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# Non-parametric analysis of infrared spectra for recognition of glass and glass ceramic fragments in recycling plants

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**Abstract**

Glass ceramic detection in glass recycling plants represents a still unsolved problem, as glass ceramic material looks like normal glass and is usually detected only by specialized personnel. The presence of glass-like contaminants inside waste glass products, resulting from both industrial and differentiated urban waste collection, increases process production costs and reduces final product quality. In this paper an innovative approach for glass ceramic recognition, based on the non-parametric analysis of infrared spectra, is proposed and investigated. The work was specifically addressed to the spectral classification of glass and glass ceramic fragments collected in an actual recycling plant from three different production lines: flat glass, colored container-glass and white container-glass. The analyses, carried out in the near and mid-infrared (NIR–MIR) spectral field (1280–4480 nm), show that glass ceramic and glass fragments can be recognized by applying a wavelet transform, with a small classification error. Moreover, a method for selecting only a small subset of relevant wavelength ratios is suggested, allowing the conduct of a fast recognition of the two classes of materials. The results show how the proposed approach can be utilized to develop a classification engine to be integrated inside a hardware and software sorting architecture for fast "*on-line*" ceramic glass recognition and separation.


## 1. Introduction

In the glass recycling sector, the presence of glass ceramic fragments mixed with glass resulting from waste collection, can negatively affect the production process and the overall quality of the final recycled product. Glass ceramics are characterized by a melting point higher than that of glass and cannot melt during the furnace cycle (Pannhorst, 1997). As a consequence, the furnace and other glass producing machines can be damaged and the final products (bottles, jars, etc.) can break during the manufacturing or handling process or can show some defects (Fig. 1). Such a problem dramatically increased in these last years due to the introduction on the market of large quantities of glass ceramic manufactured goods, characterized by high thermal-shock resistant properties, such as dishware, cookware, stove tops, and cooking surfaces for electric and gas stoves (Höland and Beall, 2002). According to market demand, glass ceramics are nowadays not only opaque white colored, but also transparent, being practically undistinguishable from common glass, both for human senses and for the sorting devices usually utilized in recycling plants.

It is well known that glass collected from both domestic and commercial waste is accompanied by several polluting materials, such as plastic, metal, paper and wood, as well as the previously mentioned glass ceramic or glass-like contaminants. While good strategies have been developed in the last years for removal of several contaminants using automatic on-line sorting systems, no really effective or low cost solution has been found until now for the recognition of glass ceramic fragments inside a glass waste stream for recycling. Glass recyclers are strongly interested in solving such a problem, being one of the major causes of economic loss.

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Fig. 1. Example of glass bottles showing defects due to the presence of glass-like contaminants.

The only two currently pursued strategies, at the industrial scale, to reduce the presence of glass ceramic contaminants are "reduction at source" and "manual sorting", the approaches both gave scarce results. The "reduction at source" is strongly conditioned by the fact that citizens, in spite of public education programmes, confuse glass ceramic with glass. "Manual sorting" is usually based on the utilization of trained operators that, looking carefully at the waste stream, try to identify glass ceramic fragments. Such an approach is clearly expensive and not reliable. One of the parameters usually adopted in human-based recognition is related to the reflectance characteristics of fragments; such a property can be estimated in different ways according to human expert knowledge, his level of attention and environmental conditions.

The possibility of recognizing glass and glass ceramic fragments by spectroscopic techniques, both in the visible and infrared field, has been preliminary investigated previously (Bonifazi and Serranti, 2006; Serranti et al., 2006). In those studies the attention was addressed to the evaluation of the spectral response of glass ceramic fragments in respect to their surface characteristics, color and polluting elements and to the comparison of spectral signature of glass fragments (cullet) characterized by a similar set of attributes. Results showed that a hyperspectral approach in the visible and near infrared (VIS–NIR) field could allow recognition of the different products especially in the near infrared field (Bonifazi and Serranti, 2006). According to these results, systematic investigations have been thus carried out in the mid-infrared field (MIR) also. The results demonstrated a higher sensitivity of the approach in this spectral range, thus allowing achievement of a better distinction between glass and glass ceramic pieces (Serranti et al., 2006). In both cases the classification was realized by selecting specific wavelengths and adopting a "*band ratio approach*" to perform the requested identification.

In this study, the attention has been focused on the application of statistical classifiers for recognizing the near mid-infrared spectral signatures of the two materials, in order to achieve the best percentage of recognition. The use of non-parametric analysis of infrared spectra can be in fact adopted in the development of an integrated hardware and software architecture for "*on-line*" recognition and sorting of glass ceramic contaminants.

## 2. Materials and methods

### 2.1. Glass and glass ceramic samples

Glass and glass ceramic samples have been collected inside the Bernhard Reiling Glas GmbH recycling plant, located in Marienfeld (Germany).

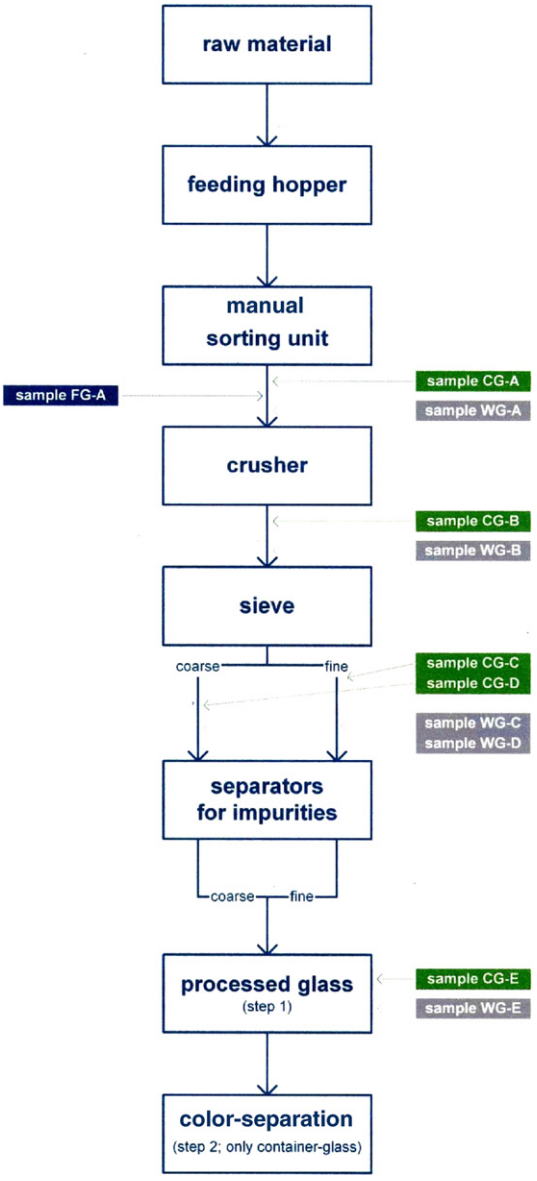


Fig. 2. Flow-sheet of Bernhard Reiling Glas GmbH recycling plant (Marienfeld, Germany) with location of glass sample collection points.