Clementine Flame Ablation

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Context and Purpose

I got the idea for this video while browsing the previous years' image galleries from the "Flow Visualization" course at CU Boulder. In the course, students are encouraged to find unique ways to visualize fluid flows. I found a previous image by Dustin Grace, Marilyn Poon, Robert Neilson, and Jessica Todd that entranced me, and I decided to re-create their set-up. I found that the clementine exhibited very dramatic behavior when exposed to a propane torch. Also, I experimented with different flame times to find the effect I liked the most.

Visualization Technique

To obtain this image, I used a clementine, a propane blow torch, and an aluminum heat shield. During each burn, I rotated the clementine to use every possible surface before the clementine was completely black and unusable. An aluminum heat shield was used to protect my garage floor and to reflect some light. A diagram of the setup is shown below.

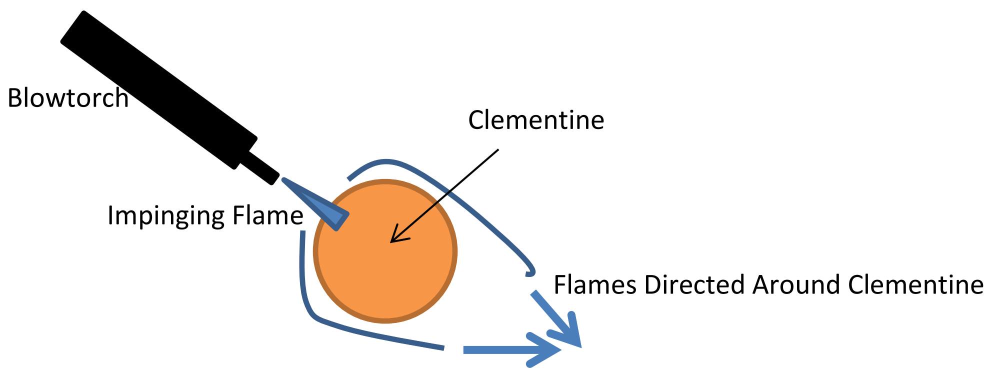

Figure 1
Visualization Set-Up

I found that different flow rates of propane produced very different results. At a low flow rate, the small jet would impact the surface of the clementine and not curve around. At high flow rates, the powerful flame would impact the clementine and carry burnt parts of the front surface around the clementine.

It is commonly known that all citrus fruits contain oils, which can be used for a variety of purposes. The oil in oranges (closely related to clementines) is so flammable that is being considered for use as a biofuel.[1] It can be seen in the picture that each pore shoots a jet of flame as the oil in it ignites.

To calculate the Reynolds number of the flow, I found the optimal laminar flame speed of propane(.4 m/s). I assumed this to be the speed of the jet impinging on the clementine.[2] I used the diameter of the clementine (.06m) as the characteristic length. The Reynolds number is defined as:

$$Re = \frac{pvD}{u}$$

Assuming dry air at STP as the fluid, the properties are p = 1.2754 kg/m3, and a dynamic viscosity of 1.983 kg/m-s. Plugging those values into the equation above yields.

$$Re = \frac{1.2754\frac{kg}{m^3} * .4\frac{m}{s} * \ .06m}{1.983\frac{kg}{m * s}}$$

$$Re = .015$$

This is well below 10, so the case must be laminar. This explains the jet shape, as visualized by Viskanta.[3]

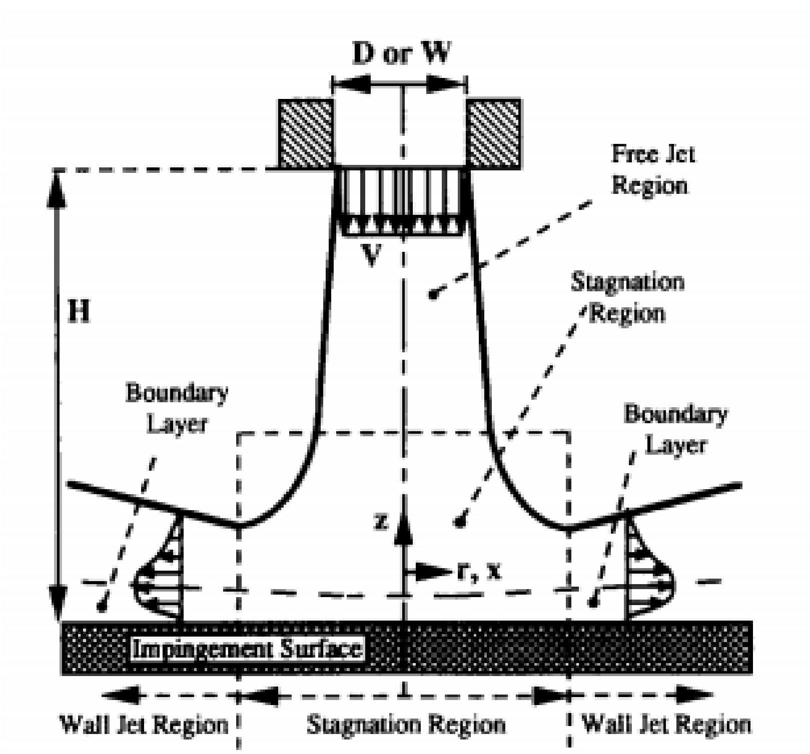

Figure 2
A free jet impinging on a surface

This diagram shows how a boundary layer forms. This is what causes the flames to wrap around the clementine. Also shown is the stagnation region, which is visualized by the red-hot area on the surface of the clementine.

Photographic Technique

To take this photo, I used an 18 MP Canon T2i DSLR. The lens I used was a 50mm 1.8. To get the clementine in focus, I used manual focus to get the front surface in focus. To get a large amount of light in for the dark environment, I set my aperture to 2.5. To minimize noise, I set the ISO to 100. I used a slightly longer shutter speed of ¼ to capture more light in order to compensate for the low ISO and to create a better visualization of the glowing particles curving around the clementine. The original picture was 5184 x 3456 pixels, and I cropped it to 3876 x 2472 to compose the picture better. Contrast and saturation was increased very slightly during post processing to highlight the flames.

Conclusion

Overall, I like this final image. It reminds me of a meteor entering the atmosphere and burning up. I wish I had a better understanding of the physics behind the impinging jet flame and the heat transfer so I could better quantify the situation. Hopefully I will be able to do this with more research and education.

Works Cited

1 Purushothaman, K., and G. Nagarajan. "Performance, emission and combustion characteristics of a compression ignition engine operating on neat orange oil." *Renewable Energy* 34.1 (2009): 242-245.

2 Vagelopoulos, C.M., Egolfopoulos, F.N. *Proc. Combust. Inst.* 1998, 27, 513.

3 Viskanta, R. "Heat transfer to impinging isothermal gas and flame jets."*Experimental Thermal and Fluid Science* 6.2 (1993): 111-134.

Appendix

Firgure 1