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Sensitometric curve of radiographic films by X-ray fluorescence

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Abstract: Radiographic film exposure is traditionally measured by the transmittance of a beam of light through the film. There are many mathematical and computational models to characterize the curve behavior and its properties, but almost none of them considers the limitations caused by the equipment used. As long as exposure in film increases, light intensity measured after the film decreases in a way that from a certain exposure, light couldn´t be distinguished from any kind of noise. This work aims to propose x-ray fruorescence as a solution for better measure high exposed films and show how it could be modeled mathematicaly.

Keywords: Sensitometric Curve, X-ray fluorescence, dosimetric films

1. INTRODUCTION

Radiographic film is a well known and still very used way to measure ionizing radiation exposure both in research and in individual dosimetry.[1,2] The main propriety is the metallic silver concentration adhered to film after development due reaction with fotons [3-6].

As the metalic silver is opaque, its concentration increase turn the film also opaque. A way to measure this is by light trasmission across the film and how it is atenuated. The main models consider radiation exposure proportional to silver concentration, wich is proportional to light atenuation. So, read the optical density is indirectly measure the exposure before development [5,6].

For high values of optical density, the light that crosses the film is to low to be read, and it makes a upper limit for equipement, even if the silver concentration still growing. This fact brings a question about if another way to read silver concentration could be better for high exposures.

If the new method to measure silver had no limit, the H&D curve could have a range bigger than made by light measurement.

This work aims to show a litle correction in mathematical model for radiographic film due the light limitation and also sugest the x-ray fluorescense (XRF) as a way to read films avoiding this limitations.

2. MATHEMATICAL MODEL AND INSTRUMENT CORRECTION

2.1. The tradicionals models

Most of the models to the sensitometric curve are similar and take two considerations to make a mathematical model:

- The probability to a foton to interact to a halide silver grain in film (turning it into a black metalic silver grain) is proportional to the number of grains and the number of photons (wich is proportional to the total exposure)[7,8];
- To increase the optical density, a unsensitized grain must interact with a photon, and once sensitized, no matter if a new photon hits it again. It creates a saturation behavior, once number of the unsensitized grain decreases due exposure[7,8]

This behavior could be represented by the equation:

$$dN = -N\alpha QX \quad (1)$$

Where N is the number of unsensitized grains per area, α is the cross section of a single grain to x-ray photons, Q is a constant and X is the exposure. Solving this, we can find [7,8]:

$$N_a = N_0(1 - \exp^{-\alpha QX}) \quad (2)$$

N_a and N_0 are blackened and total number of grains per area, recpectively. As optical density is defined by reading values I_0 of light intensity entering and I crossing the film [7,8]:

$$OD = \log\left(\frac{I_0}{I}\right) \quad (3)$$

If we treat light photon interaction with matter like x-ray photons,

$$I = I_0 \exp^{n\sigma s} \quad (4)$$

$$OD = n\sigma s \log(e) \quad (5)$$

Where n is the grain concentration por volume, σ is the cross section for light and s is the emulsion tickness.

As said before, OD is proportional to N_a [7,8]:

$$OD = N_0 \sigma \log(e)(1 - e^{\alpha QX}) \quad (6)$$

This equation gives the OD in function of exposure X. The behavior can be seen in figures (1) and (2).

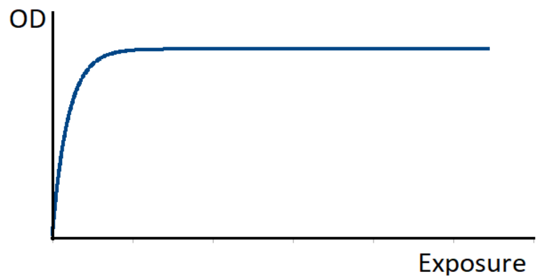

Figure 1 – OD x Exposure by equation (6). It starts increasing fastly but saturates soon.

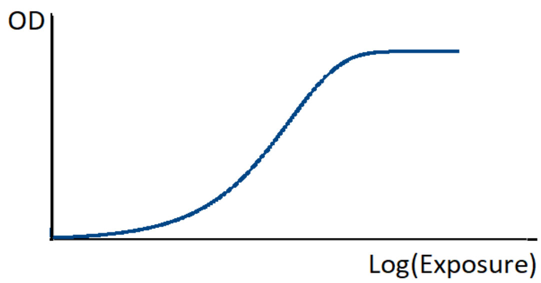

Figure 2 – OD x log(Exposure) by equation (6). It starts increasing slowly, became fastly but saturates soon. Between the slow part and the saturated part there is a linear.

2.2. Instrument correction

In equation (3), I is the light read in OD measurement after crossing the film. If we add a noise, the equation will be:

$$OD = \log\left(\frac{I_0}{I+\varepsilon}\right) \quad (7)$$

Doing same as did before the new final equation is:

$$OD = \log\left(\frac{I_0}{I_0 \exp\left(-\sigma N_0\left(1-e^{-\alpha Q X}\right)\right)+\varepsilon}\right) \quad (8)$$

For low values of X, ε is insignificant. For high' values, it gives a limitation in OD. This is shown in figure (3).

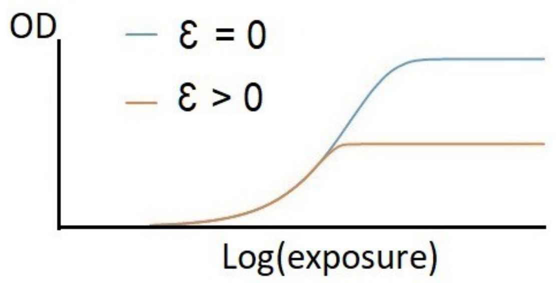

Figure 3 – OD x log(Exposure) by equation (8). When ε > 0, the saturation is in low values, hiding a signigicant range from characteristic curve.

3. MATERIALS AND METHODS

3.1. Exposing the films

Odontological KodaK E type films were exposed in a 40kV 80μA x-ray been, from an Amptek mini-X tube, in diferent exposures controled by time. A non exposed and a film exposed to light for a day were also made for create a "zero" and "infinite" exposures. The films were developed using a portable Kodak developing chamber and chemicals, using times and temperatures sugested by the manufacturer. The optical density by light was obtained using a X-rite densitometer, model 341.

3.2. XRF measurement

After read optical densities, each film was also read in a Amptek XRF equipement, 40 kV and 80 μA. The area of each Kα peack was taken to buld a XRF sensitometric curve.

3.3. Light and X-ray measurement fitting

.The next step is to fit Light and X-ray fluorescence reads, at least the low values. in the same graph , finding the proportion between them.

3.4. Finding paremeters to the equation corrected.

.Fitting curves and, theirs limits and proportion, its possible to find all the paremeters to build the film equation corrected by instrument limits. After, the theoretical optical density for all the exposures were calculated, to plot togheter.

4. RESULTS

4.1. Sentitometric curves by X-ray, light and theoretical

The graph showing the three curves is shown below.

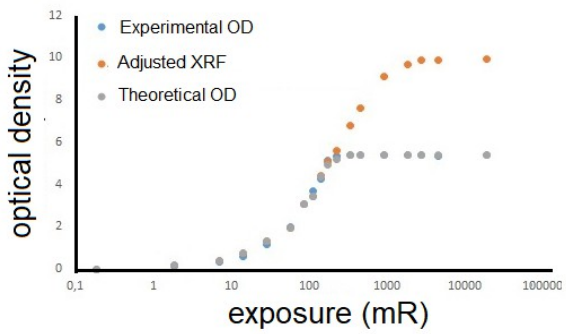

Figure 4 – OD x log(Exposure) and XRF measurement. XRF behaves like the total range without limitation.

.4.2. the equation corrected

The proportion between read optical density and Kα peak area (in number of counts) is β = 0,0012. Using this value, o better plot equation is given below:

$$OD = \log\left(\frac{4495}{4495^{\left(-22{,}9\left(1-e^{-0{,}0043X}\right)\right)}+0{,}0176}\right) \quad (9)$$

4. DISCUSSION

The mathematical model was created with a small correction of preexisting models, giving rise to a slightly larger expression because there were no simplifications previously used. Within a small statistical variation this model seems to be at least a good approximation for the relationship between the H & D curve and the limitation for optical density reading. The model still suggests ways to overcome the problem in some situations, requiring minimum and maximum values. For the light readers used in the curve construction, and consequently in the scanning of radiographic films. The model was successful in its experimental validation. The data used in this work has a pretty good fit. It was thus possible to construct the equation of the H&D curve for the film used in this work and predict how far it would go without limitation. The use of the X-ray fluorescence peak in place of the optical density was very successful avoiding the existence of a maximum value of the concentration of the plot. A characteristic curve made through XRF are due to the adjustment of the geometry and correction, showing purely proportional silver concentration, and convenient for use, besides proving the fact that the limiting density of the H&D curve is in the measure by optical density.

5. REFERENCES

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