State-of-the-Art Reject Treatment Systems for Recycled Fiber Lines

1. Introduction

Waste from paper mills has long been neglected and simply sent to landfills. This situation is changing rapidly due to legal requirements, and even more because of the huge economic benefits that can be accomplished by converting the rejects into valuable sources of energy or new raw materials. These benefits include

- avoiding costs for transportation, handling, and disposal
- saving energy costs by generation of RDF (refuse-derived fuels): burning the reject fraction with high calorific value instead of purchasing fossil fuels, especially as energy and fuel prices are steadily rising
- income generated from selling various fractions of the reject compound
- government subsidies and funding

By way of example, the following figures show price trends for various fuels and for electricity over the last decade. These trends show clearly that alternatives for energy generation and greater independence from market energy prices are the main drivers for "waste-to-energy" reject treatment.

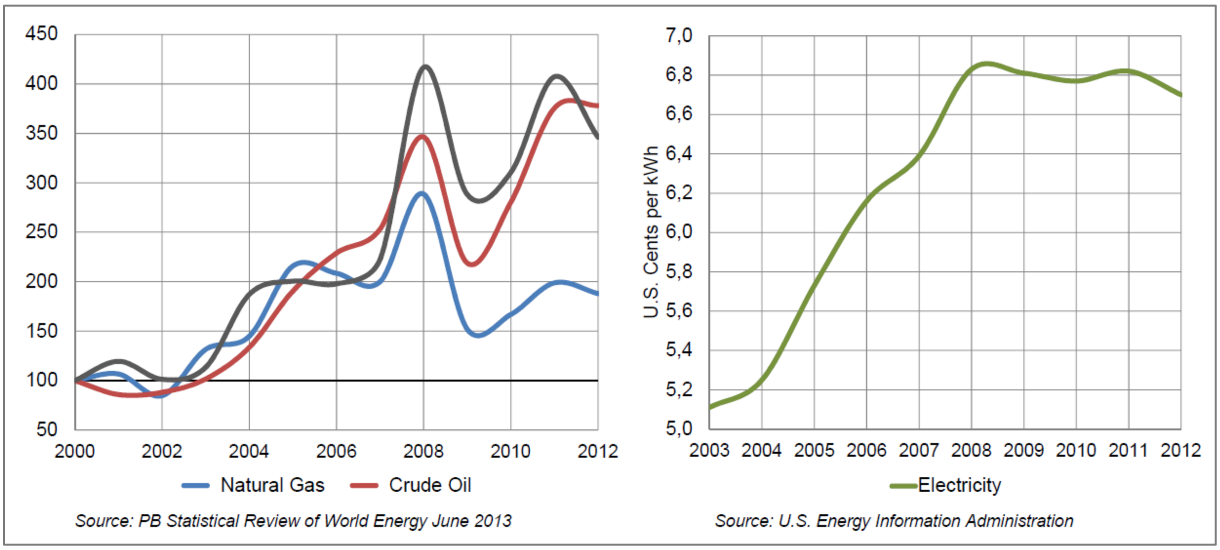

Figure 1 – Indexed price development of fossil fuels (left) and electricity costs (right)

Recycled fiber lines generate a wide range of different sludges and rejects at various points of origin and with very different properties. Rejects are remarkably inhomogeneous, with a wide variety of particle sizes, densities, dry contents, etc. – this makes effective processing a challenging task.

The following presents the major unit operations for treating the various rejects and processing them in order to obtain several fractions. These include:

- coarse and fine metal separation,
- ballistic separation of heavy particles, such as stones and bricks,
- screening by particle size,
- mechanical dewatering and compacting,
- cutting and shredding to set the desired particle size,
- sorting of unwanted materials and impurities,
- "ancillary processes" and unit operations such as sand separation or channel screening and – last, but not least – conveying, bunkering (including baling and wrapping), and dosing the rejects.

However, the individual unit operations alone are useless unless they are combined properly and arranged in a customized reject treatment system – adapted to the given circumstances for any mill or location. These framework conditions include the final purpose of the rejects (e.g. combustion, gasification, pelletizing), the existing or planned technologies for this purpose (such as the boiler type), and the market prices that can be achieved for several fractions (e.g. ferrous or non-ferrous metals) depending on their cleanness.

There is no "one-type-fits-all" reject system; it must be developed together with the customer and tailored to his goals and requirements. However, there are some typical, general concepts that are introduced and explained in the final part of this paper.

2. Origin and composition of rejects from recycled paper mills

The amount of total rejects and sludge is determined by the type and origin of the raw material and the set-up of the recycled fiber line. Table 1 shows typical amounts of rejects and sludge.

Paper grade	Recovered paper grade	Wastes (% dry mass)				
		Total	Rejects		Sludges	
			heavy and coarse	light and fine	flotation deinking	white water clarification
Graphic paper	news, magazines	15 - 20	1 - 2	3 - 5	8 - 13	3 - 5
	high grades	10 - 25	< 1	≤ 3	7 - 16	1 - 5
Sanitary paper	news, magazines, office paper, medium grades	27 - 45	1 - 2	3 - 5	8 - 13	15 - 25
Market DIP	office paper	32 - 46	< 1	4 - 5	12 - 15	15 - 25
Liner, fluting	old corrugated containers, kraft papers	4 - 9	1 - 2	3 - 6	-	0 - 1
Board	sorted mixed recovered paper, old corrugated containers	4 - 9	1 - 2	3 - 6	-	0 - 1

Source: Gavrilescu, 2008

Table 1 – Amount of rejects and sludge depending on recovered paper grade and paper produced

The rejects occur in many different forms, with particles including

- glass, sand, stones
- metals (wire, staples)
- synthetics
- wood, textiles, other combustible materials
- fibers
- water, sludge

Rejects can be split into two major categories: coarse and fine rejects. While the coarse rejects mainly come from the pulping process, including de-trashing, the fine components originate from the cleaning and screening stages. Both categories – coarse and fine – can be divided into light and heavy rejects. Table 2 gives an overview, including examples and main point of occurrence.

Category	Coarse rejects		Fine rejects	
Type	light	heavy	light	heavy
Example	plastics, foils, fiber bundles	stones, pieces of metal	fibers, stickies, wax	sand, glass, staples, small metals
Occurrence	pulping, coarse screening	detrashing	slot screening, light-weight cleaning	cleaning, junk traps

Table 2 – Categories and types of reject in recycled fiber lines

In terms of size, rejects contain particles ranging from the size of a grain of sand to large sheets measuring more than a square meter or massive lengths of rag with diameters around 700 millimeters. On top of this, the characteristics of rejects also vary over a wide range. The materials differ in dryness from very wet with plenty of free water to relatively dry. Densities can differ by a whole order of magnitude from very light plastic films to stones and metals. Last, but not least, the material occurs in different shapes, from loose to compacted or twisted.

All these different compositions and types require a tailor-made reject treatment system.

Figure 2 shows the composition of the total reject (including sludge) from a European OCC line (bales with wires fed to the pulper), and thereof the composition of the combustible materials in more detail.

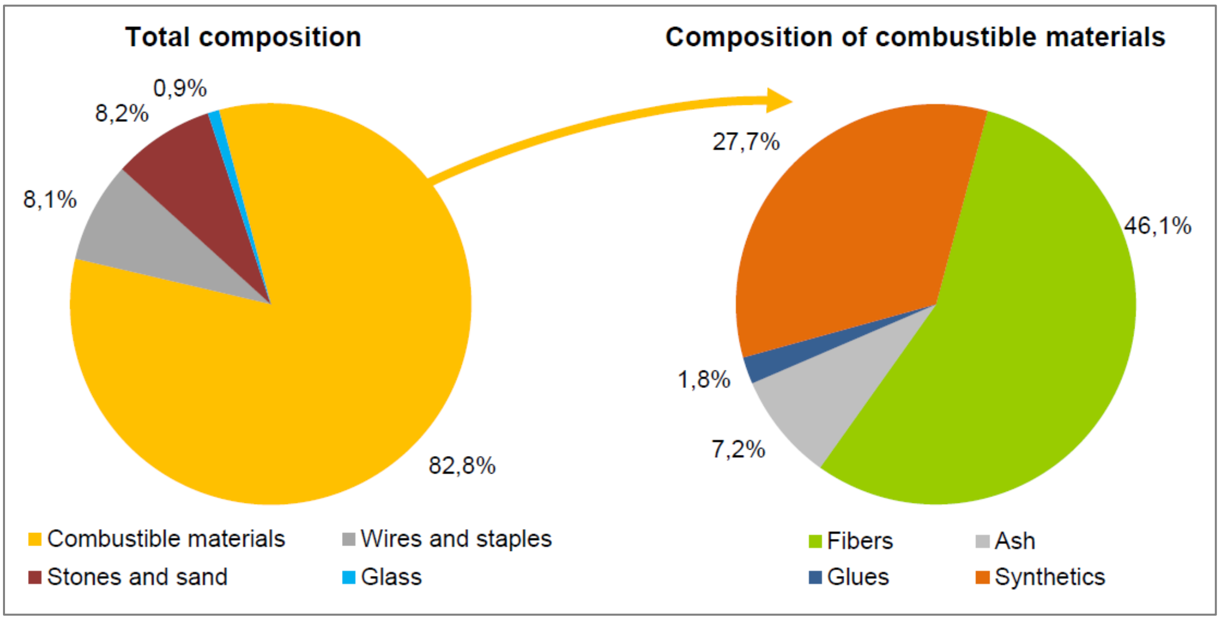

Figure 2 – Total composition of rejects and sludge from an industrial grade line, and thereof composition of combustible materials

As mentioned above, the waste paper has a considerable influence on the composition of the reject. This can vary a lot according to waste paper grade, but also according to collecting area and (local) collection system.

Different rejects also show a wide range of heating values. The different heating values shown in Table 3 indicate the relevance of rejects and sludge in thermal conversion.

Fuel / Reject	Humidity [%]	Inorg. share [%]	Heating value, wet [MJ/kg]
rags, pulping rejects	35	5 - 10	14 - 17
rejects from coarse screening	45	30 - 45	7 - 10
DIP sludge	35 - 45	55 - 75	4 - 8 *
biological sludge	78 - 85	5 - 15	1 - 3
bark	65 - 75	5 - 10	3 - 5
waste wood	15 - 25	2 - 8	12 - 15
heavy oil	-	-	38 - 42

** depending on ash content*

Table 3 – Heating values of different fuels and reject materials

3. Unit operations for reject treatment

The following chapter describes the most common process steps for reject treatment (Figure 3) in recycled fiber lines. It also explains why the particular unit operation is required and where it is typically or best applied. Machine concepts are introduced briefly.

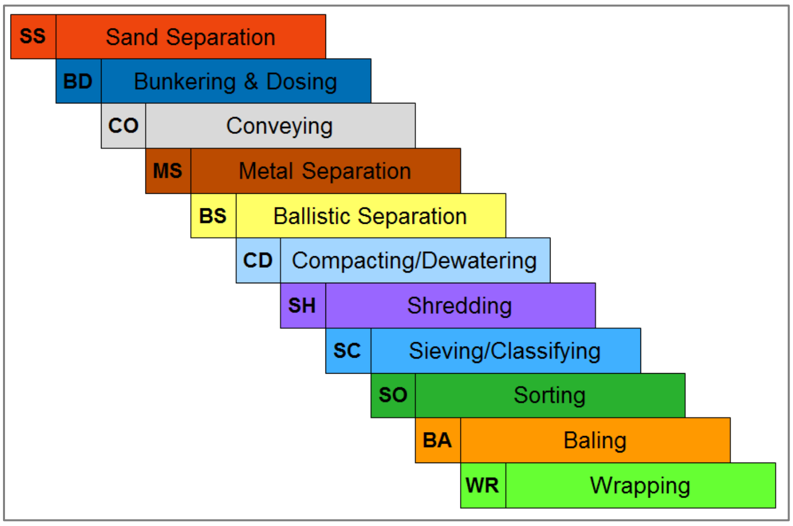

Figure 3 – Overview of most common unit operations

3.1. Metal separation

Metal pieces cause wear in subsequent process steps, they can damage equipment, or are unsuitable for certain unit operations, for example pellet press dies, dryers, or boilers. Moreover, metals can be sold as a valuable fraction in many cases.

One of the first stages in a reject line is coarse metal separation, included immediately after the pulping process. Rejects from drum pulping can contain metal particles of significant size, as these rejects leave the drum largely unchanged and in full size. Thus, metal separation is always required. Rejects from a conventional pulping stage (light-weight rejects from wash drums) normally do not contain many heavy materials or metals, however a separation stage should still be applied for safety reasons.
Coarse metal separation typically uses an overband magnet, which can be electro-magnetic or permanent-magnetic. Coarse metal separation targets ferrous metals only.

Another field of application is removal of the extensive amount of metals from pulper rags. Of course, these rags have to be shredded first so that the metals can be removed.

In most cases, a second metal separation stage is implemented as fine metal separation. This stage is included after fine shredding, when particle sizes are smaller and much more uniform. The shredder also loosens up and separates the material, thus increasing the efficiency of fine metal separation. Otherwise, too much combustible material would be removed with the metals, which are stuck and twisted together, or small metals would not be removed or detected because of being wrapped in sheets of plastic or the like.

While coarse metal separation only tackles the large ferrous metal parts, fine metal separation is a two-stage unit operation in most cases. First of all, the ferrous parts are removed. This is achieved

either by another overband magnet – which can be mounted much closer to the conveying belt due to the smaller particle size – or by a magnetic drum. The advantage of a magnetic drum is the direct contact of the medium with the magnet.
Finally, an eddy-current separator ejects the non-ferrous particles, such as copper, aluminum, and so on. The so-called "eddy-current effect" arises if nonferrous conductors are exposed to an alternating magnetic field. The eddy currents in turn generate magnetic fields whose flux is opposed to the fields generating them. Hence, they cause repelling forces that eject and discharge the non-ferrous metals, while the ferrous parts stick to the magnetic roll. An eddy-current separator thus creates three fractions: the non-ferrous metals ejected by the eddy currents, the inert fraction gushing along the eddy-current roll before freely falling down, and the ferrous metals sticking to the roll and released into a container.

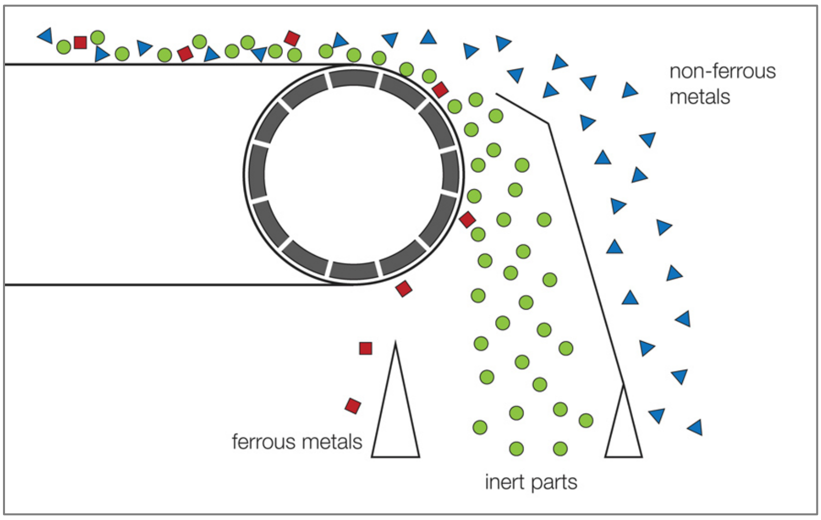

Figure 4 – Working principle of an eddy current separator

A prerequisite for any good metal separation stage is uniform distribution over the conveying belt. The material must be separated as effectively as possible and the distance between the material and the overband separator should be kept as short as possible.

3.2. Ballistic separation

Waste paper can contain a significant amount of heavy particles, such as stones or bricks. These components also bear a risk for subsequent process steps and cause greater wear. Thus, it makes sense to remove these worthless components from the main stream of combustible rejects at the earliest possible stage. A very effective method of doing this is ballistic fractionation.

A ballistic separator is applied very early on in the process, either directly after coarse metal separation or even before it. It is recommended particularly in reject systems for drum pulping lines, where the heavy particles enter along with the main reject stream, while these stones and bricks typically end up in the heavy fraction in conventional pulping lines.

The separation into fractions is based on the different trajectories and ballistic characteristics of the reject components. An inclined, perforated tray that also rotates sets the material in motion. Light and flat particles – such as paper sheets, plastic films, fabrics – are pushed upwards and transported towards the light fraction. Heavy and spherical or cubical particles fall and roll downwards to the

heavy fraction. The tray itself is perforated, creating a sieve fraction for smaller particles.
The heavy fraction is removed from the process, but can still be cleaned further or separated into different fractions – stones and bricks on the one hand, aluminum cans and plastic bottles on the other hand.
The light fraction and the sieve fraction are further processed in the main line, but they may undergo different treatment. They can either be mixed together again as the "total combustible fraction" or treated in different unit operations – depending on their final use.

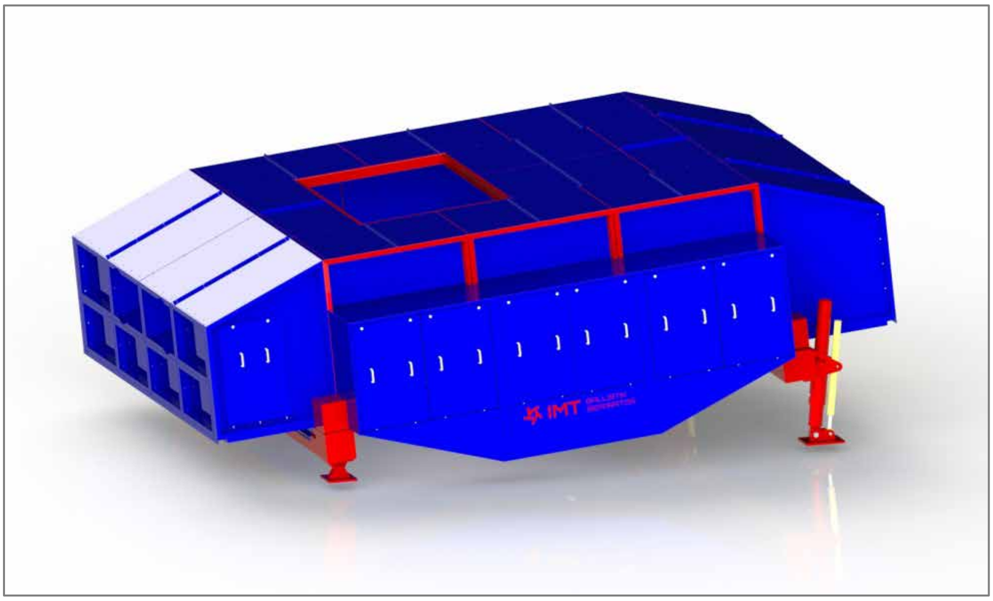

Figure 5 – Ballistic Separator (courtesy of IMT)

3.3. Shredding

The main purpose of shredding is to set a required particle size for the following treatment and process steps. These requirements mainly come from the "end use", i.e. boiler type or demands from pelletizing or gasification. Also the entire process setup of the reject preparation line has an influence. Subsequent process steps – such as fine metal separation or sorting of unwanted materials – impose certain prerequisites on particle size and particle size distribution.

The challenge is to cut down a wide range of particles – that may be of significant size – to a quite small and uniform particle size in the range of 40 to 60 mm. Depending on the process set-up and the unit operations applied, this may be done in one single shredding stage, but can also require two stages, namely coarse and fine shredding.
Fractions that need to be shredded are the pulping rejects (with coarse metals and heavy contaminants possibly removed by metal and ballistic separation) from both drum and conventional pulping and the rags from conventional pulpers. If a compacting and dewatering stage is applied, a shredding stage has to follow in any case to make the material suitable for fine metal separation and sorting.
Shredding in reject treatment lines can be split into coarse and fine shredding.
The purpose of the coarse shredding stage is to make the material suitable for treating in the subsequent reject system. Very large particles (like rags) have to be cut into pieces that can be

conveyed and transported and do not harm the equipment that follows. Machine concepts used for coarse shredding include double-shaft shredders (rotary shears), but also single-shaft shredders.

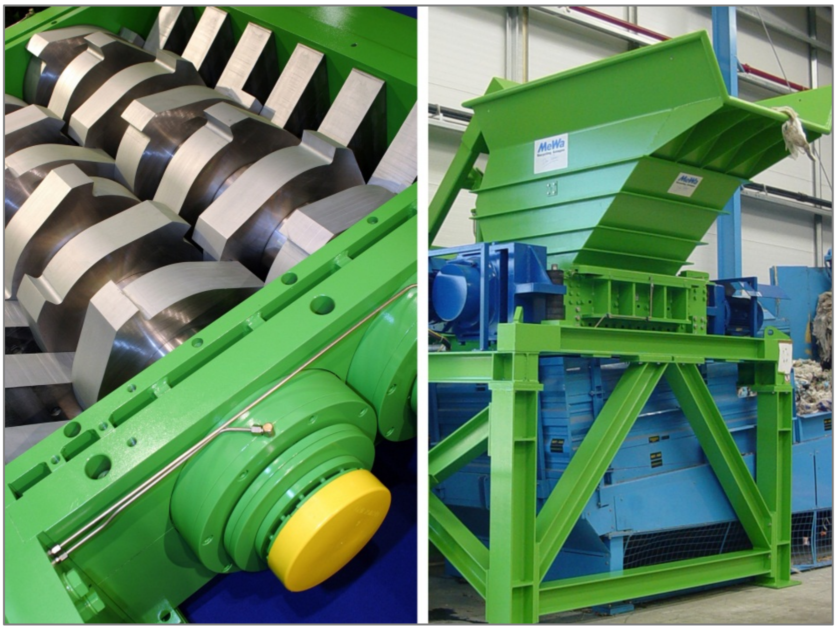

Figure 6 – Coarse shredder (rotary shear)

The best suited concept for fine shredding of typical rejects from recycled fiber lines are fast-running, single-shaft shredders. The material is fed to the unit via a conveyer belt to the cutting room. In the cutting room, the material is then cut between a massive, high-speed cutting rotor equipped with knives and a static counter knife. The gap between the moving rotor knives and the static counter knives is essential; it must be as accurate as possible. As shredding is a wear-intensive operation and knives have only a limited life time, the adjustability and accessibility of the shredding knives and their gaps are crucial for any shredder.

In many cases, a hydraulic pressure device is used in addition to press the light material against the rotor and knives. The crushed material then passes through a screen and drops down onto a conveyer. The particle size of the crushed material can be adjusted by using different meshes (hole sizes) and different knife shapes. The high-speed, single-shaft shredder loosens up the material, ensuring the most uniform particle size distribution, and separates the material as best possible so that the following process steps are more efficient.

3.4. Compacting/Dewatering

The material is quite wet when it leaves the pulping process, with a lot of free water and water stored in the fibrous reject. While free water is relatively easy to remove, the water attached to fibers is more critical. High forces or pressures are needed to bring the material to an acceptable dry content. Nevertheless, putting effort into mechanical dewatering still pays off because it still requires much less energy compared to thermal drying. However, there are certain limits to what can be achieved mechanically. The dry content achievable is strongly dependent on the fiber content of the reject material. The higher the fiber content, the lower the final dry content.

In a reject line, the material is typically dewatered after coarse shredding and removal of large contaminants (coarse metal separation, ballistic separation). The volume is reduced significantly and the dry material is less prone to sticking to conveying belts and similar. This is crucial for the subsequent process steps, such as optical sorting or fine metal separation. Machine concepts include both piston presses and screw presses. Piston presses with large loading chambers have the advantage of operational safety for larger particles, but this is not relevant in systems with a coarse shredder. Screw presses achieve higher dry contents – especially for reject with a certain fiber content. This is explained by the high shear forces and the shorter distance to be covered by the water to the filter surface (wire or screen basket). Screw presses can also be controlled much more easily (similar to screw presses for pulp or sludge), keeping the dry content at a maximum level and avoiding plugging.

Figure 7 – Reject compactor

3.5. Screening/sieving

After fine shredding, the particle size is much more uniform than at the beginning. Still, there is always a significant amount of fine particles, mainly fibers and small plastic pieces. These particles cannot be treated in optical sorting processes or fine metal separation. On the contrary, the fine particles can even distort those processes. They cause dust problems and can influence the measurement – especially in optical sorting –thus reducing the efficiency of the sorting stage. This is why a dry sieving stage is applied. It splits the material at a certain cutoff point of approx. 10 millimeters into a fine, fibrous fraction and a coarse “main” fraction that is larger than the cutoff point - but smaller than the maximum particle size coming from the fine shredding stage.

The fine fraction bypasses the process steps that are applied in the main fraction, especially optical sorting. As the fibrous fine fraction typically holds more water than the coarse fraction – which consists mainly of plastic and pieces of wood – it might be worth dewatering this fraction in a further compacting stage.

There are many machine concepts in the sieving sector. The machines best suited for typical recycled fiber rejects have turned out to be vibrating screens, especially flip-flop screens.

A double-decker sieve applies a second wire with a much coarser cutoff point, therefore creating 3 fractions. On top of the two fractions discussed above (fine fibrous fraction and coarse main fraction), a third, much coarser fraction is created with a cutoff point roughly the same size as the wire of the fine shredder. This oversize fraction is returned to the shredding stage. Thus, the sieving process also acts as protection for the boiler in case particles larger than the desired maximum size manage to pass through the fine shredding stage. This can always happen as plastic sheets tend to fold and wrinkle in the shredder and may expand again afterwards.

3.6. Sorting

Spectroscopic sorting is required to remove unwanted or even harmful components. For example, the chlorine content in the fuel mix sent to the boiler is very critical, chlorine causes corrosion. PVC is the major chlorine source in typical reject from recycled fiber lines and has to be removed to control the chlorine content.
The PVC can be removed efficiently by means of spectroscopic sorting. The reject flow is separated, distributed over an acceleration belt, and exposed to infrared light, typically with a wave length range of 1100 to 1700 nanometers. Every material/element sends back a unique signature when exposed to this source of light because the infrared light signal is bounced off or transmitted through objects.
High-speed sensors (spectrometers) read the signal returned from each object, thus the composition of every particle can be determined using a certain algorithm.
An ejection unit (high-speed valves and air jets) blows out the detected and unwanted components, such as PVC.

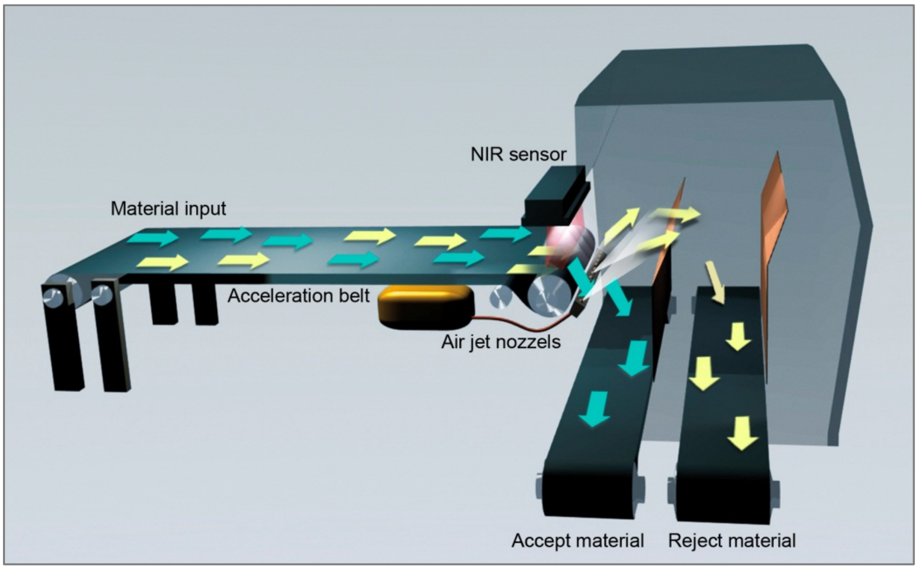

Figure 8 – Working principle of spectroscopic sorting

Such a sorting procedure can never be 100% efficient due to the fact that there are some composite materials. Also black and very dark colors cannot be detected satisfactorily.
The machine must be fine-tuned to find the optimum balance between meeting the minimum required PVC content in the accept fraction on the one hand, but keeping losses as low as possible on the other hand.
Thus, the "cleanness" of ejected material must be as high as possible. This is why the material going

to a sorting stage should have a uniform particle size. Sorting units are applied as the final treatment stage (after fine shredding and fine metal separation) and only before possible fuel storage or drying.

3.7. Auxiliary unit operations

The unit operations described above are applied in the "main line" of the reject system. They treat the major fraction to be used as a fuel or recycled.

Beside the process stages mentioned, there are a number of ancillary operations that are optional or treat ancillary material flows. These include

- sand separators for cleaner rejects or junk traps
- channel screens
- rag cutters to cut the pulper rags into reasonable lengths
- bale presses and wrappers to store or transport the treated rejects

4. Concepts of reject treatment lines

The basic concept of a reject treatment system is dependent on two major factors: firstly, the type and set-up of the recycled fiber line and of the pulping system in particular; secondly, the major targets and requirements of the processed reject materials, such as particle size or cleanness. These requirements are mainly determined by the final use: combustion (including type and requirements of the boiler), pelleting, gasification, or recycling to manufacture new products.

In principle, the same unit operations as described above are used for both drum and conventional pulping systems – only their sequence and detailed application may differ.

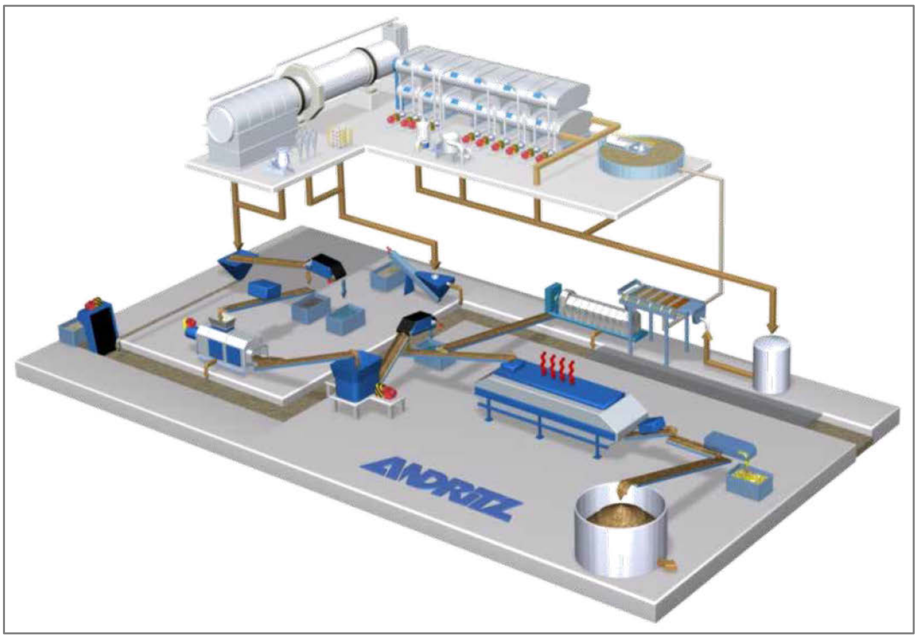

Figure 9 – Overview of reject system for recycled fiber line with drum pulping

The main difference between the concepts for drum and conventional pulping is the way in which the rag from the pulper is treated. Obviously, a rag has to be shredded in order to treat it further in subsequent unit operations.

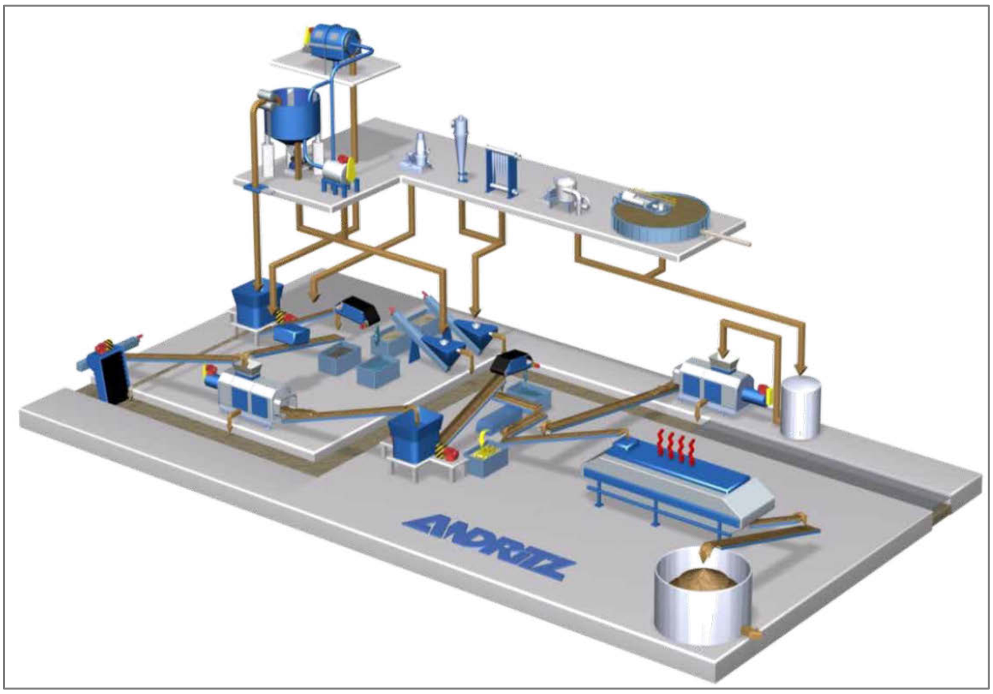

Figure 10 – Overview of reject system for recycled fiber line with conventional pulping

Possible major concepts are introduced in the following:

4.1. Full reject preparation for RDF – Stora Enso Ostrołęka, Poland

Stora Enso's investment at its Ostrołęka mill is timed perfectly as new collection and sorting infrastructures come into place to boost the recycling rate in Poland, which is still the lowest in the EU. ANDRITZ delivered a complete recycled fiber processing line for testliner and fluting– with a capacity of 1,665 t/d– and a unique reject treatment system.

Today, there are still nearly two million tons of valuable, recyclable raw materials going to landfill or waste every year in Poland, mainly due to the lack of an effective waste management infrastructure. This is all changing in 2013 as Poland is establishing a common waste tax to fund the infrastructure development needed to meet European standards. Even with the lack of an organized public system, companies like Stora Enso did not just stand by and watch as valuable materials were dumped into landfills, but created their own national network of 20 collection and sorting stations. Two of Stora Enso's major goals for this new line were to lower energy consumption and reduce the volume of waste going to landfill.

The rejects (120 t/d) from the RCF plant are also processed in a line delivered by ANDRITZ, helping to fuel the mill's new power boiler. The mill has the flexibility to mix fuels (biomass rejects or coal) in different proportions depending on market requirements. In many mills, the metals and plastics in rejects used to be discarded; now Stora Enso is utilizing this stream of additional revenue and exploiting this valuable energy source.

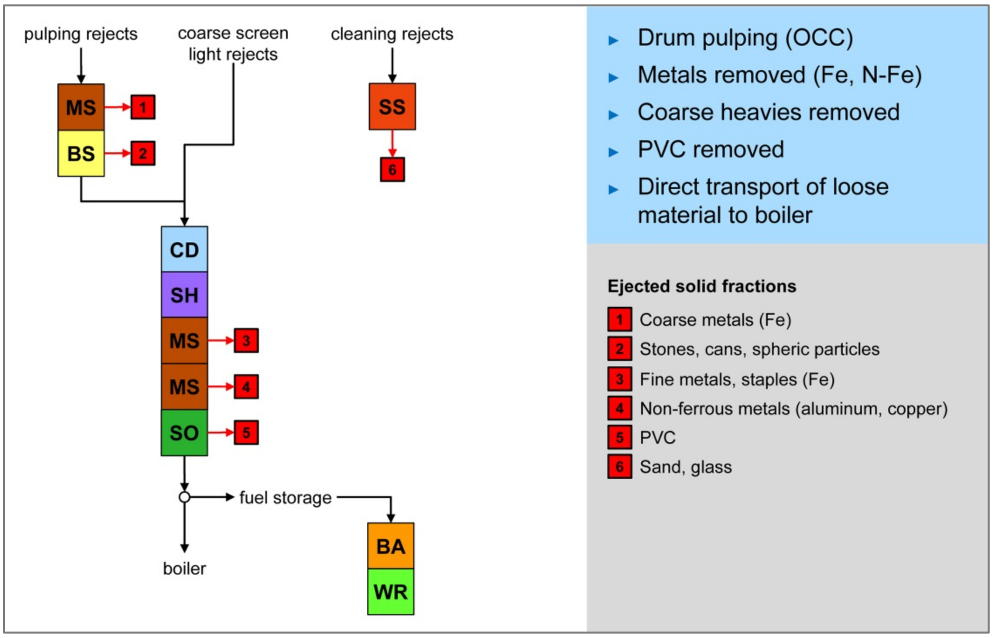

Figure 11 – Reject system for OCC line at Stora Enso in Ostrołęka, Poland

The pulping rejects from the ANDRITZ FibreFlow drum pulper first pass through a coarse metal separator and are then fed to a ballistic separator. These rejects – free of large metals pieces and stones – are then dewatered and compacted together with the light rejects from coarse screening. A fine shredding stage loosens the material up and reduces it to the particle size required by the boiler – as well as by the subsequent treatment stages. These are fine metal and non-ferrous metals separation, followed by a spectroscopic sorting system to control the PVC content. Finally, the prepared rejects can be fed to the boiler directly or can be baled and wrapped for storage or transportation.

4.2. Concept for RDF preparation including both pulping methods

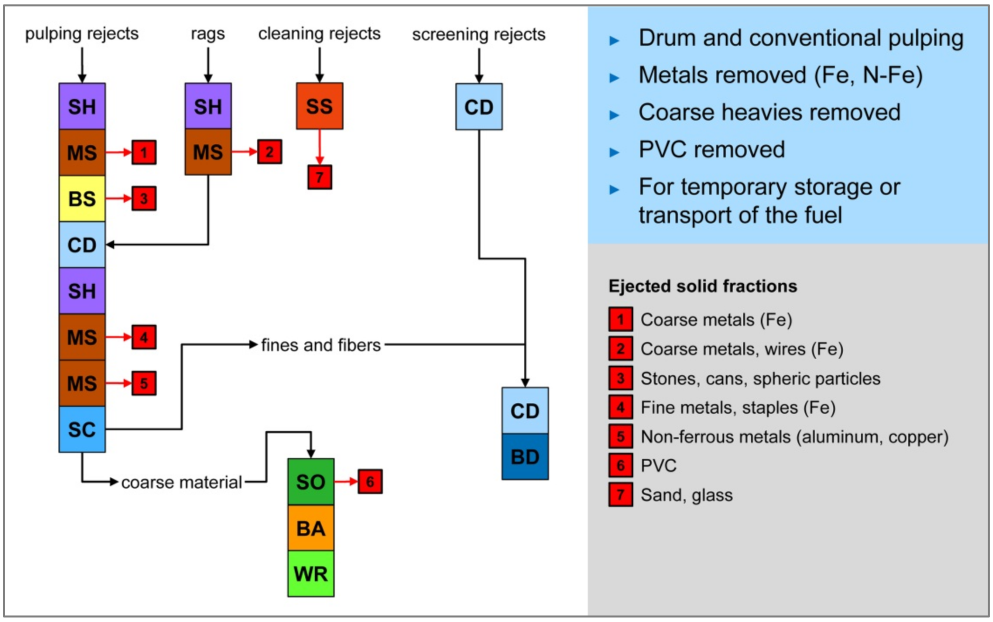

Figure 12 – Reject line for both drum and conventional pulping

As soon as a conventional pulping system is in operation, a shredder is needed for the rags. In many mills, both pulping methods are applied and thus, the mills need a reject treatment system that can handle rejects from both. In addition to the rag shredder, a coarse shredder is also recommended for the loose pulping rejects. This homogenizes the reject stream, reduces the size of very large particles and cuts the longish, rag-like components that can come from drum pulping – especially if there are too many wires entering the drum pulper.

A first separation stage removes large metal pieces and the bulk of the wires from the rag. After passing through an optional ballistic separator for the pulping rejects, both streams are then compacted and dewatered together. A fine shredder provides the required particle size for the subsequent sorting processes and for the boiler.

As an additional step, a sieving unit is recommended. Only the larger particles (larger than approx. 15 to 20 mm) reach the optical sorting stage. The smaller components – mainly fibers – are dewatered together with screening rejects and are finally bunkered.

4.3. Concept for reject treatment including waste from external sources

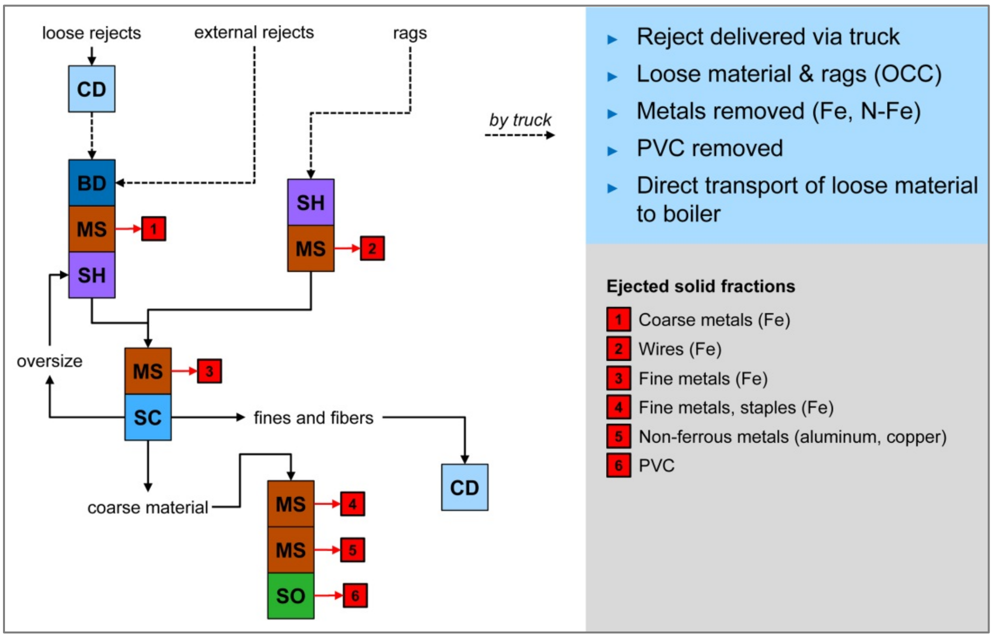

Figure 13 – Reject line for rejects delivered from external sources

In many cases, one mill location contains several lines. It makes sense to treat those rejects centrally in a single reject system – often with additional waste and rejects delivered from external sources. The internal logistics for those rejects is then a major concern; typically, the only way to bring all rejects to one central point is to bring them there by truck. The loose rejects from drum pulping or from wash drums in conventional pulping are often dewatered directly at their point of occurrence in order to minimize the (internal) transportation effort.

Unloading the trucks and feeding the material from internal and external sources in a homogenous and uniform way requires a proper bunkering and dosing system. It makes sense to store and treat loose material and rags separately. Coarse shredders and metal separation are again the first unit operations. A sieving stage splits the total stream into a coarse fraction, which is further treated in fine metal and non-ferrous metal separation followed by optical sorting, and a fine fraction mainly containing fibers that can be dewatered additionally.

5. Conclusions

Rejects from recycled fiber lines contain a high proportion of combustible materials, such as plastics and fibers. The landfill solution used in the past is no longer economically viable and actually prohibited in many locations by legal requirements.

It makes much more sense to recycle these materials to make refuse-derived fuels (RDF) for energy generation or treat them in order to obtain saleable, clean fractions that can be used in new products.

However, the exact configuration and design of any reject system is strongly dependent on the situation and circumstances on site. These include (existing) possibilities to convert these rejects into energy and the market prices that can be achieved with certain recycled fractions.

Besides these economic framework conditions, the setup of the recycled fiber line and, in particular, the method of pulping used – drum or conventional – have a considerable influence. There is no "one-type-fits-all" reject system; it must be developed together by user and supplier and tailored to the respective goals and requirements.

In addition to the unit operations and general concepts introduced above, the detailed engineering and layout of the plant are of great importance. While typical fiber lines mostly contain "closed" processes or machines, machines in the reject treatment sector – especially in the conveying system – are more likely to be "open" systems. This presents a greater challenge. While it is easy to pump a suspension of water and fibers or convey a dewatered fiber cake, rejects occur in a wide range of particle sizes at different densities. Hence, the layout, accessibility for cleaning, removal/change of containers, and maintenance is very important. Although some parameters, such as brightness or dirt specks, can be measured easily online in a fiber line, quality parameters of this kind cannot really be measured in the reject material because it is much less homogeneous.

It is important to consider all these aspects and ensure that the concept and design of the reject treatment system fit the given circumstances and targets of the owner or user. Then, a well-functioning, reliable, and flexible reject system will make a major contribution to the bottom line of any recycled fiber mill.

Table of figures used

Tables used