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MCEN 5151-001
2/17/2018

Get Wet: Convective Turbulence

For my initial image I wanted to capture the more scientific elements of fluids, and look further at their physical constraints. I wanted to show both moving gasses and liquids in harmony, and illustrate the transition and power of the fluid. Overall, the image shows a striking relationship between these properties and the complex patterns they can produce in fluid flow.

The setup started with a shallow beaker set over a piece of white paper. The beaker was filled with tap water making sure to not let it splash, as that would show on the paper. Next, bolts were heated to around 400F on a hot plate, with help from an electric heat gun. Note that there was a piece of aluminum foil between the hot plate and the bolts to make it easier to transfer them in a group without touching them. Also note that large bolts were selected to hold a high thermal mass. This is a similar process as is used in 'Modelling the optical turbulence boiling and its effect on finite-exposure differential image motion'. [1]

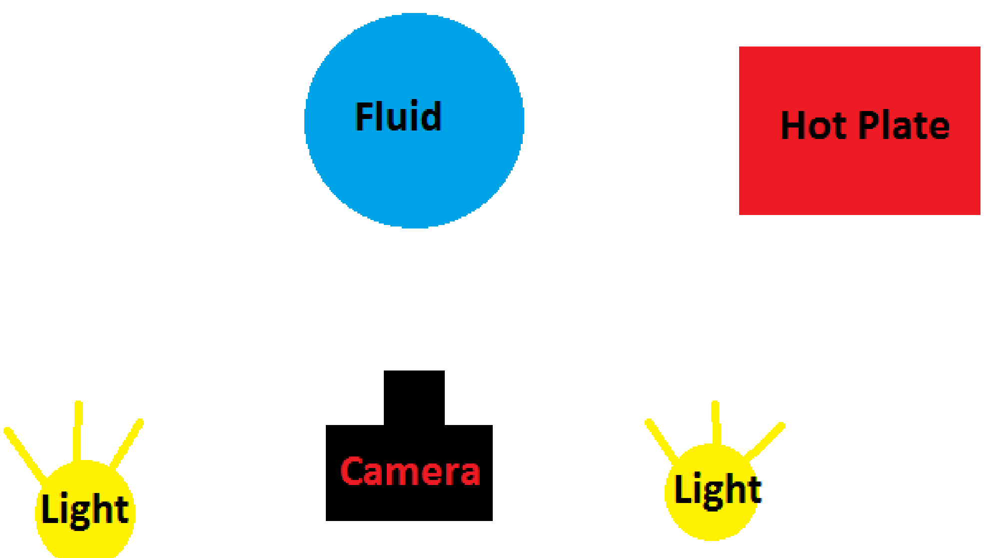
With everything in place, the bolts were dropped into the water. The momentum from the falling bolts was transferred to the water on impact, creating turbulence and sloshing. Further, the instantaneous boiling of the water caused convective turbulence, thus making greater motion.

To analyze the system in a more mathematical sense, let's start by finding the Reynolds number at impact. The bolts hit the water with a certain velocity, calculated in the first equation, and input that momentum onto the water. For this we assume a falling height of 10 cm. Next, we will calculate the Reynolds number given this velocity and the size of the bolt falling, 6mm in diameter. This can be seen in the second equation. [2], [3]

$$V_f = \sqrt{2gZ} = \sqrt{2 * 9.8\frac{m}{s^2} * .1m} = 1.4\, m/s$$

$$Re = \frac{\rho u L}{\mu} = \frac{1000\frac{kg}{m^3} * 1.4\frac{m}{s} * .06}{8.9E - 4PaS} = 94382$$

We find that the Reynolds number is very high, which numerically illustrates the high turbulence shown in the figure. The flow apparatus was very simple, it was only a single dish with the bolts heated by the hot plate. The system can be seen in the figure below.

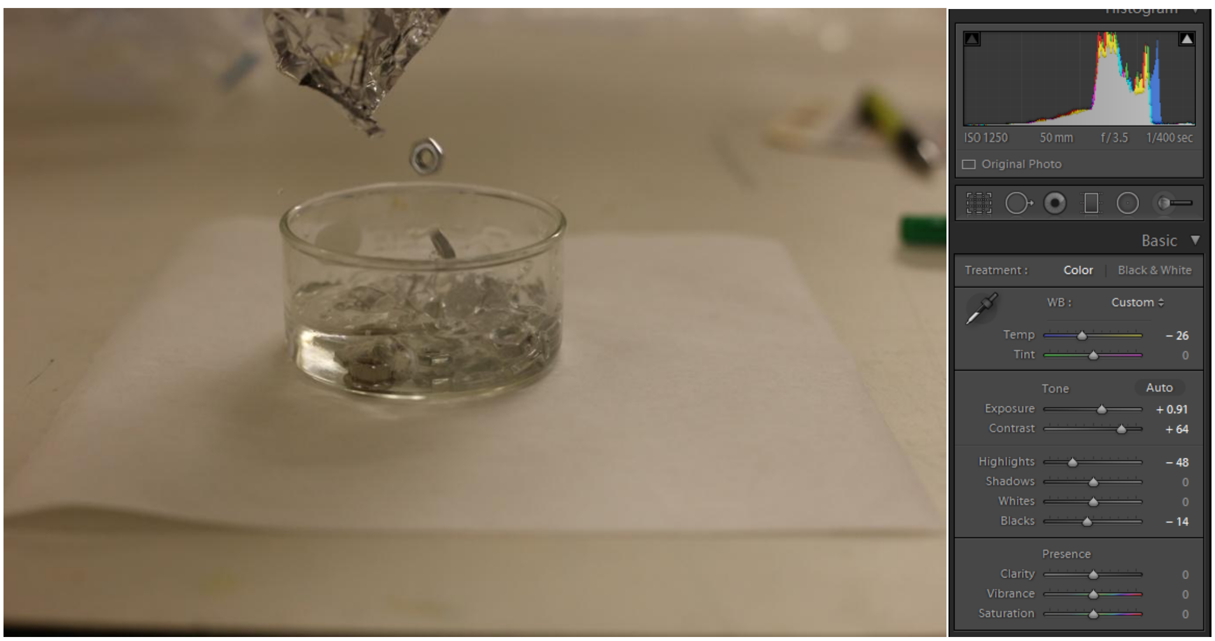


The visualization techniques used are very straight forward. A clear beaker hold water and a camera is able to see into the water and capture it's flow patterns. Two fluorescent lights overhead were used to illuminate the water, giving good contrast when looking at the ripples.

The picture was taken with a Canon 6D set up on a tripod. A fixed 50mm lens was used, and the object was about half a meter away from the lens. The picture was taken in 1/400 seconds, at f/3.5.

Note that the ISO was a 1250. As seen, there is some motion blur in the image from the quick fast-dropping bolts. I tried to take up the shutter speed, but it made it too dark. Further I found that if I adjusted the F-stop any more it would make certain parts of the image out of focus, so I avoided that as well. Lastly, any change in the ISO would make the picture grainy, so I was somewhat stuck with the motion blur.

Photo editing was kept to a minimum. Note that all editing was done in Adobe Lightroom. First, the photo was cropped down to a more reasonable layout with only the subject in view. Next, the color temperature was taken down to -26 to create a more 'cool' blue effect on the image. In addition, the exposure was increased to +.91 to make the overall image brighter and add detail. To show more activity in the image, the contrast was increased to +64, the highlights were taken down to -48, and the blacks were reduced to -14. This combination overall made a more defined and interesting image. Note that no other properties, such as the tone curve or effects were changed. The edits can be seen in the image below, along with the original image.



Overall, I feel that the image with edits came out very well. All the aftereffects benefit both the aesthetics and fluid visualization. Changing the contrast and color scheme give a nice clear image that is very visually appealing, and give the viewer something to enjoy. However, I do not like the motion blur in the falling bolt; I wish it was possible to increase the shutter speed to negate that effect. Further, I would have liked to see more steam billowing up from the fluid to give a nice transition from liquid from gas. The fluid physics shown are based in both the impulse of the impact and the convective heat forces on the fluid. Overall, this image fulfilled my intent of capturing image that nicely illustrates multiple aspects of water physics. To further develop the concept I would probably create more convective heat transfer in the fluid, and experiment with different fluids and add more color, to really drive home the fascinating effects boiling and turbulence.

References

1 - A. Berdja, J. Borgnino, Modelling the optical turbulence boiling and its effect on finite-exposure differential image motion

2 - M. Shamsuzzoha, S. Alam, Effect of Bubble Turbulence and Submergence on Boiling Incipience in Vertical Thermosiphon Reboiler

3 - R. Zhang, T. Cong, W, Tian, S. Qui, G. Su, Effects of turbulence models on forced convection subcooled boiling in vertical pipe