CHROMATIC KINETICS IN THERMAL FIELD

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Abstract

The first section of the paper outlines the thermal kinetics of the thermoelectric cell and defines the thermistor as the heating element during the isothermal period. The paper then focuses on uniform wetting and heating by adding ethylene glycol. Data collection and processing algorithms are employed to convert between various color spaces and to provide the mathematical equations which describe the evolution of the specific L, a, b components.

Key words: kinetics, coloring, thermoelectric cell, color space

Description of the electrotechnical system.

Thermoelectric cell

![Thermoelectric cell diagram]

Figure 1 Laboratory set-up

A - amperemeter; CT – thermal cell; T – digital thermometer; TC – thermocouple; P – potentiometer

Figure 2 Heating kinetics curves (power voltage 220 V, 150 V, 80 V and 40 V) – cooling (power-off)

Figure 3 Volt-ampere characteristics

Thermistor

Figure 4 Electrotechnical representation of the thermistor

The thermistor as a low voltage heating element is characterized by the I.S. Steinhard and S.R. Hart model as follows [1 – 4]:

\[ \frac{1}{T} = f(\ln(R)) \]

where T is the temperature (°C) and R – resistance (Ω).

According to electrotechnical measurements, the constant temperature regime yields the following matrix of values which includes – by column – voltage (V), amperage (A), and temperature (°C):

\[ A = \begin{bmatrix} 220 & 0.01175 & 82 \\ 150 & 0.013 & 80 \\ 80 & 0.032 & 77 \\ 40 & 0.050 & 74 \end{bmatrix} \]

based on which the matrix RT = [resistance temperature] – by column – is calculated, using the formula:

\[ RT = \begin{bmatrix} A(:,1)/A(:,2) A(:,3) \end{bmatrix} \]

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Mathematical processing yields the following values:
\[
\frac{1}{T} &= [0.012195121951220, 0.012500000000000, 0.012987012987013, 0.013513513513514] \\
\ln(R) &= \log(RT(:,1)) \\
\ln(R) &= [9.837529584744331, 9.353441215616856, 7.824046010856292, 6.684611727667927].
\]

According to the graphical representation (1/T; ln(R)) as outlined in Figure 4, the dependence below results:
\[
\frac{1}{T} = 1.0e+003 \times [-2.487246719788137 \times \ln(R) + 0.040258959304479],
\]
which means that, in the present case, the thermistor is a Positive Temperature Coefficient Thermistor (PTC), i.e. the correlation higher temperature-higher resistance is observed. Moreover, the thyristor is a ceramic, Switching Type PTC, with rapid resistance increase as the temperature rises.

Wetting homogeneity

Based on the sequence: 
\[
A = \text{imread('4ic4-40V.jpg')}; \\
\text{% selecting n pixels from image} \\
[C,R,P] = \text{impixel(A)}; \\
\text{RGB = P./255}; \\
\text{the specific RGB values of the examined test samples.}
\]

Figure 5

Filter paper soaked with the cobalt chloride solution

Figure 4 Specific dependence of thermistor

MATERIAL AND METHOD

Compared to the vast field of chromatic studies included in the bibliographical references [5-16], for the purposes of this paper cobalt chloride on cellulose base (filter paper) with 1% ethylene glycol was used. Worldwide, no chromatic research has been performed previously, while chemistry literature has indicated that heating yields a color transformation from pink to blue [17, 18, 19].

It has also been specified that cobalt chloride – CoCl₂ 6H₂O – upon heating loses water molecules successively. The states with a number molecules standing at n = 6, 4 are pink, while forms containing n = 2, (1,5), 1 water molecules are blue. This effect is used on meteorological paper to deliver the qualitative indication of air humidity – dry (blue) and humid (pink).

Wetting homogeneity

Based on the sequence:
\[
A = \text{imread('4ic4-40V.jpg')}; \\
\text{% selecting n pixels from image} \\
[C,R,P] = \text{impixel(A)}; \\
\text{RGB = P./255}; \\
\text{the specific RGB values of the examined test samples.}
\]

Figure 6 RGB distribution for the cobalt chloride - distilled water system.

DS1 = std(RGB) \\
RGB = mean(RGB) \\
DS1 = [0.0103 0.0106 0.0104] \\
RGB = [0.4753 0.2930 0.5040]

Figure 7 RGB distribution for the cobalt chloride - ethylene glycol system

DS2 = std(RGB) \\
RGB = mean(RGB) \\
DS2 = [0.0087 0.0078 0.0144] \\
RGB = [0.4919 0.2898 0.4897]

Following the addition of 1% ethylene glycol in the wetting solution, with a 10 g/l concentration, uniform distribution on the sorption surface is observed as well as the uniform heating of the test sample on the thermoelectric cell. The values R - red, B - blue in the RGB triad are close in value. The standard deviation (DS) is lower for the chemical system containing ethylene glycol.
The matrix of time – temperature values for different power voltages

\[
\begin{align*}
T_{220}(t) &= -0.0004t^2 + 0.2948t + 22.0571 \\
T_{150}(t) &= -0.0004t^2 + 0.2752t + 21.3429 \\
T_{80}(t) &= -0.0003t^2 + 0.2526t + 21.1714 \\
T_{40}(t) &= 0.0003t^2 + 0.0731t + 20.2571
\end{align*}
\]

Table 1. Working matrix: by column: time (seconds), (1,1) – temperature at: 220 (V), (1,2); 150 (V), (1,3); 80 (V), (1,4); 40 (V), (1,5)

\[
p(\cdot,\cdot) =
\begin{bmatrix}
20.0000 & 27.7778 & 26.6889 & 26.0889 & 22.6822 \\
30.0000 & 30.5071 & 29.2429 & 28.4464 & 21.8222 \\
40.0000 & 33.1492 & 31.7175 & 30.7365 & 23.5937 \\
50.0000 & 35.7040 & 34.1127 & 32.9591 & 24.5567 \\
60.0000 & 38.1714 & 36.4286 & 35.1143 & 25.5714 \\
70.0000 & 40.5516 & 38.6651 & 37.2020 & 22.6822 \\
80.0000 & 42.8444 & 40.8222 & 39.2222 & 27.7556 \\
90.0000 & 45.0500 & 42.9000 & 41.1750 & 32.7422 \\
100.0000 & 47.1683 & 44.8984 & 43.0603 & 35.5467 \\
110.0000 & 49.1992 & 46.8175 & 44.8782 & 38.5556 \\
120.0000 & 51.1429 & 48.6571 & 46.6286 & 41.4187 \\
130.0000 & 52.9992 & 50.4175 & 48.3115 & 44.2677 \\
140.0000 & 54.7683 & 52.0984 & 49.9270 & 47.1177 \\
150.0000 & 56.4500 & 53.7000 & 51.4750 & 50.1777 \\
160.0000 & 58.0444 & 55.2222 & 52.9556 & 53.1277 \\
170.0000 & 59.5516 & 56.6651 & 54.3687 & 56.1777 \\
180.0000 & 60.9714 & 58.0286 & 55.7143 & 59.2277 \\
190.0000 & 62.3040 & 59.3127 & 56.9925 & 62.2777 \\
200.0000 & 63.5492 & 60.5175 & 58.2032 & 65.3277 \\
210.0000 & 64.7071 & 61.6429 & 59.3464 & 68.3777
\end{bmatrix}
\]

RESULTS AND DISCUSSION

In the dynamic heating regime, every 10 seconds, the digital images saved in .jpg format were stored.

Using the appropriate mathematical algorithm under the Matlab environment, successive transformations were performed in the RGB →XYZ →Lab color spaces using the Bradford spatial transformation matrixes:

\[
\begin{bmatrix} \text{cx} & \text{cy} & \text{A} \end{bmatrix} = \text{improfile}(\text{RGB}) = [\text{A}(:,:,1) \ A(:,:,2) \ A(:,:,3)]/255
\]

\[
\begin{bmatrix} \text{M} \text{xyzLab} \end{bmatrix} =
\begin{bmatrix} 0.4125 & 0.3576 & 0.1804 \end{bmatrix}
\]

By the chromatic kinetics presented below was aimed at tracing the influence of temperature, correlated with time, on L, a, b chromatic indicators. In the first stage, the aim was to determine rules for the representation of color dynamics.

Thermochromic dynamics

![Figure 9](image)

L(t) =
\[
\begin{bmatrix} 0.0003 & -0.0214 & 0.7059 \\
0.0001 & -0.0044 & 0.4822 \\
0.0037 & 0.3558 \\
0.0035 & 0.3574 \end{bmatrix}
\]

a(T) =
\[
\begin{bmatrix} -0.0031 & 0.0823 \\
-0.0030 & 0.0664 \\
-0.0020 & 0.0311 \\
-0.0018 & 0.0304 \end{bmatrix}
\]
CONCLUSIONS

The technical application of intelligent materials is an avant-garde movement in the scientific world, with expanding areas of use. Materials with variable chromatics are used as sensors to indicate humidity, temperature, electromagnetic radiation of various wavelengths, as comfort coloring substances (intelligent textiles), etc.

The present paper provides the foundations of a scientific methodology to induce coloring by setting up a 2 W thermoelectric cell with a PTC (Positive Temperature Coefficient Thermistor) serving as the active element, characterized by the dependence:

\[ \frac{1}{T} = 1.0e+003 \times [-2.487246719788137*\ln(R)+0.040258959304479] \]

in the isothermal period, with variables \( T \) – temperature \( [^\circ\text{C}] \) and \( R \) – resistance \( [\Omega] \).

Uniform wetting was indicated by the standard deviation of RGB values:

- \( DS1 = \begin{bmatrix} 0.0103 \\ 0.0106 \\ 0.0104 \end{bmatrix} \)
- \( DS2 = \begin{bmatrix} 0.0087 \\ 0.0078 \\ 0.0144 \end{bmatrix} \)

In most cases, the independent values \( L, a \) and \( b \) are assessed using first degree equations, corresponding to linear transformations. The values \( L40 \) and \( L80 \) undergo non-linear transformations, and the correlated time and temperature factors determine a second-degree dependence.

In the first 210 seconds of heating the heating kinetics were generated, expressed by second-degree mathematical equations:

\[
\begin{align*}
T_{220} &= -1.5714*t^2+17.6857*t+22.0571 \\
T_{150} &= -1.4285*t^2+16.5143*t+21.3429 \\
T_{80} &= -1.2143*t^2+15.1571*t+21.171 \\
T_{40} &= 0.9286*t^2+4.3857*t+20.2571,
\end{align*}
\]

where \( T \) – temperature \( [^\circ\text{C}] \) and \( t \) – time \( [\text{s}] \).

sRGB photographic sequences made every 10 seconds and stored in the .jpg format were processed through the \( \text{RGB} \rightarrow \text{XYZ} \rightarrow \text{Lab} \) conversion, tracing the kinetics of the transformation of the characteristic \( L, a \) and \( b \) values, to assess coloring achieved at the following power voltages: 40 V; 80 V; 150 V and 220 V.

- \( L_{40} = 0.0003*T^2 - 0.0214*T + 0.7059; \)
- \( L_{80} = 0.0001*T^2 - 0.0044*T + 0.4822; \)
- \( L_{150} = 0.0037*T + 0.3558; \)
- \( L_{220} = 0.0035*T + 0.3574; \)
- \( a_{40} = -0.0031*T + 0.0823; \)
- \( a_{80} = -0.0030*T + 0.0664; \)
- \( a_{150} = -0.0020*T + 0.0311; \)
- \( a_{220} = -0.0018*T + 0.0304; \)
- \( b_{40} = -0.0163*T + 0.1433; \)
- \( b_{80} = -0.0062*T - 0.1846; \)
- \( b_{150} = -0.0042*T - 0.2440; \)
- \( b_{220} = -0.0040*T - 0.2450; \)
- \( b_{40} = 2.6020*T - 0.2865; \)
- \( b_{80} = 2.4473*T - 0.2953; \)
- \( b_{150} = 2.4633*T - 0.2981; \)
- \( b_{220} = 4.96338*T - 0.3022. \)
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