Model examinations of edge effects in light-sensitive materials

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The results of theoretical examinations of the dependence of edge effects on the optical density, which influence directly the contour sharpness in the image, are presented. Besides, the results of calculations of the influence of contrast in the characteristic curve of the radiation sensitive layer on the shape and properties of the limiting curve are shown. The results obtained are presented in the form of functions of changes in the relative edge enhancement indicator and maximum gradient of the limiting curve as dependent on the level and difference of the optical density in the image and background, respectively.

1. Introduction

The sharpness in the photographic image depends on two effects. The first effect is the light scattering during exposure while the other is due to edge effects occurring during the process of photographic development. The light scattering is caused by the discontinuous structure of the photographic emulsion which is composed of the silver halogen crystals suspended in the binding gelatin medium. This phenomenon worsens the quality of photographic image due to the lowering of its sharpness. However, the main cause of edge effects are local differences in the concenteration of both the developer components and the products of developing reactions which appear at the border of fields of different degrees of irradiation. Depending on the kind of edge effects at the border of strongly and weakly irradiated fields some local increase or decrease of the contrast is observed which is interpreted by the eye as an increase or decrease of image sharpness. In practice, the first effects occurs most frequently being caused by the deccelerating action of the products of the developing reactions. The intensity of edge effects depends on many parameters. The first one is the kind of developer used. In this case, the intensity of edge effect is inversely proportional to the energy of developing action.

Many works indicate that intensity of edge effects is proportional to the mass of silver appearing in the photographic film during the developing process [1] – [5], while the mass of the reduced silver is connected with the value of optical density [5], [6]. This connection is linear to a lower or higher degree. In the further part of this work we shall use the term optical density only. It should be remembered, however, that optical density is connected with the mass of silver attributed to the unit area.

As shown by Nelson [1], a local increase in contrast at the border between the image and the background, following from the edge effects, is proportional both to the absolute values of optical density in the image and the background and to their difference. In Figure 1, the limiting curves are presented which were obtained on the basis of experiment [1] where the value of irradiation was chosen in a way allowing one to obtain proper values of optical density ouside the operation range of the edge effects. All the limiting curves were obtained from samples developed in the same developer under the same developing conditions.
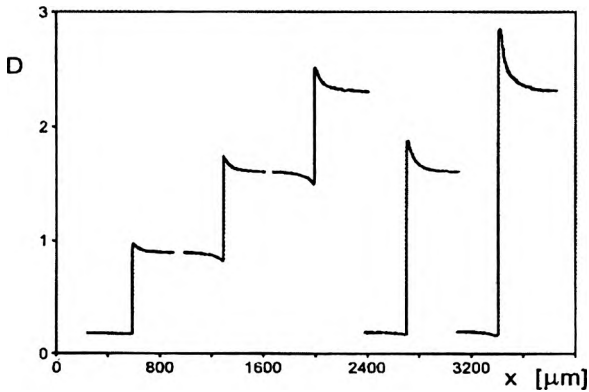

Fig. 1. Limiting curves illustrating the dependence of the intensity of edge effects on the levels of optical densities in the image and the background (*i.e.*, strongly and weakly irradiated fields) and their differences.

The intensity with which edge effects act on the fields of low and high optical density of the limiting curve can be expressed by the following equations (Fig. 2):

$$\Delta D_1 = D_1 - D'_1, \tag{1}$$

$$\Delta D_2 = D'_2 - D_2 \tag{2}$$

where: ΔD_1 — difference of optical densities following from the intensity of the edge effects action in the field of weaker exposure (lower part of the limiting curve), ΔD_2 — difference in optical density following from intensity of edge effects action in the field of stronger exposure (upper part of the limiting curve), D_1 and D_2 — the values of optical density of the weakly and strongly exposed fields obtained outside the action range of the edge effects, D'_1 and D'_2 — minimal and maximal values of the optical density in weakly and strongly exposed fields, respectively, obtained in the place of edge effects action.

The differences in density expressed in Eqs. (1) and (2) are proportional to the absolute values of optical density in the image and background (D_1 and D_2) and to their differences:

$$\Delta D_1 = aD_1(D_2 - D_1), \tag{3}$$

$$\Delta D_2 = aD_2(D_2 - D_1) \tag{4}$$
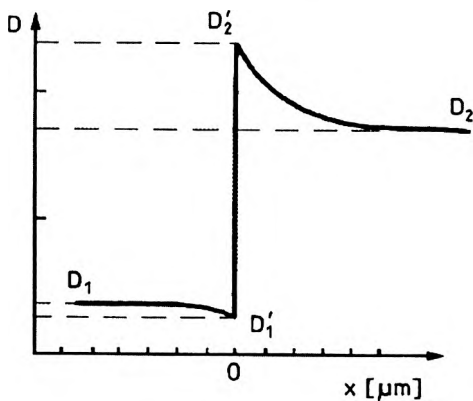
Fig. 2. Criteria of selection of the minimal (D'_1) and maximal (D'_2) optical densities of the weakly and strongly irradiated fields and the optical densities of these fileds obtained outside the operation range of the edge effects (D_1, D_2). These values are needed to calculate the intensity of the edge effects action.

where: a is a proportionality coefficient dependent on the kind of developer and the developing method.

Changes in the contour sharpness are caused by the edge effects and can be expressed in the form of a relative edge enhancement (REE) factor [7]. The value of REE can be found from the following equation:

$$\text{REE} = \frac{\Delta D' - \Delta D}{\Delta D} = \frac{(D'_2 - D'_1) - (D_2 - D_1)}{D_2 - D_1} \tag{5}$$

where: $\Delta D'$ — difference between the maximal and minimal densities within the edge effect range, ΔD — difference in high and low density outside the edge effect range.

The difference in optical densities ΔD follows from the exposure of both image and background, while the difference in optical densities expressed as $\Delta D'$ presents the result of the edge phenomena action (Fig. 2).

2. Characteristics of the model

An analytical model described by the Frieser function [8] was applied in the investigations taking advantage of the fact that the operation mechanisms of edge effects occurring during the chemical processing of the silver halogen photographic materials is as regards in its character and outcome similar to the effects caused by the light scattering in a layer. The simplest form of this function is presented by the equation

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

where: $L(x)$ — light spread function, x — distance from the light incidence place, K — Frieser factor of the first approximation.

This analogy allows us to apply the light spread function (6) to description of the edge effect action which has been called chemical spread function (ChSF) in reference to these phenomena. The superposition of those two functions gives the effective spread function (ESF) which permits description the total influence of the light scattering and edge effects on the sharpness of photographic images. The particular elements of this model are described in papers [9], [10]. In this work, a few modifications have been proposed based on the following assumptions:

— Chemical spread function is symmetric [1] − [3], but its intensity of operation is proportional to the level and difference of the optical density in the image and background.

— Chemical spread function acts H_2/H_1 times weaker on the side of the field of low optical density than on the side of high optical density, where H_1 and H_2 are the values of exposure in these fields.

— Contribution of the chemical spread function to the effective spread function is proportional to the difference of the optical density in the image and the background $(D_2 - D_1)$, respectively, and to the absolute value of the optical density in the image D_2.

— Characteristic curve describing the dependence of optical density on the logarithm of exposure is approximated by a straight line of proper slope (dependent on the assumed contrast of the irradiation-sensitive layer).

— Photometric coefficient describing the dependence of optical density on the content of silver in the unit area is expressed as a straight line of inclination tangent equal to one.

A scheme of model functioning allowing to calculate the influence of optical density in the image and background on both the intensity of edge effects and the changes of the limiting curve shape are presented in Fig. 3. This model is composed of six stages. At the first stage, the characteristic curve of the photographic material is generated on the basis of the equation (ChC block)

$$D = g \, \mathrm{Log}(H) \tag{7}$$

where: D − optical density, $\mathrm{Log}(H)$ − exposure logarithm, g − average gradient of the characteristic curve.

At this stage, the characteristic curve is used to calculate the optical densities of the image and the background (D_1, D_2) in terms of the values corresponding to the image and background exposures (H_1, H_2), respectively. At the next stage, the light spread function is generated on the basis of Frieser equation (6) (LSF block). In the module denoted as ChSF, the chemical spread function $b(x)$ is generated. The further stage consists in superposition of the light spread function with the chemical spread function which results in creation of an effective spread function (ESF(x)). After having performed the integration, within the limits H_1 and H_2, of the effective spread function and normalization (in block IN) the spatial distribution of exposure inside the layer $H(x)$ is obtained. Taking account of the characteristic curve the spatial distribution of exposure inside the layer is calculated to obtain the spatial optical density $D(x)$, i.e., the limiting curve.
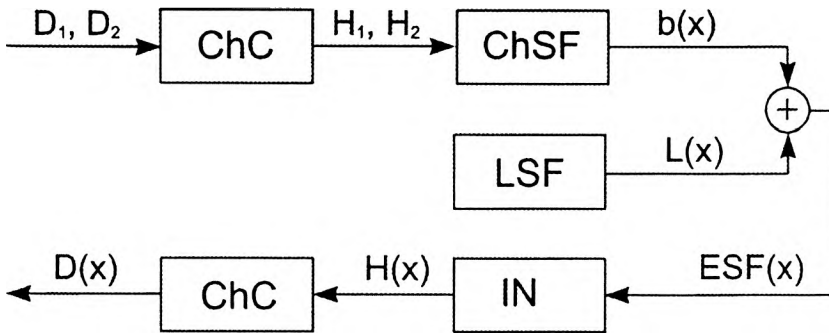
Fig. 3. Scheme illustrating the course of model examination of the edge effects occurring in the silver halogen light sensitive layers.

3. Results

The present model has been used to theoretical examinations of the influence of optical density on the edge effects. A quantitative analysis of the influence of the optical density level in the image and background on the shape of the limiting curve
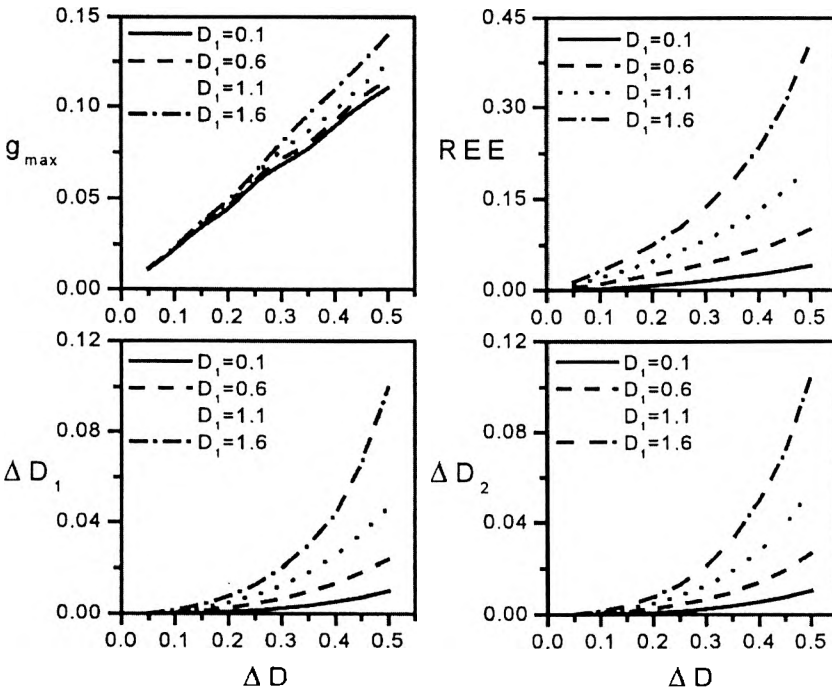

Fig. 4. Changes in maximal gradient of the limiting curve (g_{max}) and the intensity of edge effects action expressed in terms of REE indictor and the optical density differences ΔD_1 and ΔD_2 determined as a function of optical density difference in the image and the background (ΔD). These values were obtained for four levels of background optical density (D_1) amounting to 0.1, 0.6, 1.1 and 1.6, respectively. The calculations were carried out for the irradiation-sensitive layer of contrast equal to unity.

has been carried out the results of which are presented in Fig. 4. The calculations were performed for four levels of the optical density in the background amounting to 0.1, 0.6, 1.1, 1.6, respectively.

In these examinations the characteristic curve of gradient equal to unity was applied to calculate optical density in terms of exposure. Additionally, an analysis of the influence of contrast in the irradiation-sensitive layer on the shape of the limiting curve was carried out.
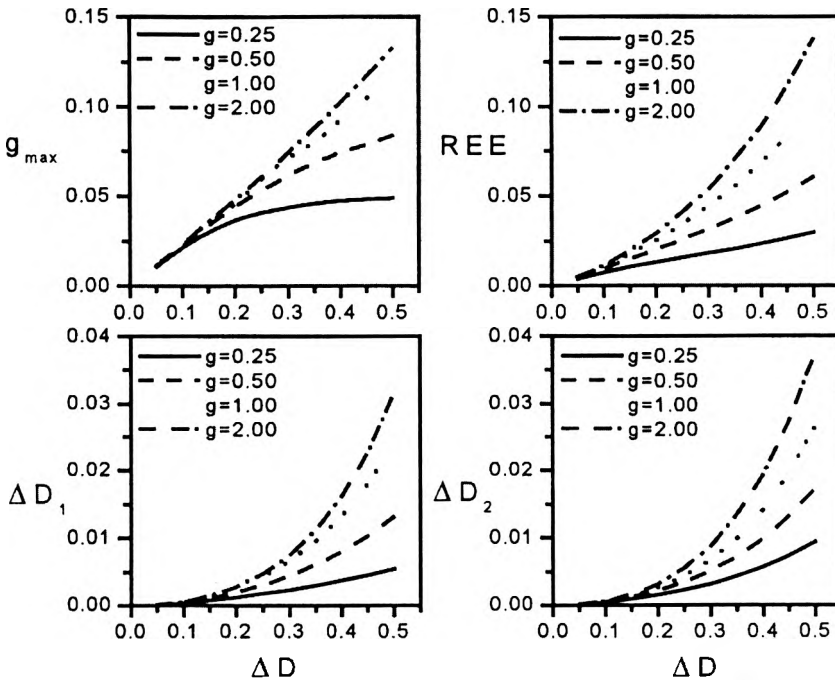

Fig. 5. Changes in both the maximal gradient of the limiting curve g_{max} and the intensity of the edge effects action expressed in terms of the REE indicator and the differences of optical density ΔD_1 and ΔD_2 determined as a function of the optical density differences in the image and the background ΔD. These values have been obtained for four irradiation-sensitive layers of different contrast for which the average gradients of the characteristic curves g were 0.25, 0.5, 1.0 and 2.0. The calculations were performed for optical density level in the background equal to 0.6.

In Figure 5, the results of this analysis are shown for four layers of average gradients equal consecutively to 0.25, 0.5, 1.0 and 2.0. The calculations were performed for the optical density levels in the background amounting to 0.6.

4. Conclusions

The results of the model examinations of the influence of the optical density on the edge effects permit us to state that the increment of the exposure level (increment of the optical density) and similarly the increment of the optical density difference for the image and the background cause some intensification of the edge effects action.

The quantitative analysis proved that the increment of both the optical density difference in the image and the background and the level of the two densities result in an increase of the value of the maximal gradient of the limiting curve for the optical density difference ΔD_1 (lower part of the limiting curve) and ΔD_2 (upper part of the limiting curve) as well as the relevant REE indicator (Fig. 4). The increase of the contrast of the irradiation-sensitive layer causes also the increase of the maximal gradient value for the limiting curve g_{max}, the differences in the optical density ΔD_1, ΔD_2 and the REE indicator (Fig. 5). The increase of these values speaks for an increase of the contour sharpness in the photographic image. These results are consistent with the results obtained experimentally.

Summing up, it should be stated that the consistency of the results obtained using the computer simulation with the results obtained experimentally is now much higher in comparison with those obtained using the previous model [9], [10]. It is achieved by defining the contribution of the chemical spread function to the effective spread function, the latter being proportional to the optical density difference in the imahe and the background $(D_2 - D_1)$ and the absolute value of the optical density in the image D_2 as well as to taking the contrast of the photographic material g into account.

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