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Soiling of silica-soda-lime float glass in urban environment: measurements and modelling

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Abstract

Modern silica-soda-lime float glass samples were exposed to background pollution conditions in Paris, sheltered from rain, during 1, 2, 6, 12 and 24 months. Analytical scanning electron microscopy pointed to the importance of soot particles and soluble salts as fine and coarse deposited particles. Four pertinent soiling parameters were measured: total mass of deposited particles (by weighing), mass of total carbon (by thermo-coulometry), mass of water soluble ions (by ion chromatography on glass surface rinsing water) and haze (by spectrophotometry). Model fitting to experimental data showed a continuous increase of soiling in time, following a variable slope sigmoid (Hill equation) for all the four soiling parameters. This similar evolution allowed defining one general model for soiling.

Keywords: Particle deposition; Carbon; Salts; Optical glass properties; Hill equation

1. Introduction

According to Haynie and Spence (1984), Pio et al. (1998) and Watt and Hamilton (2003), "soiling is a visual nuisance resulting from the darkening of exposed surfaces by deposition of atmospheric particles".

Many studies concern the soiling mechanism acting on several types of material (see exhaustive bibliography in Watt and Hamilton, 2003). Some of them present a model describing soiling evolution. These models are based on the variations of optical parameters (i.e. reflectance or lightness) and they are expressed as a square root, an exponential form or a combination of both, against time.

Beloin and Haynie (1975) proposed a square-root form for the soiling of different types of materials (painted wood, concrete, brick, limestone and window glass) in an urban environment, using data collected during a period of two years : $R(t) = R_0 - k\sqrt{Ct}$, where R is the reflectance, t is time, R_0 is initial value of reflectance, k is constant and C is concentration of total suspended particles. Creighton et al. (1990) obtained a reflectance change obeying a square-root model for a 13-week experiment on opaque substrates. Pio et al. (1998) fitted a square-root function to results obtained for painted wood and Portland stone exposed 900 days. Grossi et al. (2003) conducted an exposure campaign of building stones exposed sheltered and unsheltered in two urban sites in Spain. The parameter used to describe soiling, the L*-value (Lightness), followed a square-root function of time in sheltered conditions. Brimblecombe and Grossi (2004) affirm that the square-root form is

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valid only for short time intervals, because the reflectance would become negative at times greater than $R_0^2/(k^2/C)$. Several experiments were performed on white painted wood (Mansfield and Hamilton, 1989; Hamilton and Mansfield, 1993) for periods of 110–250 days, in a road tunnel and in an urban area. Time evolution of soiling was monitored by measuring daily sample reflectance. The best fitting equation was a square root, for the urban environment, and an exponential for the tunnel experiments.

Haynie (1986) and Lanting (1986) expressed the soiling of glossy painted surfaces as an exponential decrease of reflectance: $R = R_0\ \exp(-kt)$. Finally, Brimblecombe and Grossi (2004) proposed an exponential form, such as $R(t) = (R_0 - R_\infty)\ \exp(-kt) + R_\infty$, where R_∞ represents reflectance after infinite soiling for building materials. This equation is more realistic because is got from a first-order rate equation.

In spite of its wide use as a building material and its particular properties (see Section 2.1) making it a good support to study soiling, few studies focused on glass soiling and its modelling. According to Lanting (1986), particulate elementary carbon (PEC) is the main cause of soiling on glass in urban area: its reflectance decreases with increased light absorption by PEC. Sharples et al. (2001) carried out in the UK a field measurement of light transmittance on windows. Glass loss in transmittance was characterised by an average of 7.3% and a maximum of 33.2%, values corresponding to sheltered windows. The authors affirmed that the loss in transmittance is due to the deposit, without mentioning deposit's nature and composition. Chabas and Lefèvre (2000, 2002), Lombardo (2002) and Lombardo et al. (2004) observed on unsheltered glass samples an abundant concentration in number of carbonaceous particles (soot), associated with sulphates on sheltered ones.

Glass soiling was focused on in several studies presented by Schwar (1998) and Adams et al. (2002). The parameter selected to characterise soiling was the reduction in surface gloss. One of the particularities of these two studies is the fact that the glass samples were exposed horizontally. The results were expressed in soiling units (su), where 1 su is equivalent to a 1% reduction in the reflectance of a glossy surface measured at 45° (Adams et al., 2002). In Schwar (1998) experience, samples were exposed, as for all the previous studies, outdoors; Adams et al. (2002) studied the accumulation of particles on glass in an indoor museum environment as well as outdoors, extending thus the external study to the indoor environment. Exposure was carried out up to 20–30 weeks in both studies. Soiling modelling was expressed by Schwar (1998) and by Adams et al. (2002) by equivalent exponential forms, with 2 coefficients S_0 and τ in $S = S_0[1 - \exp(-t/\tau)]$ (Schwar, 1998) or k_1 and k_{-1} (Adams et al., 2002) in $S = \{k_1/(k_1 + k_{-1})\}[1 - \exp\{-(k_1 + k_{-1})t\}]$, where S is the measured soiling level at time t and S_0 is the soiling level that S tends to when t approaches infinity, τ is the time constant for the soiling process, k_1 and k_{-1}, respectively are the rates of gain and loss of soiling by the surface.

The purpose of this paper is to complete the previous works concerning the soiling of glass by: (i) the study of other parameters than optical to characterise soiling; (ii) modelling over a longer period (2 years); (iii) exposing glass samples in vertical position, as commonly used for windows and building façades.

2. Experimental

2.1. Material and field exposure conditions

A silica–soda–lime glass was selected due to its properties making it a good candidate for the measurement of the soiling phenomenon:

(i) It is weakly leached in urban polluted conditions. The leached layer measured by Lombardo et al. (in press) was only 44 nm thick after 24 months of exposure. Consequently, the contribution of chemical elements coming from the substrate to the in situ development of products on the glass surface is negligible.
(ii) It has a smooth and non-porous surface. The deposition of the atmospheric particles is not favoured by surface roughness, at least during the incipient phase of soiling.
(iii) It is transparent. Heating effects influencing deposition mechanisms like thermophoresis are reduced.
(iv) It is used world-wide and it has a quite normalised composition. Thus, differences in soiling development from one place to another are only due to spatial variability of environmental factors (gaseous and particulate pollutants, acidity of rain, etc.) and atmospheric parameters (temperature and relative humidity of air, quantity of rain, etc.).

The material is a float glass (SiO_2 71.7; Na_2O 13.1; CaO 9.6; MgO 4.1; K_2O 0.3; Al_2O_3 0.7; Fe_2O_3 0.1, in mass percentage) usually used for building facades and windows. Samples ($15 \times 10 \times 0.2$ cm and $1.8 \times 1.8 \times 0.2$ cm) were exposed sheltered from rain, for up to 2 yr. The exposure began on 1 August 2000, and samples were withdrawn after 1, 2, 6, 12 and 24 months. The field campaign took place in the historical centre of Paris, in a pedestrian area considered as representative of the background urban atmospheric pollution (Fig. 1). According to the conditions defined by the *UN-ICP Materials Programme* (Tidblad et al., 2001) samples were hanged in a vertical position (Fig. 2) inside a box ($115 \times 72 \times 60$ cm) with an open bottom and openings at