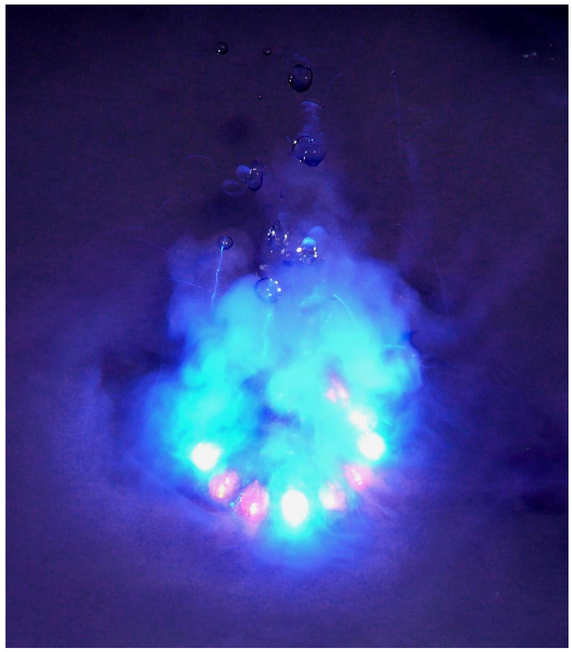
Ultrasonic Nebulizer Visualization



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I. Introduction

This image was created for the second group project photo for the University of Colorado at Boulder Flow Visualization course. An ultrasonic nebulizer fountain was used to create water vapor while backlit with LEDs. Ultrasonic nebulizers are typically used in medical inhalers to vaporize medication or as humidifiers to add moisture to the air. In this case the technology is merely used to create an interesting fountain, but also serves as a humidifier. I’ve been fascinated by this fountain before and it was a unique opportunity to capture an image and study this phenomenon.

II. Set-Up, Methods and Post-Processing

To create this image, the fountain was placed in a dark room and shot from above. The multicolored LEDs were cycled and each color was photographed. The bluish color proved to illuminate the most water vapor and create the best image. It also allowed enough light into the lens to focus on the individual droplets more precisely. Distilled water was used to fill the basin. The fountain fill level greatly affected the height of the drops and the amount of fog created. An optimum level that fully submerged the nebulizer, but wasn’t too full was found to create large droplets that could be captured in the image. The camera was about 10 inches from the fountain. The camera settings used were an f-stop of 3.3 and a shutter speed of 1/30 sec. The ISO was set to 100 and the flash was used to capture a freeze frame of the drops in air. A diagram of the setup is seen in Figure 1.

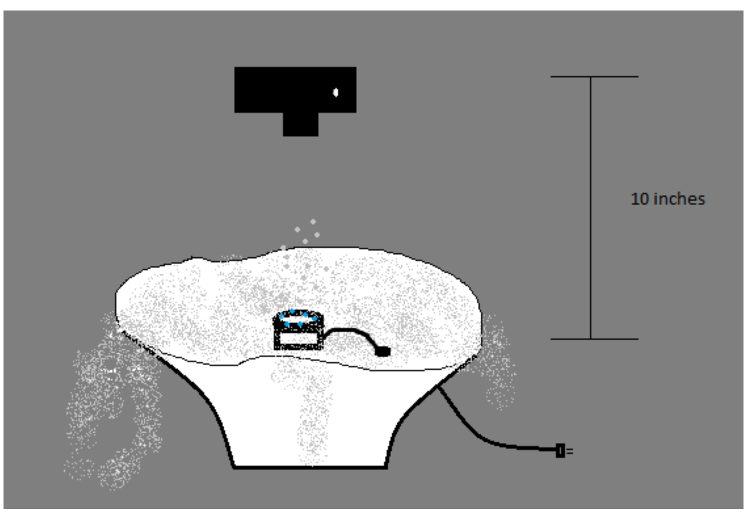

Figure 1- Image Set-up

The post-processing of the image was fairly tedious. The power cable for the nebulizer was very distracting in the shot but also very prevalent. Using GIMP photo editing software I was able to nearly erase the entire cord. This was done using mostly the clone tool as well as the heal tool. The colors were also varied in post-processing to achieve higher contrast. Increasing the blue in the image allowed for more fog to be seen but would wash out the drops slightly. A balance was found to highlight both fog and droplet aspects of the image. Finally the photo was cropped slightly to bring the drops to the center of the image. The final image size after cropping was 1416 pixels wide by 1617 pixels tall.

III. Analysis

In its most basic description, an ultrasonic nebulizer uses a series of sound waves to break down water particles into a smaller form creating water vapor. The water vapor is then propelled by a small pump to fill the bowl with vapor. In the process of propelling the vapor, the pump propels water droplets as well. The droplets create wakes behind them which can be seen in the fog. The small ceramic plate that creates the vibrations uses a piezoelectric transducer to convert electrical loads into mechanical oscillations and create the high frequency vibrations. The transducer oscillations create vapor using cavitation. The water attempts to follow the plate back and forth and it oscillates but is unable to due to the mass inertia and weight of the water. During the negative oscillation, a vacuum is created causing cavitation and creating the water vapor. Then on the positive oscillation, high pressure compression creates waves on the surface of the water and the water vapor is released into the air. It is this process that is the reason for the warning on the fountain and on many humidifiers to use only diltilled water. All the particles in the water are aerosolized by the transducer and released into the air therefore if impurities exist in the water, they can potentially be inhaled. The vapor created is approximately 1 micron in size and is generally quickly evaporated, but since the plate is oscillating at around 1 MHz, enough fog is created to be visible.

The driving force behind an ultrasonic nebulizer is the piezoelectric transducer. The transducer is the white disc that can be seen in Figure 2.

Figure 2 - Ultrasonic Nebulizer Close-up

Typically piezoelectric transducers use a ceramic plate to create the oscillations seen in Figure 3.

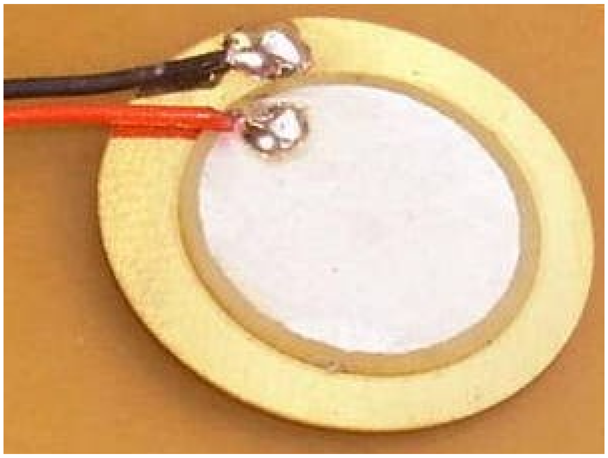

Figure 3 - Piezoelectric Transducer

The positive and negative elements of the transducer align themselves in the presence of an electric field. An alternating electrical field is applied to the plate to cause it to oscillate. The wavelength created is twice the thickness of the plate, therefore very thin plates are needed to create ultrasonic wavelengths.

Acoustic streaming can also occur in water. Some of the ultrasonic oscillations can be absorbed by the water during propagation and at the plate boarders. During propagation the attenuation coefficient is calculated using Stokes' law.

$$\alpha = 2\eta\omega^2 / (3\rho c^3) \qquad \text{Equation 1}$$

Where α is the attenuation coefficient, η is the dynamic viscosity, ω is the frequency, ρ is density and c is the speed of sound. At 1 MHz, attenuation would occur at around 100m. Obviously the ultrasonic nebulizer fountain is not in 100 m of water and therefore attenuation is not seen during propagation. At the plate borders the attenuation follows the Stokes boundary layer theory.

$$\delta = [\eta / (\rho\omega)]^{1/2} \qquad \text{Equation 2}$$

Where δ is the localized attenuation length. At 1 MHz attenuation occurs at a distance of a few microns from the source. This attenuation is created by a shear wave and is small enough to be experienced in the ultrasonic nebulizer. It creates some loss in magnitude of the wavelengths although not enough to affect the function of the fountain.

IV. Conclusions

Overall, I believe the set-up and the image were successful. The phenomenon of vaporizing water by using ultrasonic sound waves was captured well and enhanced by post processing in GIMP while not losing any information. The result was a visually pleasing and creative photo.

If I were to do this experiment again, I would attempt to capture the creation of the fog and droplets with a slow motion camera. I believe this would reveal the physics of the ultrasonic nebulizer more accurately. Although the actual ultrasonic pulses are too fast to capture on camera, the creation of the water droplets and fog could be better displayed using a high speed camera.

Ultrasonic nebulizers have been used in the medical industry for years and have been recreated at a fraction of the cost to create fountains. Now when I see an ultrasonic nebulizer I can not only appreciate its beauty but also understand the physics and fluid dynamics that drive its function.

V. References

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