Single Stage Processing of Waste for Cost Efficient RDF Production

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Recovery of thermal energy from municipal solid waste (like residual waste and mixed household waste) usually is accomplished by mono-incineration plants (for example grate-firing systems) or in co-incineration units (like utility boilers, power plants or cement kilns), where pre-treated *waste fuel* is used as alternative feedstock for substitution of fossil fuel.

When preparing high quality solid recovered fuel (SRF) with strictly defined specifications, a multistage process including shredding steps with different particle sizes (for example d_{95} = 60 to 100 mm and 10 to 40 mm), magnetic separation (removal of Fe-metals), eddy-current separation (removal of non-Fe-metals) and sieving steps is state of the art.

New technical requirements and a high marked pressure coming from recovery solutions (such as plants for energy recovery) have an influence on the intensity of waste processing. The greatest impact on the overall performance of a plant and thus also on costs has the shredding technology applied. A single-stage shredding/comminution process enables the implementation of a less complex technology (a few shredding machines, not much conveyor, equipment, and others). To ensure subsequent process steps such as the separation of valuable materials in good quality, the correct grain size distribution of the comminuted material is important. A single-stage shredding solution often has the disadvantage, that the throughput is relatively low.

In this paper, the question of shredding performance, such as throughput capacity and grain size distribution is dealed by applying single-stage shredding, implementation of single stage processing technology in waste treatment plants and selected best practice cases which will be shown and discussed.

1. Thermal utilisation of waste with system boundaries

Modern waste management consists of a system of elements with mutual dependencies that requires a combination of different types of waste treatment plants. The individual elements are interrelated and interdependent. The plants may be considered both, elements but also subsystems of the entire system defined as: thermal utilization of wastes. The connections between the conceptual elements are material- and freight-flows.

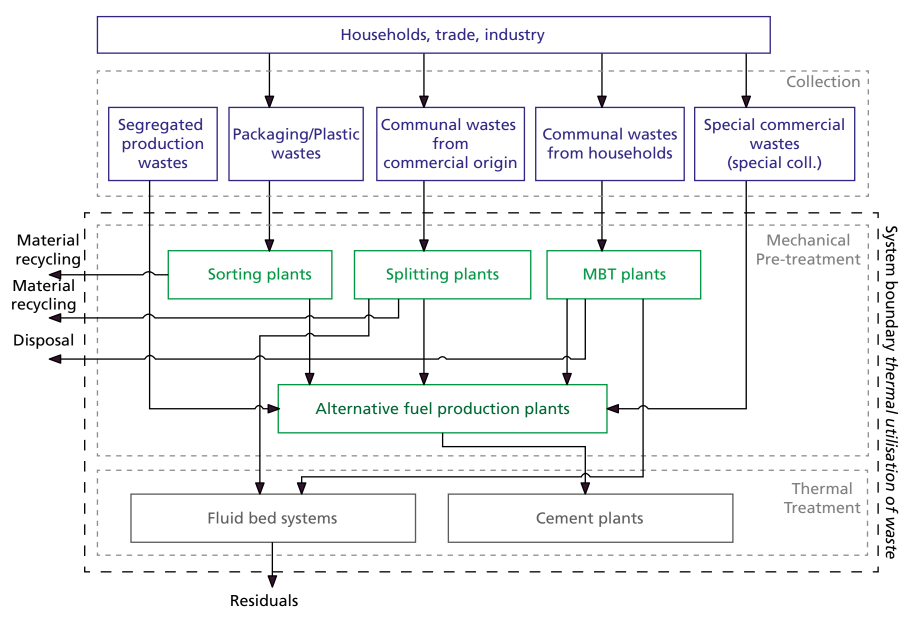

Figure 1: System overview: thermal utilization of wastes

Source: Sarc, R.; Lorber, K.E.; Pomberger, R.: Production of Solid Recovered Fuels (SRF) in the ThermoTeam Plant in Retznei, Austria – Experience, Quality and Quality Assurance of SRF. In: Thomé-Kozmiensky, K.J.; Thiel, S. (eds.): Waste Management, Volume 5. Neuruppin: TK Verlag Karl Thomé-Kozmiensky, 2015, pp. 399-412; ISBN: 978-3-944310-22-0

In Figure 1, the system thermal utilization of waste is depicted by the example of an Austrian waste management company. The assignment of waste streams to an appropriate plant type is made according to the quality of wastes. [12]

1.1. Waste streams and pre-treatment process

The input waste materials that are treated in SRF processing plants (*alternative fuel production plants*, Figure 1) can be described by their European waste code and description in accordance with the European List of Waste [2].

04_02_09	Waste from composite materials (impregnated textile, elastomer, plastomer)
07_02_13	Waste plastic
15_01_01	Paper and cardboard packaging
15_01_02	Plastic packaging
15_01_06	Mixed packaging
17_09_04	Mixed construction and demolition wastes other than those mentioned in 17_09_01, 17_09_02 and 17_09_03
19_12_12	Other wastes (including mixtures of materials) from mechanical treatment of wastes other than those mentioned in 19_12_11
20_01_01	Paper and cardboard
20_01_39	Plastics
20_03_01	Mixed municipal waste (household waste)
20_03_01	Mixed municipal waste (commercial wastes)
20_03_07	Bulky waste

Table 1:

Input waste materials for SRF production

Splitting plants treat mixed commercial waste and operate on the principle of qualitative splitting of waste streams. Various waste types mentioned before are undergoing distinct treatment and manufacturing steps, like: multistage shredding, classifying, separation of Fe- and non-Fe-metals, exclusion of heavyweight inert materials, as well as sorting out of unwanted materials like polyvinyl chloride (PVC) or recycling materials like PET. [11]

The output/produced SRF legally is not considered as a product but still is waste, classified by two waste codes:

- 19_12_10: (quality assured) combustible waste (that is SRF) and
- 19_12_12: other wastes from mechanical treatment of wastes – in other words RDF. [11]

1.2. SRF types and quality requirements

In before mentioned mechanical treatment plants (Figure 1), in total, the following three SRF types are produced and finally used for energy recovery in (co-)incineration plants (namely fluidized bed systems and cement plants, Figure 1):

- *SRF low quality*: having $d_{95} \leq 120$ [mm] and $3 \leq LHV \leq 12$ [MJ/kg$_{OS}$] and being used for energy recovery in WtE stationary fluidized bed incinerator,

- *SRF medium quality:* having $d_{95} \leq 80$ (for Hotdisc: $d_{95} \leq 300$) [mm] and $12 \leq LHV \leq 18$ [MJ/kg_{OS}] and is used for energy recovery in secondary firing systems of cement kiln and/or being special pre-combustion chambers like Hotdisc,
- *SRF premium quality:* having $d_{95} \leq 30$ (up to 35) [mm] and $18 \leq LHV \leq 25$ [MJ/kg_{OS}] and being used for energy recovery in primary firing system of cement kiln.

The recovery rate of a certain defined SRF quality – low, medium and/or premium – will depend on the input waste quality and the multistage SRF-production process applied. In some cases, this may lead to a conflict of interests between quantity (amount of SRF recovered from a certain type of input waste) and quality required by customer. [11]

Normally, there are two types of requirements regarding the SRF quality:

a) Legal limits for the delivered (unburnt) waste fuel – this is a special situation for Austria only, at EU level there is EN 15359:2011 [4] that is not legally binding according to the Waste Incineration Directive [3]

Limits for the delivered (unburnt) waste fuel define which kind of material the SRF producer can deliver to the cement plant by giving legally binding threshold values for eight heavy metals in the input-material the cement plant can accept. It is possible for the cement plant to set even stricter or additional acceptance criteria (specifications) than these legal requirements (Table 2) if desired.

Table 2: Austrian limit values for coincineration of refuse derived fuel (RDF) in cement plants

Parameter	Median	80th percentile
	mg/MJ_{DM}	
Sb	7	10
AS	2	3
Pb	20	36
Cd	0.23 (0.45)	0.46 (0.7)
Cr	25	37
Co	1.5	2.7
Ni	10	18
Hg	0.075	0.15

SRF is a subgroup of RDF

Source: BMLFUW: Verordnung des Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft und des Bundesministers für Wirtschaft, Familie und Jugend über die Verbrennung von Abfällen (Abfallverbrennungsverordnung – AVV) Waste Incineration Ordinance (WIO), StF: BGBl. II Nr. 389/2002, 2002

Table 3: Classification system for solid recovered fuels according to EN 15359

Classification Characteristic	Symbol	Statistical measure	Unit	Classes				
				1	2	3	4	5
Net calorific value	NCV	Mean	MJ/kg^{-1} (ar)	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3
Chlorine	Cl	Mean	% (d)	≤ 0.2	≤ 0.6	≤ 1.0	≤ 1.5	≤ 3
Mercury	Hg	Median	mg/MJ^{-1}(ar)	≤ 0.02	≤ 0.03	≤ 0.08	≤ 0.15	≤ 0.50
		80th percentile	mg/MJ^{-1} (ar)	≤ 0.04	≤ 0.06	≤ 0.16	≤ 0.30	≤ 1.00

(ar) = *as received*, equal to (OS): original substance; (d) = *dry*, equal to (DM): dry matter

Source: European Committee for Standardization (CEN): European Standard EN 15359:2011-Solid recovered fuels – Specifications and classes. Brussels, Belgium, 2010

Due to the heterogeneous distribution (80th percentile/median ≥ 1.5) of heavy metals in SRF, median and 80th percentile values are used for definition of limit values instead of the mean value. This is a special feature of the Austrian Waste Incineration Ordinance (WIO) [1], where for the first time, statistical methods are used instead of the principle of fixed limit values. [12]

Here, the classification system according to EN 15359:2011 is given and an example of classification shown (Table 3).

Example of classification:

The class code of a SRF having a mean net calorific value of 19 MJ/kg (ar), a mean chlorine content of 0.5 percent (d) and a median mercury content of 0.016 mg/MJ (ar) with a 80th percentile value of 0.05 mg/MJ (ar) is designated as:

Class code NCV 3; Cl 2; Hg 2.

b) Technical requirements (specifications) for waste fuel defined by plants

Next to the legal requirements regarding the necessary quality of SRF for energy recovery, additional plant-depending technical specifications (chemical-, mechanical-, calorific properties and others) like:

- lower calorific value (LHV): [MJ/kg_{OS}],
- particle size (d_{95}) [mm],
- water content [$\%_{OS}$],
- ash content [$\%_{DM}$ or $\%_{OS}$],
- chlorine content [$\%_{DM}$] as well as
- bulk density [kg/m_{OS}^3].

may be defined and requested by different SRF-(co-)Incineration plants, for being fixed in the contract between suppliers and users. [11]

2. Single stage SRF production with system boundaries and description

In the cement industry, energy substitution at secondary firing system of the rotary kiln (i.e. the calciner or a combustion chamber like Hotdisc) is increasingly gaining importance from a customer point of view. In contrast to the SRF quality required for main burners, for secondary firing a coarser ($d_{95} \leq 80$ mm) SRF medium quality with higher portion of three dimensional particles and lower calorific value can be used. This creates benefits for SRF producers regarding intensity depths of processing, and allows for simpler process and plant concepts. The central process in SRF production is the comminution of coarse input material. This treatment significantly influences subsequent process steps such as the recovery of valuables, separation of contaminants and unwanted materials as well as the final SRF quality. Furthermore, the applied shredding technology is one of the largest cost drivers in SRF processing plants, impacting investment costs as well as operating and maintenance costs. Figure 2 shows a schematic diagram of an SRF processing plant for SRF medium quality using a single-step comminution process.

An adequate machine for single-step shredding, as described before, is the Polaris 2800 manufactured by Lindner Recyclingtech GmbH.

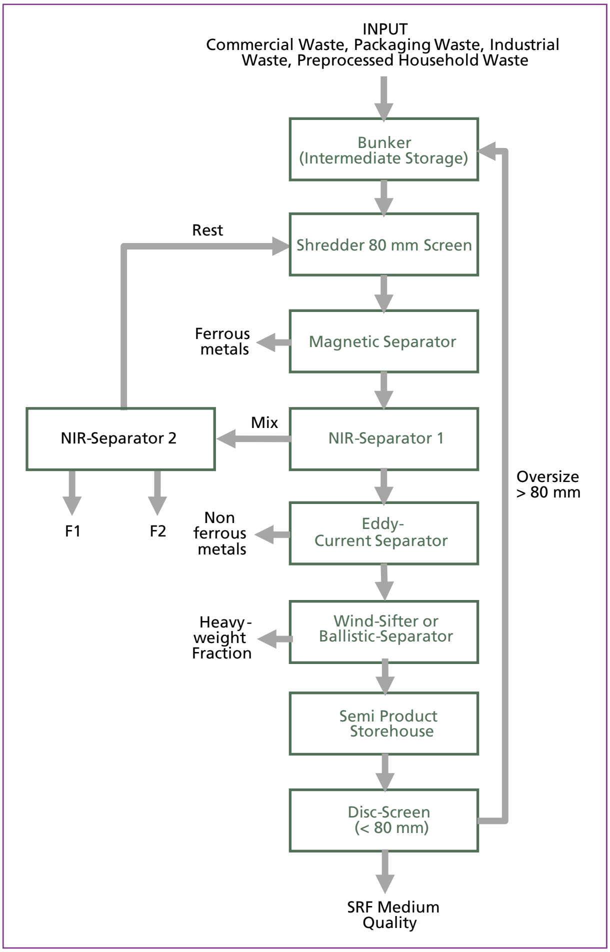

Figure 2:

Schematic diagram of a SRF processing plant for SRF medium quality applying single-step comminution process

Table 4: Technical data for Polaris 2800

Dimensions [mm] and weight	
Overall dimensions	6,065 x 2,925 x 4,799
Feed opening	4,779 x 2,370
Filling height	3,480
Hopper volume	about 10.5 m^3
Total weight	30 t
Cutting unit	
Rotor length	2,805 mm
Rotor speed	112 min^{-1}
Rotor knives	80 pcs.
Screens	8 pcs.
Drive unit	
Drive power	2 x 132 kW
Drive type	2-stepped belt

The Polaris 2800 is a single-shaft shredder, which can be used for single step shredding of untreated household waste as well as industrial and commercial waste.

The Polaris 2800, with a feed opening of 4,779 x 2,370 mm and a rotor length of 2,805 mm, achieves a throughput of up to 35 t/h (Figure 3). [10]

3. Case study – Large-scale testing and comparison of performance for Polaris 2800 and one conventional shredder

Performance comparison, as a part of a project established at North West Recycling company in northern England, between the Polaris 2800 and a comparable single-shaft shredder *X* (built in year 2015) was carried out.

The practical comminution tests have been used for acquisition of representative data for a comparison of the two aggregates, the Polaris 2800 and the shredder *X*, regarding shredding performance, throughput, and energy demand.

3.1. Materials and Methods

In this subchapter, materials and methods applied are explained.

3.1.1. Input materials

In total, three different materials (M1 to M3) were tested using both aggregates:

M1 Commercial & industrial waste pre-shredded

Material 1 was pre-crushed with a coarse (300 to 400 mm) mobile dual-shaft-shredder. Optically, this sample looked like the usual untreated material (Figure 3).

Figure 3: C&I – commercial & industrial waste pre-shredded

M2 Commercial & industrial waste as received (not pre-shredded) (Figure 4).

The commercial & industrial (C&I) waste had also characteristics of household waste. The characteristics of the household waste used are as follows:

- large content of organic material, like food residues,

- children's toys (small quantities),
- household items (small quantities).

Figure 4: C&I – commercial & industrial waste not pre-shredded

M3 Plastic bales (square shaped)

The 7-fold vertically strapped bales consisted of plastic foils with sizes between 300 and 2,000 mm (Figure 5).

Figure 5: Plastic bales

3.1.2. Legal and technical fundamentals

The sampling concept for the experiments has been designed according to the existing European standard specifications. Considering that single fractions would end up as SRF after the comminution process, the following normative standards and technical specifications have been chosen for the concept development:

- ONR CEN/TS 15401 Solid recovered fuels – methods for the determination of bulk density [8],
- ÖNORM – EN 15442 Solid recovered fuels – methods for sampling [6],
- ÖNORM EN 15415-1 Solid recovered fuels – determination of particle size distribution part 1: screen method for small dimension particles [5],

- NORM CEN/TR 15310-1 Characterization of waste – sampling of waste materials – part 1: guidance on selection and application of criteria for sampling under various conditions [7].

3.1.3. Technical sampling and procedure concept

The three different input materials (M1 to M3) are to be comminuted consecutively in three comparisons using both shredders: the Polaris 2800 with a 60 mm sieve insert, and the shredder *X* with a 50 mm sieve insert. Relevant partial quantities of the M1 to M3 samples were prepared. A test duration of one hour each per fraction and aggregate is considered as representative and practicable as well. Comminution efficiencies are compared based on sieve analyses of the shredded output materials. Considering the listed standards and technical specifications, the sampling concept developed for the on-site experiments had to be practicable and representative (for example with respect to range and distribution of results) achieved. Consequently, during each experiment, six random samples (that is one sample every ten minutes during the one hour) were taken. In accordance with the specifications of ÖNORM EN 15415-1 and calculations of ÖNORM – EN 15442, a minimum sample size of 2 kg was determined. Due to local circumstances, samples were taken manually from a falling material stream using a 100 L sampling container where the whole material stream was captured. The sample volume was subsequently reduced using the quartering method.

Figure 6 shows the schematic sampling concept for the comparative study.

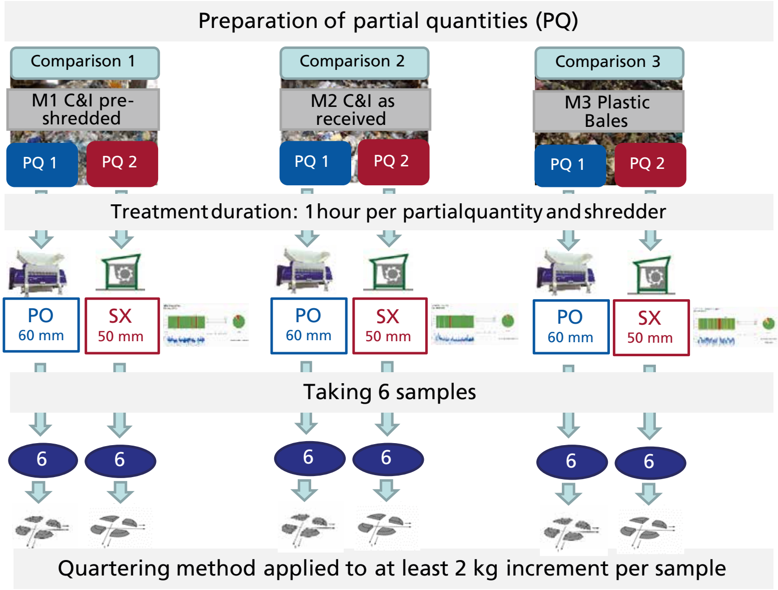

Figure 6: Sampling concept for the comparative study performed

In order to gain additional information about the representativeness of the applied sampling concept, each random sample was separately subjected to a sieve analysis.

Screen mesh size were mainly chosen following ÖNORM EN 15415-1. However, due to the material features (such as high moisture content), screen mesh size < 6.3 mm had to be spared. The standard generally recommends a stepwise doubling of the sieve's hole or mesh size. To increase the grade of characterization (namely the resolution) of sample's size distribution range, the number of screen mesh sizes cuts was increased as follows:

- 6.3 mm, 10 mm, 20 mm, 25 mm, 40 mm, 50 mm, 63 mm, 80 mm and 100 mm.

From the grain size distribution curve of each sample, median, average screen underflow in m.-$\%_{OS}$, the average 90-percentile particle size (d_{90}) in mm and relative standard deviation of each experiment have been determined.

In parallel with the experiments, energy measurements to allow for statements about the energy consumption and operational efficiency were carried out.

3.2. Results and discussion

The following summarizing statements can be made, based on the comparison of comminution performance, energy demand, and throughput observed during the described experiments.

a) Comminution performance and resulting grain size distribution

Figure 7 shows that for all comparisons, the average 90-percentile particle size (d_{90}) in mm of the Polaris 2800 (60 mm sieve insert) is smaller than that of shredder *X* (50 mm sieve insert). The difference is less pronounced for comparison 1, as the material used for this test had been pre-crushed. The largest differences were observed for the comminution of plastic bales. The experimental results lead to the conclusion, that the shredder Polaris 2800 shows somewhat better comminution performance than shredder *X*.

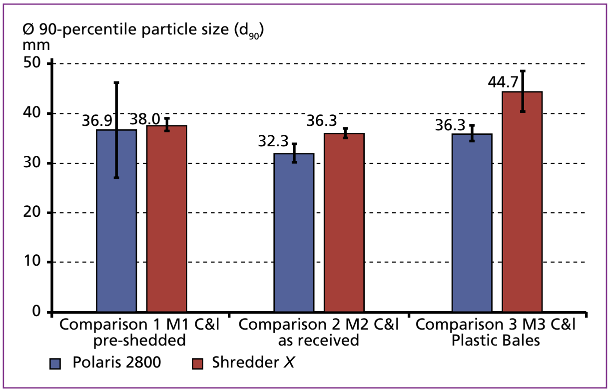

Figure 7:

Overview of the average 90-percentile particle size (d_{90}) in mm achieved by the shredders

b) Throughput

With regard to the gross duration, the throughput performance (Figure 8), of Polaris 2800 was 2 to 2.4 times higher than that of shredder *X*. This large difference can be explained by the numerous downtimes of shredder *X*.

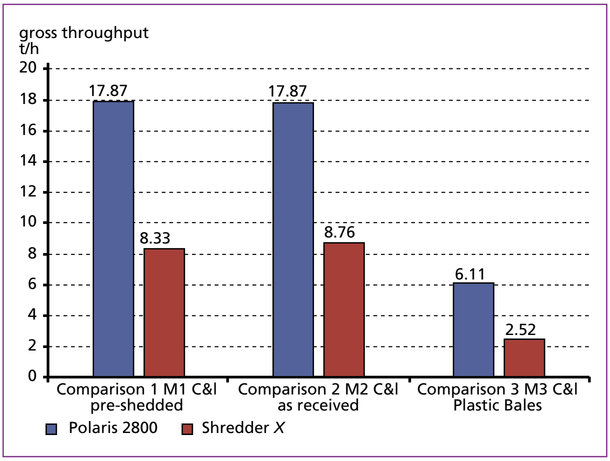

Figure 8:

Overview of specific gross throughputs

c) Specific energy consumption and energy costs

Figure 9 depicts the specific energy consumption of shredders for every single experiment in kWh/t. Due to toughness of the material, the specific energy consumption for plastic foil bale comminution is many times higher than that for shredding loose material.

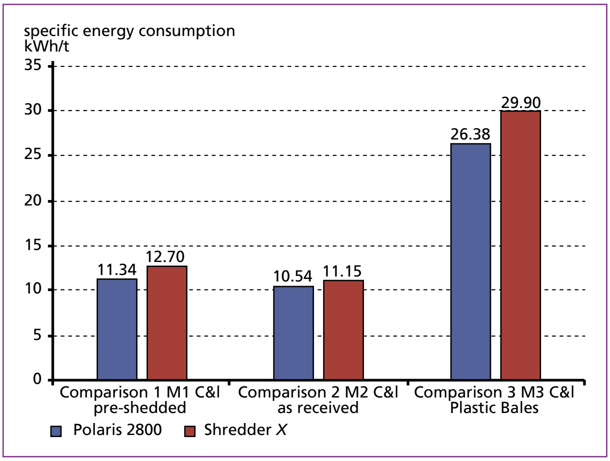

Figure 9:

Overview of specific energy consumption

Specific energy costs in EUR/t (Figure 10) behave analogously to specific energy consumptions. For energy cost calculations, a price of 0.11 EUR/kWh was assumed.

Especially when shredding materials that are difficult to comminute, as it is the case for plastic foil bales, the Polaris 2800 exhibits significantly (twelve percent) lower energy costs. Comparing both shredders with regard to comminution of pre-shredded or as received (not pre-shredded) industrial and commercial wastes, the Polaris 2800 as well shows 0.07 EUR or 0.15 EUR lower energy costs per produced metric ton of shredder output.

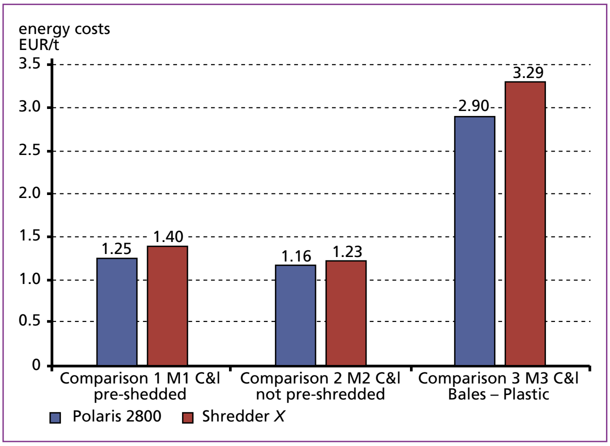

Figure 10:

Overview of specific energy costs

4. Selected best practise case studies [9]

This chapter reports some case studies regarding the operational practice of different SRF processing plants in which plant performance and economic efficiency were significantly improved by means of a single-step shredding process.

4.1. North West Recycling

North West Recycling is a company, producing medium calorific SRFs with several comminution aggregates in Carlisle, Northern England.

Among other comminution aggregates, the Polaris 2800 shredder from Lindner Recyclingtech company and a shredder of a competitor company are used. From previous operational practice of North West Recycling, a performance advantage of the Lindner aggregate is noticeable and reported.

4.2. Alba Nordbaden

In a new RDF production plant in Karlsruhe, Germany, single-step comminution is applied for the first time. Up to 33,000 tonnes of calorific RDF for use in power plants and in cement industry are produced each year out of mixed construction and commercial wastes.

The Polaris 2800 showing the best performance during the benchmark tests is used as a comminution aggregate. The specific energy consumption is reported with less than 15 kWh/t.The throughput performance for a grain size of < 80 mm amounts to > 23 t/h and thereby exceeds the requirements by 15 percent.

In the fully automated plant process, recyclable plastics, iron, non-ferrous metals, and chlorine-containing constituents are separated and removed from the material stream by means of overband magnets and near-infrared (NIR) technology. Sorting quota for iron and non-ferrous material of about 90 percent are achieved, and may also be attributable to the good material preparation.

4.3. Zuser

At its headquarter in Peggau, north of Graz, Austria, Zuser company uses municipal, commercial, industrial, and mixed construction & demolition waste to produce more than 100,000 tonnes of RDF per year, with grain sizes ranging from 30 to 250 mm. Zuser supplies cement factories and other coincineration plants in Austria and bordering countries. High calorific SRFs, for example, are used in the main burner of a cement plant, while medium calorific SRFs are utilized in calciners, and rejects with low calorific value are burnt in waste incineration plants. Since January 2017, the Polaris 2800 is employed for single-step comminution successfully.

Several benchmark-tests performed on-site under real conditions, and current opera-tional experiences have shown that the high requirements on the SRF's material quality and comminution performance (throughput performance, robustness, durability, low energy- and wear costs) can be met with a single-shaft shredder in a single-step operation. The hydraulic impurities flap allows for a very fast removal of impurities and simple maintenance, thereby having specifically positive impact on the availability. The throughput performance for a grain size of < 80 mm amounts to 28 t/h. A lifetime of about 400 operating hours is expected for the cutting tools.

5. Conclusions

The RDF industry is highly dependent on the prevailing situation of energy recovery market, characterized by a high price pressure. Supplementary payments to consumers taking over the ready-to-burn material (namely energy recovery solutions) for have increased recently, while material recovery of valuables for recycling are decreasing or stagnating at a low level. The amount of high calorific SRF that cement plants can take over is limited by their technical capacity. Comminution and preparation of different input material represents the centrepiece of SRF processing. It impacts SRF quality and thereby its behaviour in the clinker burning process. The type of comminution, process technology (single-step or multi-step comminution), and the operating mode have a significant influence on the overall performance and thus on the economic performance of a plant.

Aiming to take into account framework conditions that are changing more and more rapidly, new concepts for SRF producers have been developed.

Continuous advancements in comminution technologies made it possible, that today defined SRF qualities with respect to grain size, such as SRF medium quality for application in secondary firing systems, for example, can be achieved with a single-step instead of a multi-step comminution process. This conclusion is supported by the results of the presented case study as well as reports from operational practice too.

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