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

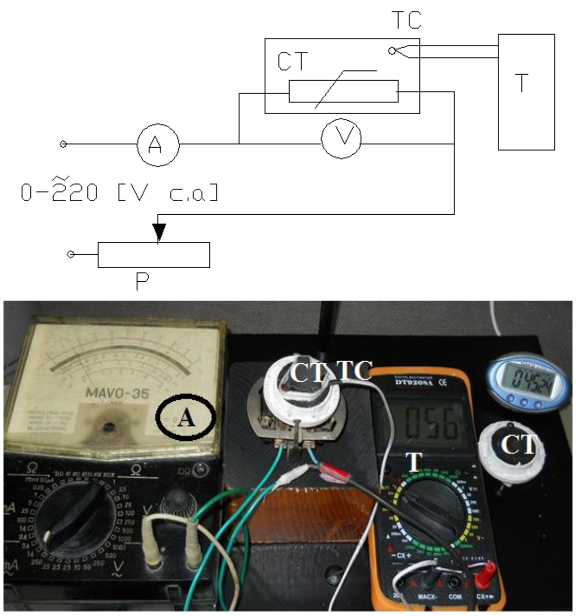

Figure 1 **Laboratory set-up**
A- amperemeter; CT – thermal cell; T – digital thermometer; TC – thermocouple; P – potentiometer

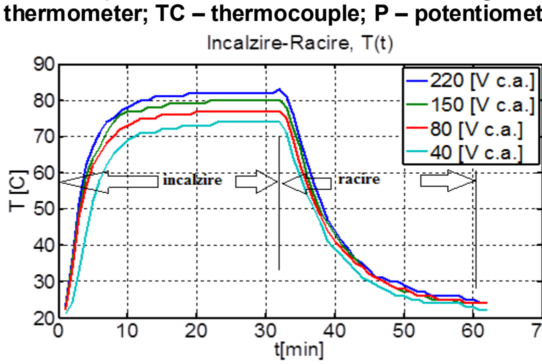

Figure 2 **Heating kinetics curves (power voltage 220 V, 150 V, 80 V and 40 V) – cooling (power-off)**

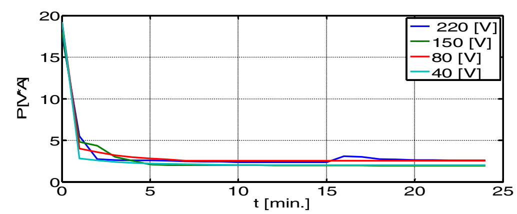

Figure 3 **Volt-ampere characteristics Thermistor**

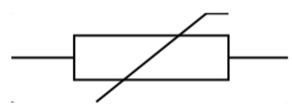

Figure 4 **Electrotechnical representation of the thermistor**

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

$$1/T=f(\ln(R)),$$

where T is the temperature (^{0}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 (^{0}C):

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

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

$$RT = [A(:,1)./A(:,2)\ A(:,3)]$$

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Mathematical processing yields the following values:

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:

1/T = 1.0e+003 * [-2.487246719788137*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.

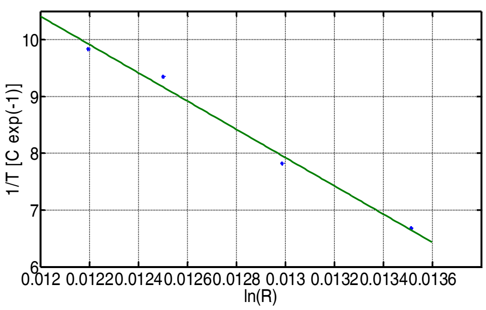


Figure 4 **Specific dependence of thermistor**

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].

Figure 5 **Filter paper soaked with the cobalt chloride solution**

It has also been specified that cobalt chloride – $CoCl_2$ $6H_2O$ – 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=imread('4ic4-40V.jpg');
% selecting n pixels from image
[C,R,P]=impixel(A);
RGB=P./255;
```

the specific RGB values of the examined test samples.

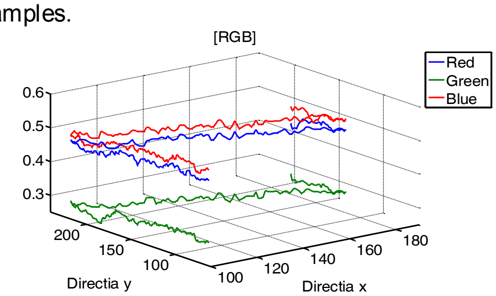


Figure 6 **RGB distribution for the cobalt chloride - distilled water system.**

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

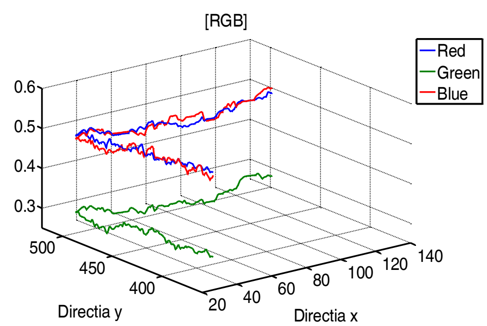


Figure 7 **RGB distribution for the cobalt chloride - ethylene glycol system**

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

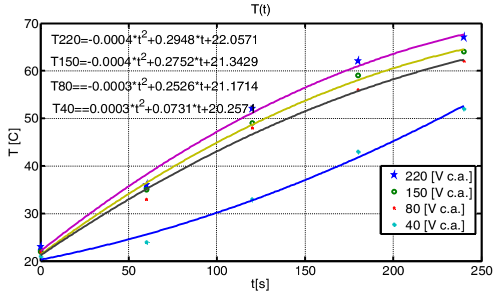


Figure 8 **Heating kinetic curves**

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

p(:,:) =[0	22.0571	21.3429	21.1714	20.2571
10.0000	24.9611	24.0556	23.6639	21.0139
20.0000	27.7778	26.6889	26.0889	21.8222
30.0000	30.5071	29.2429	28.4464	22.6821
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	26.6377
80.0000	42.8444	40.8222	39.2222	27.7556
90.0000	45.0500	42.9000	41.1750	28.9250
100.0000	47.1683	44.8984	43.0603	30.1460
110.0000	49.1992	46.8175	44.8782	31.4187
120.0000	51.1429	48.6571	46.6286	32.7429
130.0000	52.9992	50.4175	48.3115	34.1187
140.0000	54.7683	52.0984	49.9270	35.5460
150.0000	56.4500	53.7000	51.4750	37.0250
160.0000	58.0444	55.2222	52.9556	38.5556
170.0000	59.5516	56.6651	54.3687	40.1377
180.0000	60.9714	58.0286	55.7143	41.7714
190.0000	62.3040	59.3127	56.9925	43.4567
200.0000	63.5492	60.5175	58.2032	45.1937
210.0000	64.7071	61.6429	59.3464	46.9821]

RESULTS AND DISCUSSION

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

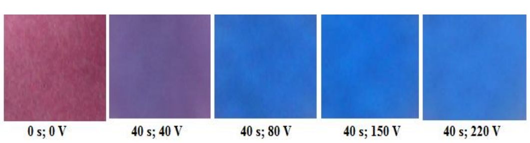


Figure 8 **Sequence of .jpg-type images**

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:

[cx,cy,A]=improfile
RGB=[A(:,:,1) A(:,:,2) A(:,:,3)]./255

Msrgbxyz =[0.4125 0.3576 0.1804
0.2127 0.7152 0.0722
0.0193 0.1192 0.9502]

M xyzLab=[0 1 0
1 -1 0
0 1 -1]

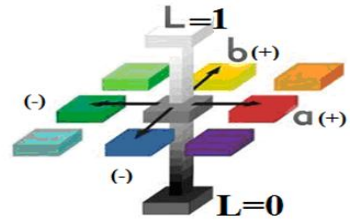
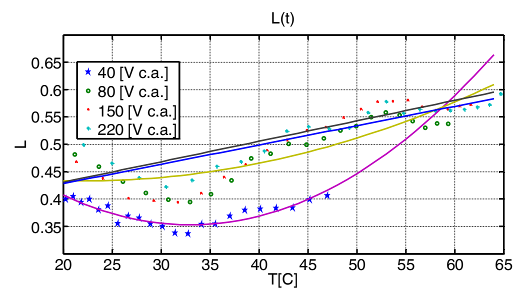


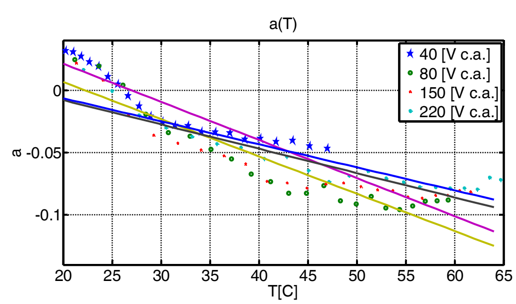
Figure 9 **Meaning of color shifts in the L*a*b* space**
a(-) – more green, a(+) – more red,
b(+) – more yellow, b(-) = more blue,
white at L=1.00 and black at L=0.

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.

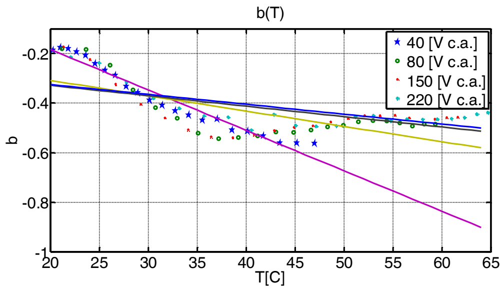
Thermochromic dynamics



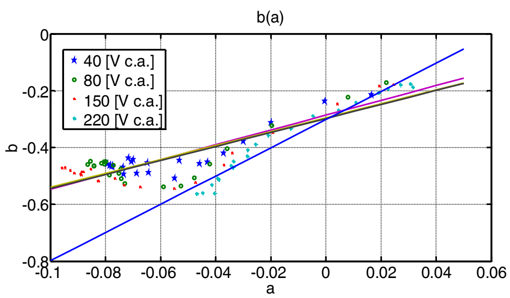
L40 = [0.0003 -0.0214 0.7059]
L80 = [0.0001 -0.0044 0.4822]
L150 = [0.0037 0.3558]
L220 = [0.0035 0.3574]



a40 = [-0.0031 0.0823]
a80 = [-0.0030 0.0664]
a150= [-0.0020 0.0311]
a220 = [-0.0018 0.0304]



b40 = [-0.0163 0.1433]
b80 = [-0.0062 -0.1846]
b150= [-0.0042 -0.2440]
b220 = [-0.0040 -0.2450]



b40 = [2.6020 -0.2865]
b80 = [2.4473 -0.2953]
b150 = [2.4633 -0.2981]
b220 = [4.9633 -0.3022]

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:

1/T = 1.0e+003 * [-2.487246719788137*ln(R)+0.040258959304479],

in the isothermal period, with variables T – temperature [^{0}C] and R – resistance [Ω].

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

DS1 = [0.0103 0.0106 0.0104]
DS2 = [0.0087 0.0078 0.0144]

Uniform wetting is correlated with uniform heating when ethylene glycol is added.

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

T220=-1.5714*t^2+17.6857*t+22.0571
T150=-1.4285*t^2+16.5143*t+21.3429
T80==-1.2143*t^2+15.1571*t+21.171
T40==0.9286*t^2+4.3857*t+20.2571,

where **T** – temperature [^{0}C] and **t** – time [s].

sRGB photographic sequences made every 10 seconds and stored in the .jpg format were processed through the **RGB →XYZ →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.

L40 = 0.0003*T^2 -0.0214*T + 0.7059;
L80 = 0.0001*T^2 -0.0044*T + 0.4822;
L150 = 0.0037 *T + 0.3558;
L220 = 0.0035 *T + 0.3574;

a40 = -0.0031*T + 0.0823;
a80 = -0.0030 *T + 0.0664;
a150 = -0.0020 *T + 0.0311;
a220 = -0.0018 *T + 0.0304;

b40 = -0.0163*T + 0.1433;
b80 = -0.0062*T - 0.1846;
b150 = -0.0042*T - 0.2440;
b220 = -0.0040*T - 0.2450;

b40 = 2.6020*T - 0.2865;
b80 = 2.4473*T - 0.2953;
b150 = 2.4633*T - 0.2981;
b220 = 4.96338*T - 0.3022.

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.

REFERENCES

Baker B.C., 1999 -*Thermistor in Single Supply Temperature Sensing Circuits*, DS00685B – pg. 1 -11, AN685, Microchip Tehnology Inc.;

Bamfield P., 2001 - *Chromic Phenomena. The Technological Applications of Colour Chemistry*, The Royal Society of Chemistry, ISBN 0-8404-474-4, 371 pg.;

Beretta G., 2008 - *Understanding Color, In-Company Courses for US Patent and Trademark Office 2600*, Alexandria, VA, Hewlett-Packard Co;

Bull K., 2008 - *Thermistors and Thermocouples: Matching the Tool to the Task in Thermal Validation, JVT* – The Journal of Validation Technology, vol. 14, no. 2;

Fritsch E., Massi L., Rossman G.R., Hainschwang T., Jobic S., Dessapt R., 2007 - *Thermochromic and photochromic behaviour of "chameleon" diamonds*, Diamond & Related Materials, no. 16 , pg. 401-408

Hiltunen Jouni - 2002, Accurate Color Measurement, University of Hoensuu, Finland, ISBN 952-458-077-2;

Keum S.R., Ma S.Y., Lim H.W., Han T.H., Kyu-Hyun C., 2012 - *Facile Evaluation of Thermodynamic Parameters for Reverse Thermochromism of Indolinobenzospiropyran-6-carboxylates in Aqueous Binary Solvents*, Bull. Korean Chem. Soc., Vol. 33, No. 8, pg. 2683;

Klanjšek M.G., 2010 - *Dynamic Colour of chromogenic materials*, IX Congreso Nacional del color, Alicante;

Kooroshnia M., 2013 - *Leuco dye-based thermochromic inks: recipes a quide for designing textile surfaces*, 13th AUTEX World Textile Conference, May 22nd to 24th , Dresden, Germany

Konopelnyk O.I., Aksimentyeva O.I., 2011 - *Thermochromic effect in conducting polyaminoarenes, UDC 78.40, 78.66*, Chemical Department of Ivan Franko, National University of Lviv, Ukraine;

Krichevsky G.E., 2013 - *"SMART" dyes and pigments and their use for a new purpose: Chrome - can reversibly changes color*;

López Muñoz G.A., Gerardo. A., Orozco V., 2009 - *Three Dimensional Temperature Distribution Analysis of Ultrasound Therapy Equipments Using Thermochromic Liquid Crystal Films, New Developments in Liquid Crystals, Book edited by: Georgiy V. Tkachenko*, ISBN 978-953-307-015-5, pp. 234, I-Tech, Vienna, Austria;

Negoiu D., 1972 - *Tratat de chimie anorganică*, vol. III, Editura Tehnică, pg. 1135;

Pauling L., 1972 - *Chimie generală*, Editura Ştiinţifică şi enciclopedică, pg. 637;

Robert C.M., Robertson S., Taylor S., 2007 - *Design Concepts for a Temperature-sensitive Environment Using Therochromic Colour Change*, Colour: Design&Creativity, no. 1 -5, pg. 1 – 11, School of Textile$Design, Heriot Watt University, Scottish Borders Campus, Galashiels, UK;

Petruševski V.M., Bukleski M., 2008 - *The economic demonstrator: Prepare it once, use it many times. III. Phenomena of discontinuous thermochromism*, Chemistry, Vol. 17, Iss. 2, University, Skopje, MACEDONIA

Ripan R., Ceteanu I., 1969 - *Chimia metalelor*, vol. II, Editura Didactică şi Pedagogică Bucureşti, pg. 514;

Shubhaschandra S. N., 2013 - *Effect of some selective surfactants on the thermochromic behavior of polyvinyl alcohl* - borax gel, Int. J. Chem. Sci., ISSN 0972-768X, 11(1), pg. 29-38

Saeli M., Piccirillo C., Warwick M.E.A., Binions R., 2011 - *Thermochromic Thin Films: Synthesis, Properties and Energy Consumption Modelling, Materials and processes for energy: communicating current research and technological developments* (A. Méndez-Vilas, Ed.);

Slanska P., 2008 - *Application of thermochromic compounds in polymeric materials, Faculty of Chemistry, Brno University of Technology*;

Sage Ian - 2011, *Thermochromic liquid crystals*, Liquid Crystals, 38:11-12, pg. 1551-1561;

Seeboth A., Lotzsch D., 2012 - *Thermochromic Polymers, Encyclopedia of Polymer Science and Technology*, Ed. John Wilwy&Sons, www.aspeak.net,vol. 12, pg. 143, Fraunhofer Institute of Applied Polymer Research, Berlin, Germany;

Seeboth A., Ruhmann R., Mühling O., 2010 - *Thermotropic and Thermochromic Polymer Based Materials for Adaptive Solar Control*, Materials, no. 3, pg. 5143-5168;

Tamburini A., Micale G., Ciofalo M., Cipollina A., 2013 - *Experimental Analysis via Thermochromic Liquid Crystals of the Temperature Local Distribution in Membrane Distillation Modules*, Chemical Engineering Transactions, vol. 32, pg. 2014;

Uhrikova D., Sarka K., 2008 - *Phisical characteristics of thermistor*, www.fpharm.uniba.sk/fileadmin/ user _ upload/english/Fyzika/Thermistor.pdf

van der Werff L., Kyratzis I.L., Robinson A.,. Cranston R, Peeter G., 2012 - *Formation of novel composite fibres exhibiting thermochromic behavior*, 18th international Conference on Composite materials, Australia;

Waseem I., 2012 - *An Investigation into Textile Applications of Thermochromic Pigments*, Heriot-Watt University, School of Textiles and Design;

Wiberg R., Noam L., 2004 - *Errors in thermochromic liquid crystal thermometry, Review of Scientific Instruments*, vol. 75, no. 9, American Institute of Physics ;

Xia T., Cui L., Zhao Y., 2004 - *Confinement Effects on Photoalignment, Photochemical Phase Transition, and Thermochromic Behavior of Liquid* Crystalline Azobenzene-Containing Diblock Copolymers, Macromolecules , no. 37, pg. 3101-3112;