Developing the Combined Magnetic, Electric and Air Flow Separator (KLME) for RMSW Processing

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Abstract

A consortium, comprised of the machine producer 3B Hungary Ltd. and the scientific partner, the Institute of Raw Materials Preparation and Environmental Processing is working on the development of a processing plant to prepare the non-selectively collected residual municipal solid waste (RMSW) of the Zalaegerszeg (Hungary) region. Key element of this processing plant is the newly developed and so called “KLME” separator. This separator is a combination of three widely applied separators, namely the magnetic-, the eddy current- and two types of air flow separators without the necessary cross connecting belt conveyors and feeders.

Before designing the technology and for getting model materials extensive RMSW sampling and analyses were carried out in Zalaegerszeg, Vaskút and Miskolc. These analyses were based on the actual Hungarian Standards but these tests were more detailed, because size as well as material compositions were analyzed by sieving, hand sorting and drying.

Fundamental research was carried out simultaneously to support the development and design of the machine. After some laboratory scale testing the pilot scale KLME separator prototype was made. The working width of the pilot scale separator is 0.4 m, its height is 3.24 m and length is 4 m. It has one input stream and five output streams. Products are the 2D like materials (foils), the 3D like light materials, the magnetic materials, the electrically conductive materials and the heavy inert materials. Systematic pilot scale testing had been carried out, 18 discrete technological setups were tested. The flow rates of the blown in as well as the sucked out air streams, the type of the air nozzle and its angle were systematically changed during the pilot scale testing. Yields and recoveries were measured by hand sorting and weighing of the products. The technology as well as the machine was continuously improved and modified based on the on-site observations. The achieved best yields and the gained experiences are serving for the design of the industrial size machine.

Keywords: non-selectively collected residual municipal solid waste, air flow separator, KLME separator, yield and recovery, separation efficiency.

1. Introduction

According to the European environmental policy, notably the European Commission's Roadmap on a resource efficient Europe (EC, 2011) and the EU's Waste Framework Directive (EU, 2008) landfilling of municipal solid wastes (MSW) is the least preferred waste management option. However, modern lifestyle results in significant municipal waste generation and a considerable part of this MSW, the so called kitchen rubbish is contaminated with biodegradable materials. Even the developed countries have to take the long time generation of the residual municipal solid wastes into account, because even with the application of a sophisticated selective collection system there are still large amounts of residual materials have to be non-selectively collected and handled (Aich and Gosh, 2016). The social, natural and economical features of local communities are really diverse; therefore the beneficial managing options for the RMSW materials might be different as well (Hanc et al. 2011; Montejo et al. 2011). In Hungary landfilling is still the most widely used managing option, but the old landfills (many thousands) had been closed and recultivated and some tens new modern landfills have been built. The municipality of the Zalaegerszeg region has decided the improvement of the MSW management of the region according to the mentioned EU directives. Nowadays 100 % of the non-selectively collected RMSW is landfilled into the up-to date landfill of the community. The 3B Hungary Ltd. as the machine and technology producer, the Institute of Raw Materials Preparation and Environmental Processing of the University of Miskolc as the scientific partner and the Zala-Depo Ltd. as the public waste managing service company have started the development and construction of an RMSW processing technology targeting no-landfilling for this waste stream. The development and construction of the mechanical processing plant is supported by the GINOP-2.1.1-15-2016-00904 project.

The principles of the generally applied physical separation machines, namely the drum magnetic separator, the nozzle air flow separator and the eddy current separator are well known in the literature (Zhang et al. 1999; Miller and Miller 2009 and 2013; Maraspin et al. 2004; Lungu 2005; Everett and Peirce 1990). According to the typical construction of the eddy current separators - applied in waste processing -, the rotated magnetic pole motor is installed into another drum used to reverse the belt of the conveyor part of the machine (Maraspin et al. 2004). The disadvantage of the common construction of the eddy current separators is that between the particles and the magnetic pole motor there must be the belt conveyor reversing drum and the belt itself, therefore, this distance cannot be minimized. The magnetic force because of the induced eddy current is inversely proportional with the square of this distance; therefore, the efficiency of the general construction is low. There are many different constructions of the air flow separators in the literature and the industry (Miller and Miller 2009 and 2013). Common feature of the application of the mentioned physical separators is that they are discrete machines; and feeders, buffer containers and connecting belt conveyors are necessary among them to build waste processing technologies. Another issue, that lack of information can be found in the literature about the design of such separators. Two main issues are that the separation of MSW particles in these machines happens in multi force fields (magnetic, gravitational, inertia …) and the heterogeneous nature of the given material stream (Kaartinen et al. 2013).

After the idea of combining four separators into one unit was born, development had been started. Fundamental studies had been carried out first with single model air flow and eddy current separators. The 400 mm wide model KLME separator was built and systematic tests had been carried out with single MSW particles. Then the machine was further modified and improved based on the experiences and the pilot scale 400 mm wide KLME was built. This paper reports about the pilot scale testing of this combined machine with real processed RMSW materials. The industrial size (1200 mm width) KLME separator is under construction recently.

2. Materials and methods

2.1. Producing test materials for the pilot scale tests by sampling

a. Processed RMSW for pilot scale KLME tests:

The proper placement of the KLME separator into the RMSW processing technology is crucial. The most important design factor is the particle size range of the feed for the machine. Another serious question is if the pre-crushing of the raw RMSW is necessary or only the rubbish bags' tearing is sufficient. There are industrial examples for both solutions. The model RMSW material for the pilot scale tests had been gained by sampling in a mechanical RMSW processing plant in Miskolc (Hungary). This plant has a relatively low capacity (2-4 t/h) technology producing fuel for the neighboring methanol processing plant. The technology of this Miskolc RMSW plant comprises pre-crushing by a hammer shredder, drum sieve, magnetic separator, eddy current separator, final crushing by hammer shredders, and pneumatic transport and cyclone separation of the product RDF (refuse derived fuel). The 30-120 mm size fraction product of the drum sieve was sampled (Figure 1). The output belt conveyors were stopped and the technology was in operation for 20 minutes. All the produced materials were taken into a big bag as the sample. Mass of the 30-120 mm RMSW fraction sample was 18 kg.

Figure 1. Sampling of the 30-120 mm product of the drum sieve

b. Processed electronical waste for the pilot scale KLME tests:

Another promising application of the developed KLME separator might be the processing of electronical wastes (WEEE). Therefore, WEEE materials had been sampled in Baja (Hungary) at the local electronical waste processing plant. An average sample (26 kg) was taken there, shown in Figure 2.


Figure 2. WEEE average sample

The electronical waste average sample was crushed by a hammer mill at the Institute of Raw Materials Preparation and Environmental Processing, Miskolc, then it was sieved by hand sieving with laboratory sieves.

Table 1. Particle size composition of the WEEE average sample

Sieve mesh size [mm]	Mass of size fraction [kg]
+ 30	0.95
14 – 30	7.2
5 – 14	12.9
- 5	4.9
Total:	**25.95**

2.2. Sampling of the non-selectively collected RMSW for the design of the waste processing technology for the Zalaegerszeg region

However, the waste management public service company in the Zalaegerszeg region does waste analysis regularly, -namely twice a year- according to the MSZ 21420 28 and 29 Hungarian Standards, a more detailed analysis was necessary for the design of the RMSW processing technology. In addition to the standard analysis, information about the material composition as function of some discrete size fractions was necessary to measure. During the 2016 autumn campaign 5 waste collecting vehicles were selected and sampled. The service area of the company (about 150 000 habitants live there) was subdivided into sectors. Each of the raw samples in the selected 5 collecting vehicles was sampled and each sample characterized the sampled and the similar sectors. The standard average sample mass (500 kg according to Gy 1979) was increased up to about 800 kg. Practically an average sample was at least 4 m^3. Figure 3 shows the longitudinal downloading of the raw sample from the selected collecting vehicle and Figure 4 shows the manual rubbish bag tearing of the taken average sample before drum sieving.

Figure 3. Downloading a raw sample

Figure 4. Manual rubbish bag tearing of the average sample

Each average sample was taken from a longitudinal RMSW strip -downloaded from the vehicle- by a front-end shovel loader (about 4 m^3 shovel volume) transversely. After the manual rubbish bag tearing the total average sample was sieved by a drum sieve machine equipped with a 40x40 mm square shape mesh drum sieve (Figure 5). The mass of the total <40 mm size fraction was measured by an appropriate balance. A 5 kg subsample was taken from this material stream at the drop-off end of the belt conveyor. This 5 kg <40 mm subsample was sieved at 20 mm and the 20-40 mm fraction was hand sorted into combustible (mainly paper and plastic) and residual components. The total >40 mm fraction of the average sample was processed as the following. The sample was gradually sieved and hand sorted simultaneously from coarser into finer particle sizes. Simple 1.2 x 1.2 m sieve frames were used; the applied square mesh sizes were 200, 150, 100 and 75 mm. The sorted material components and their numbering are shown in Table 2.

Table 2. Sorted material components

No	Material component
1	Bio (biologically degradable materials, food residues, plants …)
2	Paper (paper and cardboard)
3	Composite (two components packing materials)
4	Textile
5	Hygienic (pampers, tampon, tissue …)
6a	2D plastic (mainly foils)
6b	3D plastic (3 dimensional plastic wastes except PET)
6c	PET
7	Combustible (other not categorized combustible, wood, leather …)
8	Glass
9a	Fe (magnetic metals)
9b	Al (electrically conductive metals)
10	Noncombustible (other not categorized noncombustible, stone, brick …)
11	Hazardous (medicine, battery …)
12	Extraneous (non RMSW, electronical equipment, cables …)

Figure 5. Hand sorting of the 40-75 mm size fraction

After sorting the total >40 mm material on the 200 mm mesh sieve, the mass of the fine (40-200 mm) fraction was reduced by the well-known diagonal quartering. Afterwards the sample was processed on the 150, 100 and 75 mm sieves similarly. By this way the necessary minimal mass determined by the corresponding sampling nomogram for a given RMSW particle size was accomplished. Above 5 kg a 150 kg nominal range and 50 g sensitivity, below 5 kg a 5 kg nominal range and 5 g sensitivity balances were used. All the sorted components and the size reduced parts were weighted. The total amount of the last 40-75 mm size fraction was sorted and its “sorting residue” was added into the <40 mm fraction. The dry material content was measured by a heated chamber at 105 °C for all material components regardless of the particle size. Table 3 shows the final result of the campaign, namely the wet composition of the examined RMSW. Results of the 5 average samples analyses were averaged, weighted according to the number of habitants of the different sectors. This data was used for the design of the RMSW processing technology described later.

Table 3. The wet composition of the examined RMSW
(material component names are listed in Table 2)

1	**2**	**3**	**4**	**5**	**6a**	**6b**	**6c**	**7**	**8**	**9a**	**9b**	**10**	**11**	**12**			mass of size fraction
> 200 mm																	[%]
7.8	15.0	0.7	32.9	5.7	21.4	2.8	0.6	5.4	0	1.5	0	2.6	0.1	3.4	100	%	**12.1**
150 – 200 mm																	
9.4	18.2	3.1	9.6	11.5	22.1	5.8	1.4	13.2	0.2	2.5	0.2	1	0.4	1.5	100	%	**5.6**
100 – 150 mm																	
15.5	16.7	4.5	3.2	12.5	10.9	8.0	8.6	7.9	2.8	3.8	0.5	3.6	0.5	0.8	100	%	**13.3**
75 – 100 mm																	
12.5	16.5	3.0	1.5	8.1	8.9	7.5	10.1	5.2	2.7	6.0	6.9	6.9	3.1	1.0	100	%	**11.2**
40 – 75 mm																	
37.3	24.0	1.1	0.6	1.9	2.6	7.2	0.9	4.0	2.2	3.2	2.2	10.4	1.7	0.6	100	%	**18.5**
< 40 mm																	
< 20 mm					20 – 40 mm residual					20 – 40 mm paper – plastic							
57.9					33.1					9					100	%	**39.3**
																	100

2.3. Development of the pilot-scale KLME separator

Figure 6 shows the simplified schematics and Figure 7 shows a photo about the built 400 mm width KLME separator.

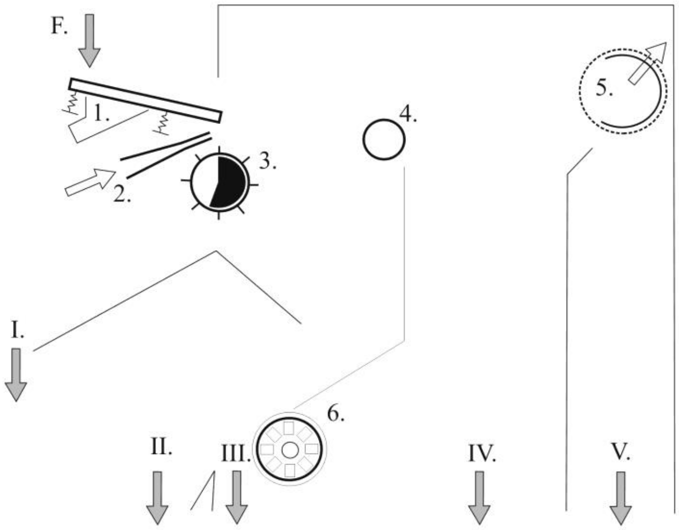

Figure 6.

The material is fed into the separator by a vibrated feeder. The RMSW particles fall down through an air stream blown in from the air nozzle. Light particles are transported by the air stream to the direction of the exhaust cage. Heavier particles fall into the magnetic drum and magnetic particles are dragged into output I. The rest goes to the eddy current separator. The magnetic pole motor was installed inside a rotated plastic cylinder without the application of any belt conveyor. By this construction the distance between the particles and the magnetic pole motor had been minimized. The electrically conductive particles are pushed into output II, and the rest goes into output III.

Figure 7. Photo of the 400 mm width KLME separator and auxiliary air system

The blown light particles fly above the rotated auxiliary cylinder. The 3D shaped particles fall into output IV. The rotated exhaust cage is sucked from inside by a ventilator. The 2D like materials are also sucked on the surface of the cage and because the rotation they are transported into output V.

Table 4. Main units and products of the KLME separator

Main technological units:	**Numbers and short names of products:**
1. Vibrated feeder	I. Magnetic
2. Air nozzle	II. Conductive
3. Magnetic drum	III. Inert
4. Rotated auxiliary cylinder	IV. 3D
5. Exhaust cage	V. 2D
6. Eddy current separator	

Table 4 shows the main technological units and the short names and numbers of the products of the built pilot scale KLME separator. The working width of the pilot scale separator is 0.4 m, its height is 3.24 m and length is 4 m. The pilot KLME separator was complemented with an air system, consisting of a ventilator, a bag filter, junctions and a choke.

3. Results and discussion

3.1. Pilot scale RMSW processing tests

Basic aim of the work described in this paper was the development of the machine. Scientific and theoretical work had been carried out simultaneously but results are published elsewhere (Faitli et al. 2017). The development work started with the construction of single model devices, afterward a model KLME was built and that was tested by single MSW particles. Based on the results, the first version of the 400 mm KLME was built. 19 systematic separation tests had been carried out with the average Miskolc RMSW sample described in Chapter 2.1.a. The sample was fed by a given flow rate and then the products of the given test were analyzed by hand sorting. Afterwards the products were mixed and the sample was used again for the next test. The RMSW feed flow rate, the flow rate of the blown in and sucked out air, the construction of the nozzle, and the angle of the nozzle were systematically changed. During and in between the tests the construction of the machine was many times modified according to the observations. Only one test, the last one (0606/II) is described here. Table 5 shows the main technological parameters and Table 6 shows the achieved yields and recoveries of the test number 0606/II.

Table 5. Main technological parameters of test number 0606/II

Total air flow rate [m^3/h]	Total pressure difference [Pa]	Air flow velocity in the nozzle [m/s]	Angle of nozzle [°]	Revolution of magnetic pole motor [1/min]
4000	1800	36	25	1280

Table 6. Yields and recoveries of test number 0606/II

	Mass of components in the products, [kg]					
KLME	**Magnetic**	**Conductive**	**PET**	**Glass**	**Residue**	**Total**

product no.						
I.	0.04	0	0	0	0	0.04
II.	0	0.03	0	0	0	0.03
III.	0	0	0.03	0.06	0.74	0.83
IV.	0	0.08	0.22	0.03	1.05	1.38
V.	0	0	0	0	0.69	0.69
Total mass of components [kg]	0.04	0.11	0.25	0.09	2.48	**2.97**
	A – Component contents of products, [%]					
	Magnetic	**Conductive**	**PET**	**Glass**	**Residue**	**Total**
I.	100	0	0	0	0	100
II.	0	100	0	0	0	100
III.	0	0	3.6	7.2	89.2	100
IV	0	5.8	15.9	2.2	76.1	100
V.	0	0	0	0	100	100
a- Component content in the feed, [%]	**1.3**	**3.7**	**8.4**	**3.0**	**83.5**	100
	k – Recovery of components into the products, [%]					**m – Yields of products, [%]**
	Magnetic	**Conductive**	**PET**	**Glass**	**Residue**	
I.	100	0	0	0	0	**1.3**
II.	0	27.3	0	0	0	**1.0**
III.	0	0	12	66.7	29.8	**27.9**
IV	0	72.7	88	33.3	42.3	**46.5**
V.	0	0	0	0	27.8	**23.2**
	100	100	100	100	100	100

The material content and volume of the products can be well seen on Figure 8.

I. II. III. IV. V.

Figure 8. Photos of products of test 0606/II

The recovery of the magnetic materials was 100 %, however the component content of this material was just 1.3 % in the feed. The electrically conductive material component, mainly the aluminum cans was recovered into two products (II and IV), and unfortunately only 27.3 % was recovered into the right product, into output number II. It has a serious consequence. However, the material densities of the PET bottles and the aluminum cans are really different, but the resultant body densities of the damaged condition waste particles are similar, therefore, their separation with an air stream from a nozzle is difficult. This observation has resulted in the change of the industrial size KLME layout. The recoveries of the PET (88 %) and the foil like 2D and the 3D like materials (residue) were sufficient.

3.2. Pilot scale electronical waste processing tests

The mentioned GINOP-2.1.1-15-2016-00904 project focuses only on the mechanical processing of the RMSW. However, the developed KLME separator might be applied for the processing of electronical (WEEE) wastes as well, therefore, 4 tests had been carried out with the sample described in Chapter 2.1.b with the 400 mm KLME separator. Data of the achieved best separation test (0527/II) are shown in Table 7 and 8.

Table 7. Main technological parameters of test number 0527/II

Total air flow rate [m^3/h]	Total pressure difference [Pa]	Air flow velocity in the nozzle [m/s]	Angle of nozzle [°]	Revolution of magnetic pole motor [1/min]
4400	3300	43	25	1280

Table 8. Yields of test number 0527/II

KLME product no.	**Product [kg]**
I.	3.56
II.	0.24
III.	1.61
IV.	0.8
V.	0.63

Figure 9 shows photos about the products of the 0527/II test. Unfortunately, these products were not further analyzed; therefore, recoveries had not been determined either. However, simply based on only these photos, good separation of the different material components can be observed.

I.	II.	III.	IV.	V.

Figure 9. Photos of products of test 0527/II

3.3. Design of the mechanical RMSW processing technology for the Zalaegerszeg region

Flow sheet result of the process engineering design of the first stage of the technological developments for the Zalaegerszeg region is shown in Figure 10, based on the sampling data described in Chapter 2.2. The processing plant has been designed for 20 t/h capacity RMSW mechanical processing.

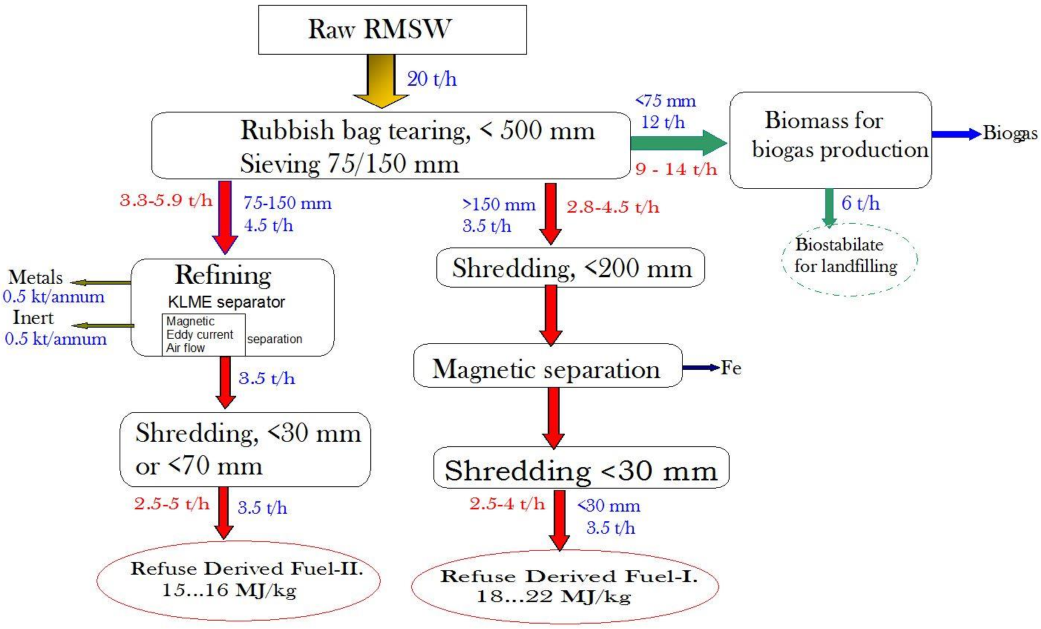

Figure 10. Technological flowsheet of the designed mechanical RMSW processing technology

The main products of the processing plant under construction will be the different quality RDF products, the <75 mm biomass for further processing and many smaller material streams for recycling. Toward to the no-landfilling aim, the further processing of the RDF and biomass products is under consideration. After the rubbish bag tearing the commonly used drum sieve separates the RMSW into three size fractions. The 75-150 mm size fraction is the designed feed for the developed KLME separator. Some of the products of the KLME separator are not shown in Figure 10. The technology under construction will be flexible in this respect because by NIR separators, the recycling of PETs, or the PVC removal will be possible options as well. There are two RDF production lines with two final shredders in the design. This design ensures flexibility because the fine fraction shedder maintenance is a serious issue and the products can be tailored for the market's needs.

4. Conclusion

Today's challenge is the solution of handling of the non-selectively collected residual municipal solid wastes (RMSW). One possible option is the mechanical processing producing material streams for recycling and for energetic utilization. The newly developed KLME separator combines four separators into one unit and eliminates the need of many feeders, storage buffers and belt conveyors. The combination of the separators has caused considerable difficulties in creating joint operation but at the same time it was beneficial as well.

The pilot scale 400 mm KLME tests with the 30-120 mm Miskolc RMSW sample have resulted better recovery than 88 % for the magnetic, PET, 2D and 3D plastics, and inert material components. However, the recovery of the aluminum cans was as low as 27 %. It was observed that the body density and therefore the terminal settling velocity of the damaged PET and aluminum can particles are not so different; the separation of these materials is not efficient by the nozzle air flow separator. This observation has resulted the change of the layout of the industrial size KLME separator.

The pilot scale 400 mm KLME separator was applied for the separation of the Baja WEEE sample with satisfactory results.

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