Image 3

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Flow Visualization

MCEN 5228

5/3/2010

This picture was the final image submitted for the course. It was taken individually for the Group Project 3. The intent of the image was to show how an impinging jet of water reacts when it hits a concave surface. I thought the top surface of an apple would be an interesting surface to do the experiment due to the irregular shape as well as to see what effect the stem would have on the impinging stream. We know that when a jet of water hitting a perfectly concave surface will spread out evenly in a uniformly thick layer over the concave surface, so I figured this would be interesting.

The flow apparatus for this experiment was extremely simple. It consisted of placing an apple under a stream of water from a faucet of a sink to demonstrate an impinging stream of water acting on a concave surface. The apple was placed off-center from the stream so that the stem of the apple wouldn't affect the impinging stream of water. The setup is shown below in Figure 1.

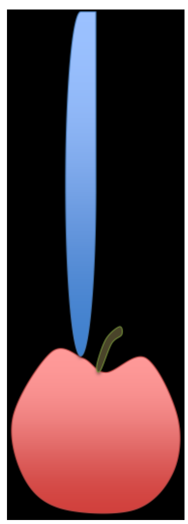

Figure 1: Simple but effective flow apparatus used

The apple was 3.5" in diameter and was 4.5" tall. The apple was placed 9" below the faucet of the sink 13" below the faucet. The diameter of the stream of water was approximately 0.25" and the stream was flowing at an estimated 0.5 in^3/sec from the faucet. This results in velocity of 10.2 in/sec at the faucet. Since the stream of water is accelerating due to gravity, the velocity at the bottom of the jet will be higher than the initial velocity of the stream. Using conservation of mass at

$A_1v_1=A_2v_2$, and plugging in arbitrary values for v_2 to solve the equation for A_2, it is evident that the cross sectional area of the stream when it hits the apple will be less than when it started with. Estimating a diameter at the bottom of the stream of 0.18", this gives a calculated velocity at the bottom of the stream of 19.6 in/sec (0.49784 m/s). This is the velocity of the impinging stream at the surface of the apple. At room temperature, water has a density of 997.62 kg/m^3 and a viscosity of 0.000933 kg/(m*s)[1]. The formula for the Reynolds number is $\frac{\rho v L}{\mu}$. Solving this equation with all of the known values and a characteristic length of 9 in (.2286 m), gives a Reynolds number of 12,168.8. This value is indicative of the flow being turbulent in an open channel. This looks to be consistent with the flow observed in the picture where the flow is not broken up into droplets.

The portion of the flow that is broken up into droplets is due to the ratio of the inertia of the fluid to the surface tension of the fluid being higher than a critical value. What this means is that a jet of water hitting a surface will remain a thin-film flow if below a critical Weber number value, and the flow will splash or turn in to droplets if above the critical Weber number value. The equation for the Weber number is given by $\frac{\rho v^2 L}{\sigma}$ [2]. σ is the surface tension of the drop and is 79.97 dyne/cm at room temperature[3] and the characteristic length used is the diameter of the stream, or 0.18 inches. Plugging in all of the known values gives a Weber value of 15.7. This is a lower Weber number, but it is high enough to cause the stream to turn into droplets. When looking at the image, it can be seen that the droplets are in a transition range where the surface tension is not high enough to form complete, perfect spheres, which is indicative of a lower Weber number.

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1 http://www.thermexcel.com/english/tables/eau_atm.htm

2 http://en.wikipedia.org/wiki/Weber_number

3 Lange's Handbook of Chemistry, 10th ed. pp 1661–1665

The visualization technique used in the image was mostly scattering of light, but there is diffraction in the water droplets and the stream. There was a ambient day light lighting the scene, but due to the extremely fast exposure needed for the desired effects an off-camera strobe was used. The strobe was placed on the countertop above the sink, about 8 inches above the bottom of the sink. Also, it was 90 degrees to the left from where the camera was.

The field of view for the image is roughly 10 inches wide by 8.7 inches tall. The apple was about 10 inches from the camera when the image was taken. The camera type, lens type, and other settings for the image are listed below.

Camera	Nikon D90 DSLR
Lens	Nikkor 50mm f/1.8
Flash	Nikon Sb-900
ISO	400
Exposure	1/4000 sec
Aperture	f/5.6

The image was edited in Adobe Lightroom 2 using a preset that I have previously created and saved. The preset adjusts boosts the contrast and saturation of the image. The preset also adds a vignette to the image.

The image shows how a stream of water acts when it hits a concave shaped object. It also reveals something a little more interesting. That is the water after hitting the top of the apple has to go somewhere and it seems that it goes up the stem of the apple and then follows that up before breaking off into drops. After much investigation and looking into this behavior, I believe this is due to the Coanda effect. This effect says that a jet of water is attracted to a nearby surface and will move to flow around that surface[4]. Some aspects of the image that I really like are how it reveals this effect and you can see the water traveling up the stem and then I

[4] http://en.wikipedia.org/wiki/Coandă_effect#cite_ref-0

also really like the drops that appear to be “frozen” in time and are refracting the light from the flash and the room that the image was taken in. The intent of the image was most definitely fulfilled and I am pretty happy with how it turned out. Something I would like to improve with the image would be to use a different backdrop. Something with a lot of color could make this picture very interesting with the water diffracting light.