I.D. Mironescu, et all. Journal of Agroalimentary Processes and Technologies, Volume XII, No. 1 (2006), 7-12
Full Paper - Food Technologies and Processing Section

IMAGE ANALYSIS FOR CRYSTALLIZATION PROCESS CONTROL

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Abstract

The paper investigates the possibility to estimate the crystal size distribution of a massecuite sample through the analysis of images taken from it. The fractal character of these images and possible correlations with size distribution characteristics that can be used for this estimation are presented.
***Keywords**: fractal dimension, crystal size distribution, sugar crystallization*

Introduction

The crystal size distribution is an important parameter in the sugar industry, for technology, but also for the product quality. Technologically, this parameter influences significantly operations like centrifugation, afination and storage. Rheological properties, floatability, solubility, lump formation and hygroscopic behaviour are related to the size and implicit to the size distribution of crystals.

The crystallisation process is determinant for the crystals size distribution. The main influencing factors are seed quality, supersaturation field distribution and secondary nucleation. Image analysis for crystal size distribution was first used in 1976. At that time, the measurement was performed off-line because the samples necessitated special preparation. In short time the disadvantages (high cost and off-line operation) were surpassed by the rich information provided about the crystallisation process. In the last years, the LUCIA system was successful tested for on-line analysis (Bubnik et al., 2000) (Hinkova, 2003). The method is going to be standardized despite the differences to the classical sieving methods. Meanwhile the image analysis methods are diversifying (O'Donell 2003).

This paper proposes the use of fractal analysis. The great variety of crystal forms that appear in impure solutions gives to the whole ensemble a irregular aspect that justify the investigation of his fractal character. For such irregular structures Logan (1995) has found that the slope of the distribution curve (particle number as function of particle length) in log-log representation corresponds with their fractal dimension.

Experimental

Images taken from massecuites with controlled crystal size by amount and dimension of sugar seed were used (Verhaart,et al. 1967).

The size distribution characteristics — Mean Aperture (MA) and Coefficient of Variation (CV) — for the processed images were determined by classical wet sieving and are summarized in Table 1.

For each sample a normal distribution of sizes was assumed and the corresponding cumulative distribution was constructed. The slopes of the distributions in log-log representation are also summarized in table 1.

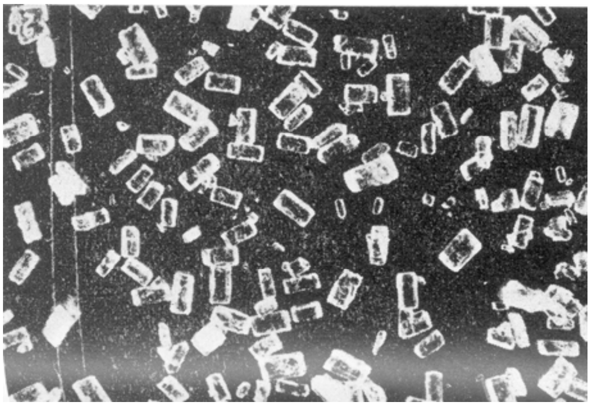
Table 1. Characteristics of the size distribution of samples

Sample	1	2	3	4	5	6	7	8
MA	0.52	1.04	0.5	0.86	0.83	1.15	0.9	0.95
CV	0.4	0.279	0.4	0.262	0.3	0.3	0.29	0.29
Slope	4.1604	5.8647	4.082	6.3321	5.5608	5.4931	5.6538	5.7035
Sample	9	10	11	12	13	14	15	16
MA	0.62	0.94	0.88	0.84	0.86	0.96	1.06	1.1
CV	0.27	0.27	0.262	0.215	0.256	0.219	0.235	0.182
Slope	6.2188	6.1118	6.2557	7.6361	6.3988	7.4824	7.2237	9.0063
Sample	17	18	19	20	21	22		
MA	0.9	1.08	0.86	0.98	0.98	0.94		
CV	0.222	0.227	0.2	0.17	0.21	0.197		
Slope	7.5926	7.3021	8.2518	9.8768	7.9313	8.4552		

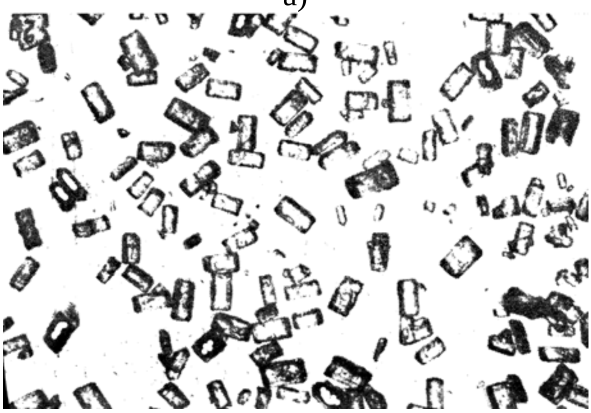
The source images were scanned at 600 dpi as greyscale image and stored as uncompressed PNG file. The file was processed with GIMP in order to obtain the image suitable for the fractal analysis.

By using the threshold tool only the pixels with grey levels corresponding to the crystal border where selected and transformed in black pixels. This manipulation also separated the noise introduced by the typographical reproduction and the scanning process. A similar use of the threshold tool for fractal analysis is reported in (Vessel et al 2002).

An example of an original and transformed image is presented in figure 1. The fractal dimension of the transformed image was determined by using a box counting method (Falconer, 1990). The image was partitioned in rectangular areas (boxes) by using a grid with a constant spacing in both directions. The number of box containing crystal borders (black pixels) where counted. The grid spacing was then reduced (increasing the number of boxes that cover the image) and the boxes recounted. The process was continued until a spacing of 1 pixel was achieved. The fractal dimension was determined as the slope of the log-log plot of the number of boxes containing the borders as function of the inverse of grid spacing).



a)



b)

Fig. 1. Image manipulation: a) scanned original b) after applying the threshold tool

A Matlab function was written to perform this task. The function takes the name of the black and white image as argument and returns the computed fractal dimension.

Results and Discussions

The resulted set of fractal dimension for the investigated images was compared with the characteristic measures of the crystal size distribution in order to find correlations between them. The best correlation (R^2 = 0.8004 for the regression line) was found between the fractal dimension and the cubic root of the slope of the cumulative distribution of crystals (Figure 2).

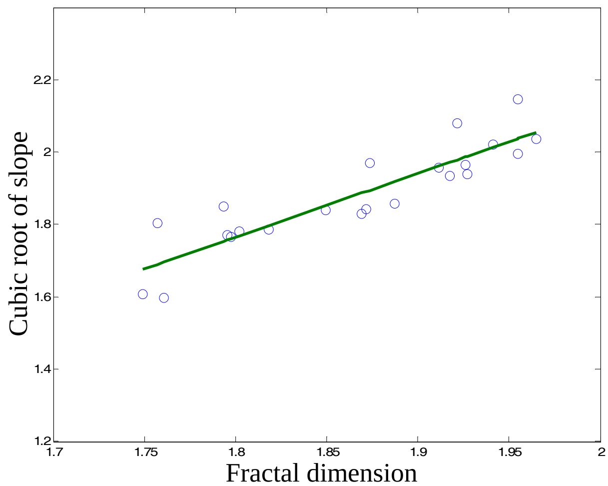


Fig. 2. Correlation between the fractal dimension and the cubic root of the slope of the cumulative distribution

This is consistent with the correlation described by Logan (1995), taking account that in the present case the cumulative distribution is a mass distribution (proportional to volume and to L^3).

As expected, a relative good correlation (R^2 = 0.7595 for the regression line) exists also between the fractal dimension and the variation coefficient (Figure 3). This indicates that the fractal dimension of the image can be used to appreciate the uniformity of crystal size distribution.

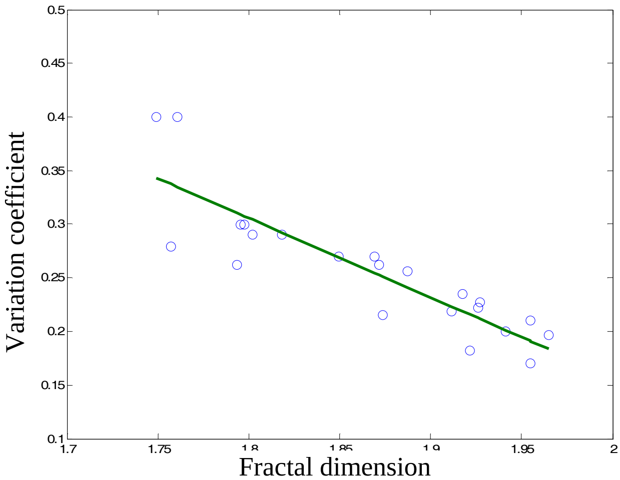


Fig. 3. Correlation between the fractal dimension and the variation coefficient

As observed in Figure 4, the other characteristic of the size distribution, MA, don't correlate (R^2 = 0.19 for the regression line) with the fractal dimension, so that no information about the size of crystals can be derived from the later.

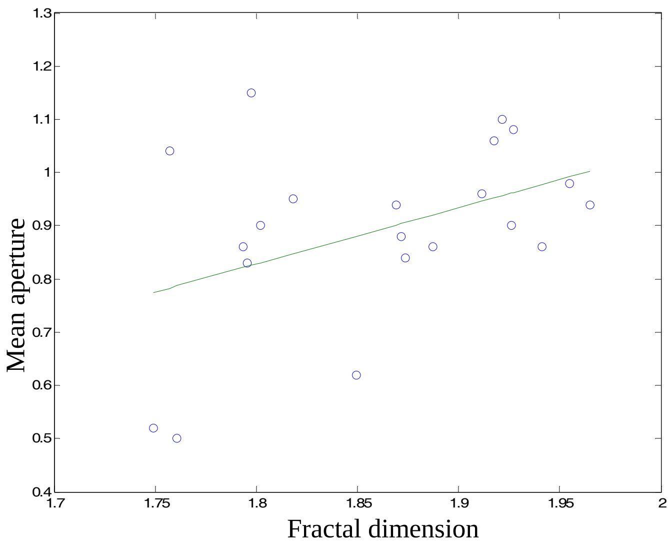


Fig. 4. Correlation between the fractal dimension and the mean distribution

Further investigation are needed to clarify the weaker correlation observed at both ends of the distributions spectrum (small and big CV) and to investigate the influence of (more sophisticated) image processing on the image fractal dimension.

Conclusions

The analysis of images taken from massecuite samples has revealed the fractal character of the crystal ensemble and the correlation between their fractal dimension and their size distribution. A method for crystal size distribution estimation based on this correlation is best suited for the control of crystallisation process.

Like other methods based on image analysis, it is fast and avoids the labour and time intensive classical sieving so that it can be used to provide (quasi) on-line feedback.

The method uses an easy to determine global characteristic of the ensemble (fractal dimension) - to determine another global characteristics of the ensemble. By doing that, the complex shape and pattern recognition algorithms, used by the other methods to extract local characteristics of the crystals from which to derive the global characteristic can be avoided.

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