Optica Applicata, Vol. XXVIII, No. 2, 1998

Model investigations of the influence of adjacency edge effects on the shape and properties of the limiting curve in the silver halide light-sensitive materials

Bogumił Rajkowski, Piotr Nowak

Institute of Physical and Theoretical Chemistry, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland.

The most important questions related to the origin of adjacency effects and their influence on the photographic image quality are described. The presented method of computer modelling of these effects allows the prediction of influence on the shape and properties of the edge curve in silver halide light-sensitive materials. The results indicate that in the case of retardation of development the existing criteria of acutance of the photographic image should be modified.

1. Introduction

In the contemporary photographic materials, especially those of multilayer structure, to be applied in colour photography the adjacent effects are consciously used. The appearance of these effects as well as the possibility of controlling their course enable us to significantly improve of the usability of the photographic carriers of image information. The present state of knowledge in this field as well as the technological successes resulting from its industrial scale application encourage to explanation the fundamental problems connected with these phenomena.

The adjacency effects are phenomena occurring during the process of photographic development. They appear at the border of low and high optical density areas being characterized by the fact that in the vicinity of this border there exist some distortions of the input signal. The gradients of the developer components concentration as well as those of the products of developing reactions which appear at the border of fields of different exposure constitute the main cause of the adjacency effects. The magnitude of the concentration gradients is connected with the speed of two processes, *i.e.*, that of diffusion of the products of development from the field of low exposure and that of the fresh developer diffusion occurring in the opposite directions. The nature of the adjacency effects allows us to distinguish two kinds of effects [1], [2]:

- adjacency effects connected with the restraining of the developing process,
- adjacency effects connected with the acceleration of the developing process.

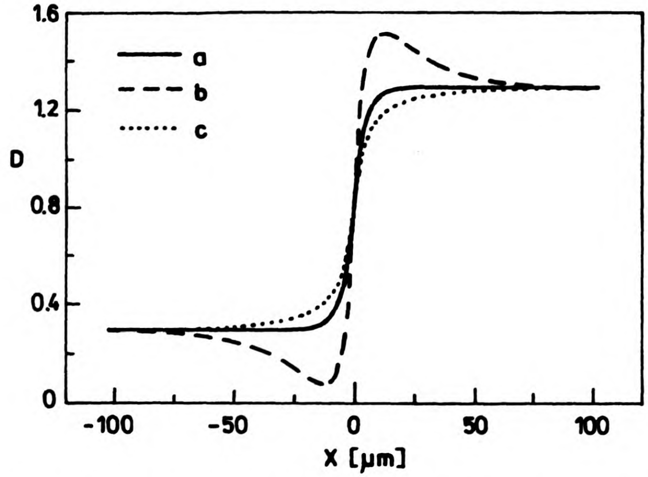

Fig. 1. Optical density distribution determined at the image-background border (edge curve). The edge curve a presents the optical density distribution for the process of photographic development in which no adjacency effects occur, the edge curve b presents the optical density distribution in the case when the adjacency effects restraining the process of development appear, the edge curve c presents the optical density distribution in the case of adjacency effects accelerating the photographic development

Depending on the kind of the adjacency effects at the border of fields of high and low exposures a local increase or decrease of the contrast appears which is interpreted by the human eye as an increase or decrease of the contour acutance, respectively.

The changes of the adjacency profile in the image evoked by the adjacency effects are shown in Fig. 1. There, edge curves, *i.e.*, the optical density distributions are shown as functions of the distance from the border between the fields of high and low. They have been obtained as a result of photographic development in three versions: without adjacency effects, with restraining adjacency effects and with accelerating adjacency effects.

It is well known from the experience that the shape of the edge curve is strictly connected with the acutance of the photographic image. In order to examine the influence of the adjacency effect on the acutance of the photographic image, it would be worth finding a mathematical relation of the acutance of the photographic image to the shape of the limiting curve. Additionally, this description should be consistent with the psychophysical sensations of the observer. As early as in 1912, GOLDBERG [3] represented the acutance of the photographic image as a magnitude proportional to the maximum gradient of the edge curve

$$O \sim \left(\frac{\mathrm{d}D}{\mathrm{d}X}\right)_{\max}. \tag{1}$$

Nowadays, there exist a number of other methods of describing the acutance of the photographic image. Below, we give most important ones. VIFANSKII and GOROKHOVSKII [4] proposed to apply Eq. (2), MÜLLER [5] suggested Eq. (3), HIGGINS and JONES [6] gave Eq. (4), and PERRIN [7] – Eq. (5), all these equations being cited below:

$$P = \Delta D\left(\frac{\mathrm{d}D}{\mathrm{d}X}\right)_{\max}, \tag{2}$$

$$\sigma = \frac{1}{\Delta D}\int\limits_{X_a}^{X_b}\left(\frac{\mathrm{d}D}{\mathrm{d}X}\right)^2 \mathrm{d}X, \tag{3}$$

$$g^{-2} = \frac{1}{X_a - X_b}\int\limits_{X_a}^{X_b}\left(\frac{\mathrm{d}D}{\mathrm{d}X}\right)^2 \mathrm{d}X, \tag{4}$$

$$A = \frac{1}{\Delta D}\,\frac{1}{\Delta X}\int\limits_{X_a}^{X_b}\left(\frac{\mathrm{d}D}{dX}\right)^2 \mathrm{d}X \tag{5}$$

where: O, P, σ, g^2, A – indicators of the contour acutance of the photographic image, $\mathrm{d}D$ – increment of the optical density in the region $\mathrm{d}X$ within which the average gradient of the edge curve is determined, X_a, X_b – criterion points determining the border of spatial integration of the edge curve gradients; the values of those points have been determined at the level of minimal spatial contrast observed by the human eye and amounting to $k = 0.005$ $[D/\mu\mathrm{m}]$.

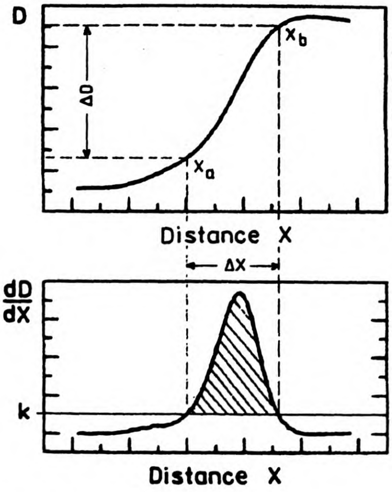

Fig. 2. Selection of the criteria when determining the contour acutance of photographic images. The edge curve (upper plot) and the distribution of its gradient (lower plot). Minimal spatial contrast perceptible by the human eye is denoted by k

In Figure 2, the way of choosing the criterion points needed to determine the acutance of the photographic image is shown.

2. Mathematical model

It is well known that the appearance of the adjacency effects contributes to the changes in image acutance obtained on heterogeneous information carriers. However, both the quantitative and qualitative analyses of these phenomena require elaboration of the model allowing us to simulate the adjacency effects and by the same means to model the structurometric properties of the single- and multilayer photographic materials. In order to make the adjacency effects subject to mathematical analysis a function describing these effects should be found. NELSON [2] described the functioning of the chemical effects occurring during the photographic development. He noticed that the function determined shows a complete analogy to the light spread function [2] and, more precisely, to the line spread function (LSF) described by the Frieser equation [8]

$$L(x) = \frac{2.303}{K}\, 10^{-(2|x|)/K} \tag{6}$$

where: $L(x)$ – LSF, x – distance from the place of light incidence, K – scattering coefficient which is equal to the distance between the point where $L(x)$ achieves its maximum value and that at which $L(x)$ drops down to 1/10 of its maximum value. The value of the scattering coefficient is expressed in micrometers. In the absence of scattering $K = 0$.

It is probably just this fact that made Nelson name this function the chemical spread function (ChSF). The difference is that the LSF deals with light diffusion in the layer during exposure while the ChSF function results from diffusion of the chemical molecules in the layer during photographic development. In Figure 3, the LSF and ChSF are illustrated which have been determined for the same

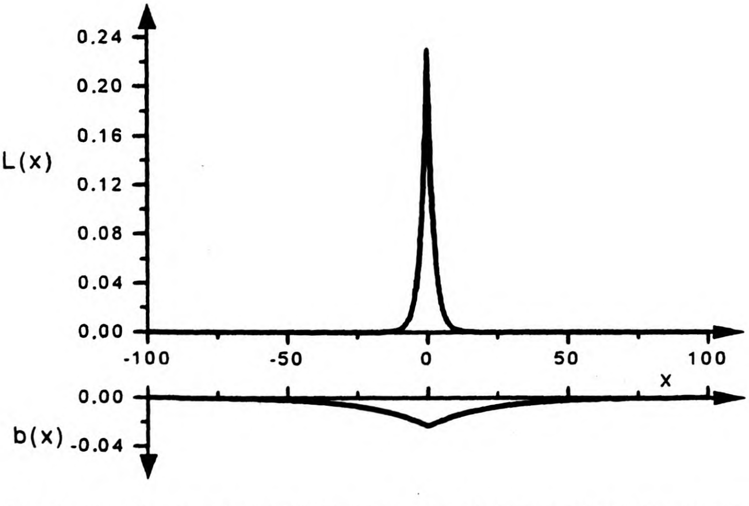

Fig. 3. LSF (upper plot) and ChSF (lower plot) determined for the same theoretical photographic film

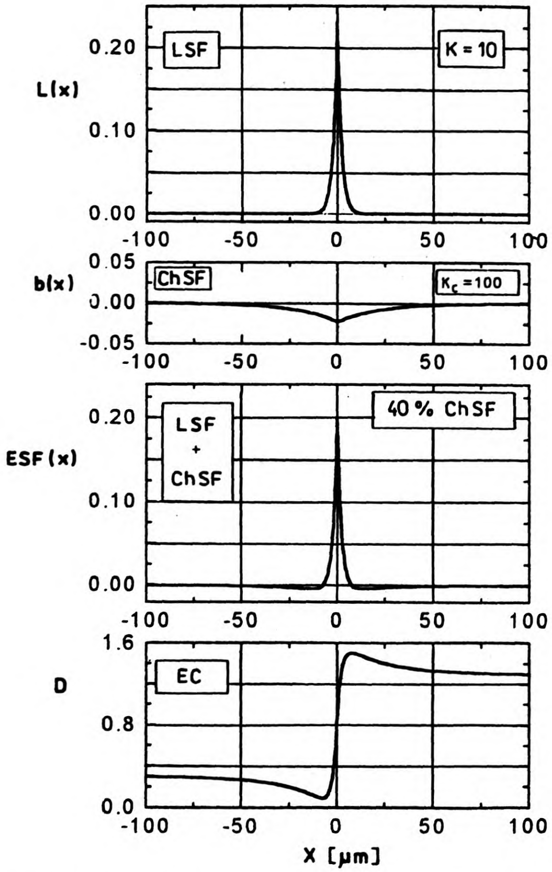

Fig. 4. Stages of calculation of the edge curves (EC) in computer simulation model of the adjacency effects

theoretical light sensitive layer. The ChSF in this case shows an opposite sign due to the opposite action of the adjacency effects in relation to the LSF (effects restraining the developing process). In the case of effects accelerating the developing process the ChSF is of the same sign as that of LSF.

Taking advantage of analogy between those two functions, it is possible, by suitably adopting the Frieser equation, to generate the ChSF. This conclusion became a basis for creating a computer model rendering it possible to examine of the influence of the adjacency effects on the shape and properties of the edge curve. The operation of this model consists in performing the following calculations:

1. Generating the line spread function using the Frieser equation where, for instance, $K = 10$ means that the diffusion range of the light scattered inside the photographic layer amounts to 10 μm.

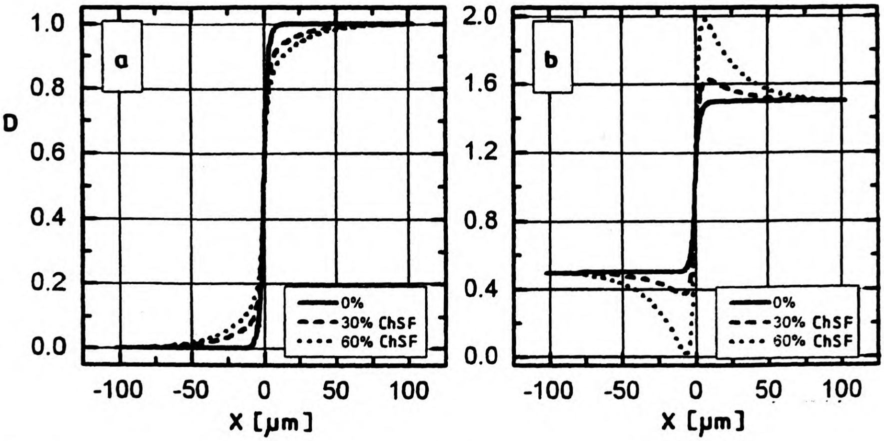

Fig. 5. Changes in the edge curve shape due to increased contribution of the adjacency effects occurring during the photographic development process. a — the optical density distribution influenced by the accelerating effects, b — the corresponding distribution as influenced by effects restraining the process of photographic development

2. Taking advantage of the analogy between ChSF and LSF and suitably adopting the Frieser equation, the generation of chemical scattering function where, for instance, $K_c = 100$ means that the diffusion range of the factors causing adjacency effects is 100 μm. In order to render it possible to compare the two functions their surfaces were normalized to unity.

3. Calculating the effective spread function (ESF) by superposing the LSF and chemical scattering function, where 40% ChSF means that 40% of the surface of the ChSF contributes to creation of the ESF.

4. Calculation of the edge curve (EC) by integrating the ESF and transforming the spatial distribution of the effective exposure obtained in this way into the optical density.

Taking advantage of the elaborated model a number of calculations have been performed. In the first of them the influence of the ChSF on shape of the edge curve has been examined. In this experiment, the LSF and the ChSF were generated, the surfaces of which were summed up with different percentage contribution of the latter. Next, the edge curves were obtained from each ESFs from which the indicators of the contour acutance were calculated. The results are shown in Fig. 5.

The shape of the limiting curve depends also on the diffusion range and thus on the action of chemical substances causing the adjacency effects. In the calculations carried out a set of ChSFs has been generated both for restraining and accelerating effects in the process of photographic development. The operating range of these effects has been determined to be equal to 25, 50 and 100 μm from the edge of the photographic image. The results are illustrated in Fig. 6.

Based on well known methods of expressing the contour acutance of photographic images some calculations have been performed, attempting at expressing numerically the changes in the photographic image acutance as a function of

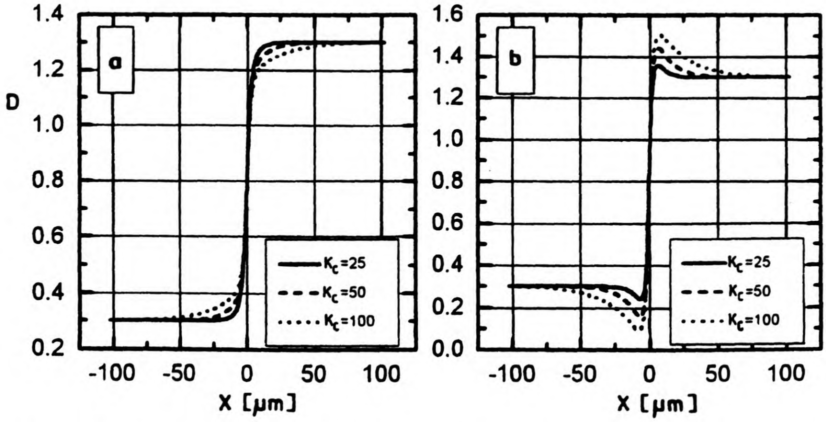

Fig. 6. Changes in the edge curve shape depending on the range of the adjacency effects, where $K_c = 25$, 50, 100 denotes the diffusion range of accelerators (a) and inhibitors (b) of the photographic development

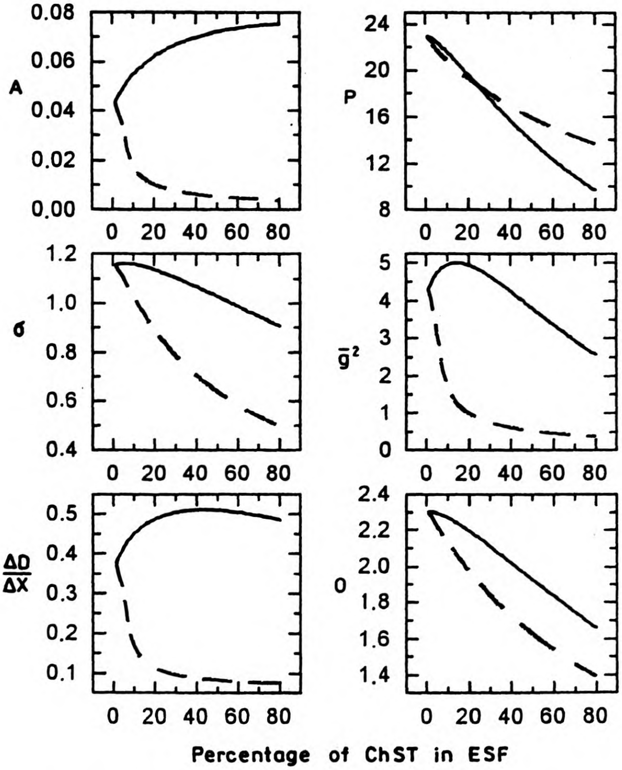

Fig. 7. Dependence of the contour acutance of the photographic image on the action strength of the adjacency effects occurring in the process of photographic development. The acutance of the image is expressed by six known measures while the adjacency effects are defined by the percentage contribution of ChSF in the summarized spread function (— effects restraining photographic development, — — — effects accelerating photographic development)

operating strength of the adjacency effects in the developing process. In the simulations carried out, the level of adjacency effects was controlled by changing the percentage contribution of the surface of the ChSF to the ESF.

The results obtained are shown in Fig. 7. The applicability criterion for a given adjacency indicator to the examination of the adjacency effects is the consistency of the physical measure with the visual acutance impression as observed by human aye. The numerical value of the acutance is highly influenced by a proper choice of the criterion points X_a and X_b determining the 3-D integration limits of the spatial distribution of the limiting curve. These are no problems as far as the determination of these points is concerned in the case of either lack of adjacency effect or exitence of the effects accelerating the development (Fig. 1). It is much more difficult is determine uniquely this criterion for the distribution of effects of restraining the photographic development (Fig. 8). In this case, the curve of spatial distribution gradient reaches twice the value $k = 0.005$ $[D/\mu m]$ in the fields of low and high optical density

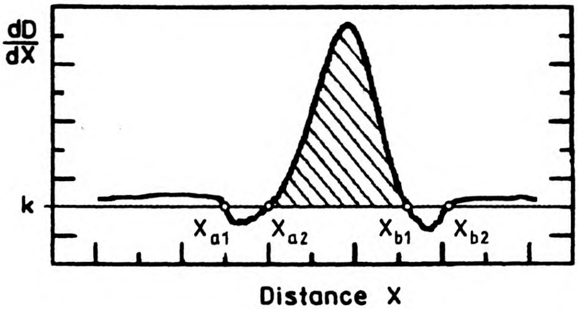

Fig. 8. Positions of the criterion points determined from the distribution of optical densities achieved during the development in the presence of the restraining effects being at the level of minimum spatial gradient values of image luminance perceptible by the human eye

In the model under consideration, the points have been chosen that are closer to the border between the fields of low and high densities (X_{a1} and X_{b1}). Such a choice of criterion points could be reason for lowering the values of acutance determined in the model for an image created in the presence of restraining effects with respect to that perceived by the human eye.

3. Conclusions

The application of the Frieser equation to the modelling of the ChSF renders wide possibilities far as regards investigation of the influence of the adjacency effects on the shape and properties of the edge curve in the light-sensitive silver halide materials. After having worked out the method of a suitable choice of the criterion points (X_a and X_b) in such a way that the obtained results be of full correlation with the acutance impression of the images percepted by the human eye a perfect tool for qualitative and quantitative examination of the phenomena occurring during the photographic film development will be achieved. This model will be applicable not only to the scientific work but also in teaching the structurometric photography. The general further development of the model should enable the examination of more complex multi-layer systems to be applied in optical information recording. Besides, the model describing the hypothetical properties of the light-sensitive layers can be useful in designing the real films of given parameters.

The preliminary version of this paper has been published in Proc. of III Local Conf. KOWBAN, Wrocław–Polanica Zdrój, October 1996.

References

[1] Mees K., James T. H., *The Theory of the Photographic Process*, 4th ed., Macmillan, New York, London 1975, Chapt. 21.
[2] Nelson C. N., Phot. Sci. Eng. **15** (1971), 82.
[3] Goldberg E., Phot. J. **36** (1912), 300.
[4] Vifanskii yu., Gorokhovskii Yu., Zh. Nauchn. Prikl. Fotogr. Kinematogr. **7** (1962), 290 (in Russian).
[5] Miller R., Photogr. Koresp. **93** (1957), 131.
[6] Higgins G. G., Jones R. A., J. Soc. Mot. Pict. Telev. Eng. **58** (1952), 277.
[7] Perrin F., J. Soc. Mot. Pict. Telev. Eng. **69** (1960), 152.
[8] Frieser H., *Photographische Informationaufzeichnung*, Focal Press, London, New York 1975, Chapt. 3.

Received April 28, 1998
in revised form May 25, 1998