A PHYSICAL STUDY OF THE ART OF MARBLING

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EBRU SANATI'NIN FİZİKSEL ÖZELLİKLERİ

ÖZET

600 yıllık bir geçmişi olan 'Ebru Sanatı' usta-çırak ilişkisi içinde günümüze kadar sürmüştür. Ebru yapımında kullanılan malzemelerin oranları ustaların yaptığı, deneme yanılmalarla geliştirilmeye çalışılmış fakat bilimsel verilere oturtulamamıştır. Ebru yapımında geven bitkisinden elde edilen kitrenin suda eritilmesi ile taban sıvısı oluşturulur. Boya, su ve öd karışımı (boya eriyiği), taban sıvısı üzerine damlatılır. Boya eriyiği taban sıvısı üzerinde kendine yer açar. Sonra atılan boya eriyikleri de kendinden önce atılanları iterek, kitreye ulaşır yüzeyde yayılır.Yüzey üzerinde meydana gelen üç boyutlu boya tabakası şekillendirildikten sonra kağıt üzerine iki boyuta alınır. Bu olaya 'Ebru' adı verilir Yapılan çalışmada malzemelerin yoğunlukları, yüzey gerilimi sabitleri ve karışım oranları belirlendi. Boya eriyiklerinin kitre yüzeyindeki hareketinde hızları, birbirleriyle etkileşmeleri ve yüzeyde oluşturdukları tabaka kalınlıkları hesaplandı. Bu tabaka kalınlığının maksimum değeri ve kalınlığın aşımındaki çökmeler incelendi.

ABSTRACT

Dating back to a 600-year history, The Art of Marbling has hitherto been living with master-apprentice relationship [1]. The ratios of the materials used have been tried to be developed by the trial and error method by masters, rather than through scientific data, which sometimes led to unsuccessful results. For the manufacturing of the marbling paper, first the basis liquid is formed by dissolving the gum tragacanth obtained from the astragalus plant in water [2]. The dye solutions prepared from dye, water and bile mixed at different ratios are dropped on the basis liquid beginning with the one having the greatest surface tension coefficient. The three-dimensional dye layer formed on the surface is figured and taken away to a two-dimensional paper. This phenomenon is called " The Art of Marbling ". The thicknesses of the dye solutions formed on the basis liquids are investigated by the optical methods and found to be $\approx 10^{-5}$ cm.

1. INTRODUCTION

Many publications can be found in literature about the art side but no scientific explanation has been made by this phenomena. The gum tragacanth is a poly saccaride, which is obtained from the astragalus plant found in high mountains [3]. The gum tragacanth should be dissolved in water. for the unit preparation (1 in Table 1) needs; 1 gram gum tragacanth and 110 ± 20 millilitres water. The surface tension coefficient of the basis liquid is approx 70 dyn/cm. Water and bile are used in preparing the dye solution [4]. Every kind of dye has a different capacity of absorbing water and bile. After the preparation of the basis liquid that forms the first layer, various dye solutions in different concentrations are prepared as shown in Table 1. These dye solutions have the surface tension coefficients in the range of 50-90 dyn/cm. Bile is used to propagate the dye solutions easily on the basis liquid [5]. The density and the surface tension coefficient of the bile is 1.2 g/cm^3 and 50 dyn/cm respectively.

Table 1. The dye-bile-water ratios used in preparing dye solutions

Dye Layer	1	2	3	4	5
Bile (cm^3)	1X1	1x2.75	1x4.5	1x6	1x9
Water (cm^3)	1X1	1x2	1x2	1x2	1x2
Surface tension coefficient (dyn/cm)	86	80	73	66	61

Pigment and oxide dyes are used in preparing the dye solutions. The elements found in gum tragacanth and dyes via XRF analysis are shown in Table 2.

Table 2. XRF analysis of the materials used.

Materials	Elements
Gum Tragacant	K, Ca
Pigment Blue	Sn, Ba, Rb, Sr, Y, Zr, Fe, Ce
Pigment Red	Sn, Ba, Se, Cu, Fe, Zn, Sr, Cr
Oxide Red	Fe, Ca, Cu, Sn
Oxide Yellow	Fe, Sn, Cu, Y
Oxide Black	Ca, Sr, Sn, Fe, Cu
Indigo Blue	Ca, Sr, Ba, Rb, Sn, Fe, Cu

2. EXPERIMENT

2.1. The Variation of the Surface Tension Coefficient with Time:

The surface tension coefficient of the gum tragacanth which is an organic matter, varies from 70 dyn/cm down to 50 dyn/cm due to the formation of fungus, a value which does not enable marbling . But salt is used to delay this variation. Tate is Law is used to determine the surface tension coefficients.

2.2. To Determine the Dropping Height for the Maximum Propagation of the Dye Solutions on the Basis Liquid:

When the dye solution is dropped on the basis liquid, it propagates radially but if the solution rate is not proper, it sinks in the basis liquid.

Dropping height is as important as the surface tension in the propagation of the dye solution on surface tension of the basis liquid. In this work, dropping heights were changed from 0 - 100 cm in the ranges of 0-25 cm and 25-100 cm, it is observed that the radius is increased and then decreased respectively as shown in Figure 2. It is well-known (by trial and error methods used) by the masters of the Art of Marbling, that the maximum propagation can be obtained by 25-30 cm of dropping height.

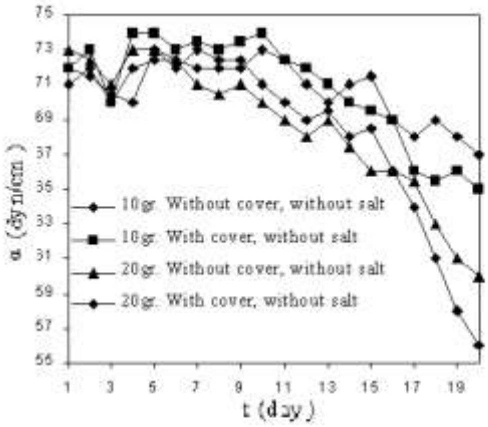


Figure 1. The variation of the surface tension coefficients with time

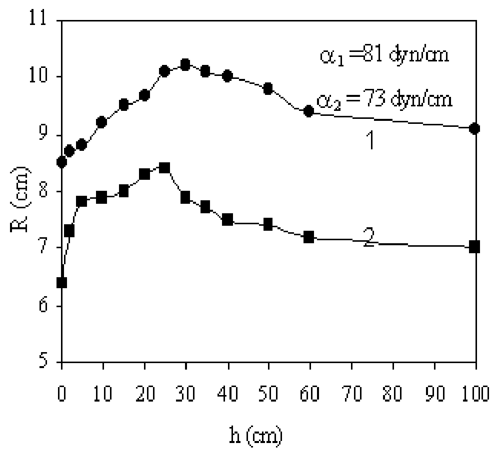


Figure 2. The effect of the dropping height on the radius (R).

2.3. The Propagation Rate of the Dye Solution on the Basis Liquid

The propagation rate of the dye solutions on the basis liquid is indirectly proportional with the surface tension coefficients. For different dye solutions, the smaller the surface tension coefficient, the bigger the propagation rates. The propagation rates of the pigment dyes are found to have larger values when compared with the oxide dyes.

2.4. Interaction of Two Dye Solutions with the Basis Liquid

2.4.1. Side by Side Interaction

Two drops of solutions are released side by side and found:
a) A and B are two dye solutions whose surface tension coefficients and volumes are equal. The drops repel each other with equal forces if they are dropped side by side simultaneously (Fig.4-1).

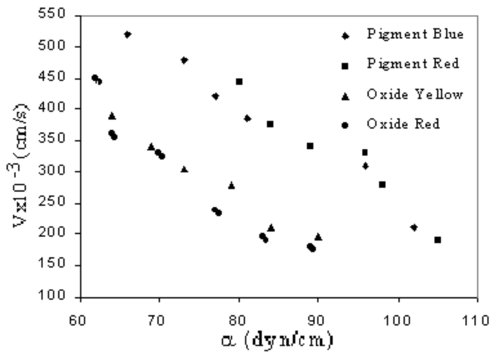


Figure 3. The propagation rate of the dye solution on the basis liquid

b) A and B are two dye solutions with having different surface tension coefficients. The latter droprepels the previous drop strongly, if they are dropped sequentially (Fig. 4- 2).
c) The latter drop repels the previous drop weakly if they are dropped sequentially (Fig.4-3).

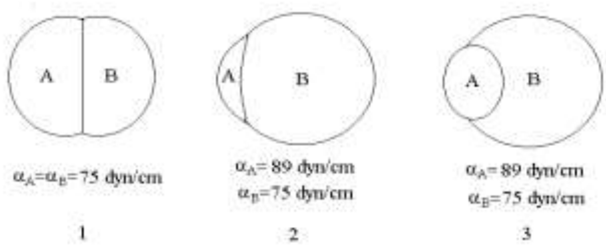


Figure 4. Side by side interaction of two dye solutions

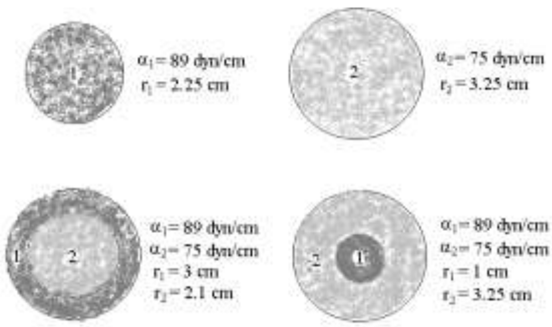


Figure 5. Sequential interaction of dye solutions

2.4.2. Sequential Interaction

When the dye solutions having different surface tension coefficients α_1 and α_2 ($\alpha_1 > \alpha_2$) are dropped onto the basis liquid sequentially , the latter drop (α_2) finds a place for itself on the basis

liquid. But if the latter drop is the one having the surface tension coefficient α_1, this does not work; in other words, the latter drop sinks into the basis liquid.
As seen in side by side interaction, dropping sequence is important. But in the sequential interaction, dye solution does not form (one after the other) layers on the basis liquid. When the dye solutions are dropped sequentially (one after the other), the latter drop reaches the basis liquid by drilling the first (Figure 6).

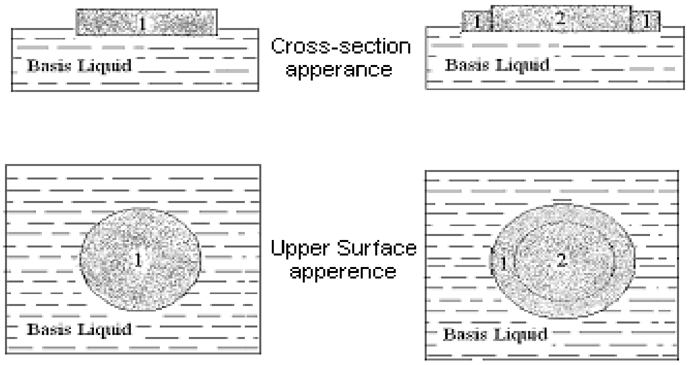


Figure 6. One after the other interaction

To prove this, dye solutions and colourless solutions are dropped sequentially onto the surface of the basis liquid, as shown in Figure 7. It is observed that the latter drop locates on the surface of the basis liquid by pushing the previous drop.

Figure 7. Location of the dye solution drop (latter) on the surface of the basis liquid

2.5. Determination of the Thickness of the Dye Solution by Optical Methods

The figure of the film formed on the dye solution is assumed to be a cylinder. The thickness can easily be determined by using the area of the film formed and the volume of the dye solution.
The method used for determining the thickness is by measuring the intensities of light before entering and after leaving the sample. For these measurements, the dye solution should cover the surface completely. The pot used is small enough to limit the propagation of the dye solution. By comparing the light intensities; absorption coefficients can be determined from

$$I_1 = I_0 e^{-\alpha x}$$

where I_1, I_0 and α are light intensities before entering, after leaving the substrate and absorption coefficient respectively.

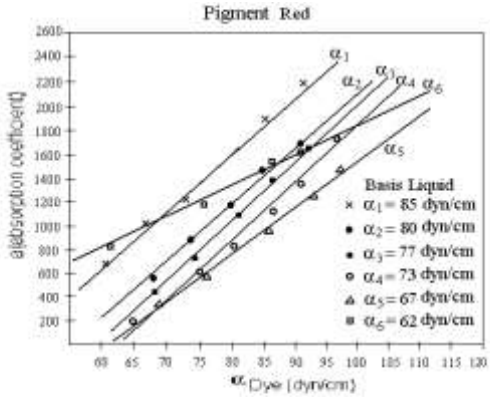
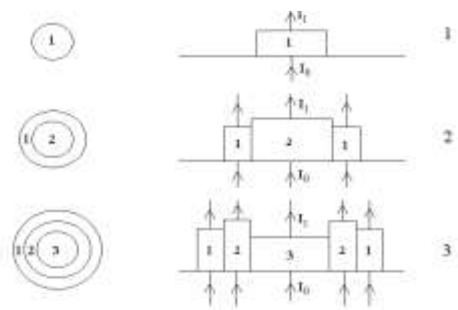


Figure 8. The absorption coefficients of pigment red dye solutions formed on dyes with various concentrations

These absorption coefficients are used to determine the thicknesses of the dye solutions.
Case 1) First layer of the dye solution is dropped onto the basis liquid. Freely propagation of the dye solution is provided by selecting the area large enough (≈ 50 cm^2). The intensities of lights leaving the basis liquid and the dye solutions are I_O and I_1 respectively. The thickness of the film formed on the basis liquid is determined by using the absorption coefficients (Figure 9-1).
Case 2) Second layer of the dye solution is dropped on the first layer centrally. The thicknesses of the first and second layers are determined by the same procedure (Figure 9-2).
Case 3) Third layer of the dye solution is dropped centrally on the second layer and again the thicknesses of the first, second and third layers are determined (Figure 9-3).



Upper surface apperance Cross section apperance

Figure 9. Investigation of the film thicknesses of various dye solutions in three cases

The thicknesses of the dye solutions on the basis liquid obtained by the absorption method is close to the ones obtained by "cylindrical form".

Table 3. The thicknesses of the dye solution films determined by absorption and cylinder form assuming cylindrical form

		Assuming cylindir form	By absorption
Oxide Yellow	case a	X_1=7.44x10^{-5} cm	X_1=8.0x10^{-5} cm
	case b	X_1=14.1x10^{-5} cm X_2=17.7x10^{-5} cm	X_1=9.5x10^{-5} cm X_2=12.0x10^{-5} cm
	case c	X_1=18.8x10^{-5} cm X_2=22.2x10^{-5} cm X_3=16.8x10^{-5} cm	X_1=23.0x10^{-5} cm X_2=22.0x10^{-5} cm X_3=15.5x10^{-5} cm
Pigment Blue	case a	X_1=7.8x10^{-5} cm	X_1=6.5x10^{-5} cm
	case b	X_1=13.5x10^{-5} cm X_2=17.7x10^{-5} cm	X_1=7.9x10^{-5} cm X_2=14.1x10^{-5} cm
	case c	X_1=13.8x10^{-5} cm X_2=23.8x10^{-5} cm X_3=21.0x10^{-5} cm	X_1=14.0x10^{-5} cm X_2=17.0x10^{-5} cm X_3=12.6x10^{-5} cm

2.6. The Variation of the Thicknesses Formed by Dye Solutions

Dye solutions sink into the basis liquid and also they diffuse into the other dye solutions when the film height is over the critical value. The film thicknesses and the sinking process after the 6 th dye solution (pigment blue and oxide red) is shown in Table 4 and Figure 10.

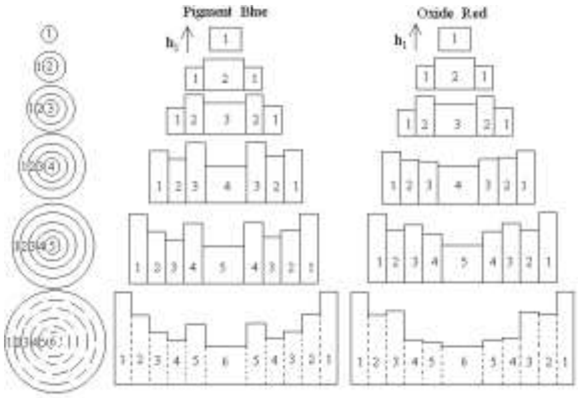


Figure 10. The film thicknesses after the 6th dye solution

3. RESULTS

The surface tension coefficients of the gum tragacanth vary with time from the value of 70 dyn/cm down to 50 dyn/cm by the formation of fungus. Salt is used to prevent the formation of fungus, the surface tension coefficients are kept nearly constant. The surface tension coefficients of the dye solutions dropped onto the basis liquid solution, change from 50 dyn/cm to 90 dyn/cm. Bile is used to change the surface tension coefficient which contains colic acid. The cohesion and adhesion forces between the dyes are weakened by this acid; and the surface tension coefficient of the solution decreases.

Table 4. The film thicknesses at the critical value

Pigment Blue						
Dye layers	1st layer	2nd layer	3th layer	4th layer	5th layer	6th layer
Layer thicknesses in free space V=20ml	$7x10^{-5}$cm	$4x10^{-5}$cm	$3x10^{-5}$cm	$2x10^{-5}$cm	$1.2x10^{-5}$ cm	$0.9x10^{-5}$ cm
Critical value for layers thicknesses V=20ml	$27.5x10^{-5}$ cm	$18.9x10^{-5}$ cm	$15.6x10^{-5}$ cm	$15.1x10^{-5}$ cm	$16.4x10^{-5}$ cm	$15.1x10^{-5}$ cm
Surface tension coefficient (dyn/cm)	86	80	73	66	63	61

Oxide Red						
Dye layers	1st layer	2nd layer	3th layer	4th layer	5th layer	6th layer
Layer thicknesses in free space V=20ml	$7x10^{-5}$cm	$3.7x10^{-5}$cm	$2.2x10^{-5}$ cm	$1.8x10^{-5}$ cm	$1.5x10^{-5}$ cm	$1.2x10^{-5}$ cm
Critical value for layer hicknesses V=20ml	$33.2x10^{-5}$ cm	$30.7x10^{-5}$ cm	$32.5x10^{-5}$ cm	$29.7x10^{-5}$ cm	$27.4x10^{-5}$ cm	$19.2x10^{-5}$ cm
Surface tension coefficient (dyn/cm)	87	84	76	73	68	5

XRF analysis showed that the atomic numbers of the elements used in dye manufacturing are between 28-58.
Dropping height is also important for the propagation of the dye solution on the basis liquid. A height of 25cm provides the max. propagation .
The propagation rates of the dye solutions are inversely proportional with the surface tension coefficients. It is observed that the pigment dyes propagate faster than the oxide dyes.
If the dye solutions are dropped onto the basis liquid one after the other, they don't form sequential layers on the surface. The last drop, pushes the first drop and reaches the basis liquid by finding a place for itself. For the marbling, the surface tension coefficient of the latter drop should be smaller than the previous one. The reverse procedure disables marbling.
The film thicknesses formed by the dye solutions on the basis liquid are determined by two methods. The thicknesses of the films are around 10^{-5} cm . It is observed that the diffusion and sinking occur when the film thickness are over the critical value.
It is assumed that the figure of the dye solution formed on the basis liquid is similar to the form of a cylinder. But the real figure is a sphere cap in the middle and toroid on the sides.
The art of marbling is a two-dimensional configuration which is taken away from the surface of the three-dimensional dye layer.

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