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THE UNDER SINK GARBAGE GRINDER: A FRIENDLY TECHNOLOGY FOR THE ENVIRONMENT

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ABSTRACT

The use of garbage grinders is not a usual practice in Europe, but it is in other countries around the world (e.g., North America, Japan and Australia). Sometimes, garbage grinders are accused of producing problems in sewers and wastewater treatment plants and are prohibited by environmental protection laws. In this study, the different impacts determined by the use of this technology were considered to show the positive impacts of its use. In particular, it was shown that garbage grinders enable the disposal of household organic wastes with advantages for the wastewater treatment processes because of an increase in the carbon/nutrients ratio in the wastewater. This is particularly important for biological nutrients removal processes. Daily specific contributions for person equivalent (PE) due to organic waste disposal through garbage grinders were found to be equal to 75 $gCODPE^{-1}d^{-1}$ for carbon (as COD), *23* $gNPE^{-1}d^{-1}$ for nitrogen and 0.25 $gPPE^{-1}d^{-1}$ for phosphorous, respectively. Those determined a value of 30 for the COD/N ratio. Moreover, no problems with solids settling in sewers were noted. These results were extensively compared with literature data. The economical balance showed that the use of garbage grinders allowed a global saving of some 17 €$year^{1}$ for a three people family. Important benefits are also gained from an environmental point of view (e.g., organic wastes disposal, nutrients removal in wastewater treatment and increase in biogas production with energy reclamation).

Keywords: Biogas, Biological nutrients removal, economical balance, garbage grinder, solid organic wastes, sewers, wastewater treatment plants

INTRODUCTION

The disposal of household organic wastes, basically kitchen refuse, in sewers, and thus in the wastewater treatment plants, by means of under sink garbage grinders, is a common practice in the USA, Canada, Brazil, Japan and Australia, but is not so familiar in European Union Countries [1, 2]. However, some eighty countries around the world permit the use of garbage grinders for food wastes disposal [3]. The use and diffusion of this device in households is greatly different in these countries: in fact, about 50% of families use it in the USA, where garbage grinders were introduced in the early 1930s, but only 5% of families do so in the United Kingdom, although garbage grinders have been introduced 30 years ago [3]. Despite its diffusion, the garbage grinder technology encounters some problems in environmental law frameworks and acceptance: the City of New York banished this device in the 1970s in order to limit the direct discharge of raw materials into water bodies surrounding the City during wet weather and to prevent possible deterioration of the sewer system. After a period of monitoring of the sewer system and of the performances of the wastewater treatment plants, that prohibition has been recently removed [4], Furthermore, both the Swedish and the Dutch Environmental Ministries expressed some doubts to garbage grinder use in 1980s and 1990s [2, 3], whereas in Italy its use was forbidden by Law 152 of 1999. In 2002, the law was changed and the use of garbage grinders was permitted again.

In order to show and prove the possibility to co-treat household organic wastes and wastewaters, a number of studies have been carried out in the last decades: some theoretical [3, 5] and others experimental [2, 4, 6 - 12].

Basically, all the mentioned studies reported an increase of per capita loading in terms of nutrients, solids and grease and oils in sewers, as a result of garbage grinder use. The reported increases are quite different, depending on the cited studies. These increases generally were in the range 14--- gPE^{1} (person equivalent) d^{-1} for COD (chemical oxygen demand), passing from a 30% to a 100% of households using the grinder, 5-10 $gPE^{-1}d^{-1}$ for nitrogen, 0.1-3 $gPE^{-1}d^{-1}$ for phosphorous, 3-34 $gPE^{-1}d^{-1}$ for suspended solids and 2.7-7 $gPE^{-1}d^{-1}$ for oils. More details about this issue are given in the results and discussion section. Furthermore, some studies also considered the impact on the sewer system and the wastewater treatment plants (WWTPs). Generally, these studies reported that the impact on sewers was negligible [9, 10], even though an increase in maintenance interventions was sometime observed [2, 4, 6). Concerning the impacts on WWTPs, an increase in oxygen requirement and sludge production was observed as well as an increase in biogas production, when an anaerobic stabilisation process was present [2, 9,12).

Generally, all these studies pointed out that the use of garbage grinders leads to useful benefits. In fact, the reduction of wastes production (and disposal) and the reclamation of resources are fundamental issues within the concept of sustainable development. In urban areas these targets could be achieved by the integration of the wastes treatment cycles (waters and solid organics) [13-15). The integration of the treatment cycles could be achieved considering the sewers as collecting systems. According to Henze [5], organic wastes could be treated through garbage grinders and sent to wastewater treatment plants by means of sewers, saving in terms of separate collection and truck transport ("aquamobile" concept). The same was proposed in Italy in the 1980s, since this method allows the collection at source of some one third of municipal solid wastes [11].

The cycles integration is of particular interest also because of an increase in the organic load in wastewater compared with nutrients increases [14-16].

Furthermore, a sludge of good characteristics is obtained, suitable for agricultural disposal after anaerobic stabilisation, or to reclaim electric energy and heat by biogas combustion [2,12,17].

This paper considers several aspects of the use of garbage grinders technology, in order to clarify the possibilities of the application of this device. The shredding costs, in terms of water, time and energy consumption by a typical three member family are presented. Moreover, the impact of the organic wastes on the wastewater characteristics and on the sewers system, in terms of settling rates of solids, are presented. Also the impact on the wastewater treatment process was evaluated with regard to nutrients removal, sludge production and oxygen requirements. Finally, an economical evaluation was carried out to point out the feasibility of the approach.

MATERIALS AND METHODS

The study considered the use of two different garbage grinders for the shredding of the organic fraction of municipal solid wastes (OFMSW), one Italian and the other made in the USA. After shredding, the wastes were mixed with real wastewater and the profile of nutrients and solids concentrations with time were evaluated. This was to verify the behaviour of this stream in sewers of different length. Moreover, settlement tests of different shredded wastes were carried out in order to evaluate possible clogging problems in sewer systems. Finally, the impact of the additional pollutants loading on the WWTPs performances was determined through Active Sludge Model (ASM) 2 simulations.

Organic Wastes and Wastewater Characteristics

The organic wastes used in shredding tests were collected in a canteen and they were due both to garbage of food preparation and meal leftoners. Therefore, they were quite similar to source collected organic fraction of municipal solid wastes (SC-OFMSW). Table 1 reports the typical characteristics of the used wastes. Here, the typical values mentioned in other studies are also reported 13,18].

The characteristics of the wastewater used in the tests are summarised in Table 2. It was a typical low strength wastewater.

Shredding and Fermentation Tests

The shredding tests were carried out by using an American and an Italian garbage grinder with an installed power of 0.5 HP each. The consumption in terms of water, electric energy and time were evaluated. In order to determine the impact of the shredded OFMSW addition on wastewater characteristics and, thus, on the wastewater treatment plant performances, fermentation tests were carried out. These allowed the simulation of the sewer length influence on the wastewater composition and characteristics. The tests were performed on the basis of the typical per capita daily production of 250 litres of wastewater and 300 grams of

Table 1. Typical chemical-physical characteristics of the organic wastes.

Parameter	Range	Tvpical value	Ref. [3]	Ref. [18]
Total Solids, % -	21.4-27.4	25.6	28	29
Total Volatile Solids, %	21.3-26.3	24.6	20.3	na
Total Volatile Solids, % on TS	91.3-99.7	96.5	72	63
Total COD, $g\ gTS^{-1}$	1.2-1.3	1.2	1.6	na
Nitrogen, % on TS	2.6-3.7	3.2	3.4	2.2-3.4
Phosphorus, % on TS	0.13-0.28	0.2	na	0.4-0.6

Table 2. Wastewater characteristics.

Parameter		Ave. values	Typical values for low strength wastewater; Ref. [1]
TSS,	mg l^{-1}	110	100
VSS,	% on TSS	83.2	80
COD,	mg l^{-1}	150	250
SCOD,	mg l^{-1}	83.5	na
TKN,	mg N l^{-1}	36.8	20
$N\text{-}NO_3$,	mg N l^{-1}	1.8	0
Total P,	mg P l^{-1}	2.9	4
$P\text{-}PO_4$,	mg P l^{-1}	1.7	3
$S\text{-}SO_4$.	mg S l^{-1}	6.1	20

OFMSW [14]. A span of 48 hours was considered for the fermentation tests. These were carried out in vessels of 5 litres working volume, heated by an external jacket system filled with deionised water. The fermenters were the glass-one type and they were mechanically stirred. Samples were taken at t = 2, 4, 6, 8, 12, 24 and 48 h, and total (TSS) and volatile suspended solids (VSS), COD, Total Kjeldlah Nitrogen (TKN) and Total P trends were determined. This established the behaviour of hydrolysis and fermentation phenomena for different sewer lengths, according to a 0.7 m s^{-1} velocity (as an average of sewage speed in sewers) [1]. Tests were performed at 10,15 and 20 °C in order to verify the temperature influence on degradation kinetics.

All the analyses were carried out according to the Standard Methods [19], except VFA which were detected by gas chromatographic analysis according to the specific method described in Pavan *et al.* [14].

Settling Tests

The impact of the additional load of total solids in sewers was studied by shredding 300 grams of different household organic wastes (fruit, vegetables, pasta-bread, meat and fish) in a garbage grinder and using two litres of tap water to dilute. The size distribution of the different fractions of organic wastes was determined using a 0.84 mm sieve (200 mesh). This size was chosen since, according to the authors experience [20], it distinguishes between coarse (> 0.84 mm) and fine (< 0.84 mm) particles. In fact, 95% of suspended solids in wastewater are under this threshold [20]. The settling velocity of coarse particles was measured in a one litre suspension of 15-30 g of 0.84 mm sieved solids in tap water. This quantity enabled a good observation of the settling behaviour of the solids. The settling velocity of the fine particles was directly measured in a 1 litre sample of 0.84 mm filtrated mixture. Suspended solids can settle or float: to distinguish these two classes at the end of each test the floating fraction was altered and the total suspended solids (TSS) were determined [19], The weight of settling solids was calculated as a percentage of total solids.

The settling velocities of coarse and fine particles were then compared with settling velocities of total suspended solids present in the incoming wastewater flowrate of three civil wastewater treatment plants (WWTPs). These were measured on samples taken at the end of the sewer pipeline to determine the actual amount of solids reaching the WWTP. Since the solids concentrations in the wastewater were low, the samples were concentrated 10 folds in order to better identify the settling behaviour and velocity of the suspended solids.

Activated Sludge Model simulation

In order to evaluate the impact of the additional pollutants loading on the performances of the wastewater treatment processes, simulations by the Activated Sludge Model 2 [21] were performed. When running the mathematical model, both a typical pre-denitrification (C-N) and a biological nutrient removal treatment process with or without a primary settler were considered, adopting different sludge retention times (SRT) and temperatures conditions. Moreover, the simulations with the sole wastewater as incoming stream were performed and the performances and process variables of the different situations were compared.

RESULTS AND DISCUSSION

Consumption Tests and Related Costs Analysis

The costs for garbage grinder use, in terms of water, time and energy consumption, by a typical three member family were determined by experiments carried out on the basis of a daily per capita production of 250 litres of wastewater and 300 grams of OFMSW. Garbage grinders were used considering a single daily shredding mode or a multiple daily shredding mode and the results were then compared. The annual costs per family in terms of time, energy and water are reported in Table 3. As can be seen the single shredding mode was cheaper than the multiple mode. However, since the involved costs were very low (see Table 3) it could be reasonable to perform several operations during

Table 3,

	Consumption	Cost, Euro
Single shredding operation per day		
Time, h	11.6	na
Water, m^3	1.1	0.57
Energy, kWh	4.3	0.55
Multiple shredding operation per day		
Time, h	22.8	na
Water, m^3	2.1	1.08
Energy, kWh	8.5	1.10

the day. This allowed a continuous disposal of wastes, avoiding garbage storage in houses. The evaluation of the different consumption in terms of water, time and energy was carried out by shredding different amounts of organic wastes (0.1, 0.5, 1, 2.5, 5 kg) by means of two garbage grinders. Obviously, time is an additional information but it was useful for power consumption calculations. The typical consumption profiles for electric energy are plotted in Figure 1.

The parameters profiles could be plotted by an hyperbolic function with equation:

$$Y = a X^{-b}$$

where Y was the measured parameter (time, water and energy consumption), X was the shredded OFMSW (wet weight) and *a* and *b* were two constants, whose values were:

a = 118.55 and b = 0.6195 , for specific shredding time, s kg^{-1};

a = 3.5099 and b = 0.6205 , for specific water consumption, l kg^{-1};

a = 0.0123 and b = 0.6165 , for specific electric energy consumption, kWh kg^{1}.

Typical per capita daily consumption are compared with literature data in Table 4.

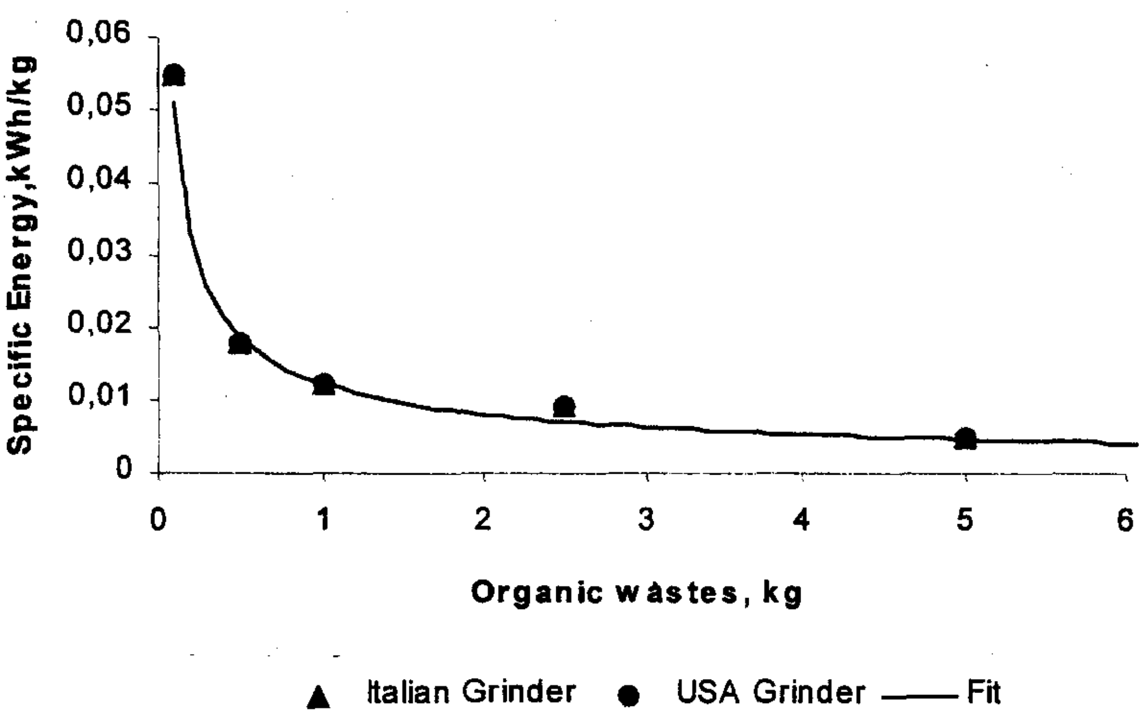

Figure 1. Specific electric energy consumption versus amount of shredded OFMSW.

Table 4. Per capita daily consumption of time, water and electric energy.

Reference	This study(*)	Ref. [2]	Ref. [11]
Time, min $PE^{-1}d^{-1}$	0.6-1.25	---	0.4
Water, litres $PE^{-1}d^{-1}$	1.0-1.9	1.1-45	1.5
Energy, Wh $PE^{-1}d^{-1}$	3.9-7.7	6.0	2.0

(*) The range is related to single and multiple shredding operations ---

Fermentation Tests

In order to determine the impact of the shredded OFMSW addition on wastewater characteristics, several fermentation tests were carried out. Typical trends of concentration for different pollutants obtained at 15 °C are shown in Table 5. Here, as a comparison, the profiles obtained using the grinders made in Italy and in the USA are reported. Results were substantially equivalent.

Concerning total suspended solids (TSS) the impact of shredded OFMSW on wastewater was estimated in 100-150 mgl"^{1} whereas the percentage of volatile suspended solids (VSS) remained almost constant (about 90% of TSS); in particular, the VSS increased in the early hours of the tests, passing from 200 to 250 mgl^{-1}, and achieved a stable value after 8 hours. The most evident effect of the OFMSW co-disposal with wastewater was the total COD increase: about 300 mgl"^{1}. This means a specific contribution of 75 $gPE^{-1}d^{-1}$ of COD rather than the theoretical 85 $gPE^{-1}d^{-1}$ {based on average composition of organic wastes). According to the fermentative anaerobic conditions, the value of COD concentration remained almost constant after the addition of the shredded OFMSW at 430-450 mgl^{-1}; this even after a relatively large span of time (24-48 hours). The soluble fraction (SCOD) represented one half of total COD: this parameter remained constant after the addition of shredded wastes in the first 8 hours of the tests and then sharply decreased after 24 hours passing from 150-250 mgl^{-1} to 70-90 mgl^{-1}. Therefore, changes obtained in wastewater characteristics after the addition of the organic wastes did not significantly affect the COD composition: in fact, the SCOD/COD ratio was similar, passing from 0.50 to 0.56. Concerning the soluble fraction of the COD in sewers, an increase in concentration in medium-short length sewers (< 24 hours retention time) was evident but this was not a readily biodegradable COD. This evidence was also confirmed by the qualitative distribution of the short chain volatile fatty acids (SC-VFA). The C2-C5 (acetic-penthanoic) species were practically absent while C6 and C7 were present in small amounts (15-50 mgl^{-1}). Therefore, the hydrolytic processes were predominant on the fermentative ones and no methane production was observed: risks of explosions in sewers should not be expected.

Despite the decrease in SCOD concentration, no increases in VSS concentration were observed. This was because typical yields for fermentative biomass in anaerobic conditions is in the range 0.02-0.07 mgVSS $mgCOD^{-1}$ removed [22], therefore variations in VSS concentration could not be easily detected.

Concerning nutrients, nitrogen and phosphorous increases were about 20% and 16%, respectively. In particular, specific contributions of N and P determined by organic wastes disposal in sewers were equal to 2.75 $gNPE^{-1}d^{-1}$ and to 0.5 $gPPE^{-1}d^{-1}$, respectively. These productions were very low if compared to a specific production of 75 $gPE^{-1}d^{-1}$ of total COD. Therefore, an improvement of the typical COD/N and COD/P ratios was obtained and advantage in biological nutrients removal processes should be expected.

Table 6 summarises the specific contributions of the pollutants in this and other studies.

When comparing the data in Table 6 an important

Table 5. Fermentation tests: parameter profiles versus time at 15 °C

Parameters	TSS, mgl^{-1}	VSS, mgl^{-1}	TCOD*, mgl^{-1}	TCOD*, mgl^{-1}	SCOD*, mgl^{-1}	SCOD**, mgl^{-1}	TKN*, $mgNl^{-1}$	TKN*, $mgNl^{-1}$	TP*, $mgPl^{-1}$	TP**, $mgPl^{-1}$
Wastewater	110	91	160	160	80	80	36	36	3	3
Time, h										
0	220	190	450	400	205	200	50	45	3.5	3.1
2	240	200	500	425	250	235	55	47	3.5	3.4
4	240	200	435	430	250	235	38	42	3.6	3.4
6	260	225	435	410	260	280	40	46	3.9	4
8	310	260	435	410	270	200	45	47	4	4
24	300	250	450	400	250	150	44	45	4.1	4.1
48	300	255	435	400	90	70	45	50	4.1	4.1

* Italian garbage grinder
** USA garbage grinder

Table 6. Per capita additional loading for different pollutants due to the garbage grinder application.

Specific contributions	This study	Ref. [2]	Ref. [31	Ref. [4]	Ref. [4]	Ref. [6]	Ref. [11]	Ref. [12]
Penetration index, %	100	100	100	40	100	30	Variable	Variable
TSS, g $PE^{-1}d^{-1}$	50	34	48	29.7	50.9	50	20.8-90.6	28-40
COD, g $PE^{-1}d^{-1}$	75	88	76	75.8	121.6	106	na	18-36
SCOD, g $PE^{-1}d^{-1}$	30	14	na	na	na	na	na	na
BOD, g $PE^{-1}d^{-1}$	na	31	52	26.4	59.1	na	10.4-36	6-15
SBOD g $PE^{-1}d^{-1}$	na	19	na	14.1	24.4	na	na	na
Total Kjeldal Nitrogen, gN $PE^{-1}d^{-1}$	2.5	10.2	1.6	8.3	14	12	0.6-2	1,5
Ammonia Nitrogen, gN $PE^{-1}d^{-1}$	na	1.2	na	4.1	5.9	na	na	na
COD/TKN ratio	30	8.6	47.5	9.1	8.6	8.8	16.18	25
Phosphorous, g P $PE^{-1}d^{-1}$	0.25	3.1	na	1.27	1.77	0.9	0.1	0.13-0.25
Oils and greases, g $PE^{-1}d^{-1}$	na	na	na	5.26	7.8	*72*	2.1-7.7	na

[3] determined on BOD increase

parameter to be considered is the penetration index, that is the number of households equipped with a garbage grinder to the totality of the households served by a sewer.

According to studies here mentioned, the same range of values for the increase in pollutants is reported. Specific contributions for total suspended solids and COD were in the range 30-50 $gPE^{-1}d^{-1}$ and 75-120 $gPE^{-1}d^{-1}$, respectively. The SCOD and BOD values were 50% of total COD. Differences were observed concerning nitrogen specific production: the values ranged between 1.6 and 14 $gNPE^{-1}d^{-1}$. Therefore, the COD to N ratio is reported to be variable although always sufficient (a 8.6) to perform a nitrogen biological removal process. Its value ranged between 8.6 and 47.5. Actually, half of the referenced studies reported values of 8.6-9.1. These values are the same of typical civil wastewater. On the other hand, some studies reported a value of the COD/N ratio 3 or 4 times greater. Phosphorous contribution did not seem particularly important. The increase ranged between 0.1 and 3.1 gP $PE^{-1}d^{-1}$, generally < 1.5 gP PE'M[1].

Some problems could arise from the increase in oils and greases discharge in sewers. Specific increases were in the range 2.1-7.7 g $PE^{-1}d^{-1}$ and condensation phenomena should be expected. However, specific studies showed that no problems were caused by these pollutants [2, 4, 6].

Settling Tests

Since shredded kitchen wastes have a similar density compared with wastewater, they form a fluid stream and no troubles for sewers should be expected even though the sewage velocity is low. Therefore, occlusions in sewers should not be expected [3]. Obviously, this is not strictly true, as some material (e.g., pieces of bones, shells....) show a larger density than wastewater. In fact, some materials show a density of 2 kgm^{-3} and size > 1 mm and some deposition could be observed [2, 10]. However, if the garbage grinder is properly used, these materials are not present in disposed wastes as they could damage the device. Actually, the studies carried out in last decades showed that no real problems were encountered with materials settling [2, 6]. This was because velocity is sufficient enough to maintain sewers sewage clean. Generally, self-cleaning velocity is reported to be in the range 0.5-1.6 ms^{-1} for sewers with a diameter in the range 200 - 2000 mm [9,10].

On the other hand, other problems, maybe more frequent, can be related to the direct discharge of raw organic material and solids into water bodies during wet weather periods, when the first flash of sewer runoff is directly discharged with low or no treatment [4].

In order to clarify all these issues, the settling behaviour of shredded garbage was studied to verify its impact in sewer systems. The wastes used in the experimental work had the typical composition shown in Table 7.

Firstly, the settling rates and the floating fraction of total suspended solids of the following fractions of OFMSW were considered: meat, fish, pasta-bread, fruits and vegetables. Each of these fractions was shredded by a garbage grinder and then passed through a sieve so to split the material into two classes of size: coarse particles, size >= 0.84 mm, and fine particles, size < 0.84 mm. The settling velocities were measured as an average of ten different tests. Except for

Table *7.* Composition of the typical organic wastes.

Kind of waste	Percentage on wet weight
Fruit	24
Pasta-bread	31
Vegetables	40
Meat	3
Fish	2

fish (settling velocity 11.3 mh"^{1}), all the other fine particles showed low settling velocities (1.7 • 4 mh^{-1}). The rates for the coarse particles were from five to ten times higher (see data in Table 8).

In order to ascertain the type of suspended solids transported in sewers and those lost for settling during transportation, three real WWTPs with size in the range 40.000-80.000 PE were considered (Table 9). The idea was to check the settling velocity of suspended solids transported by sewers during dry weather. The method adopted was the sampling of incoming flowrate in civil wastewater treatment plants at the end of the sewer pipeline. Samples were concentrated ten folds to better understand the solids behaviour during settling experimentation (see Material and Methods section). The final suspended solids concentration was in the range 800-3300 mgl^{-1} (Table 9). The settling velocities of these solids were in the range 10-15 mh"^{1}. These values have to be compared with the typical settling velocities of the organic wastes.

The comparison of this velocity value with those of fine and coarse particles in the different fractions of organic waste (Table 8) show that only a part of the pasta-bread and fish could be lost in sewers by settling. Table 10 summarises the fractions of the different organic wastes conferred to the WWTPs. The comparison was carried out according to an organic waste similar to the one reported in

Table 8. Settling velocity and floating fraction of different fractions of organic waste.

Organic fraction	Size distribution. (mm)	Floating fraction (%)	Settling velocity (mh^{-1})	
			Average	std. dev.
Fruit	>=0.84	78.0	16.6	4.0
	<0.84	54.7	3.3	0.8
Pasta-Bread	>=O.84	0.0	22.7	3.1
	<0.84	8.0	1.7	0.4
Vegetables	>=0.84	0.0	19.4	3.3
	<0.84	37.3	2.3	0.4
Meat	>=0.84	62.0	17.3	1.1
	<0.84	30.3	4.0	0.5
Fish	>=0.84	0.0	24.5	1.6
	<0.84	40.0	11.3	0.2

Table 9. Settling velocity in real wastewater sewers.

Sewer	WWTPsize Population Equivalent	TSS mgl^{-1}	Settling velocity (mh^{-1})	
			average	Sdt. dev.
Ancona	80000	3300	15.5	1.8
Falconara	60000	2150	14.0	2.9
Jesi	40000	800	10.1	0.4

Table 10. Total Suspended solids behaviour in sewers.

Kind of waste	Size distribution (%)		Solids conferred to the WWTP (%);		Solids settled (%)
	< 0.84 mm	> 0.84 mm	< 0.84 mm	> 0.84mm	
Fruit	79	21	79	19.5	1.5
Pasta-bread	42.1	57.9	42.1	37.5	20.4
Vegetables	56.1	43.9	56.1	36.2	7.7
Meat	33.4	66.6	33.4	57.7	8.9
Fish	63.9	36.1	63.9	26.8	9.3
OF-MSW	50.1	49.9	50.1	33.1	16.8

Table 7. Results revealed that only 18.8% of TS weight settled in the sewer whereas the residual 8.2% reached the wastewater treatment plant: the whole fine fraction and part of the coarse one.

Therefore, only a small amount of suspended solids coming from shredded organic wastes settled and sewers should be considered a feasible method for their transport.

Impacts on the Wastewater Treatment Process

In order to evaluate the impact of the increases in pollutant loading on the performances of the wastewater treatment processes, simulations by the Activated Sludge Model 2 [21] were performed. The wastewater characteristics used as input in the simulations were the ones of a typical medium strength wastewater [1]. Those characteristics were then changed according to the specific pollutant productions determined above, when the organic wastes were also computed in the input.

Two different types of process were considered: the typical pre-denitrification process (C-N) and the biological nutrients removal (BNR) process (three steps Phoredox, with Johannesburg modification). Moreover, two different configurations were considered: with and without primary settling section. The typical conditions chosen for the simulations were a reactor temperature of 15 °C and a sludge retention time (SRT) in the range 10-20 days.

The treatment for wasted sludge considered in the simulations was the anaerobic digestion process for sludge stabilisation in a mesophilic reactor. This is an obvious choice, in order to exploit the benefits deriving from the use of biogas for the production of thermal and electrical energy.

The typical activated sludge process for carbon and ammonia oxidation was not considered as it is well known that the main consequences of organic wastes disposal in sewers for that kind of process are the increases in oxygen consumption and sludge production. Also an increase in biogas production was observed [2, 12,17]. According to Galil and Yaacov [17], the use of the garbage grinders in 60% of the households in a given urban area determined the increase in the specific sludge production from 20 to 37 $gPE'M'^{1}$ (dry solids) for the typical activated sludge process and from 50 to 80 $gPE^{-1}d^{-1}$ (dry solids) if the primary settler was present. Moreover, an increase in the additional energy potential due to the anaerobic digestion application in the range 54% - 73% was observed.

The main evidences observed in the performed simulations are summarised in Table 11.

The effect of the organic wastes presence on nutrient removal in C-N and BNR processes was evaluated by means of the variations of the "safety coefficient", Cs, that is the ratio of total nitrogen prescribed by law to nitrogen in the effluent. Here, according to the 271/91 EC Directive, a value of 10 $mgNl^{-1}$ was chosen for the standard effluent to be cautelative.

When considering the results obtained in the C-N removal process it appeared that the presence or absence of the organic wastes in the influent was only partially significant, whereas the presence or absence of a primary settler was of fundamental importance. According to the results obtained in the case of the operation without primary settier, it was clear as the Cs coefficient and the Fe required for phosphates removal were substantially the same, therefore effectiveness in nutrients removal was unchanged. The activated sludge concentration and the oxygen consumption were increased by some 20% when the organic wastes were disposed in sewers. On the other hand, the wasted sludge was doubled as was the biogas production.

When the primary settler was present in the C-N removal process, the influence of the organic wastes disposal was evident: the Cs coefficient passed from 1.03 to 1.36 and

Table 11. Main results of the ASM 2 simulations of the OFMSW and wastewater co-treatment.

		C-N removal process		BNR process	
		Sole wastewater	Wastewater + OFMSW	Sole wastewater	Wastewater + OFMSW
Without primary settler	Cs	1.76	1.83	1.43	1.47
	Fe^{2+}, mgl^{-1}	16	18	4	0
	MLSS, kgm^{-3}	5	7.7	5.4	8
	Oxygen consumption, kgh^{-1}	340	566	360	587
	Wasted sludge, $kgTSd^{-1}$	1867	4035	1360	5670
	Biogas, m^3d^{-1}	1470	2460	1070	3455
With primary settler	Cs	1.03	1.36	1.19	1.21
	Fe^{2+}, mgl^{-1}	14	8	8	6
	MLSS, kgm^{-3}	3.2	4	3.75	4.2
	Oxygen consumption, kgh^{-1}	280	316	284	325
	Wasted sludge, $kgTSd^{-1}$	4530	7185	4318	8032
	Biogas,m^3d^{-1}	3320	4470	3153	4990

the iron requirement decreased from 14 to 8 mgl^{-1}. Therefore, a clear improvement in nitrogen removal was observed as well as a decrease in iron salts requirement for phosphates removal. The MLSS concentration was nearly the same in the two cases (3.2 and 4 kgm^{-3}), as was oxygen consumption (280 and 316 kgh^{-1}). Also in this case the wasted sludge production was nearly doubled (from 4530 to 7185 $kgTSd^{-1}$): these values are significantly increased compared to the ones observed when the primary settler was not present. The biogas production passed from 3320 to 4470 m^3d^{-1} (30% increase).

When considering the BNR process application, the role of the organic wastes contribution was more significant. Considering the data obtained in the case of the primary settler absence the same Cs was observed (1.47 rather than 1.43) but the phosphates removal was performed without the iron addition when the organic wastes were present. A biological phosphorus removal was favoured. Owing to the presence of the organic wastes in the wastewater, the activated sludge concentration was increased (from 5.4 to 8 kgm^{-3}) as was the oxygen consumption (from 360 to 587 kgh^{-1}). The wasted sludge passed from 1360 to 5670 $kgTSd^{-1}$ and the biogas production was three folds greater.

If primary settling was present, the BNR process showed only little variations when the OFMSW was added or not. All the parameters were similar except for the wasted sludge: it icreased from 4318 to 8032 $kgTSd^{-1}$. Consequently, biogas production was significantly increased, passing from 3153 to 4990 m^3d^{-1} In conclusion, the presence of a primary settler does not seem sensible when operating a BNR process.

Generally, it has to be observed that, even though the increases in excess sludge and oxygen consumption can be considered negative aspects from an economical point of view, the organic fraction of MSW is disposed with less impacts on the environment, [23].

Overall Economical Evaluation

On the basis of the data discussed above an economical evaluation of the garbage grinders application was performed.

The main cost items considered in the economic balance were:

amortisation of the garbage grinder cost: the cost of the grinders used in this study were in the range 100 - 350 €. If a life time of 10 years and an interest rate of 3% were considered, the resulting amortisation share was in the range 12-41 €$year^{-1}$. As an average, 26 €$year^{-1}$ was considered;

- energetic and hydraulic consumption: were about 2.2 €$year^{-1}$ for a three people family;
- wastewater treatment plant facilities: the case of the co-treatment in a BNR plant with primary sedimentation was considered to be cautelative. In fact, this was the worst situation. The oxygen requirement and the produced wasted sludge were about 7800 kgO_2d^{-1} and 8032 $kgTSd^{-1}$, respectively. On the basis of a specific energy consumption for oxygen transfer of 1 $kWhkgO_2^{-1}$ and an energy cost of 0.1 € kWh^{-1} it was possible to estimate a daily expense of 780 €. Concerning sludge disposal, it was assumed that about one third of produced sludge was removed during the anaerobic stabilisation process. Therefore, some 5500 $kgTSd^{-1}$ have to be disposed. Assuming a cost of 0.05 €$kgTS^{-1}$ for disposal, an expense of 275 € can be determined. This means a specific cost of about 2.8 €$PE^{-1}year^{-1}$ for oxygen supply and sludge disposal;
- no increase in other maintenance and operating costs were considered (i.e., personnel, sewers cleansing).

The economical benefits were evaluated as:

- No expenses for organic wastes collecting and treatment, or disposal in landfills: even neglecting the environmental benefits, it was possible to estimate a saving of some 0.15 € per kg of OFMSW per day (collecting and disposal). This is equal to 48 €$year^{-1}$ per family;
- Biogas production and reclaim: some 1850 m^3d^{-1} were over-produced in the integrated approach. This means a gaining of about 2 €$PE^{-1}year^{-1}$.

Table 12 summarises the performed economical balance.

Therefore, the application of an integrated approach achieves a positive economical balance of some 18 €$year^{-1}$ per family, even though an initial investment, i.e. the food waste disposer, is needed.

Table 12. Economical evaluation of the integrated approach €$year^{-1}$ per family (three people).

Economical balance items	Passive	Active
Garbage grinder	26	
Consumption (water and energy)	2-2	
Oxygen requirement and sludge disposal in WWTP	8.4	
OFMSW collecting and disposal		48
Biogas production		6
Total	appr. 37	appr. 54
Settlement		17

CONCLUSIONS

The use of the garbage grinder enables the flux of the organic wastes to be diverted from the collecting and disposal /treatment system to the wastewater treatment plants. This is feasible both from a technical and an economical point of view.

In particular on the basis of the carried out experimentation some important remarks can be drawn:

- the electric and hydraulic consumption were very low and estimated to be a 2.1 m^3year^{-1} of water and 8.5 $kWhyear^{-1}$ of energy for multiple shredding operations. This means an annual cost of about *22* €year"' for a three member family;
- Specific contributions for COD, nitrogen and phosphorous after OFMSW disposal were estimated as 75 $gPE^{-1}d^{-1}$, 2.5 $gNPE^{-1}d^{-1}$ and 0.25 $gPPE^{-1}d^{-1}$, respectively. Therefore the COD/nutrients ratio was increased with benefit for BNR processes performances;
- the VFA distribution analysis suggested that no fermentative processes were involved and only the ydrolytic phenomena occurred in sewers, avoiding odour production;
- the settling tests showed that 78% of the disposed organic wastes arrive to the wastewater treatment plants, while the rest probably do so more slowly;
- the impacts on the wastewater treatment process are evaluated: generally, an improvement in nutrient removal was observed, owing to the improved COD/N and COD/P ratios. The increases in oxygen requirements and wasted sludge due to the integrated approach application were partially counterbalanced by the increase in the biogas production. On the other hand, the organic wastes were disposed with less impacts on the environment;
- the economical evaluation varified the feasibility of the studied approach. The global balance gave an active settlement of some 17 €$year^{-1}$ per family.

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