SS-OFMSW SORTING APPROACHES ORIENTED TO ANAEROBIC DIGESTION: PRELIMINARY COMPARISON FOR FULL SCALE IMPLEMENTATION

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Abstract
The paper considers a comparison between the three widely used approach to mechanically sort OFMSW prior anaerobic digestion/codigestion treatments: wet pulper, press extrusion and wet sorting approach. Three real substrates were collected from three OFMSW treatment devices in Europe, considering to have as input similar kind of materials. The effluent coming from the lines are analysed in terms of class fractionation, chemical physical parameters and size distribution of particles. The results obtained show that the wet pulper option lead to a more disrupting action on waste, producing a 25% higher amount of fines than the other sorting techniques.

Keywords
Anaerobic digestion; mechanical sorting; OFMSW; class fractionation; size analisys

INTRODUCTION
In the last years the development of more ‘quality-oriented’ approaches in MSW collection have completely changed the scenario of its disposal treatments. As well known, MSW is a very heterogeneous substrate, but it can be divided roughly into three different types of sub-fractions: digestible organic fraction, with high content of moisture (i.e., kitchen wastes, grass cutting etc.); combustible fraction (i.e., wood, paper, cardboard, plastic and other synthetics materials etc…) and inert fraction (i.e., stones, sand glass, metals etc…). In general about 50% of MSW consists of organic matter with different origin and characteristics, and only a small part of the MSW is usually recycled, excluding the digestible fraction (Braber, 1995). In Europe, up to last decade, landfill, incineration and composting were the most commonly used methods for disposal. Recently, through the landfill directive, the European Union has set a target for reducing the biologically degradable waste fraction sending to landfills, and this is the reason why the actual streams obtained in OFMSW collection are substantially different from the past. The macroscopic difference which can be immediately noted is the higher solid content in the so called ‘dry-fraction’, combustion-oriented substrate, and at the same time the increase of water and putrescible materials in the ‘wet fraction’. These characteristic suggest a wider use of AD process instead the direct composting to this last substrate, because in this way a first important energy recovery can be made, using at the same time the possibility to product a soil amendant from effluent stream composting. For these reason in the last two decades there has been a big increase of AD plants for OFMSW treatment (De Baere, 2006). The amount of gas produced varies depending mainly from the substrate characteristics before the digester feeding (Mata Alvarez et al., 1990; Lewis, 2010). In fact, despite the success of separate collection programs of MSW in different country, the waste streams of SS-OFMSW contain variable amount of contaminants, which have to be drastically reduced before digester feeding with an adequate mechanical system. Each sorting systems is designed to promote in order:

- removal of contaminants from organic fraction by means of physic, dimensional, gravimetric and magnetic property;
- size reduction of particles which results an increase of specific surface area available.

This leads to an increase of gas production and to more rapid digestion (Mata Alvarez et al 2000);
- Homogenize and adjust water content which depend the type of AD process (wet < 10 %TS, semidry from 10 to 20 %TS, dry >20%TS).

The choice of the more adequate sorting technology must be based on a proper compromise between stream separation efficiency and specific energy applied. Referring to the quality of input waste stream and energy consumption, unsorted municipal solid waste (i.e., mechanically sorted MS-OFMSW) needed sorting approaches using high power requirement, due to the high inerts and non biodegradable contents to be treated. Now, the actual streams of separately collected (SC-) or source sorted (SS-) fractions can be treated with very low specific energy consumptions, due to the high water content. In fact, treating the actual streams of wet fraction with heavy power specific approaches could lead to an increase of inerts dispersion into the main stream, as clearly demonstrated in the paper. A high sand content in the mixture feeding cause settling in digesters, leading to the generation of materials with a concrete-like consistency, and furthermore a remarkable increased abrasion in stream transfer systems (pumps and pipes). Other problems came from light non biodegradable fractions (plastics, packaging residues etc.): these materials may float on the surface of digester content and, with other materials, may form a solid blanket (Ritzkowsky et al., 2006). If this materials are not completely shredded, is much more simple to separate them using a wet approach before the digester feeding, avoiding the problems linked to a solid floating blanket and also to reduce the amount of plastics in the final effluent which have to be sent to composting. Considering these aspects, is more than clear that mechanical pre-treatment of OFMSW is a primary step of the whole AD process, and have to be considered as an integrated part of the whole process.
The aim of this study is to evaluate the separation efficiency of different sorting systems in full scale application of AD OFMSW treatment in terms of waste stream quality. Separation efficiency based on substrate class fractioning, physical-chemical aspects and particle size distribution are considered, leading to a comprehensive evaluation of techniques on a comparative basis

METHODS
The experiments were carried out at the University research area in WWTP facilities of Treviso council. The solid waste was collected from 3 different plants in Europe. The sorting approaches chosen for the test are: wet pulper (plant 1), extruder press (plant 2) and “wet selection” (plant 3). A sampling campaign was carried out at MBT plants, in which three fraction were sampled for each plants: waste inlet to pretreatment step (Waste), rejects of pretreatment step (Rejects) and output stream from mechanical sorting step (Output, inlet to digester). Waste sampling was performed according with a simplified MODECOM™ procedure for waste class analysis (MODECOM™ 1998).In order to make interpreting the results easier, the 13 categories from MODECOM™ procedure were grouped together into 6 categories:
- Garden /vegetable waste
- Other food waste (pasta, rice, bread and bakery, meat and fish etc…)
- Paper/cardboard
- Plastics
- Inerts (bones, egg shells, seeds, fibrous materials, glass, metals)
- Unclassified materials (miscellaneous < 20mm)

The unclassified materials represent wastes in a partial degraded condition, so that it is impossible to associate them with a specific waste family. Furthermore, the sorting stage proves to be difficult for the more wet fractions, like degraded compounds, which tend to be linked to other waste categories. The same classification was carried out for Rejects samples: in this case, the class garden/vegetable waste, other food waste and unclassified materials are considered as green wastes. Total and volatile solids, chemical oxygen demand, TKN and total phosphorus were made on dry fraction in accordance to the Standard Methods (APHA-AWWA-WEF, 2007). Particle size distribution was detected with Sieving Machine Type AS 200 Control (Retsch GmbH) in accordance with wet sieving method (APHA-AWWA-WEF, 2007). The size analysis was carried out in the particle size range between 250μM and 3mm, considering 6 fractions: > 3.15 mm, 2 to

3.15 mm, 1 to 2 mm, 0.5 to 1 mm, 0.25 to 0.5 mm and < 0.25 μm. Each fraction was characterised in terms of TS and TVS contents

Plant 1

This anaerobic digestion plant was designed to process 40,000 t/y of separate collected organic fraction municipal solid waste, which is being planned to increase its capacity up to 60,000 t/y in a second phase. The process adopted is a two stage thermophilic anaerobic digestion process working in wet conditions. The waste to be treated is collected in two different lines (wet and dry line), in accordance to their source and quality. The wet line was designed to receive waste of better quality, mainly from canteens and markets, and dry line was conceived to receive the waste from restaurants, hotels and supermarkets, where a higher level of contaminants is expected (SC-OFMSW). The waste from the wet line passes through a sieve and hammer mill before entering the hydrolysis phase. The waste from the dry line has to be pre-treated by a manual sorting, shredding and sieving steps. Before sent to hydrolysis, waste also passes through a wet pulper to increase size reduction and contaminants removal. Sampling campaign was carried out only from dry line, which can be considered more representative of the kind of substrates found in other plants in Italy. Biogas is burn to produce heat and electric energy in co-generation units. After the digestion step, the organic suspension is dewatered and the effluent is pre-composted in 5 tunnels, with forced aeration and post composted in windrows in a covered area.

Plant 2

The plant was designed to treat some 90,000 t/y of unsorted MSW. When the plant was still under construction the strategy of waste collection in the area was changed and the differentiation of waste streams was introduced. Actually, the plant treats the source sorted organic fraction of municipal solid wastes (SS-OFMSW). The waste is fed into the hopper of a single-shaft "bag-opening" shredder by means of a grab bucket. The shredded material is then fed into the extruder press using a conveyor belt system equipped with a ferrous separation device. The input waste is pushed in the extrusion chamber to the working pressure (287 bar); under these conditions the organic fraction is in part liquefied, passing through the extruder holes. A special alloy drum, constituted of three cylinders, is placed in the centre of the chamber, and it is made to rotate by an oleo-dynamic device. The treatment cycle is constituted by three phases: the feeding, the true compression, and the extraction; the last phase is driven by a secondary cylinder, that pushes out the dry rejected fraction. Actually the anaerobic digester is under construction, so the flow stream after pretreatment step is sent directly to a composting facilities, mixing a bulking agent to increase its TS content adequately.

Plant 3

This plant consists of an integrated waste/wastewater treatment. The wastewater treatment line adopt a BNR process (Johannesburg configuration) with a 70,000 PE capacity. In this plant, also the OFMSW and septages produced in the city are treated. The sludge treatment line considers a single-stage anaerobic digestion mesophilic reactor. After co-digestion, the effluent is then mechanically dewatered. The OFMSW from separate collection is treated in a sorting area, adopting a low specific energy patented approach (Pat. RN 2004 A 000038). The OFMSW used is not properly coming from a SS- approach, but as a mix between this and street collection, using a single big container for 10-20 families typically. The OFMSW sent to the treatment is firstly shredded using a low speed two axis mill, which has the only target to open the plastic bags which contains the waste. After this, iron materials are removed by a magnetic belt, then the residual is sent to a trommel screen, which separate the main fraction of plastics. After a non-ferrous metallic material separation, a second shredding is performed using a blade mill (15 mm) to reduce the particle size. The waste is then sent to a mixer/separator where the dry matter content is lowered to 7–8% using sludge coming from the BNR unit, and the floating (upper part) and inert (bottom) materials are withdrawn. From this point on, the blend can be treated in three different ways: a) direct mixing with waste activated sludge and feeding of the anaerobic digester; b) mesophilic pre-fermentation in complete stirred tank reactor, mixing with other sewage sludge and then sent to digester; c) pre-fermentation and phase separation by screw-press, addition of the liquid fraction in the denitrification section of the wastewater treatment plant and mixing of the solid fraction with other sewage sludge and sent to digester. Depending on the chosen pathway, energy recovery or nutrients removal are alternatively enhanced

RESULTS AND DISCUSSION

Source waste composition

To optimize the management of waste line treatment, the choice of pre-treatment technology should be based on quality of input stream. The typical categories percentage class fractionations and characteristics of waste input samples used for this study are reported in Table 1 and 2 respectively

Table 1. Composition of input Waste

Waste class	Plant 1		Plant 2		Plant 3	
	% WW	% DW	% WW	% DW	% WW	% DW
Fruit/vegetable	35-45	25-35	26-35	13-20	38-46	30-38
Other food waste	4-10	4-8	33-50	44-55	13-16	12-19
Paper/ cardboard	10-15	10-15	5-10	9-11	13-18	15-19
Plastics	10-15	16-20	5-10	9-11	5-10	7-14
Inerts	5-8	10-15	4-7	8-10	3-9	14-19
Unclassified materials	18-23	18-21	4-6	4-6	10-20	13-25

Table 2. Characteristics of input Waste

Waste class	TS (g/kg)	TVS (g/kg)	TVS/TS, %
		Plant 1	
Fruit /Vegetable	249	226	90.8
Other Food waste	340	323	95.0
Papers/cardboard	343	312	90.9
Plastics	475	444	93.6
Inerts	650	168	25.9
Unclassified materials	320	269	83.9
		Plant 2	
Fruit /Vegetable	171	160	93.7
Other Food waste	330	315	95.6
Papers/cardboard	420	393	93.6
Plastics	352	331	94.0
Inerts	514	244	47.5
Unclassified materials	355	310	87.2
		Plant 3	
Fruit /Vegetable	288	260	90.1
Other Food waste	443	399	90.0
Papers/cardboard	411	389	94.6
Plastics	465	422	90.9
Inerts	757	276	36.5
Unclassified materials	439	286	65.1

As it can be seen from the data presented, the plants considered in this study showed a similar composition of input waste stream, even if the waste treated in plant 2 seems to be more rich in organic materials. Putrescible waste class (i.e., food and vegetables), that also includes some unclassified material, is the biggest fraction. Plastics, inerts, paper and cardboard as a whole are less than 35% of total wet weight. In plant 3 samples, the amount of these fractions is clearly higher, due to the different approach in collection, which is less efficient. However the three plants adopt different technologies to sort the waste before the biological step, with different specific power requirements and differences in the effluent streams. Table 2 show that, for each plant, total volatile solids are more than 90% of total solids for each category, showing a general high yields in collection approach used.

The high content of volatile matter in unclassified category (more than 80% in plants 1 and 2) is due the presence of small particles of fruit/vegetable and other food waste, less present in plant 3 waste, where this fraction is more rich in inerts or other non biodegradable compounds

Lines rejects

Important differences concerning the yields of the different choice in sorting waste approaches can be found in table 3 and 4, where the characteristics of the reject fraction from lines are considered. Table 3 show that the main component of reject streams in wet pulper system and wet selection (plants 1 and 3 respectively) is grey fraction (paper/cardboard/textile, plastics and inert materials). The evaluation of putrescible fraction in extruder approach system (plant 2) is not possible, due to the high grade of mixing obtained after the pressing, and the same is for inert fraction. Thus, we can say that these fraction could be mainly present inside plastics and non classified materials fractions, but in general it seems that the extruder approach lead to a more 'clean' reject stream (less putrescible organic inside rejects, so better streams separation)

Table 3. Composition of lines rejects.

Line rejects	Plant 1		Plant 2		Plant 3	
Waste category	% WW	% DW	% WW	% DW	% WW	% DW
Putrescible waste	27-35	14-22	n.d	n.d	25-40	15-30
Paper and cardboard	12-15	12-15	5-15	4-8	9-16	10-15
Plastics	25-34	35-44	78-85	78-82	20-42	32-48
Inerts	10-18	16-24	n.d	n.d	15-24	21-36
Unclassified materials	13-18	11-16	15-22	10-18	10-23	12-20

With specific reference to the unclassified materials in reject stream from wet pulper system (plant 1) (table 4), it has to be emphasized that it is characterized by a low content of volatile matter (36,3%), suggesting the presence of higher percentages of small inerts particles in the stream (the impossibility to classify is linked mainly to the size of the particles) due to the powerful disrupting action of the pulper system, which generates a lot of sands.

Table 4.Characteristics of lines rejects.

Waste class	TS(g/Kg)	TVS (g/Kg)	TVS/TS (%)
	Plant 1		
Putrescible waste	233	210	902
Paper and cardboard	437	344	78.6
Plastics	539	487	90.0
Inerts	590	238	40.3
Unclassified materials	434	157	36.3
	Plant 2		
Putrescible waste	n.d	n.d	n.d
Paper and cardboard	306	260	84.7
Plastics	352	331	94.0
Inerts	n.d	n.d	n.d
Unclassified materials	360	279	77.4
	Plant 3		
Putrescible waste	295	236	80.0
Paper and cardboard	390	366	94.3
Plastics	452	402	88.1
Inerts	630	233	37.2
Unclassified materials	410	278	68.0

Lines output - waste as fed to digesters

The chemical characteristics of flow streams sent to anaerobic digestion are given in table 5. The output samples of plants 1 and 3 shows a low content of total solids (< 10%TS) because they have to be sent to a wet process, while W1 from plant 2 (around 24%TS) is sent to a composting unit. Total volatile matter is around 80% TS in each samples, which shows also a similar concentration.

Nutrients contents are similar in samples from plant 1 and 3, slightly less in plant 2, may be due to the different kind of substrate at source.

Table 5: Chemical characteristics after mechanical sorting step.

	TS, g/kg	TVS, g/kg	TVS/TS, %	COD, g/kgTS	TKN, g/kgTS	P, g/kgTS
Plant 1	58.4	47.3	81.0	861	43	4
Plant 2	243.0	201.0	82.6	823	28	2
Plant 3	63.3	50.1	79.1	792	42	3

To compare the effect of sorting approach on the waste fed to digesters, an analysis of the effluent stream from a size distribution point of view was also done. Table 6 shows percentage particle size distribution of waste stream after sorting line treatment, also reporting TVS/TS for each fraction. The main size class is always the < 0.25 mm: 82.9, 67.8 e 64.1 % on a TS basis for the wet pulper, extruder press and wet selection, respectively. This confirm the higher amount of small particles generated from the pulper action in respect to the other less-destructive approaches. Furthermore, considering the 0.25 to 0.50 mm fraction for plant 1 which is mainly composed by inerts (TVS/TS content near 20%), it can be observed that this fraction is smaller than in the other samples, and this can be also linked to the shredding action of the pulper, giving more small size particles. The extruder approach seems to be the approach which generates higher fraction of large-medium size particles, and this can be linked to the complete absence of any cutting/shredding device in the line. In fact, in >3.15 mm class the extruder press shows 17.8% on a TS basis, while it is 10.9% in the wet selection and 7.9 in the wet pulper system. For the other classes between 0.5 to 2 mm the different systems of pre-treatment show a similar distribution of size, always below 7% on a TS basis, except for wet approach 1 to 2 mm fraction, which show 9.8 % TS basis. This aspects could be linked to the co-digestion approach of plant 3, where waste is diluted with sewage sludge in the final part of the sorting. In this case, in fact, part of the solids coming from sludge addition can be found in this fraction, thus this can explain the higher amount of this fraction linked to this sample.
A more immediate evaluation in terms of comparison between the approaches studied can be found reducing the fraction considered after sorting into three main categories: COARSE (more than 1mm), MIDDLE (from 250μM to 1mm) and FINE (less than 250μM). This lead to the situation reported in Fig. 1, which is more readable than the whole size distribution evaluation done before. As can be seen, the different effect coming from the approaches used is perfectly clear. Looking at the coarse and middle fractions, it is clear that moving from wet pulper to wet sorting approach the weight of this part increase, suggesting that the action of the sorting is more conservative in these last option. This is confirmed by the trend of the fines fraction, which have an opposite behaviour, showing the higher fines production associated to wet pulper, which is surely the more disrupting technique adopted. TVS fractionation follows the same behaviour, indicating that this action is widely distributed between organics and inerts

Fig. 1: Size distribution on Total solids basis (A) and total volatile solids basis (B) after sorting mechanical treatment.

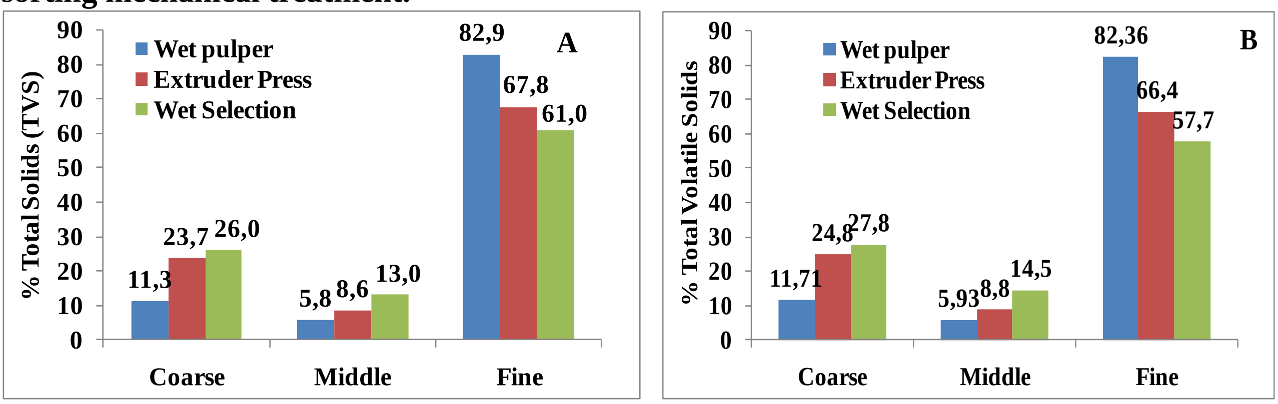

Table 7: Particle size distribution after pre-treatment step (Average value).

Waste class	TS %	TVS %	TVS/TS %
		Plant 1	
> 3.15 mm	7.9	8.7	86.5
2 to 3.15 mm	0.9	0.5	41.9
1 to 2 mm	2.4	2.6	84.0
0.5 μm to 1 mm	5.5	5.8	84.5
0.25 μm to 0.5 mm	0.4	0.1	20.1
< 0.25 μm	82.9	82.3	78.6
		Plant 2	
> 3.15 mm	17.8	19.5	90.5
2 to 3.15 mm	2.2	1.9	69.2
1 to 2 mm	3.6	3.4	78.9
0.5 μm to 1 mm	3.2	3.2	82.1
0.25 μm to 0.5 mm	5.3	5.6	86.8
< 0.25 μm	67.8	66.4	80.9
		Plant 3	
> 3.15 mm	10.9	12.4	92.5
2 to 3.15 mm	3.2	2.5	62.4
1 to 2 mm	9.8	10.8	90.3
0.5 μm to 1 mm	5.9	6.3	87.1
0.25 μm to 0.5 mm	6.1	7.1	95.0
< 0.25 μm	64.1	60.9	77.5

CONCLUSIONS

The approaches studied can be considered as representative of the global scenario of OFMSW sorting techniques before AD treatment. A complete fraction analysis was done to compare the OFMSW used in each plant considered, revealing only small differences concerning the composition of plant 3, in which the collection cannot be considered completely as source sorted. Apart from this, the efficiency of each mechanical treatment was considered and compared in terms of fraction distribution in the effluent streams, rejects and output to digester. Main evidences are as follows:

- considering the rejects stream, the extruder press seems to be more effective in terms of plastic removal (more than 70 % on TS basis), even if in this case a complete separation during analysis from organic putrescible contents is quite impossible, due to the partial loss of initial structure generate from extruding step;
- an evidence of the disrupting effect of the wet pulper option is already clear even considering the reject unclassified fraction characteristics, which shows a lower TVS content in respect to the other samples (36% in plant 1 vs. near 70 % in plants 2 and 3). This suggests the presence of a lot of small inert particles in the unclassified fraction, coming from the disrupting action of the pulper;
- this evidence is widely confirmed using the particles size distribution of the samples, in

which the action of the different techniques in terms of size portioning in the sorted waste is more than evident. Coarse and middle fraction raise up from 11.3 % and 5.8 % on TS basis respectively in wet pulper effluent to 26% and 13% in wet selection approach, showing this last approach as a more ‘conservative’ technique. Considering the fines distribution, the behavior is opposite: from 83 % in wet pulper to near 60 % in wet selection approach, showing the higher amount of sand production linked to the action of the pulper;

- TVS distribution in size distribution fractions follows the TS distribution, confirming that the disrupting action of the pulper is widely distributed over all the materials in the waste treated.

As a final remark, it can be definitively stated that wet pulper option lead to an output stream which is more rich in fines, at least 25 % more than in the other option studied. This fact have to be deeply considered in terms of process selection: in fact, inert fines are the most important cause of management problems in full scale applications, due to pipes clogging, digester volume reduction, pump abrasion etc. Even if an higher organic material fragmentation probably lead to a more quick biological conversion in digesters due to the higher surface/volume ratio in the substrate, this advantage could be not enough to balance the amount of other negative effects coming from the heavier presence of inert fines. It seems to be much more profitable to less reduce organics in size before digestion, avoiding the connected sand formation problems, demanding the effective degradation to the biological step inside the digester. However, the real advantages coming from the different approaches in terms of biogas conversion possible improvement are studied in the ongoing experiments on a BMP basis.

ACKNOWLEDGEMENT

Author wish to thanks VALORGAS EU research program for technical and financial support, and Alto Trevigiano Servizi (ATS) for its hospitality.

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