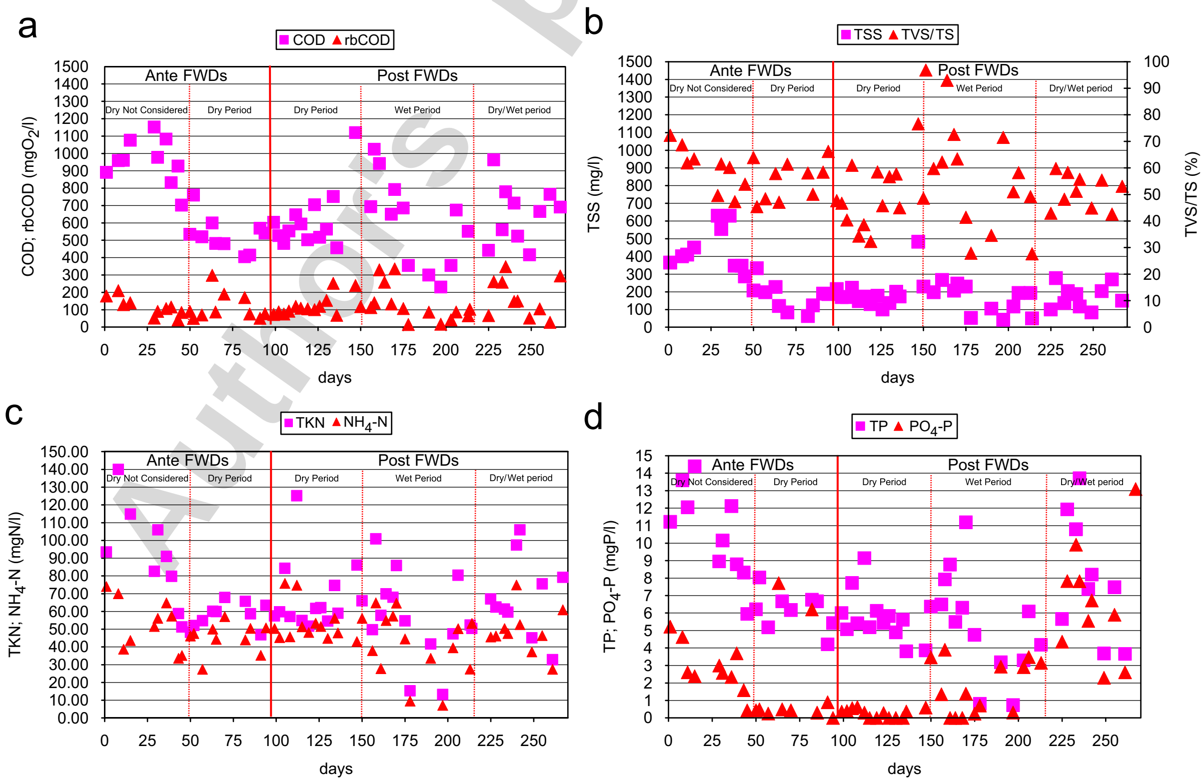

Fig. 3 – (a) COD, (b) suspended solids, (c) nitrogen and (d) phosphorus.

Table 2 – Inflow characteristics comparison (dry weather periods) for wastewater (WW) and wastewater+ground food waste (GFW)

Inflow	TSS	COD	rbCOD	$N\text{-}NH_4$	TN	TP	COD/TN	rbCOD/COD	rbCOD/TN
WW									
mg/L	172	574	115	45	58	10	9.9	0.20	1.98
St. dev.	±46%	±30%	±65%	±21%	±12%	±110%			
kg/day	8.6	28.7	5.7	2.2	2.9	0.5			
g/(capita day)[a]	37	125	25	10	13	2			
WW+GFW									
mg/L	223	827	195	49	69	6	12.0	0.24	2.88
St. dev.	±14%	±31%	±49%	±26%	±23%	±14%			
kg/day	11.2	41.4	9.8	2.5	3.5	0.3			
g/(capita day)[a]	49	180	42	10	15	1			
Impact of the GFW									
%	30	44	71	11	19	−40	21	20	45
g/(capita day)	11	55	17	1	2	na			
Literature range[b]									
g/(capita day)	20–90	18–121	nd	1.2–5.9	0.5–14	0.1–3.1	8.6–47		

[a] Calculated considering the design treatment capacity of the plant.
[b] Range depending on the market penetration factor ranging from 30% to 100% (Bolzonella et al., 2003).

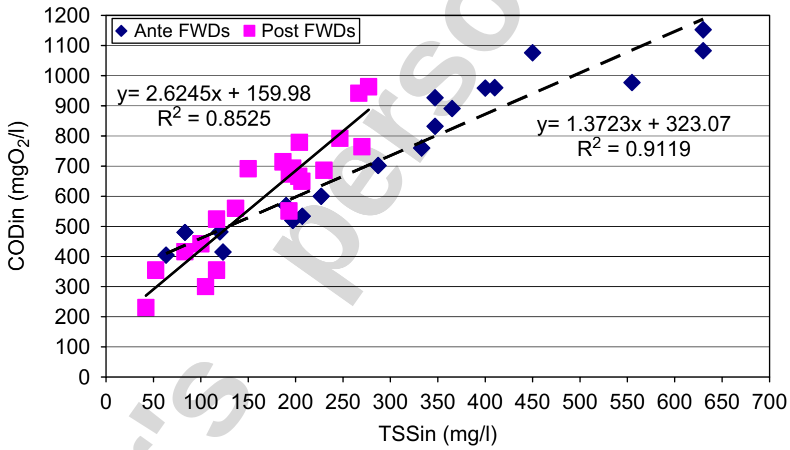

Fig. 4 – Influent COD vs. TSS ante- and post- the FWDs installation.

30%, 44% and 19%, corresponding to 11, 55 and 2 g per capita per day, was found for TSS, COD and TN, respectively (Table 2). Concerning the COD and its biodegradability, the COD/TN ratio increased from 9.9 up to 12.0, simultaneously the rbCOD/COD ratio passed from 0.20 to 0.24, so the rbCOD/TN ratio passed from 1.98 to 2.88 (45% increase). As for the characteristics of the suspended solids into the inflow, Fig. 3 shows how the COD/TSS ratio increased from 1.4 up to 2.6 (Fig. 4).

Since settled solids are expected to enter the plant during rainy periods, the inflows were compared also between dry and wet weather periods (Table 3 and Figs. 3a–d): during wet periods, the incoming flowrate doubled compared to the values observed in dry periods and increases of 12% and 38% for COD and TSS, respectively, were observed. The overload observed during the wet periods was associated not only with the GFW, but also to fine particles associated with rainfall run-off.

3.3. *Impact of FWDs on WWTP process performances*

The actual WWTP treatment capacity determined on the influent and weather conditions is summarized and compared in Table 4.

As often happened in Italy for small plants, the specific volume and the power installed for air supply were originally oversized: 304 $L_{reactor}$ per capita (based on COD) and 14.6 W per capita (based on COD), respectively. Therefore, the extra-loading determined by the GFW could be easily coped with by the wastewater treatment facilities. In fact, even after the FWDs application, the lowest specific tank volume observed was higher than 185 L per capita, that is, high enough to

Table 3 – Inflow characteristics comparison: influence of the ground food waste (GFW) in different weather conditions

Weather conditions	TSS	COD	rbCOD	N-NH_4	TN	TP	COD/TN	rbCOD/COD	rbCOD/TN
Dry									
mg/L	223	827	195	49	69	6	12.0	0.24	2.88
St. dev.	(±14%)	(±31%)	(±49%)	(±26%)	(±23%)	(±14%)			
kg/day	11.2	41.4	9.8	2.5	3.5	0.3			
Wet									
mg/L	141	422	98	36	49	4	8.6	0.23	2.00
St. dev.	(±50%)	(±40%)	(±51%)	(±41%)	(±50%)	(±73%)			
kg/day	15.5	46.4	10.8	4.0	5.4	0.4			
Proportional difference of mass loadings									
%	38	12	11	65	59	47	−28	−4	−31

Table 4 – Plant effective potentialities

Weather	Dry	Dry	Wet	Original design
Inflow	WW	WW+GFW	WW+GFW	
Q_{in} (m^3/day)	50	50	111	55
Plant treatment capacity on COD basis ($capita_{COD}$)[a]	273	394	441	250
Plant treatment capacity on N basis ($capita_N$)[b]	242	292	450	250
Specific tank volume ($L_{reactor}/capita_{COD}$)	304	211	188	332
Specific air power supply ($W/capita_{COD}$)[c]	14.6	10.1	9.1	16.0

[a] Calculated considering a unit mass loading factor $Lu_{COD} = 105$ g/capita day.
[b] Calculated considering a unit mass loading factor $Lu_N = 12$ g/capita day.
[c] Air supplied by volumetric blowers and microbubbles air diffusers.

Table 5 – Process management during the experimental periods

Time period	Days 1–49	Days 50–93	Days 94–149	Days 155–275
Inflow	WW	WW	WW+GFW	WW+GFW
Process	Extended	Fixed time	Fixed time	Automatically controlled
Applied	Aeration process	Aerobic/anoxic cycles	Aerobic/anoxic cycles	Alternate cycles process

perform efficient COD and TN removal. Regarding the air supply, the oversized design value of 16 W per capita involved remarkable energy wastes especially when operating the extended aeration process. After the application of the FWDs, this specific power decreased to values as low as 9 W per capita; that was still sufficient to supply adequate air for the aerobic biochemical reactions.

The WWTP operated three different biological processes along the 275 days of experimentation. Further, considering also the influent changes, 4 different periods were singled out as shown in Table 5.

After the original extended aeration, the intermittent air supply was applied to perform also nitrates denitrification, so as to take the maximum advantage from the increased availability of organic substrates in the influent. The length of the anoxic and aerobic cycles was firstly based on a timeout set point, and then automatically controlled by the control device described above.

The operating parameters adopted during the experimentation are summarized in Table 6: a solid retention time (SRT) of some 11 days was enough to guarantee the growth of autotrophic bacteria so to obtain the required ammonia nitrification. The solids in the reactor were maintained between 3.4 and 4.5 g/l, and the Food to Microorganism (F/M) ratio increased from 0.13 to 0.25 kg COD kg/MLVSS/day. Regarding the sludge properties, no remarkable MLVSS/MLSS variations were observed after the FWD application. The excess sludge was wasted to keep the target MLSS concentra-

Table 6 – Operating parameters

	Days 1–49	Days 50–93	Days 94–149	Days 155–275
T (°C)	20	24	18	12
MLSS (g/l)	4.5	3.5	3.4	4.0
MLVSS/MLSS (%)	78	77	77	76
SVI (ml/g)	139	129	182	198
RAS (m^3/day)	43	43	43	43
SRT (day)	12	11	11	12
WAS (kg/day)	31	26	32	34
F/M (g COD/g MLVSS day)	0.16	0.13	0.15	0.25
OLR (kg COD/m^3 day)	6.8	4.2	4.7	9.2

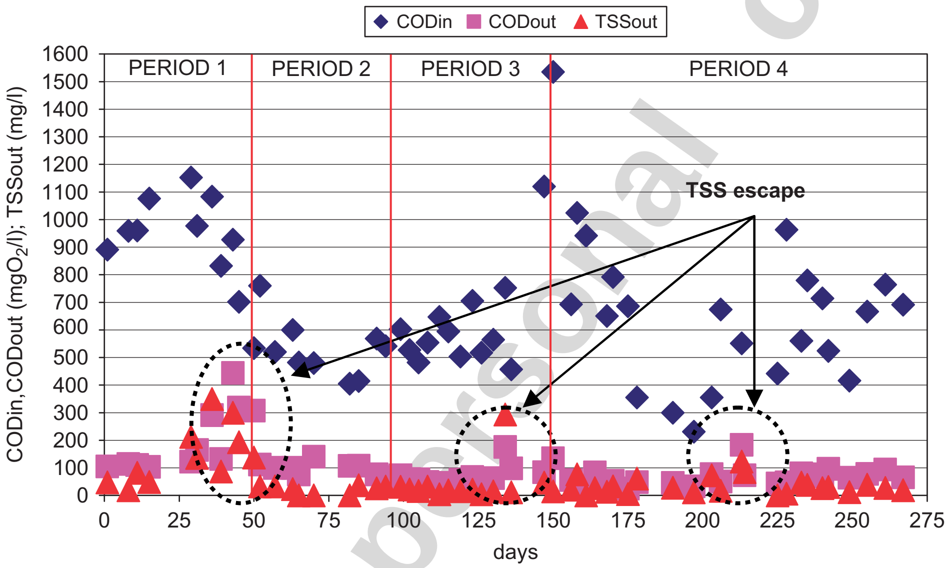

Fig. 5 – Profile of influent and effluent COD and TSS.

tion, its increase was basically related to the applied organic loading rate but it was not possible to clearly identify the influence of the FWD owing to the statistical dispersion of experimental data. The Sludge Volume Index (SVI) and the sludge settling properties showed typical variations according to the mixed liquor temperature. Finally, it has to be pointed out the role of the low recycled activated sludge (RAS) in the reduction of the energy requirements of the system.

As far as the removal performances of pollutants was concerned, the COD removal ranged between 80% and 91%. Isolated cases of higher effluent COD were observed during maintenance periods, when hydraulic overflows involved the escape of irregular solids from the secondary clarifier (see Fig. 5: higher effluent COD corresponds to higher TSS in the same stream). As a result, the effluent soluble COD was always lower than 60 mg/L.

As for the TN, the most remarkable improvement was due to the automatic control of the intermittent aeration according to the alternate cycles (Fig. 6).

The nitrogen mass balances were calculated according to Battistoni et al. (2002). The nitrification and denitrification performances were calculated taking account of the nitrogen discharged with the WAS stream, which was experimentally determined and considered in the mass balances. Therefore, Table 7 shows the nitrifying efficiency, E_{nn}, which is related to the nitrifiable nitrogen, and the denitrifying efficiency, E_{dd}, which is related only to NO_x-N (sum of nitrified ammonia and influent nitrites or nitrates).

Owing to the simultaneous effects of an adequate SRT, large bioreactor volume and air supply, the nitrification efficiency was always very high (efficiency higher than 86%).

The effect of the GFW on the denitrification process was emphasized comparing the results observed in periods 2 and 3, where anoxic and aerobic phases of 30 and 90 min were alternated: here, despite the application of a simple and rigid intermittent system, the denitrification capability rose up from 0% to 27%. Finally, when the alternated cycles process was applied, because of its reliability and elasticity, the nitrogen removal reached a remarkable 84% (during period 4). This efficiency was observed during both wet and dry periods as shown from the data reported in Table 8. Hence, the long-term flexibility of this system was proved on-site.

The statistical analysis of cycle's behaviour is an easy and useful tool to understand the performances and reliability of

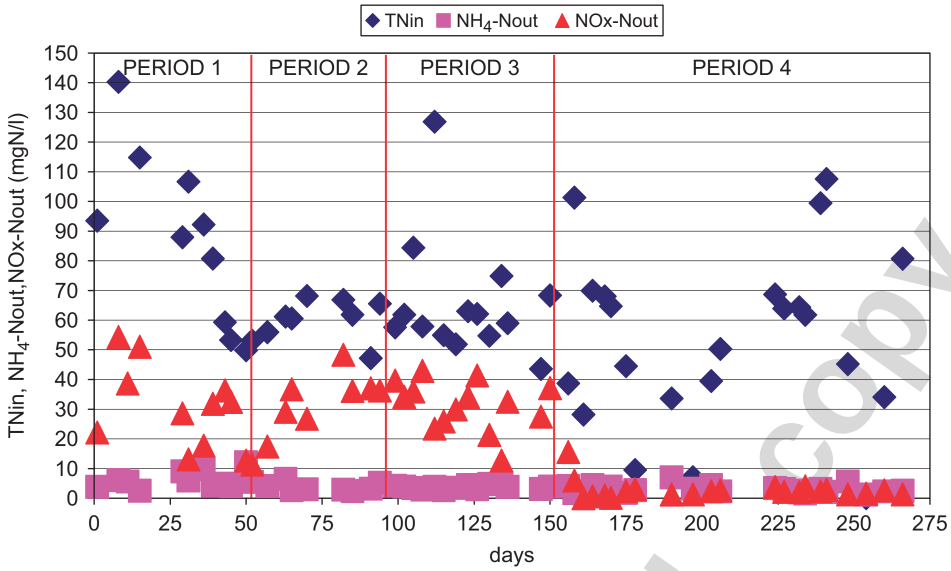

Fig. 6 – Influent TKN and effluent NH_4-N and NO_x-N.

Table 7 – Nitrogen removal efficiencies in all the experimental periods

	Days	L_{TNin} (kg/day)	L_{TNout} (kg/day)	NLR (kg/m^3 day)	E_{nn} (%)	E_{dd} (%)
Period 1	1–49	5.4	1.1	0.06	93	0
Period 2	50–93	2.9	0.6	0.03	86	0
Period 3	94–149	3.4	0.3	0.04	92	27
Period 4	155–175	6.1	0.6	0.07	93	84

Table 8 – Nitrogen mass balance during the alternate cycles operation—wet and dry periods

	L_{TNin} (kg/day)	L_{TNout} (kg/day)	NLR (kg/m^3 day)	E_{nn} (%)	E_{dd} (%)
Dry	3.7	0.4	0.044	92	92
Wet	4.2	0.6	0.050	80	89

Table 9 – Statistical analysis for the alternate cycles process—wet and dry periods

Weather	Oxic phase length (min)	α (%)	Anoxic phase length (min)	β (%)
Dry	20	81	42	86
Wet	36	29	84	79

the control device. Moreover, studying the different behaviour of the process (i.e., the profiles of DO and ORP), the main characteristics of the raw influent, in terms of loadings and biodegradability, can be deduced. In particular, the statistical analysis of the performed cycles allows to determine the percentage of success for the control device in detecting the ammonia breakpoint during the aerobic phase (α) and the nitrates breakpoint in the anoxic phase (β). The output of the data processing is showed to discuss the behaviour of the alternate cycles process with respect to the fluctuations of the inloadings both in wet or dry weather (Table 9) and within a day (Table 10).

Owing to the increased influent ammonia and decreased COD/TN ratio, the anoxic/oxic cycles were longer in wet

Table 10 – Statistical analysis 0–24 h

h	Oxic phase length (min)	α (%)	Anoxic phase length (min)	β (%)
0–6	23	54	76	64
6–12	32	76	67	79
12–18	28	97	64	97
18–24	27	94	58	96

Table 11 – Energy consumptions

	Days	Electric energy (kW h/year)	Relative energy savings (%)
Period 1	1–49	42.048	0
Period 2	50–93	33.069	21
Period 3	94–149	33.069	21
Period 4	155–175	25.789	39

(120 min) rather than in dry periods (60 min). During the dry periods the reliability of the control device was satisfactory both in aerobic ($\alpha = 81\%$) and anoxic ($\beta = 86\%$) phases, determining very high performances (E_{nn} and E_{dd} of 92%). On the other hand, when considering wet periods, over-aeration often occurred and the reliability of the system during the aerobic phase was only 29%.

During wet periods, over-aeration phenomena involved following longer denitrification phases. As a matter of fact, the anoxic phases were efficiently stopped both in dry and in wet periods, showing the good COD/TN ratio and the positive impact of the FWD. Only in a few critical cases the nitrates breakpoints were not detected within the maximum time set points. This non-optimal management of the process happened more in wet than in dry periods (21% wet vs. 14% dry) because of the higher over-aeration.

The use of FWDs in small communities with short sewerage systems can increase the hourly loading variations in the inflow. Hence, the short-term flexibility of this technology holds a fundamental role to always assure the reliability of the treatment. Even if in this experimentation no significant changes were observed concerning the influent fluctuations (Fig. 2), the process showed its high flexibility as pointed out by the statistical analysis output (Table 10).

Relevant and fast over-aeration was observed during periods of low loaded influent in 0–6 h (α only 54% and 23 min-long oxic phases). Consequently, also the denitrification phase was influenced both in detecting the flex in the nitrate profile and in phase time length (β only 64% and 76 min-long anoxic phase). This scenario was lower in hours 6–12, while in hours 12–24 the reliability of the control device was very successful because of the incoming extra-load determined by the GFW.

The impacts of the GFW on the specific rates for nitrogen removal were periodically evaluated both in the lab and on-site, respectively, performing respirometric tests and investigating the nitrogen forms directly into the full-scale bioreactor. The lab and field rates, adjusted at 20 °C, had similar values: 0.07–0.10 and 0.06–0.07 kgN kg/MLVSS/day, respectively, for nitrification and denitrification.

3.4. *Energy consumptions and economic remarks*

The increase in energy consumptions due to the FWDs operation was calculated for all the experimental periods (Table 11).

Shifting from extended aeration process (period 1) to fixed aerobic/anoxic cycles (period 2), a proportional decrease of energy consumptions of 21% was observed for the WWTP operation, while the FWDs showed no impact on the energetic consumptions (compare periods 2 and 3).

After the application of the alternate cycles process (ACP), the proportional energy consumption savings increased up to 39%, which was also associated with the maximum removal performances.

On the basis of the costs calculated at the end of the experimentation, the estimation of the capital and management costs have been carried out for a town of 10 000 inhabitants. Therefore, Table 12 compares the costs due to the waste management by the FWDs and the following treatment in the WWTP with the costs involved by the traditional source collection and the centralized treatment of the organic fraction of the municipal solid waste (OFMSW).

As expected, the application of the FWDs technology involved high capital costs, mainly linked to the FWDs purchase and installation. However, the operating costs are then very sustainable especially when operating a cost effective process like the alternate cycles process in the WWTP. On the other hand, the source collection of biowaste involves lower capital, but comparing the options proposed in Table 12, the application of the FWD technology in a town of some 10 000 inhabitants involves an amortization time of 4–5 years because of the high operating cost of the source collection of biowaste.

Table 12 – Costs for the integrated (waste+wastewater) management vs Traditional Source collection for 10 000 inhabitants

		GFW+WW integrated cycles	Traditional source collection
Capital cost			
Collection organization	€	963.400	14.800
Management costs			
Source collection+transport	€/year	0	191.400
Treatment+disposal	€/year	6.900	47.100[a]

[a] Treatment in a centralized composting plant.

4. Conclusions

The paper deals with the coupled application of food waste disposers (FWDs) and the alternate cycles process (ACP) for the management of WWTPs in a small and decentralized village. The coupled technology proved to be sustainable for the integrated management of organic food waste and municipal wastewaters. The main remarks are itemized in the following list:

- the installation of the FWDs, with a market penetration factor of 67%, involved maximum proportional increases of TSS, COD and TN of 30%, 44% and 19%, respectively. These corresponded to 11, 55 and 2 g per capita per day. As a consequence, the COD/TN ratio passed from 9.9 to 12 and the rbCOD/COD from 0.20 to 0.24. This change of the inflow characteristics involved a good enhancement of the nitrates biological denitrification (+27%). The field and lab specific denitrification rates, adjusted at 20 °C, ranged from 0.06 to 0.07 kg NO_3-N/(kg MLVSS day);
- the real influent loadings of the main pollutants were dispersed, as commonly observed in small Italian plants, therefore the real impact of the GFW was hard to distinguish. As a result the plant performances did not suffer the overloads linked to the GFW, nor in dry nor in wet weather periods;
- the plant design for this integrated purpose, 9.1 W per capita and 188 l of reactor per capita (on COD basis) can be taken as safe data for power supply for aeration and bioreactor volume;
- the automatically controlled alternate cycles process was flexible with respect to the influent fluctuations, reliable and suitable to optimize the COD and TN removal using an old and upgraded existing plant. Furthermore, since its application is easy to operate and allows the on-line remote control, it can involve remarkable cost savings regarding the skilled personnel;
- the FWDs technology has no significant impacts in increasing the energy consumption of the WWTP operation. In fact, the better availability of biodegradable carbon can optimize the use of the nitrogen-bound oxygen, so to save energy for air blowing;
- in the case of a decentralized town of some 10 000 inhabitants, the higher costs involved by the source collection of the OFMSW lead us to conclude that the application of FWDs will be more beneficial but only after it has been in operation for more than 4–5 years.

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