White-Gas Combustion Flow Visualization

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Figure 1. Pressurized stove burning white-gas and generating a blue-violet oxygen rich flame

I. Introduction

Combustion is one of the most fundamental chemical reactions in nature that generally occurs between a fuel and an oxidant producing heat and in most situations light. This basic chemical process is the driving force behind many of modern life's luxuries such as internal combustion engines that power our cars, gas turbines that power our airplanes and electric plants, gas furnaces that heat our homes, gas stoves to cook our food, rocket engines that power us into space, and many other modern marvels that people take for granted. However, given its broad applications to modern life and basic scientific principals, combustion is actually one of the most difficult physical processes to fully understand, comprising of several variables that are dependent on the chemical, environmental, and spatial nature of each occurrence. Figure 1 is an attempt to visualize some of the physical characteristics of a hydrocarbon (fuel) combustion process with air (oxidant) under pressurized fuel flow.

II. Experimental Setup and Analysis

The combustion flow presented in figure 1 was generated using a Mountain Safety Research (MSR) Whisperlite backpacking stove burning a naphtha hydrocarbon fuel commonly referred to as "white gas". Figure 2 gives an annotated image of the stove and the image setup under external lighting. White gas is supplied to the stove from a pressurized fuel bottle (not pictured) in liquid form along the stove's fuel line and is fed into a generator tube that runs inside of the stove burner and down into a fuel jet at the base of the stove. The generator tube heats the liquid white gas and vaporizes the fuel prior to entering the fuel jet for better mixing and combustion. As a result, stoves of this design typically have to be primed or pre-heated prior to ignition for proper stove operation (see owners manual). Once the gas is vaporized, the gas is injected into a mixing tube through the fuel jet where the vaporized gas mixes with outside air. The air-fuel mixture then enters the diffuser/flame holder section of the stove where the mixture combusts and propagates along the flame pan into the area above the stove. The mechanical operation of the stove is important to help identify certain flow properties seen in figure 1.

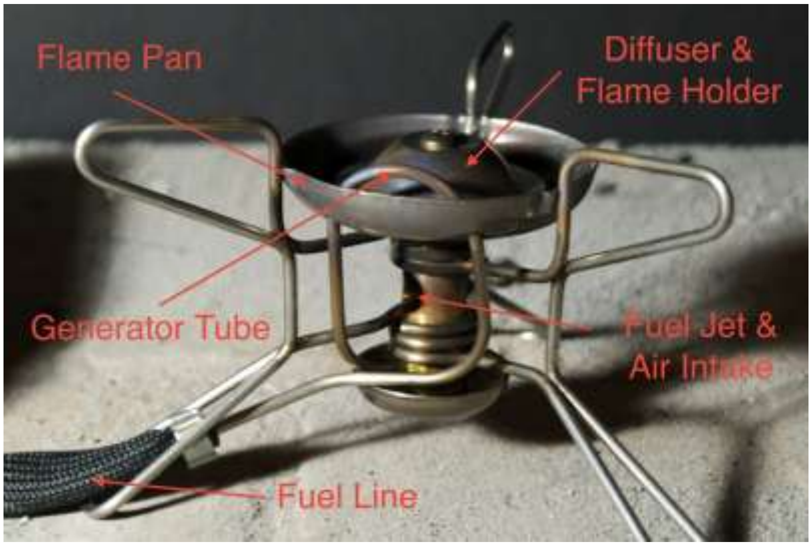

Figure 2. Annotated image of stove and image setup

The color of the flame seen in figure 1 reveals a lot about the combustion process itself, in fluid mechanical terms the rate of combustion is limited by the rate at which the fuel and air mix. If flame is blue in appearance, as in the case of figure 1, this indicates that the fuel and oxidant are sufficiently mixed prior to ignition to give almost complete combustion of the fuel with few byproducts. This is commonly referred to as an "oxygen rich" mixture. If however the flame appears orange in color, this indicates that oxygen is having to diffuse into the fuel, which is very slow compared to the premixed scenario, generating large amounts of unreacted carbon deposits or soot in the flame.[2]

III. Visualization Technique

The image shown in figure 1 was captured simply by using the ambient light generated by the blue violet flame in a dark room a few seconds after stove ignition. I wanted to capture just the oxygen rich combustion flow of the stove so it was important to capture the image within a few seconds of stove ignition. If too much time passed, the flame pan of the stove would start to emit blackbody radiation from thermal exposure to the flame and begin to glow with a reddish-orange hue washing out the blue-violet color of the flame itself. This undesired effect is shown in figure 3.

Figure 3. Stove flame pan emitting black body radiation after several seconds of thermal exposure to flame.

IV. Photographic Details

The image shown in figure 1 was taken with a Samsung NX-10 interchangeable lens digital camera featuring a 14.6-megapixel 23.4mm x 15.6mm APS-C CMOS imaging sensor producing a 4592×3056 pixel resolution image. [1] The image was captured using the full resolution capabilities of the camera and stored in the camera's RAW unprocessed image format as opposed to the typical JPEG lossy compression algorithm applied to images prior to storage on the camera's memory card. Exposure was 2.0 seconds at a focal length of 48mm, aperture of f/5.6, and a sensor sensitivity of ISO 800 at a lens distance of approximately 12 inches from the subject. No post-processing was performed on the final image; colors and composition of the image are as they appeared to the camera at time of image capture.

V. Conclusion

Figure 1 reveals a lot about the physics behind a pressurized combustion process and the chemical reactions taking place between the hydrocarbon fuel and the atmospheric oxidizer. However there is definitely room for improvement. For starters, the long exposure time results in a significant amount of motion blur around the flame and stove structure giving the image the appearance of being somewhat out of focus. While this is effective in outlining the average shape of the flow as it exits the stove, it may be worthwhile endeavor to push the sensitivity of the sensor higher to capture more instantaneous properties of the flow as it exits the burner.

References

1. Butler, Richard, and Simon Joinson. "Samsung NX10 Review: 2. Specifications: Digital Photography Review." *Digital Cameras: Digital Photography Review, News, Reviews, Forums, FAQ*. Mar. 2010. Web. 11 Feb. 2011. <http://www.dpreview.com/reviews/SamsungNX10/page2.asp>.
2. Jones, A.R. "Combustion Physics." 1985 *Phys. Educ.* 20 292