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Team 3 Report: Paint

1 Introduction

This image of various colors of paints being bored over a porous Styrofoam block was created as part of the third team project for the Flow Visualization course at the University of Colorado at Boulder. The image was inspired by David Kaufman's "Tall Painting,"[1] in which alternating colors of paint are pored over a rectangle, and the contours formed as the paint flows to the base have fine layers. This image was manipulated slightly more using a toothpick. The final image is shown in Figure 1.

Figure 1: Final Image

2 Experimental Setup

The experiment consisted of a coarsely broken piece of Styrofoam being secured to a flat base piece of Styrofoam via a toothpick through the center, but without the toothpick being exposed. The setup can be seen in Figure 2. The Styrofoam base was approximately 40 x 40 cm, and the coarse piece had a 5 x15 cm base and a height of 15cm.

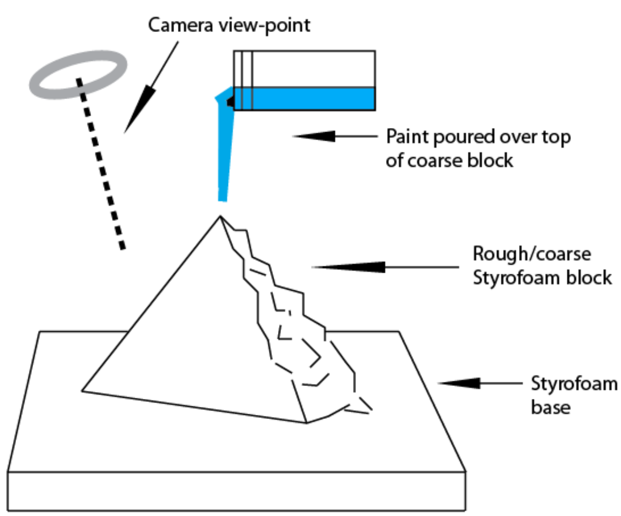

Figure 2: Experimental Setup

The first step of the experiment consisted of pouring paint on to the top of the block at a slow rate for about three seconds, then switching to a new color and repeating, as shown schematically in Figure 2.

Thereafter, team members tool turns dragging a toothpick lightly through the paint to move the contoured layers of paint from their original position, and creating new shapes from these contours. Additionally, as seen near the center of Figure 1, the toothpick was depressed into the paint, creating a "canyon," shortly before the image was taken.

3 Discussion of Fluid Properties

Three main aspects of the flow of the paint were examined: (1) the tendency of the contours to form while flowing down the block, (2) the movement of the contours with a toothpick, and (3) the formation of a "canyon" in the paint by depressing a toothpick.

While the paint is still wet, the paint particles are suspended in the fluid, and can diffuse by Brownian Diffusion [2]. Brownian diffusion is described by:

$$D_B = \frac{kT}{6\pi\mu a}$$

Equation 1: Brownian diffusion [2]

where k is the Boltzman's constant, T is the absolute temperature, μ is the viscosity of the fluid (mostly water in this case), and a is the paint particle droplet radius. This relationship shows how the viscosity of the paint acts to prevent diffusion and keep the paint layers separated, as an increase in μ decreases the diffusion coefficient. Thus, it can be concluded that the paint, especially as evidenced by the "canyon" indent, has a relatively high viscosity.

As the paint layers in the image come to a rest, the droplets compact and deform against the surface tension of the paint layer [2]. This is demonstrated by the thinner layers in the bottom of the image/on the flat base.

In the literature examined, paint diffusion can also be explained by Fickian diffusion [3,4]:

$$J = -D_{\text{eff}} \frac{\partial C}{\partial x}$$

Equation 2: Fick's Law

where J is the flux, D_{eff} the diffusion coefficient, and C the concentration. If steady state is assumed, which is a reasonable approximation given that the paint had been stationary and the color gradients constant for a few minutes, the equation can be simplified as:

$$J = \frac{D_{eff}}{l}(c_2 - c_1)$$

Equation 3: Steady state form of Fick's Law

where l is the length of the paint layer, and c_2 and c_1 are the concentrations of pigment particles in the layers on either side.

Often, these barrier measurements are classified in terms of vapor pressure so that a permeability coefficient can be determined [4]. The permeability is the product of the diffusivity and the solubility, such that:

$$P = D \times S$$

Equation 4: Permeability coefficient

where P is the permeability coefficient, D is the diffusion coefficient, and S is the solubility coefficient.

The permeability and Brownian diffusion describe the behavior *within* the paint layer, while the interactions *between* layers is also a function of surface tension.

The surface tension, σ, is a function of the pressure jump across the surface and the curvature of the interface, κ:

$$p_2 - p_1 = \sigma\kappa$$

Equation 5: Surface tension as a function of pressure gradient [6]

P_2 is the higher pressure in the fluid medium on the concave side of the interface [6]. Clearly, a larger pressure gradient results in a larger radius of curvature, so the pressure gradient at the "canyon" formed in the paint is greatest, as the paint makes a sharp corner to accommodate the imprint of the toothpick. The pressure gradient between the lines of paint also does not exceed a critical value, as the individual lines are maintained.

Crayola kids finger paint was used in the experiment, but unfortunately, Crayola does not disclose the ingredients in its paints. Therefore, it is hard to estimate the viscosity and other material properties of the paint and thus perform calculations of the previously presented equations. Various consumer information websites hypothesize that the paint may contain baking soda, citric acid, mannitol, polyethylene glycol for texture, sodium benzoate as a preservative, mineral oil, and various food colorings [5]. However, the mineral oil may well account for some of the viscous effects of the paint, and the various particles may play a role in the diffusion and bulk properties of the material.

4 Photographic Techniques and Visualization

The camera, also shown schematically in Figure 2, was oriented at an angle to the top of the image, and the images were shot approximately 50 to 80 cm from the top of the Styrofoam block. The lighting was from the afternoon sun and was not altered or hindered. The fluid properties were visualized by the color of the paint and the gradients of multiple contours near each other. Especially the viscosity was shown by the imprints and the contours left by the toothpick.

The image is a fraction of the 5 x 15cm coarse piece and some of the surrounding base, corresponding to a field of view of approximately 20 x 30cm. The final image is cropped slightly more, and is closer to a 15 x 20cm field of view.

The image was shot with a Canon EOS Rebel XSi digital camera. The original image was 4272 x 2848 pixels, but was cropped to 2528 x 1968 pixels. The focal length was 34mm, the f-stop 4.5, and the exposure time was 1/500. The original image is shown in Figure 3.

Figure 3: Original Image

5 Conclusions and Image Assessment

While the image did not achieve the scale or the impression of the "Tall Painting" video, the effects created in this small-scale image were interesting and visually appealing. Experimenting with the flow over a rough surface, and "unknown" paints added an element of uncertainty. I think it would be very interesting to try this on a larger scale, similar to the video. It would also be beneficial to perform actual calculations of the diffusion and surface tension, and compare the values to visual effects of a similar painting using different paints.

6 Works Cited

[1] Kaufman, David. Tall Painting. Web. 30 Apr. 2012. <http://youtu.be/d6egUsZvWu4>

[2] "Drying of Water Based Paints." http://www.maths-in-industry.org/miis/312/1/Drying-of-water-based-paints.pdf

[3] Özge Topçuoğlu, Sacide Alsoy Altinkaya, and Devrim Balköse, Characterization of waterborne acrylic based paint films and measurement of their water vapor permeabilities, Progress in Organic Coatings, 54 (2006) 269-278.

[4] N. L. Thomas, The barrier properties of paint coatings, Process in Organic Coatings, 19 (1991) 101-121.

[5] Descott, Marianne. "Crayola Finger Paint Ingredients." *EHow*. Demand Media, 26 July 2011. Web. 25 Apr. 2012. <http://www.ehow.com/info_8792213_crayola-finger-paint-ingredients.html>.

[6] J. U. Brackbill, D. B. Kothe, and C. Zemach, A continuum method for modeling surface tension, Journal of Computational Physics, 100 (1992) 335-354.