“Characterization of scuffing on returnable bottles”

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According to the European wish (directive 94/62/CE) to encourage the reuse of glass containers, an ever increasing percentage of glass bottles are returnable on the North European market. In other words, the bottler takes increasing responsibility for bottles after use. The bottler therefore deals with the washing of bottles, filling them, labelling them and storing them. The bottles are then put back into the distribution circuit for a new cycle of use.

Since the glass which forms the bottles is a brittle material, its potentially very high mechanical resistance is weakened by the presence of defects, which seldom occur in the mass of the glass but are frequently found on its surface. It is therefore of prime importance to protect or strengthen the surface of the glass with one or more films composed of metal oxides or organic molecules. Nevertheless, despite the presence of such treatments, the surface of bottles becomes scuffed after multiple use. As a result of bottle handling and washing operations, whitish surface marks appear. They are mainly present at the different friction points of bottles when they knock against each other, on conveyor belts for example. The term "scuffing" is given to those marks in the jargon of glass-makers and bottlers. They alter not only the mechanical resistance of the glass but especially its transparency and its visual attractiveness.

This article aims at developing a measuring method and apparatus to quantify scuffing. The interest of such a method is based on the following advantages:

- the possibility of defining a tolerable scuffing threshold,
- having a means to determine the rate of scuffing generated by a bottling line,
- being able to adjust and control the effectiveness of new means aimed at fighting the phenomenon of scuffing.

In order to approach this study, a prior analysis concerning the problem and the source of scuffing was made on the basis of bibliographical information. Next, a critical examination of the methods potentially usable to quantify scuffing led to the selection of a measuring principle used for the design of the prototype. First experiments were carried out to validate the apparatus.

METHOD CHOSEN AND DEVELOPMENT OF THE APPARATUS

It is admitted by experts on the subject that the generation of scuffing is caused by the combination of damage of a chemical and mechanical kind arising on the surface of the glass. Scuffing is not a physical scale of size. Outward signs characterising it therefore have to be identified and the means found to measure those signs. Several techniques may be considered to quantify a deterioration of the surface condition of glass such as scuffing: visual evaluation, measurement of the loss of weight, of roughness, transmission or diffuse reflection. All these methods have advantages and disadvantages which have been examined. It seemed to us that diffuse reflection method best met the constraints of the apparatus to be designed; in other words, it enables a direct, accurate and fast measurement of scuffing regardless of the influence of external parameters.

The basic principle of the instrument developed by the InV, the "scuffmeter", consists of sending a source of light onto the side wall of the bottle using an emitter-sensor cell. The direction of the ray of light is different from the normal so as to be able to differentiate normal reflection and reflection due to the surface defects of the analysed bottle. The information received on the cell is sent to a programmable automatic device and processed by software programs to build up the cartography of the surface condition of bottles. That information is converted into rates of scuffing, which correspond to the ratio of the number of positive responses (= number of defects or scuffs) over the total number of measurements taken.

The selected sensor is an inexpensive, single, digital, photoelectric sensor operating in the “all or nothing” mode in relation to an adjustable threshold of light reflected by diffusion. The sensor is included in a cell where the emitter is also located (light beam of a constant diameter). The cell driven by a stepping motor moves along a vertical axis. The bottle is held through an AGR (American Glass Research, Inc.) type grapping device, that can be manually adjusted and an automatic device operates its rotation. The measurement is taken initially at the bottom of the bottle over the whole circumference and the cell rises by one vertical step after each revolution. Binary type data (defect or no defect) are captured as far as the shoulder of the bottle.

EVOLUTION OF THE PROJECT AND RESULTS

- ***Evolution of the project***

The path followed to develop the final prototype firstly involved the setting up of a pre-prototype to allow the conception of the different device’s subparts and to choose the appropriate measurement method. The final prototype would then result from refining the formerly defined parameters. The conception of the measuring device developed as follows :

a) definition of the required characteristics and outline of the technical choices. The pre-prototype is made of :
- a photoelectric cell with focused beam and digital captor working on a 100%-0% mode. The source is a red LED (632 nm) ;
- a vacuum pump to hold the bottle ;
- 2 engines
- a PC-monitored automat to perform the measurement cycles.

b) the comprehensive drawings, electrical sketches and execution drawings of the manufactured items.
c) the assembly and setting up of the device by means of measurements on calibrated samples, the programming of the survey automatisms when necessary, and the study of the parameters which have a potential influence on the scuffing measurement.

After several tests on the pre-prototype, it was possible to make a constructive balance for the acquisition cell and the technique from the beginning of the project. The first cell has been validated with some success : it is simple to work with and gives fully satisfactory and useful reproducible results.

The « 100%-0% » acquisition cell shows intrinsically several problems :

- The angular and distance positioning is difficult to optimize and does not rest a priori on any physical law.
- The sensitivity of the captor is adjustable, but this fitting cannot be repeated easily for lack of means allowing to control the gain of the integrated amplificator.
- The measured parameter is subjective : it does not quantify on an absolute scale the scuffing and strongly depends of the angular and distance cell positioning.

However, this cell is fully sufficient to perform comparative measurements against bottles which are slightly or not at all scuffed. The basis of the scuffing measurement remains the measurement of the diffuse reflection : this phenomenon results from the surface deterioration due to the scuffing and remains therefore unavoidable. The disposal of the bottles being essentially based on aesthetic criteria, it appears fully appropriate to use this kind of method, which is more accurate than the visual inspection, in order to select the bottles to hold or dispose.

Two major changes have been brought to the pre-prototype in order to correct the small inconveniences encountered :

- the aspiration system using a vacuum pump shows two problems : firstly the noise level is very high, then the pump heats up significantly. The fixing mechanism of the bottle has thus been replaced by a mechanical preemption system of the AGR type which is less noisy and more reliable for the bottle centering ;

- the necessity to have an accurate cell positioning against the bottle : this led to installing an accurate measurement system of not only the positioning but also the slope angle.

- ***Intermediate results***

Several preliminary tests have been performed to check the validity of the choices made at scuffmeter pre-prototype design stage.
Two sets of samples having undergone 0, 5, 10, 15 and 20 standard wearing out cycles have been analyzed. Three identical zones have been tested on each bottle : at 15 mm (above the table), 50 mm and 90 mm (under the elbow) height.

Although these tests have been performed on a limited number of samples, they are encouraging and tend to confirm the validity of the technical choices. Indeed :

A neat distinction can be made between measurements corresponding to different numbers of wearing out cycles.

- The scatter of the results is low (low σ).
- The scuffing level becomes important after 10 cycles (which corroborates the visual inspection results).
- The noise level reflecting the influence of other defects than scuffing (for 0 wearing out cycle) is rather weak.

The scuffing is essentially found in the zones of preferential contact.

Parameter influence

The parameters which could influence the scuffing measurement are of three types :

- the parameters related to the bottle : measurement zone, glass colour, pre-existing defects, humidity and cleanliness of the bottles ;
- the parameters related to the equipment : angle and distance of captor toward the target, sensitivity, synchronization between automate and computer, rotation speed imposed by the automate ;
- the parameters related to the laboratory: humidity and ambient light.

The wetness of the bottles may mask the scuffing zones. Dirt substances can also create significant perturbations and invalidate the results. On the contrary, ambient conditions such as enlighting and relative humidity do not seem to have a significant influence on the results.

The colour of the bottle can also influence the measurement. The brown glass bottles show no problem but parasite reflections are observed on colourless bottles. The results obtained by scuffing measurements on a colourless Spadel 20 cl bottle (standard n°6 of the Spadel set) when the bottle is filled with a dark liquid or with distilled water show it clearly. The number of scuffs and the measured scuffing rate when the bottle is filled with distilled water are 4 times higher than with a dark liquid. This result shows the existence of parasite reflections which are registered by the cell when the bottle is full of water (or another colourless liquid).

- ***Final results***

Comparison of pre-prototype and prototype

The used samples make the two sets which will serve as reference standards and are made of type APO 25 cl brown bottles and Spadel 20 cl colourless bottles.

The scuffing rate of the ten bottles of each set has been measured with the systems installed on both the pre-prototype and the prototype. The only significant differences between both systems are the distance, the slightly different inclination angles and the bottle stabilization.

Figures 1a and 1b show the measurement differences between the two systems for both sets of bottles. The obtained values for the two sets are very similar. Slight differences are observed for some bottles which could be put down to better centering and slight positioning and angle differences of the photoelectric cell. Furthermore, the values put on the graphics for the pre-prototype are averages of three measurements while for the prototype one verification measurement was performed. One may conclude that the results are identical with both systems.

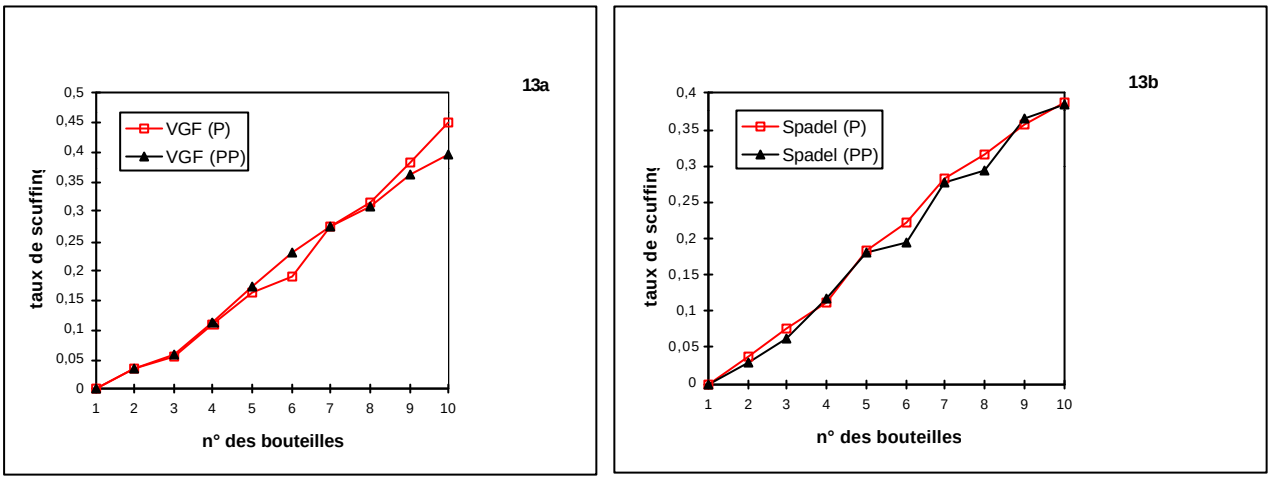

Figure 1 : Comparison of the scuffing rate values as measured with the pre-prototype (PP) and the prototype (P).

The maximum error is less than 5%, which is fully compatible with a good reproducibility.

Shaping of the results

The measurement of the scuffing requires choosing an objective method giving the most appropriate representation of the scuffing state of a bottle. Whatever the point of view on the scuffing, it is first of all related to the glass surface. Thus the method of representation must be based on the *aspect of the surface*.

The technique of discrete numeric data acquisition which represents the state of scuffing for each point of measurement provides a set of data which has to be reduced to an esay-to-use information : the experience proved that it is enough to take a unique numeric value to characterize the scuffing of the bottle. This unique value has the advantage to be an easy information, objective and conform to the recommended methods in the ISO 5725 standard.

In the case of the numeric cell (all or nothing), the data issued from the measurement are binary : a result equal to zero represents a zone without scuffing, a result equal to one represents a scuffed zone.

Thus, it was chosen to represent the ratio between the totality of the local scuffing to the measured surface. This ratio is considered as the **rate of scuffing**.

This choice has the advantage of reducing the result of the measurement to a rational number indicating the percentage of the measured surface which is scuffed.

Mechanical resistance of scuffed bottles

As the literature does not offer any information on the subject, series of tests have been carried on. The samples which were used to characterize the mechanical resistance of the scuffed bottles are described in French report version. The maximum rate of scuffing for the set of 94 bottles reaches 12% (fig. 2). No scuffing is observed on new bottles; they can stand the

test of internal pressure fixed at 40psi (pound per square inch) and considered as maximal. When the bottles are simply knocked toeach other, the resistance stays maximal. On the contrary, when the bottles are scratched, their resistance to internal pressure goes down drastically and tends to 26 to 37 psi.

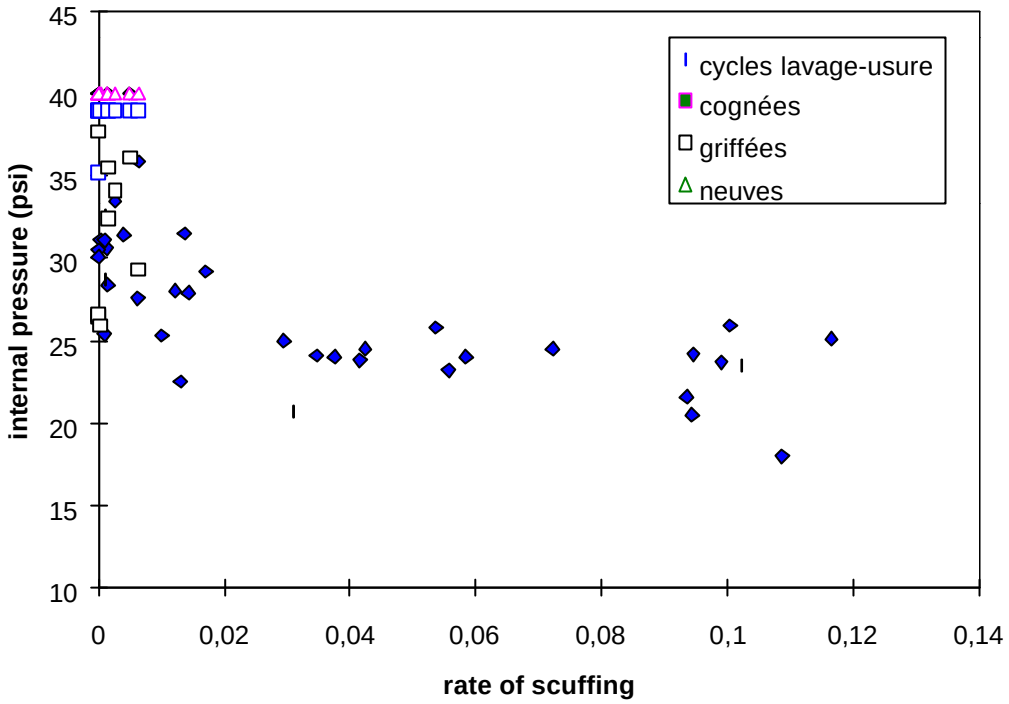

Figure 2 : Internal Pressure resistance of VGF bottles

One can conclude that surface treatments of the returnable bottles are very good protectors of the glass surface and of the packaging. The mere scratch of surface treatment destruction makes the bottle weaker and lessens drastically its resistance to internal pressure, which can cause heavy damages in the bottling lines. This mere scratch is the starting point of the scuffing phenomenon because it allows the washing solutions to reach the glass surface which is then not protected any more.

Constitution of two sets of standard bottles (non coloured glass, brown glass)

Figure 3 shows the range of scuffing rate for the VGF and Spadel bottles. The plot shows a regular dispersion of scuffing rate between 0 and 40%, which corresponds to a very scuffed zone. This range of standards will permit to define a limitation of the scuffing rate in accordance with the economic partners.

This kind of sampling will be easy to reproduce for any new type of bottle.

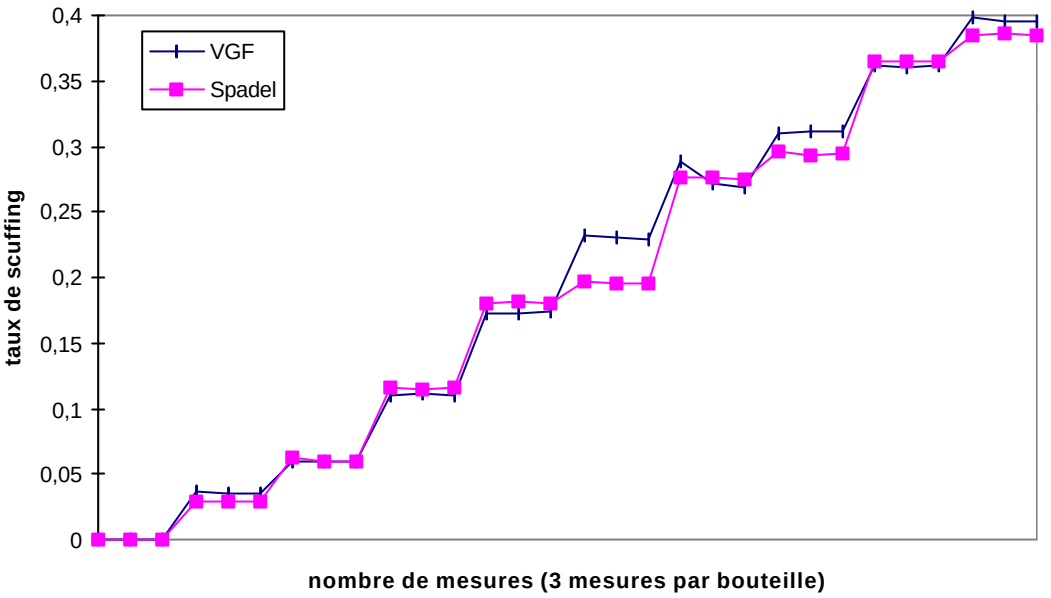

Figure 3 : sampling of VGF brown 25 cl and Spadel non coloured 20 cl.

Determination of acceptable threshold for scuffing (in accordance with the partners)

From a set of standards established for one type of bottle, in accordance with the requirements of the partners (mainly bottlers), one value of the acceptable threshold of scuffing will be established.

Starting from the plot of mechanical resistance of bottles with different scuffing rates (plot 2), it could be noticed that as soon as a scratch appears, damaging the surface treatment, the internal pressure resistance drops drastically (from 40 to 28 psi). The resistance to pressure of this kind of bottles corresponds to that of bottles with a less than 1% scuffed surface, which are considered as little scuffed. So far one can see that the criterion of internal pressure resistance will not be usable for defining a threshold for rejecting scuffed bottles.

The threshold then will be mainly based on criterion of estheticism rather than on criterion of resistance, which is over as soon as the first washing cycles. The acceptable threshold will then depend on every partner ; this is why no limit was chosen in this work.

- ***Results validation with other methods / Repeatability***

Measurement test of scuffing rate at different places on the bottle side-wall

By measuring all the surface of the bottle, the result is a nearly linear decrease of the values taken by the number of scuffs as a function of wear rate (table 1), and correspond to the TNO measurement made with an other method, except for the bottle n° 10.

Etalon	1	2	3	4	5	6	7	8	9	10
mV (TNO)	1000	900	800	700	600	500	400	300	200	100
intensité	fort				moyen					faible
taux scuf	0.399	0.322	0.318	0.298	0.209	0.131	0.126	0.069	0.019	0.042
nb scuffs	3192	2577	2540	2380	1669	1047	1006	555	157	334

Table 1 : Comparison of measurements in mV between those realized by TNO and those obtained with the pre-prototype.

But we observe that the most scuffed parts are often the top and the bottom of the bottle, and for some bottles, the abrasion is high in the middle of the body. By measuring only the top and the bottom ring, the plot is similar to that obtained before.

As a conclusion, it is possible, if necessary, to optimize the measurement of scuffed zones on the bottles. Actually, the analysis of only the two more scuffed zones (top and bottom) would greatly reduce the time needed for analyzing one bottle, which is a non negligible parameter with a view to valorize the scuffmeter for on line measurements.

Repeatability of measurement

The repeatability of measurement of scuffing with the prototype was made taking 2 sets of standard bottles. The bottles of the two sets were measured 3 times, with the same cell (fig. 3).

The results demonstrate that repeatability of the prototype is excellent. For the series VGF, the variation coefficient (fidelity estimation) is always less than 1.5% except for one bottle for which it reaches 3.8%. For the series Spadel, the variation coefficient is always less than 1% except for one bottle for which it reaches 2.2%.

For the series VGF, the bottles have also been measured 3 times, with two different cells. A comparison of the performance of the prototype with the two different cells can be observed at fig. 4. The linearity of the range were afterwards readjusted, that is why the final sampling curve (fig. 3) of the VGF is slightly different.

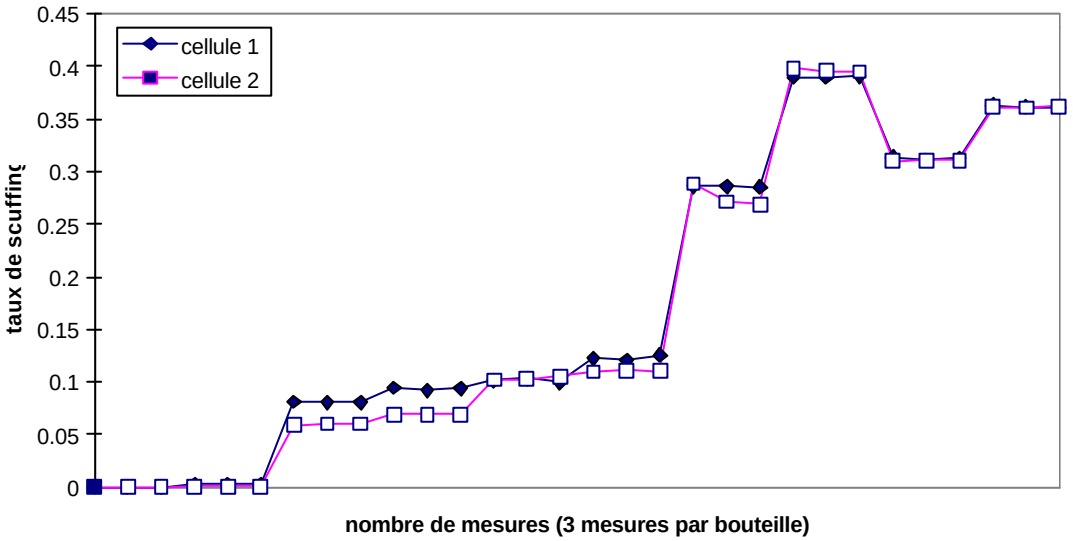

Figure 4 : comparison of the performance of the prototype with the two different cells.

BALANCE AND PROSPECTS

The main objective of this project was thus to develop and to set up an efficient method of scuffing measurement on returnable packaging glass. In order to reach this objective, several results have been obtained :

- many tests have been performed under varying conditions (varying wash/wear out cycles, use of different washing products, different wearing out modes, resistance to internal pressure after wear out, etc...). They have led to a better understanding of the scuffing phenomenon. It has been put into light that the resistance to internal pressure (a very

important factor for the bottling lines) is strongly reduced when the surface treatment of the bottles is damaged ;

- a measurement method has been chosen, ie. the diffuse reflectance, and a « scuffmeter » prototype has been set up in our laboratories. It allows the automatic measurement of the scuffing rate on different types of glass packagings (of different geometry and colour), under various conditions of humidity and temperature ;
- two sets of standard samples whose scuffing rate is used as reference to calibrate the equipment, have been collected. Both sets relate to respectively APO 25cl type brown bottles and colourless Spadel 20 cl type bottles. The constitution of any additional set of standard samples depends on the type of bottle to measure ;
- a technical procedure for the measurement of the scuffing rate has been written . It describes the sampling parameters to be adopted, the equipment to be used, the method to be followed to perform the measurement. This procedure can be adapted in the future to fit the standard 5725 or the ASTM standards, for instance, and be subjected to approval by a standardization committee.

The next steps should involve :

- the use of the laboratory prototype for some characterizations of lines
- further developments to fit standards and get approval by standardization committees
- the development of a device working in real time to be used on industrial lines.