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Numerical investigation of sharpness in photographic layers containing DIR compounds

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Adjacency effects are one of the most important factors affecting the sharpness of photographic materials. A mathematical model that makes use of the light spread function of the lens and film combination and the chemical spread function related to the lateral diffusion of development inhibiting reaction products is proposed. Parameters used in the model are determined experimentally. A comparison between theoretical and experimental results is given in this paper.

1. Introduction

Sharpness of images recorded by photographic materials is affected both by the light scattering in an exposing process and by adjacency effects in developing processes. While the light scattering makes the image unsharp, the adjacency effects make it subjectively "sharper". Thus, the adjacency effects are often considered to be a desirable feature deliberately built into the photographic process.

The adjacency effects are largely determined by the development conditions and, in particular, by local changes in the rate of development and the formation of by-products which inhibit development. These effects occur during the development and are the result of diffusion of developer and development-inhibiting compounds inside the photographic layer. The adjacency effects can be produced and controlled by the development-inhibitor-releasing (DIR) coupler in the emulsion. These compounds can be used in colour photographic processes. Let us consider the high exposure region of an image, adjacent to the low exposure region (knife edge exposure). Development-inhibiting by-products diffuse laterally from the high exposure region to the low exposure region. At the same time, the fresh developer diffuses laterally from the low exposure region into the high exposure region. Hence, the concentration of developer is higher and that of inhibitor is lower in the edge of high exposure region than in the remaining area of the high exposure region. Development runs more rapidly at the edge area, resulting in a local maximum of optical density of image. The development by-products that flow into the low exposure region of the knife-edge exposure can curtial development close to the edge, resulting in a local minimum of optical density.

The two effects thus described are called the *border effect* (high density) and the *fringe effect* (low density), respectively (see Fig. 1), [1].

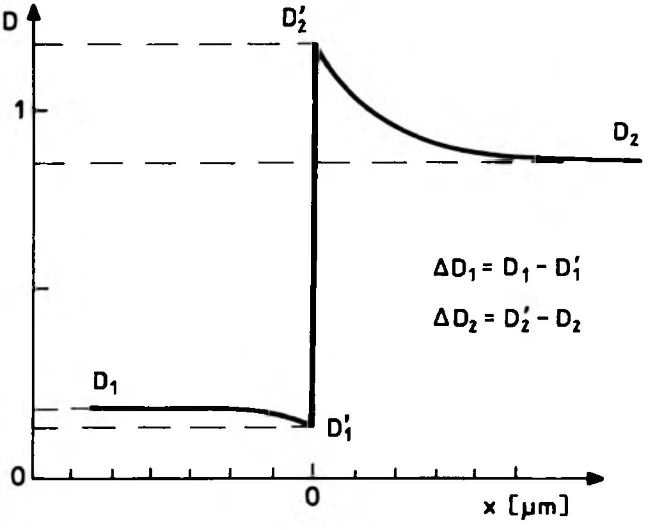

Fig. 1. Edge densities (ΔD_1 describes fringe effect, ΔD_2 describes border effect).

The consequence of the adjacency effects is similar to that of the scattering of light in photographic layer. The latter is described by the line spread function (LSF) given by Eq. (1) proposed by Frieser [2]. The LSF is defined as the distribution of illuminance in the image of a slit of negligible width. Illuminance is measured as a function of distance in a direction at right angles to the length of the slit. So, by analogy, the adjacency effect may be described by Eq. (1) in the form of Eq. (2):

$$L(x) = \frac{2.303}{K} \cdot 10^{-(2|x|)/K}, \tag{1}$$

$$b(x) = \frac{2.303}{K_c} \cdot 10^{-(2|x|)/K_c}, \tag{2}$$

where: $L(x)$ – line spread function, $b(x)$ – chemical spread function, x – distance from the line (the edge), K – constant connected with working range of the light spread in photographic layer, K_c – constant connected with working range of the adjacency effect in photographic layer.

When the product of development reaction causes acceleration [3] rather than inhibition [4], [5] of development, the chemical spread function (ChSF), [1] changes sign as illustrated in Fig. 2.

The adjacency effect has been investigated from various points of view. A number of mathematical models have been proposed to explain and predict the effect. They may be classified into two groups: an empirical model [6]–[8] which employs the chemical spread function, and the diffusion model [9] which is based on diffusions and the developer reactions.

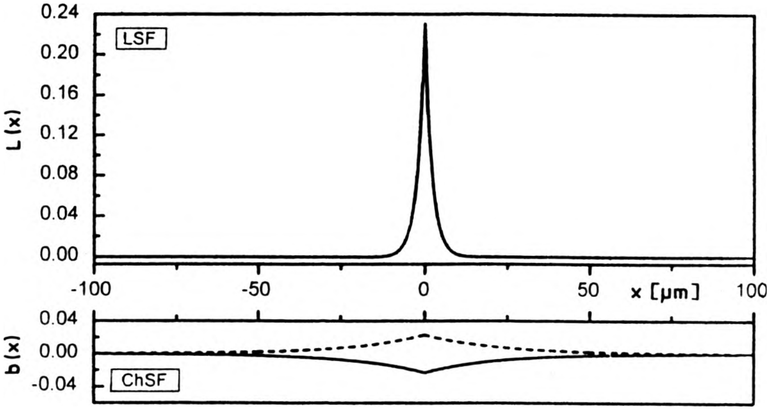

Fig. 2. Comparison of the LSF and ChSF. The ChSF for development-inhibiting compounds – solid lines, the ChSF for development-accelerating compounds – dashed lines.

2. Model

Figure 3 illustrates the empirical model for simulation adjacency effects in the light-sensitive photographic layer. The ChSF similarly to the LSF is symmetrical. The efficiency of the ChSF depends on the exposure which is expressed by the optical density. For the calculation, we assume that the effectiveness of adjacency effects varies with density.

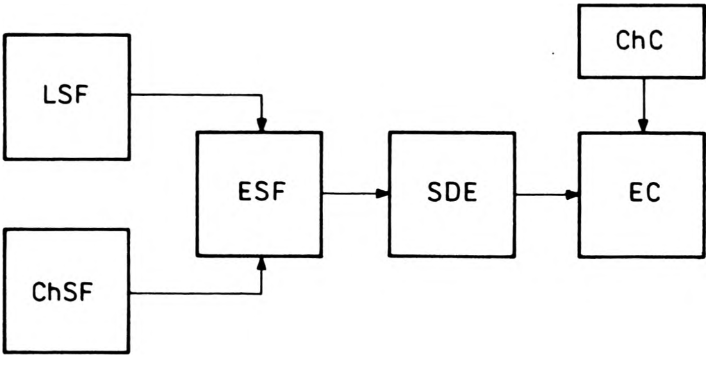

Fig. 3. Model of simulation adjacency effects in light-sensitive photographic layer. LSF – modulus of calculation of the light spread function, ChSF – modulus of calculation of the chamical spread function, ESF – modulus of calculation of the effective spread function, SDE – modulus of calculation of the spatial distribution of exposure inside light-sensitive layer, EC – modulus of calculation of the edge curve, when we take into account theoretical characteristic curve for light-sensitive photographic materials.

The stages of the model illustrated in Fig. 4 are as follows:

– Generation of the LSF from the Frieser's equation. Estimation of the range of diffusion scattered light inside photographic layer. It is expressed by the value of a coefficient K (Eq. (1)).

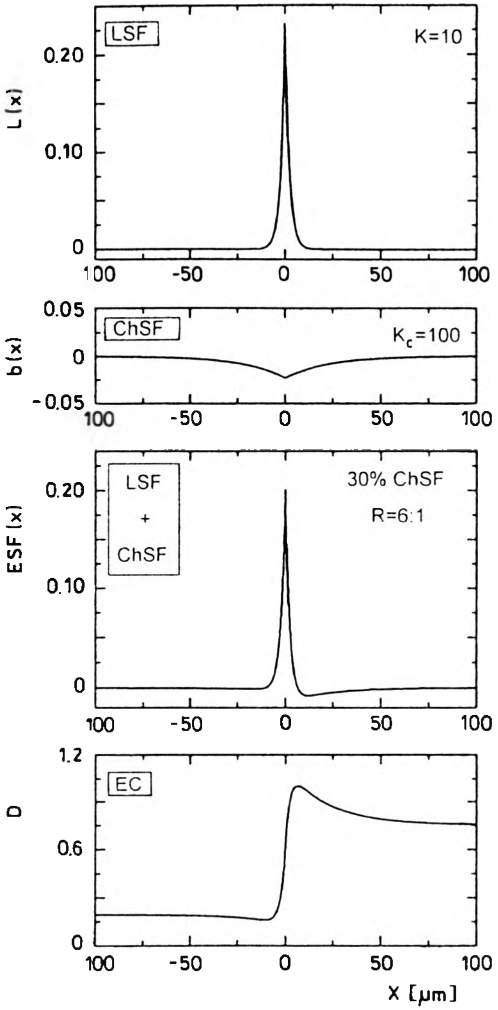

Fig. 4. Stages of the simulation model.

– Generation of the ChSF. Estimation of the range of diffusion compounds, which cause the adjacency effect. It is expressed by the value of coefficient K_c (Eq. (2)).

– Calculation of the ESF as a sum of the LSF and the ChSF

$$\mathrm{ESF}(x) = (1-\delta)L(x)+\delta b(x) \tag{3}$$

where: ESF(x) – effective spread function, $L(x)$ – line spread function, $b(x)$ – chemical spread function, δ – estimation of the contribution of ChSF in ESF.

The influence of the effectivity adjacency effect on the optical density can be expressed as the ratio

$$R = \Delta D_2/\Delta D_1 \tag{4}$$

where: D_1 — density difference due to the fringe effect, ΔD_2 — density difference due to the border effect.

The percentage contribution of the ChSF in ESF is given as the ratio

$$\%\mathrm{ChSF} = \delta \cdot 100\%. \tag{5}$$

The area under the ESF is equal to 1.0.

— Calculation of spatial distribution of the exposure as integration of the ESF.

— Calculation of edge curve from spatial distribution of the exposure. Rectilinear run of the characteristic curve and 45° slope are assumed.

3. Experimental

Some examples of experimental data on which the mathematical model for the adjacency effect is based are shown in Figs. 5–7. The microdensitometer traces in Figs. 5–7 were obtained by scanning across edges in photographic negatives made on Kodak Gold 100 (Fig. 5), Kodak Gold 200 (Fig. 6) and Kodak Gold 400 (Fig. 7), each edge being the boundary between two regions of different but uniform exposures. All exposures are developed in the Kodak C-41 process. The measurement of optical density was made in green light.

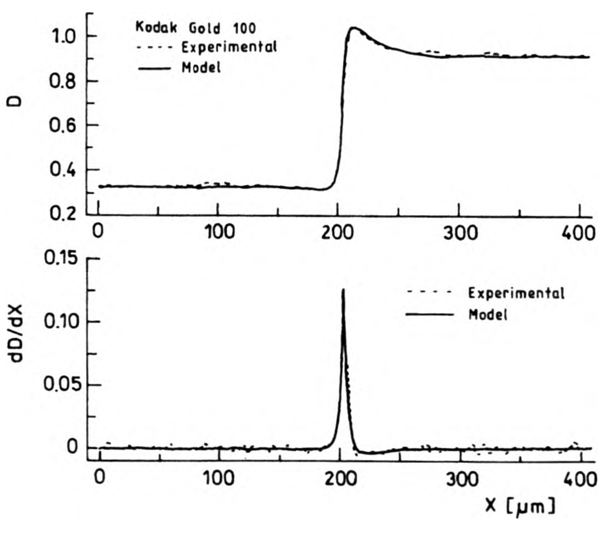

Fig. 5. Comparison of (a) experimental edge densities and their differential (dashed lines) and the corresponding (b) model edge densities, and their differentials (solied lines). Experiment made on colour negative Kodak Gold 100. The parameters of modelling are as follows: $K = 15$, $K_c = 90$, $R = 6.24\%$ ChSF in ESF.

The measure of sharpness called acutance [10] was developed. The acutance is a measure of the spread of a knife-edge exposure. Figure 8 shows the density profile resulting from the knife-edge exposure. The acutance is related to the average square gradient of the knife-edge density profile. The square of the gradient is taken in order

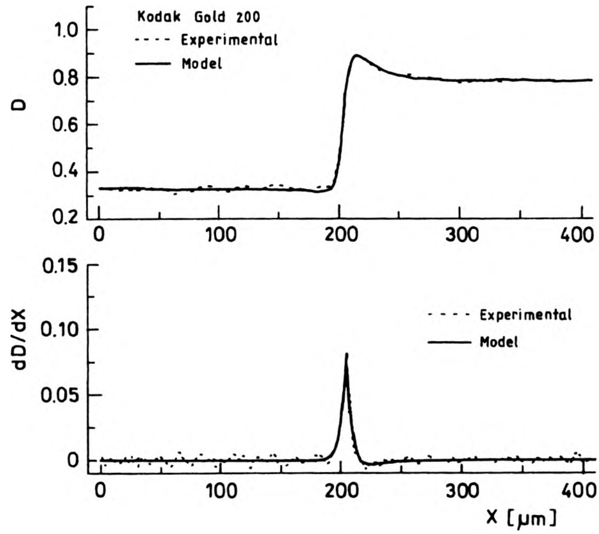

Fig. 6. Comparison of (a) experimental edge densities and their differential (dashed lines), and the corresponding (b) model edge densities and their differentials (solid lines). Experimental made on colour negative Kodak Gold 200. The parameters of modelling are as follows: $K = 20$, $K_c = 90$, $R = 5.28\%$ ChSF in ESF.

to differentiate between knife-edge exposures that are very different in shape but may have the same average value for their respective gradients. The results obtained from investigations lead to the following conclusion: Jones and Higgins' acutance

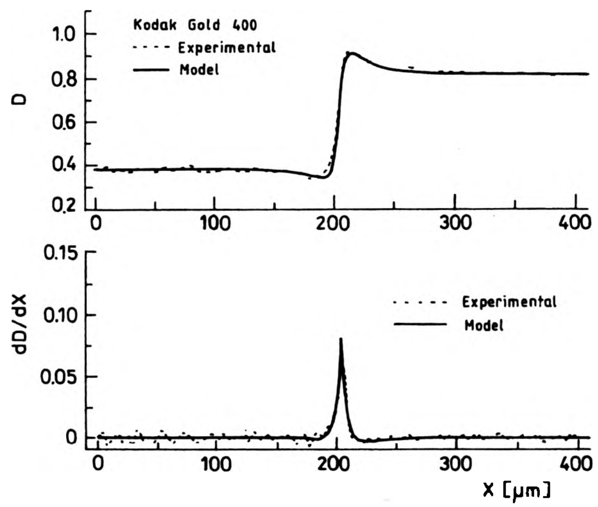

Fig. 7. Comparison of (a) experimental edge densities and their differentials (dashed lines), and the corresponding (b) model edge densities and their differentials (solid lines). Experiment made on colour negative Kodak Gold 200. The parameters of modelling are as follows: $K = 20$, $K_c = 90$, $R = 2.3\%$ ChSF in ESF.

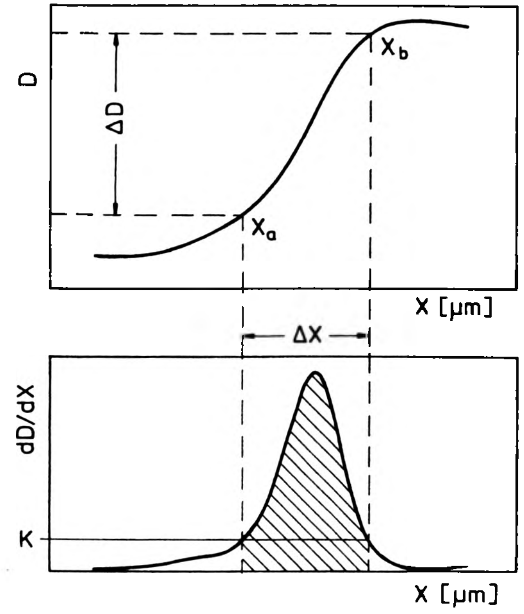

Fig. 8. Image of a knife-edge exposure used to measure acutance. ΔD is the density difference over the distance ΔX.

(Eq. (6)), [10] and Perrin's acutance (Eq. (7)), [11] are the best measures for expressing the edge curve enhancement caused by adjacency effects:

$$\bar{g}^2 = \frac{1}{X_a - X_b} \int\limits_{X_a}^{X_b} \left(\frac{dD}{dX}\right)^2 dX, \tag{6}$$

$$A = \frac{1}{\Delta D} \frac{1}{\Delta X} \int\limits_{X_a}^{X_b} \left(\frac{dD}{dX}\right)^2 dX. \tag{7}$$

The starting and stopping points, X_a and X_b, respectively, used in calculations are determined by the smallest visible density gradient: Higgins and Jones [10] found this value to be 0.005 density units per micrometer.

The influence of percentage contribution of the ChSF in ESF on the form of the edge curve (Fig. 9) and acutance (Fig. 10) is determined with the aid of this model. These results were obtained for Kodak Gold 100 negative. The results obtained for Kodak Gold 200 and Kodak Gold 400 negatives are comparable in a qualitative sense.

4. Conclusions

The results obtained from the modelling of the changes of acutance which occur as a result of adjacency effects under conditions of their variable intensity lead to

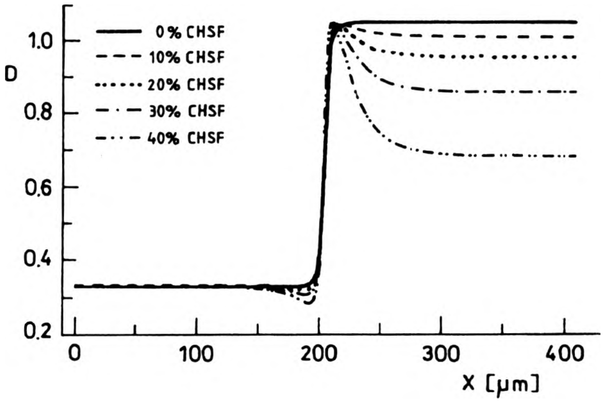

Fig. 9. Influence of percentage contribution of the ChSF in ESF on the edge curve form.

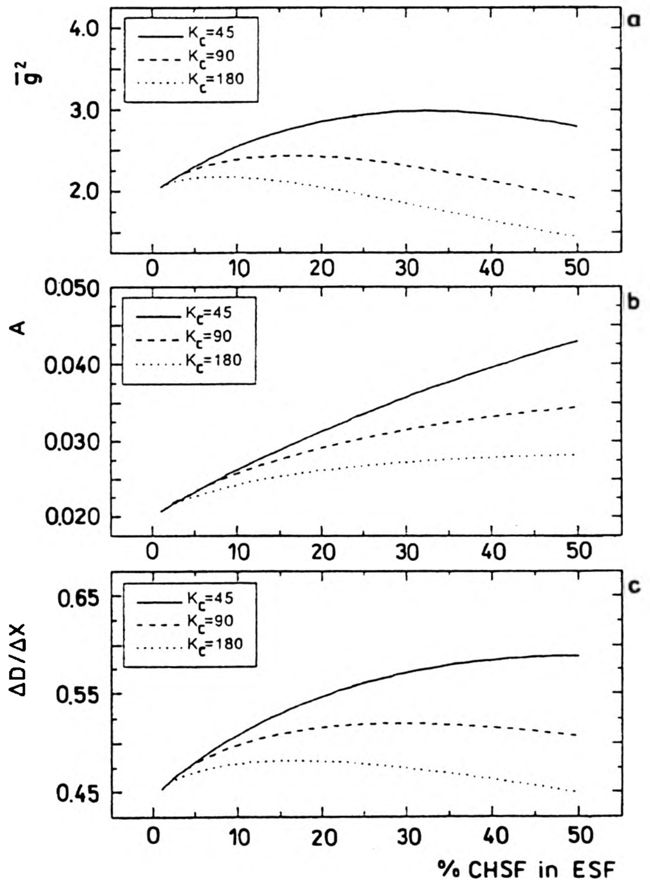

Fig. 10. Influence of percentage contribution of the ChSF in ESF on acutance (**a** — Jones and Higgins' acutance, **b** — Perrins acutance, **c** — average gradient of the edge curve).

the following conclusions:

1. Including the intensity of adjacency effect in our model allows us to obtain results comparable to experimental ones in a qualitative sense.

2. From the theoretical point of view, application of the function which defines the influence of adjacency effect with relation to the ratio of border effect to fringe effect seems to be correct.

3. The method for estimating the percentage contribution of ChSF in ESF is to be further developed.

4. The model worked out enable examination of the influence of adjacency effect on acutance and edge curve form.

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