Team Project 1:
Combustion of WD-40 Spray

Robert Irmiger
Flow Visualizations - MCEN 5228-10
Mechanical Engineering
University of Colorado - Boulder
September 20, 2007

Abstract: The chemical and fluid combustion processes of WD-40 are investigated. Using a canister of WD-40, the controlled spray is ignited and photographed to help gain a better understanding of the phenomena that drive this flammable flow. This paper aims to provide a better understanding of a flammable flow by examining the combustion process and the driving mechanisms for flow propagation.

The purpose of this project is to investigate the behavior of a sprayed combustible fluid. As a diffusion spray is ignited, the result is a turbulent fire ball with inherently complex characteristics. The physics related to these flows are somewhat understood, but extremely difficult to model or predict. Thus, the driving curiosity for producing an image of a flame is to gain a better physical understanding of the flow dynamics related to combustion. In doing so, the structure of the turbulent flame in the photograph may be better understood.

The flow in this image was generated by igniting the exiting stream of fluid particles from a can of WD-40. The flow of the WD-40 before it combusts is one of a diffusion spray, where the fluid particles are roughly spherical and diffuse radially as the distance from the nozzle increases (the nozzle in this case is oriented horizontally as to limit the possibility of flashback on the operator). The nozzle was held approximately four inches from a candle flame to ensure that an explosive concentration of WD-40 in the air was reached (1.1%-8.9% WD-40 to air mixture) [5].

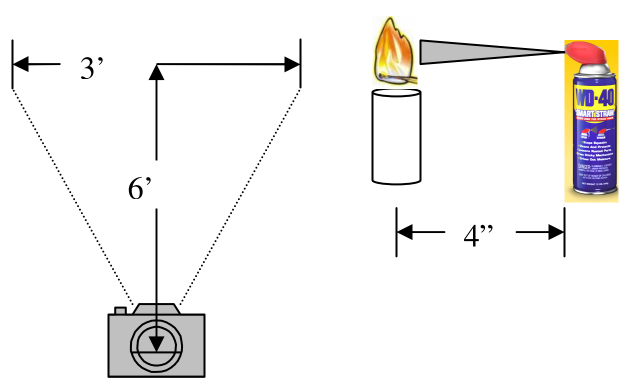

Figure 1: Experimental set up and camera placement

Upon reaching a candle flame, the spherical liquid droplets quickly ignite. Heat is transferred through the WD-40 droplets by radiation [2] and the majority of the spray that is above the lower explosive limit catches fire nearly instantaneously [5].

The rapid expansion of the gas-state flame and addition of heat from the combustion process help define the asymmetric structure of the flame ball. Because the chemical constituents of WD-40 are a secret, a general combustion formula representative of the 60-75% concentration of Aliphatic Hydrocarbons in WD-40 will have to be used to gain a better understanding of the process [5].

$$C_{(x)}H_{(y)} + O_2 \rightarrow (m)H_2O + (n)CO_2 + \text{heat}$$

where x, y, m, and n are constants. Furthermore, based on an approximation by Vince Calder that the hydrocarbons in WD-40 are of the C8-C12 categories [2], one can see that the expansion process is governed not only by heat (thermal expansion), but likely by an increase in total molecules generated in the combustion reaction (ie. for a C8 reaction; octane combustion yields: $2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$; with 27 vs. 32 molecules in the balanced, complete combustion of octane, initial and final state, respectively) resulting in a higher density pocket of gas. Rapid expansion and heating generates a large gradient in pressure between the flame and surrounding air as well as increases the velocity of the flame. The Reynolds number associated with such a flow is on the order of 20,000 [4], well within the turbulent regime. The large velocity differences between the gaseous flame and surrounding air produces shear along the boundary of the flame, thus creating circulation in the fluid [4]. The resulting vortices are visible in the rolling, folded look of the flame, called recirculation. Heating of the local environment causes the flame to rise vertically, adding a greater level of complexity to its overall structure. Furthermore, other effects such as spray velocity, wind, and slight oscillations within the flame due to uneven rates of combustion and various other factors all dictate the overall shape of the photographed flame. With the relative abundance of physics involved in a single flame, the chaotic behavior of a flame seems only to be controlled by the relationship of reaction and diffusion.

The image of the fire ball was created using a boundary marking technique. The flow was generated from a standard bottle of WD-40 in which the fuel was delivered to the flame by a fine mist. The image was taken at night were the light emitted from the fire provided enough luminosity to generate the photo.

The photograph was created using a Nikon D80, digital SLR body with an image resolution of 3872x2592 pixels. The field of view of the original (natural color) image is 3'x4.5' giving a spatial resolution of 1.9×10^{-4} in^2/pixel (length of a pixel is 0.014") and was taken approximately 6 ft from the lens. The lens focal length used was 80mm on a Nikon DX AF-S Nikkor 18-135mm 1:3.5-5.6G lens and a polarizing filter. The image was exposed at an f-stop of 5.6, a shutter speed of 1/400sec and an ISO speed rating of 100. The velocity of the flow was roughly 14 ft/s, therefore the flame moved 0.0030" during the exposure which is below the spatial resolution of the image. There was no additional processing to the original image. The second image was created by manipulations of the first image in Photoshop. First the "Glowing Edges" feature with an edge width of 7, an edge brightness of 10 and a smoothness of 6 was implemented. The "Neon Glow" feature was then used to create the final appearance using a glow size of 11 and a brightness of 20.

The final images help a viewer gain a better understanding of the structure of the fire ball. The first image provides the observer with a reference of how the actual flame appears while the second helps to describe the structure by showing the prominent edges. I am especially happy that I was able to capture an image with many layers of the flame as well the contrast created in the image. I view this image as a great introductory attempt to photographing fire physics. In researching this project, I opened a door to combustion modeling techniques and various ways of understanding the fluids flow that I am still trying to wrap my head around. I feel that I have reached my goal of describing the primary events that dictate a flames structure; however, I would like to eventually try to further develop the ideas discussed in this paper. For a future project, I would like to make a series of fires that increase in size from a match flame to a forest fire. Each case would be wood burning to keep as many aspects constant as possible. I would then aim to dissect the differences in each flow. This project was very rewarding as it was my first experience with an in depth analysis of the combustion process.

References:

1. Buckmaster, J, Et. All. "Combustion Theory and Modeling." Elsevier 30 (2005): 1-19. 21 Oct. 2007 <http://www.sciencedirect.com>.

2. Calder, Vince. "Composition of WD-40." Ask a Scientist: Chemistry Archive. 23 Oct. 2007 <http://www.newton.dep.anl.gov/askasci/chem00/chem00165.htm>.

3. Guo, Y C., C K. Chan, and K S. Lau. "A Pure Eulerian Model for Simulating Dilute Spray Combustion." Elsevier 81 (2002): 2133-2135. 23 Oct. 2007 <http://www.sciencedirect.com>.

4. Khezzar, L, S R. De Zilwa, and J H. Whitelaw. "Combustion of Premixed Fuel and Air Downstream of a Plane Sudden-Expansion." Experiments in Fluids 27 (1999): 296-297. 23 Oct. 2007 <http://www.springerlink.com/>.

5. Material Safety Data Sheet: WD-40 Aerosol. WD-40 Company. San Diego, 2007. 1-3. 19 Oct. 2007 <http://wd40.com/Brands/msds.html>.