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Decentralized integrated treatment of kitchen waste and municipal wastewater by food waste disposers and alternate cycles

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The use of food waste disposers can be an interesting option to integrate the management of municipal wastewaters and household organic waste in small towns and decentralised areas. 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 food waste disposers were applied, with a market penetration factor of 67%, in a mountain village of 250 inhabitants. Further, the existing wastewater treatment plant 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 wastewater treatment plant was able to face the overloads of 11, 55 and 2 grams 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 $kgNO_3$-N $kgMLVSS^{-1}$ day^{-1}. Therefore, not only COD removal, but also the total nitrogen removal increased (net denitrification efficiency ~ 84%). 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

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. Further, the treatment of biowaste to reclaim important elements like carbon, nutrients, 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.

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 COD, 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).
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, the wastewater treatment efficiency and energy consumptions 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 municipal solid waste 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. Inside the examined area, a small town, Gagliole, 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.

2.2 The sewer system

The typical retention time (dry weather) (1.5 hours) 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 were in good condition, but a sewerage line of 75 meters (diameter 350 mm) showed a critical slope (1 mm/m). This was periodically monitored during the experimentation by video-tape inspections.

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: 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 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, this technology was able to perform only carbon removal with low sludge production and ammonia nitrification. The plant had not a remote control and was periodically visited by skilled personnel involving high managing costs.

Since the application of the FWDs can provide additional amounts of rbCOD, so to enhance the biological removal of nutrients , the biological process was then modified into alternate processes to perform an effective nitrogen removal. This process was applied according to two modes: firstly a time controlled system, then an automatic control system (Battistoni et al., 2003; Italian patent NR99A000018, 1999).

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. The chemical-physical characterization of the WWTP influent and effluent and activated sludge, was determined twice a week on grab samples. COD, soluble COD (sCOD), NH_4-N, TKN, TP, TSS, MLSS and MLVSS, pH and total alkalinity were determined according to the *Standard Methods,* while the rbCOD was calculated according to Mamais et al (1993). HPLC was used to determine concentrations of anions and cations. Further, the specific rates for nitrogen denitrification, NUR, and oxidation, AUR, were determined through the application of batch tests (Kristensen et al., 1992).

3. Results and Discussion

3.1 Impact of the GFW on the sewers system

The impact of the ground food waste (GFW) on the sewer system was evaluated in terms of hydraulic and mass overloads and solids sedimentation into pipes.

As for the hydraulic overloads due to the additional tap water needed for the use of the FWDs, was expected an additional flowrate of 0.16 ÷ 0.70 m^3 d^{-1}. As a result, the range of the incoming flowrate between 48 and 52 m^3d^{-1} was always observed in dry weather conditions. Moreover, comparing the typical daily patterns, no significant changes were brought by the FWDs operation, and rather, the 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, 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 1).

Table 1. Inflow characteristics comparison: dry weather periods and different inflows

Inflow		TSS	COD	rbCOD	N-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
	Kg/d	8,6	28,7	5,7	2,2	2,9	0,5			
	g/PE*d	37	125	25	10	13	2			
WW+GFW	mg/l	223	827	195	49	69	6	12,0	0,24	2,88
	Kg/d	11,2	41,4	9,8	2,5	3,5	0,3			
	g/PE*d	49	180	42	10	15	1			
Impact GFW	%	30	44	71	11	19	-40	21	20	45
	g/PE*d	11	55	17	1	2	na			

Increased values were observed both for the TSS, COD and TN contents but not for TP. In particular, a proportional increase of about 30%, 44% and 19%, corresponding to 11, 55 and 2 grams per capita per day, was found out respectively for TSS, COD and TN. Concerning the COD and its biodegradability, the COD/TN ratio increased of 21 %, the rbCOD/COD ratio of 20 %, the rbCOD/TN ratio had a proportional increase of 45%. Since settled solids are expected to enter the plant during rainy periods, the inflows were compared also between dry and wet weather periods (Table 2).

Table 2. Inflow characteristics comparison: WW+GFW in different weather conditions

Weather Conditions	U.M.	TSS	COD	rbCOD	N-NH_4	TN	TP
Dry	kg/d	11,2	41,4	9,8	2,5	3,5	0,3
Wet	kg/d	15,5	46,4	10,8	4,0	5,4	0,4
Difference of mass loadings	%	38	12	11	65	59	47

During wet periods (Table 2), 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

Considering the influent changes and different biological processes, 4 different periods and the different operating parameters were individuated as shown in Table 3.

Table 3.Process management of 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 Applied	Extended Aeration Process	Fixed Time Aerobic/Anoxic Cycles	Fixed Time Aerobic/Anoxic Cycles	Automatically Controlled Alternate Cycles Process

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 (Figure 1) (COD<60 mg L^{-1}).

The Table 4 shows the nitrifying efficiency E_{nn}, which is referred to the really nitrifiable nitrogen, and the denitrifying efficiency E_{dd}, which is referred to the only NO_x-N (sum of nitrified and influent).

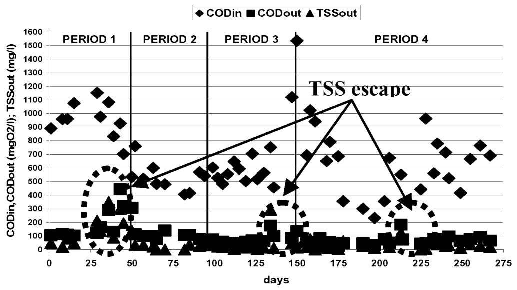

Figure 1. Influent/Effluent COD and TSS

Table 4. Nitrogen removal efficiencies in all the experimental period

	Days	L_{TNin}	L_{TNout}	NLR	E_{nn}	E_{dd}
		kg/d	kg/d	Kg/m3*d	%	%
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

The effect of the GFW on the denitrification process was emphasised comparing the results observed in periods 2 and 3, where anoxic and aerobic phases of 30 and 90 minutes 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). Hence, the long term flexibility of this system was proved on-site.

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 5).

Table 5. Energy consumptions

	Days	EE (kWh/y)	Proportional 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

Shifting from extended aeration process to fixed aerobic/anoxic cycles, a proportional decrease of the energy consumptions of 21 per cent was observed for the WWTP operation, while the FWDs showed no impacts on- the energetic consumptions.

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. Table 6 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 OFMSW. As expected, the application of the FWDs technology involved high capital costs, mainly linked to the FWDs purchase and installation. The operating costs are then very sustainable especially when operating a cost effective process like the alternate cycles process. On the other hand, the source collection of biowaste involves lower capital, but comparing the options proposed in Table 6, the application of the FWD technology in a town of some 10000 inhabitants involves an amortization time of 4÷5 years because of the high operating cost of the source collection of biowaste.

Table 6. Costs of Treatment Cycles Integrated vs Traditional Source collection

		GFW+WW Integrated Cycles	Traditional Source collection
Capital cost			
Collection organization	€	963.300	14.800
Management costs			
Source Collection + Transport	€/y	0	191.400
Treatment + Disposal	€/y	6.900	47.100

4. Conclusions

As overall result the coupled technology (FWDs and Alternate Cycles Technology) proved to be sustainable for the integrated management of organic food waste and municipal wastewaters. The main remarks are following itemized:

- the installation of the FWDs, with a market penetration factor of 67%, involved at most the proportional increases of TSS, COD and TN of 30%, 44% and 19% respectively. These correspond to 11, 55 and 2 grams 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 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 $MLVSS^{-1}$ day^{-1};
- the real influent loadings of the main pollutants were dispersed, therefore the real impact of the ground foodwaste was hard to distinguish. The plant performances did not suffer the overloads linked to the GFW, nor in dry nor in wet weather periods.
- the alternate cycles process process was flexible with the influent, reliable and suitable to optimize the COD and TN removal using an old and upgraded existing plant.
- the FWDs technology has no significant impacts in increasing the energy consumption of the WWTP operation. It is considered convenient the couple FWDs+ACP if these will have been operating for more than 4÷5 years.

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