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Team Image #2

4/12/12

Two States in One: Water

This image is the fourth visualization produced for MCEN 4151, in which water is shown in both the liquid and vapor states. This phenomenon is widely known as boiling, and it is something that is experienced and observed quite often by the general population. Boiling water is extremely useful for the many needs of humans, from a task as simple as cooking dinner, to the essential and complex energy harnessing of steam turbines. The thermodynamics of water have proved invaluable to us humans, and watching the fundamental process of boiling is fascinating, especially when one begins to understand the physics of what is happening. *Two States in One: Water* makes an attempt at capturing water changing states from liquid to gas in an artistic and visually pleasing manor.

Capturing this image required a fairly minimal amount of equipment. A clear, glass teapot was used to boil a full pot of water on a kitchen stove. After the water reached boiling temperature, the teapot was left on the heat source for continued boiling. This allowed for multiple images to be taken of the effect. Figure 1 displays the physical set up required for image capturing.

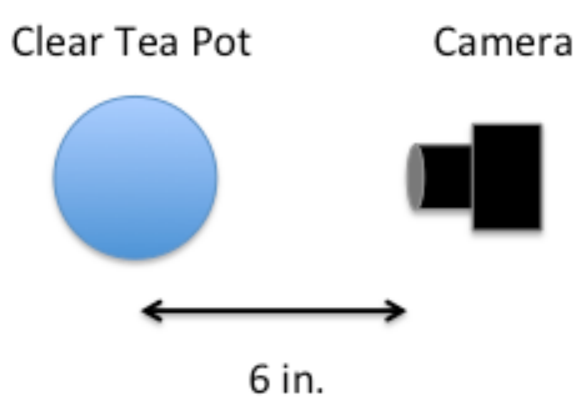

Figure 1 : Apparatus Setup

Although boiling water is extremely common, the physics behind each bubble rising is surprisingly complex. It is expected the bubbles of gaseous water rise upwards in a straight line, however this is often not the case. Many have studied this phenomenon, as bubbles with a radius larger than .8 mm will spiral or follow a jagged path as they rise (Lohse). This is due to the many forces acting upon the bubble immediately after formation. Any impurity or small movement in the water is amplified by the bubble, and thus interrupting the straight path of ascent. One may begin to inquire about the Reynolds number of the fluid around the bubble while it is rapidly rising upwards. For this approximation two dimensionless numbers, the Eötvös number (Eo) and the Morton number (Mo) are used according to Detlef Lohse (see references). The Eötvös number is found using the density, bubble equivalent spherical diameter, surface tension, and gravitational acceleration values. This results in the dimensionless relationship of Equation 1.

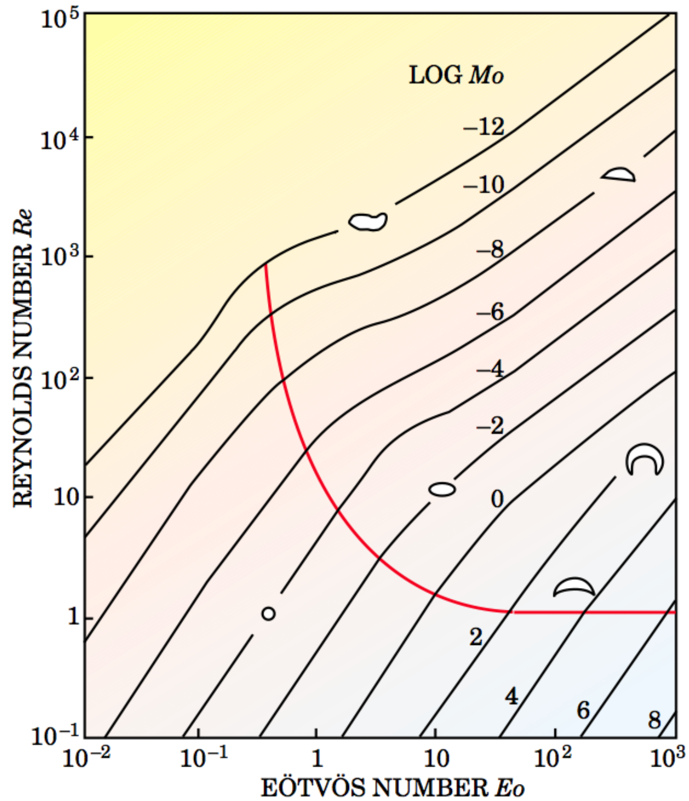

Figure 2 : Reynolds Number Relationships

$$Eo = \frac{\rho d^2 g}{\sigma}$$

This value is then compared to the Morton number, which utilizes the fluids kinematic viscosity, surface tension, gravitational constant, and density values for yet another dimensionless number of Equation 2.

$$Mo = \frac{gv^4\rho^3}{\sigma^3}$$

When these two values are compared on a logarithmic scale, we can begin to see their relationship with the Reynolds number associated with different types of bubbles. Many different bubble shapes can be seen in *Two States in One: Water*, which is just one indication of the extremely complicated physics behind the fluid interactions of the image. The velocity of the bubble rising upwards can also be examined using Stoke's Law. This law is a combination of the buoyancy force, as well as the drag force, under the assumption that the bubble is small and the surface is still [Bubbleology]. This equation is represented by Equation 3.

$$V = \frac{2gr^2}{9v}$$

Assuming a small bubble with a radius of 1 mm (.001 m) and a kinematic viscosity of $.294 \times 10^{-6}$ (m^2/s), we can find the approximate velocity of the average rising bubble. This calculation provides a fairly rapid ascension velocity of 7.407 m/s for small bubbles.

With water vapor bubbles rising at an extremely rapid pace, it was difficult to capture a crisp image of the boiling phenomenon. In order to reduce motion blur, the shutter speed was reduced to 1/250 of a second. This posed one problem, however. A shutter speed this fast did not allow enough light for the camera's initial sensor setting to produce a quality image. This required the ISO to be increased to a value of 800, which was found by cycling through a combination of shutter speeds and sensor sensitivities. Some editing was done in order to bring out the plasma-like effect of the image. The contrast and exposure were increased, while the saturation was decreased slightly. Also, the range of colors was reduced by 12% in the lowest light levels, which gave the bubbles more definition. Other effects, such as highlights, shadows, and sharpness were used in order to bring out certain qualities of the bubbles. These actions resulted in an image that shows the fascinating formation and rise of water gasses in a visually pleasing way.

This image reveals many interesting aspects of boiling water. The many different shapes that can be seen in the photo represent the many possible paths and physics involved in bubble formation and travel. I would like to improve this image by using a high speed camera to record the bubbles forming and rising in action. This would also help viewers see the many interactions not only between multiple bubbles, but even the bubbles interacting with their own wakes. This image captures a physical phenomenon that I watch every morning while boiling water for coffee, and it is something I believe most people will enjoy taking a closer look at.

Figure 4 : Original Image

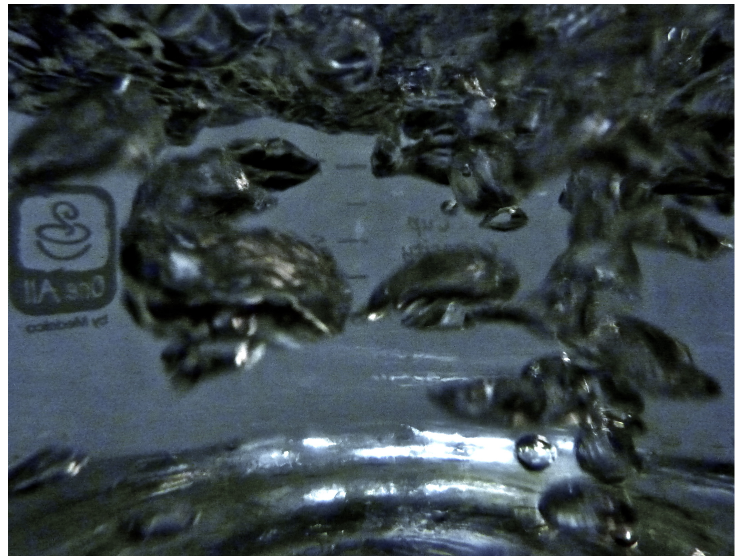

Figure 3 : Edited Image

References:

[Lohse, Detlef. "Bubble Puzzles." Physics Today 56, no. 2 (2003): 36-41.]

["Bubbleology Main Page." *Index*. Web. 24 Apr. 2012.

<http://bubbleology.com/BubbleologyFrame.html>.]