Optical Sorting for the Recovery of Glass from WIP Slags
– Pilot Plant in Bratislava –

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Today, the sensor-based detection and separation of recyclable materials is an important component of waste processing and the recovery of raw materials worldwide.

Cullet especially is an important secondary raw material and indispensable for economic and competitive hollow glass production. The more broken glass material is put into the melt, the less energy is required and fewer additives have to be used. Modern furnace designs and strict exhaust values are based on using up to eighty percent of glass fraction. With such a high proportion of glass content, the cullet quality should be appropriately high so that the melting chemistry is not adversely influenced and so as to avoid malfunctions or even hazards in the production process.

The rapid development of camera technology combined with sophisticated algorithms has revolutionised optical processing and facilitates ever more efficient and precise differentiation and sorting of diverse materials. Close cooperation between machine manufacturers, research establishments and users has paved the way for the adaptation of the sorting machines to the requirements of waste glass processing and new process technologies.

Binder+Co AG with its headquarters in Gleisdorf, Austria, has been focused on driving the development of sensor and camera technology for more than 25 years, particularly in the field of waste glass sorting. One example is the implementation of new, highly efficient UV-based technologies for sorting heat-resistant and lead-containing glasses. Today, there are efficient devices for the separation of contaminants such as ceramics, stone or porcelain (CSP) from the fine glass fraction from a grain size of one millimetre, and colour-sorting from three millimetres.

Depending on the type of source material – i.e. retrieved material from waste-disposal sites or residue from waste incineration plants – different collection systems, transport and storage, the raw glass fraction quality varies during the seasons and depending on the weather. For this reason, individually adjustable special software is used which includes summer and winter process settings and which has settings for the geographically and seasonally very different moisture content and degree of contamination of the waste glass specific to the process technology.

Some years ago, in addition to the latest optical sorting technology, operators of glass recycling plants started to focus increasingly on the preparation and conditioning of the input material in order to input the best possible cleaned and seasonally independent material into the sorting systems. This made it possible to again significantly improve the separating accuracy and efficiency. In addition, the cost of maintaining the entire process plant was reduced. This idea was implemented in the form of the so-called *cullet sublimation*, a special dry cleaning process for glass fraction. The process consists of a drying stage with fluid-bed drying, a label remover/attrition washer and subsequent de-dusting, cooling and classification. On the one hand this creates an ideal and compact pre-processing system for downstream sensor-based sorting and, on the other hand, optical sorting is not even possible without cullet sublimation – for example, in the separation of glass from combustion slag.

1. Pilot plant in Bratislava

In a Slovakian waste incineration plant, an electrical output of 6.3 megawatts is obtained from about 22 t/h of domestic waste. Up to now, the slag resulting from the thermal processing was used for sealing off waste-disposal sites.

Using the so-called *cullet sublimation* process in the glass recovery plant which was started up in January 2011, pure waste glass is being recovered from the low-value combustion residue and is being used as a high-quality secondary raw material in a Slovakian glassworks.

Plant concept for *cullet sublimation* and waste glass recovery from slag

In view of the fact that the waste glass component in the slag is heavily contaminated by the preceding waste incineration process, glass fraction has to be carefully prepared for the sensor-based sorting stage. Cullet sublimation – which has been specifically developed for this purpose – comprises the following process steps: classification of waste glass into two – or several – fractions, drying the glass and mechanical removal of any attached items by dry washing.

Currently, the combustion residue amounts to 8 t/h with a glass component of about twenty percent. In the first step following the removal of ferrous material, the raw slag is fed into the BIVITEC special screening machine. The top deck of the screening machine, which is fitted with a bar grid, is used to separate oversized non-glass materials, whereas the bottom deck separates 0/7 millimetre fine grain. The BIVITEC screening system is particularly efficient: the screenings are dynamically excited on the screen mats which thereby remain clear and allow efficient screening. Conventional screening machines would be hard pushed to cope with this process not only because slag is a difficult screening material, but also because of the high moisture content of 15% and the fine grain size of seven milllimetres.

The medium grain resulting from the classification process has a glass component of up to fifty percent and consists of the perfect grain size composition for further processing. In the next process step the moisture content of 15 percent is reduced to one percent.

In the next step, the material – which is heavily contaminated by dust and sticker remnants – is cleaned in a dry washing process. In the label remover, attrition of the material is achieved by paddles so that the glass fraction is largely cleaned of any sticker remnants and dust. Any fine grain under 7 millimetres generated is separated in the downstream screening and distribution conveyor channel.

Then the pure hard material is passed through the all-metal separator which is equipped with an overhead magnet and eddy-current separator in order to recover any ferrous or non-ferrous metal from the slag.

The final separation stage takes place in the CLARITY optical sorting machine. On a 1,400 millimetres wide sorting bed the glass fraction is separated from the clinker-type residue by positive sorting. In this way it is possible to recover 3 tonnes of waste glass per hour.

New plant concepts such as the recovery of glass from incineration slag is motivated by new legislation, limited waste disposal site capacities and the drive to make processing plants more cost-efficient.

2. The process in general

2.1. Cullet sublimation as basic pre-processing for sensor-based sorting of waste glass

The *cullet sublimation* process shown below is supplementary to the classic pre-processing of recycled waste glass and directly precedes the optical sorting process.

Before the material passes the *cullet sublimation* stage, large and bulky contaminants are separated in a handling station and whole bottles and large fractions are broken with a double-roll glass crusher. Finally, the damp crushed material runs through the drying process and, with its humidity reduced to a low residual level, it arrives at the label-remover where any labels and soiling attached to the glass fraction is removed by attrition. The downstream cooling and de-dusting channel cools the material and extracts any very fine dust with residual moisture content thus increasing the dryness of the glass fraction.

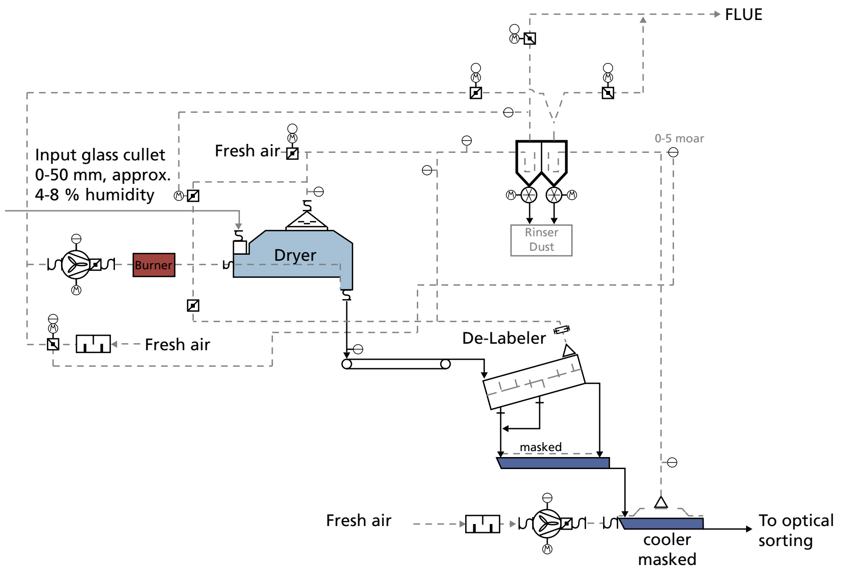

Figure 1: Flowchart of dry cleaning *sublimation* of waste glass fraction

2.1.1. Drying

In the first step, damp input material is dried to a residual humidity of 0.5 percent to one percent in a fluid-bed dryer as shown in Figure 2. The advantage of this technology is the gentle and low-wear transport of the material. This is important in order to counteract the breaking up of the glass fraction material.

Hot air streams from below through the base of the dryer and the material bed and in this way dries the glass fraction in an extremely energy-efficient manner. The vapour-saturated air is extracted via the dryer hood and is passed through a filter. Different versions of the drying base are available such as a cascade base for particularly contaminated input material or a laser-perforated or slotted base for fine material, which allow ideal processing of the respective input material. Onward transport and dwell time can be controlled by the drive – oscillation. The oscillation-based conveyor system has the additional advantage that, in the case of a plant standstill, the dryer can be run completely empty. The hot-air-based convection drying method makes it possible to use different heat sources. For example, it is possible to use waste heat or even the hot waste air from another process instead of a gas burner.

Fluid-bed drying ensures stable operating conditions and constant sliding and conveying properties, which is a prerequisite for successful optical sorting. The sortable range of input material is extended which makes it possible to sort even very small grain fractions. Owing to the low temperature – the material temperature is 70°C on average – this process is very energy-efficient and easy on the material. In spite of its abrasive properties, the glass is transported through the dryer in a gentle and low-wear fashion owing to the gentle oscillation-based conveying method and air flow.

Figure 2:

Fluid-bed dryer

2.1.2. Label remover/de-labeling machine

With its residual humidity, which can be adjusted in the drying process, the material is conveyed to the specially developed and patented attrition washer which is based on the principle of the classic log washer. A turning shaft with paddles mounted in a spiral arrangement is fitted in a slightly rising trough. The paddles dip into the material bed and convey the material towards the outlet opening. Through defined friction forces and movements within the glass fraction material, up to 80% of attached items and contaminants are gently removed and the sharpness of broken edges is blunted. As the conveyor spiral consists of individual paddles, individual glass fractions are constantly paired so that they grind against each other resulting in a type of polishing effect. By reducing the wrong information – which is caused by contamination – over-sorting – wrong discharge – of the sorters is minimised and the quality of the end-product is thereby increased. An important advantage of this dry cleaning process is that all attachments are removed without adding any water

Figure 3: Label remover

or solvents, using only mechanical energy. By comparison, other methods such as wet washing require a much greater use of energy and machinery. A dedicated washing water treatment system has to be connected and the glass fraction has to be drained and dried before it can be put through the optical sorting stage.

Figure 3 shows an example of an attrition washer/label remover or the so called De-labeling Machine.

2.1.3. Cooling and de-dusting vibratory feeder

Downstream of the attrition washing system the glass fraction is conveyed into a cooling and de-dusting channel, as shown in Figure 4. This vibratory feeder is similar to the design of the fluid-bed dryer in that the cushion of material is permeated by ambient air. Very fine dust produced during the attrition process in the label remover is extracted into the hood over the oscillating channel and the air is then cleaned in a filter system. This process step is important on the one hand to cool the material and thus to avoid any thermal wear on downstream equipment, such as the screening mats. On the other hand this aggregate reduces soiling of the downstream equipment and optical sorters through the removal of dust, which results in a reduced load on the sorters while product quality is increased and over-sorting is minimised. Depending on the residual moisture in the extracted air and the temperature, the air can be returned to the process after is leaves the filter; in some applications it is used for pre-warming fresh air for the burner.

Figure 4: Cooling and de-dusting vibratory feeder

2.2. Optical detection and pneumatic ejection of glass fraction as recycling material

The entire process in the slag processing plant in Bratislava includes the automatic separation of ferromagnetic metal with the help of overhead magnets installed in various positions and an eddy-current separator for non-ferrous metal as well as an optoelectronic sorting stage, which is the heart of the plant.

Figure 5: Sensor-based separator for glass fraction with feed system; installation in Bratislava

With the help of the sensor-based separation system free glass fraction, which has been made detectable in the *cullet sublimation* system, is detected and ejected via a compressed air jet. Opaque material such as inert incineration residue with a crystalline structure, which has no significant glass-type transparency in a visible wavelength range, is conveyed into the through-path of the separator without deviation. In addition, sorting programmes that have been developed for a wide range of different conditions and final product qualities are included in the machine control system and can be opened and activated at any time.

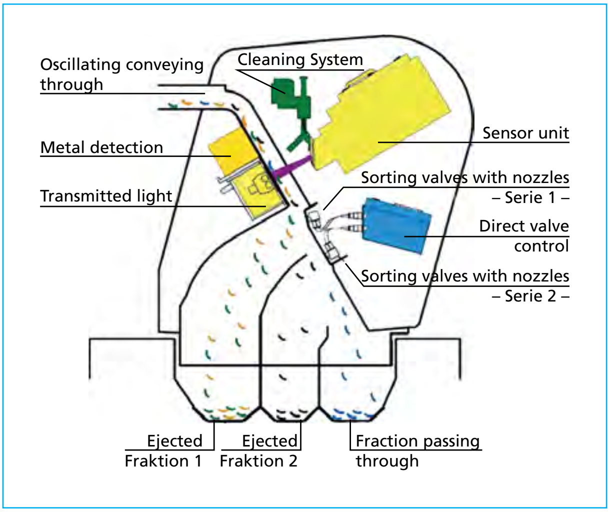

Figure 6:

Principle of sensor-based separation; the example here shows a three-stream process

3. Positive aspects of *sublimation* for optical sorting

The cleaning efficiency of *sublimation* is illustrated in Figure 5. On the left-hand side one can see the damp, contaminated input material and on the right-hand side the glass fraction material after specific pre-conditioning. The clearly improved transport characteristics of the glass fraction and its clean surface significantly improve the selectivity of optical sorters based on grain size. In addition, the manual servicing and cleaning work of systems with an integrated *sublimation process* is significantly reduced.

Practical experience has shown that, in the special case of slag processing, any attached inert residual matter is released with the help of the cullet sublimation system. In waste processing plants these systems are used to dislodge organic residues such as sugar, oil and plant fat from the glass fraction and discharge it via the exhaust air from the dryer. Clean glass fraction product which is suitable for an effective melting process free from malfunction can only be achieved after detaching and removing any attached contaminants.

Figure 7: Cleaning effect of glass fractions from WIP slag

Figure 8 shows the results of samples with respect to grain distribution with and without *cullet sublimation*. The blue curve shows the grain distribution of a typical glass fraction without pre-processing. Owing to the poor transport characteristics and extensive surface soiling, the lower limit of the efficiently sortable range is about nine millimetres. The red curve indicates that on average the total fraction is slightly reduced in size due to the mechanical processing. However, the dry cleaning process also increases the proportion of sortable fine fraction, because the lower sorting limit for this type of conditioned glass fraction is less than five millimetres. This means that it is possible to sort about seven percent to eight percent more glass fraction material.

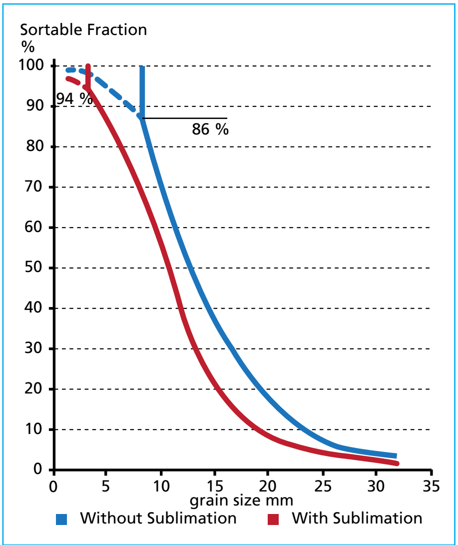

Figure 8: Increase in the range of sortable grain size

It is the attrition washer/label remover in particular which helps to detach any attached slag residue, dirt particles and labels from the glass fraction. Figure 9 shows the composition of the glass fraction material before and after passing through the label remover. The cyan-coloured bars represent the respective weight proportion of the input material in the three material classes *glass/full paper*, *glass/part paper* and *paper loose*. The violet bars represent the distribution after the process. In these examples, the attached *paper* is taken to represent all residue attached to glass fraction from incineration slag.

The diagram clearly shows the extensive amount of labels or contamination coating detached in the process. The proportion of *glass/full paper* is reduced by up to eighty percent The detached coatings increased the proportion of *paper loose*, which can easily be separated in the downstream sorting process. In the case discussed here, the material to be removed by separation is dust, i.e. the process involves the discharge of mineral dust.

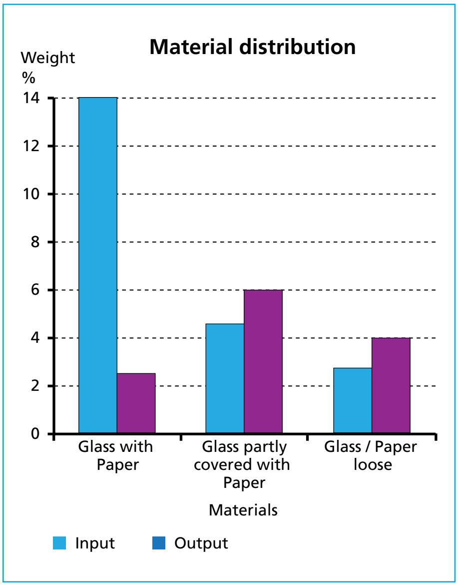

Figure 9: Efficiency of label detachment and general example of the detachment of unwanted coatings (slag residue) from glass fraction

New evaluation algorithms allow the reliable identification of objects in the *glass/part paper* material class or, put another way, of partially covered fraction material as *clean* glass fractions.

With the help of the *sublimation* process in combination with state-of-the-art sensor-based sorting technology, it is possible to substantially reduce the formerly large proportion of glass in the waste material which in turn results in greater glass fraction quantities and reduced disposal costs. In addition, the more accurate selectivity leads to a medium increase in the finished cullet quality.

The implementation of *cullet sublimation* increases investment and running costs. At current energy prices, these are between three and five EUR per tonne. There are also increased purchase costs; however, these are compensated for by the positive aspects of the *sublimation process* mentioned above, which results in a reduced number of sorters and cost savings in other aggregates and plant components. The reduced number of sorting machines required results from the pre-conditioning of the glass fraction and an improvement in the selectivity. The improved material properties provide the manufacturer with more options for glass processing methods so that individual requirements can be met.

4. Summary and outlook

The above-described sensor-based sorting in combination with *collet sublimation* has now become an established element in the processing of waste glass. By using this system it is now possible, for the first time, to separate glass material from slag residue and to recover it as a secondary raw material. Thermal drying, dry washing and de-dusting are not only energy-efficient processes but also prepare the glass fraction extremely well for the subsequent sorting process, thus leading to more ejected final product and a significant increase in its quality.

The investment cost for *sublimation* is compensated for by the smaller number of sorters as well as savings in aggregates and plant components. The amount of maintenance and number of standstill periods is reduced. Additional investment and energy costs for *cullet sublimation* are compensated for by more stable operating conditions and better product quality and quantity and – above all – by the recovery of valuable glass raw material as well as the reduction in the amount of waste to go to waste disposal sites.

Furthermore, the use of dry cleaning generally extends the areas in which optical sorting can be used, an example being the efficient treatment of slag from waste incineration plants described above. In addition to the recovery of ferrous and other metals, it is possible to recover up to 3 tonnes of glass per hour – that represents ninety percent of the glass content – which can be sold off to glass producers as a high-quality raw material.

Alternative concepts for waste incineration plants involve thermal recycling of the fraction larger than thirty millimetres whereas the fraction is smaller than ten millimetres is channelled to biogas plants. The ten to thirty millimetres fraction is primarily discharged to waste disposal sites. If inert material such as glass or stone is separated from organic material before disposal, the quantity of material to be put into landfill is reduced and the disposal cost is reduced by two thirds. Initial analyses have shown that the proportion of glass is up to seventy percent. Trials with drying, attrition, light material discharge and subsequent optical sorting have produced promising results. Up to 73 percent of glass with a purity of 98 percent could be recovered from the sortable fraction.

The pre-processing could also play an important role in urban mining (landfill mining). Initial mining trials at various waste disposal sites have shown that the recycling material is often in very good condition, albeit very damp and soiled. If it is intended to use optical sorters to separate and recover these different materials, it is at least necessary to install a drying process – if not the complete cullet sublimation – before passing the material through the sensor-based sorting process. Initial trials using optical preparation of material from landfill sites are already underway as part of feasibility studies.

Raw materials are becoming increasingly scarce, the price of resources keeps rising and waste disposal sites should be avoided; it is therefore imperative that the preparation of residual and secondary raw materials be economically viable, something that is a prerequisite for making the use of these materials possible.