Fire Vortex

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Group 10

Introduction

For this project, we decided to make a fire tornado and observe this phenomenon by capturing the movement of the flame. Fire tornado has been observed in the nature at the hot days and it's extremely dangerous. We tried to simulate the environment which creates the fire vortex. The image above was taken at home and the twisting flame can be observed pretty clear. When doing this experiment, a fire extinguisher should always be within reach since safety is our first priority.

Image Set-up

In this experiment some materials were used, shown in table 1. The set-up was quite easy, shown Fig 1. I pulled alcohol into the small bowl with the cotton in it. The purpose of the cotton was to prevent the liquid splash from the spinning. Placed the metal trash can onto the spinning table, and tape the trash can to the spinning table which prevent the trash can from falling. Place the lighted bowl into the trash can and spinning the spinning table, fire tornado will be created.

Table 1. Experiment material

1	Cylindrical metal mesh trash can
2	Spinning table
3	Small bowl
4	Alcohol
5	Cotton

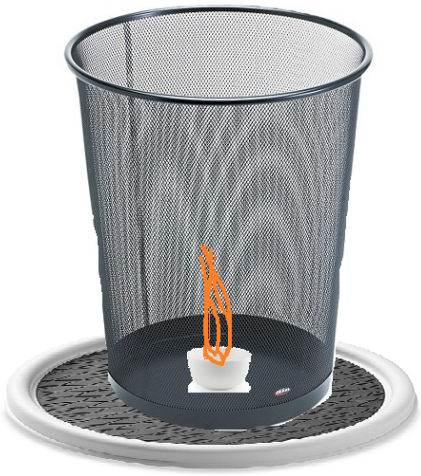

Figure 1: Schematic

Camera set-up was shown in the table 2. Since the flame was spinning, I set the shutter speed to 1/400 sec to capture the flame. The hardest part was the focus, I tried so many times and there were something that I figured. If I focused on the trash can I would get a nice clean picture of the flame, the down side was there would be mesh screen showed in the flame, as seen in the cover page flame. The other way was focusing on the flame, so I wouldn't get the mesh screen in my flame but the image of the flame would have motion blur. So I preferred the clear picture with mesh screen in it. After the picture was taken, I tried to remove the mesh in the flame using Photoshop but it didn't really work. So I ended up just changing the background to black and curve of the picture. Original and edited picture showed in figure 1 & 2.

Table 2. Camera set-up

Camera	Canon EOS REBEL T2i
Focal length	35mm
Exposure	1/400 sec; f/5.6; ISO 1600
Image size	3456 x 2304

Physical Analysis

The key in this experiment was to use the mesh trash can. I've tried spinning the bowl without the mesh trash can, it didn't give me the fire vortex. The idea is that the rotating mesh screen creates the rotational momentum to the ambient air, and the rotating air molecules collide with the hot air rising from the flame and the flame twists into the tornado shape. [1] The fire heated the surrounding gas and produces a column of rising air which turbulently mix with and carry lot surrounding vorticity-bearing air. The vorticity is thus concentrated and stretched in the rising column. The rotation of air in and at the boundary of core decrease the turbulence of the rising air due to the centrifugal force opposes movement toward the axis of air. The ground slows the rotational motion of air and radial pressure gradient pushes the boundary lay air toward the axis which explains the rising height of the flame. [2]

Before spinning, the flame was about 5cm in height and after spinning the height of the flame raise to ~15cm. The flame height stopped increase after the fire whirl generated. Researchers showed that there is balance between the flame temperature, volume fuel rate, and the flame shape. [3] From the observation, the angular velocity and the height of the flame has a positive relationship. As the angular velocity goes higher, the height of the flame goes up and the flame rotational speed goes higher. Vortex height equation had been derived as following [4]:

$$H \approx \frac{\rho_0 V_0^2}{2g(\rho_0 - \rho_1)} \qquad (1)$$

H is the vortex height; g is the free-fall acceleration; V_0 is the characteristic value of the velocity rotational component at the core boundary; ρ_1 & ρ_0 are the characteristic densities of the

medium inside and outside of the vortex core. In this experiment, all the variables were unknown.

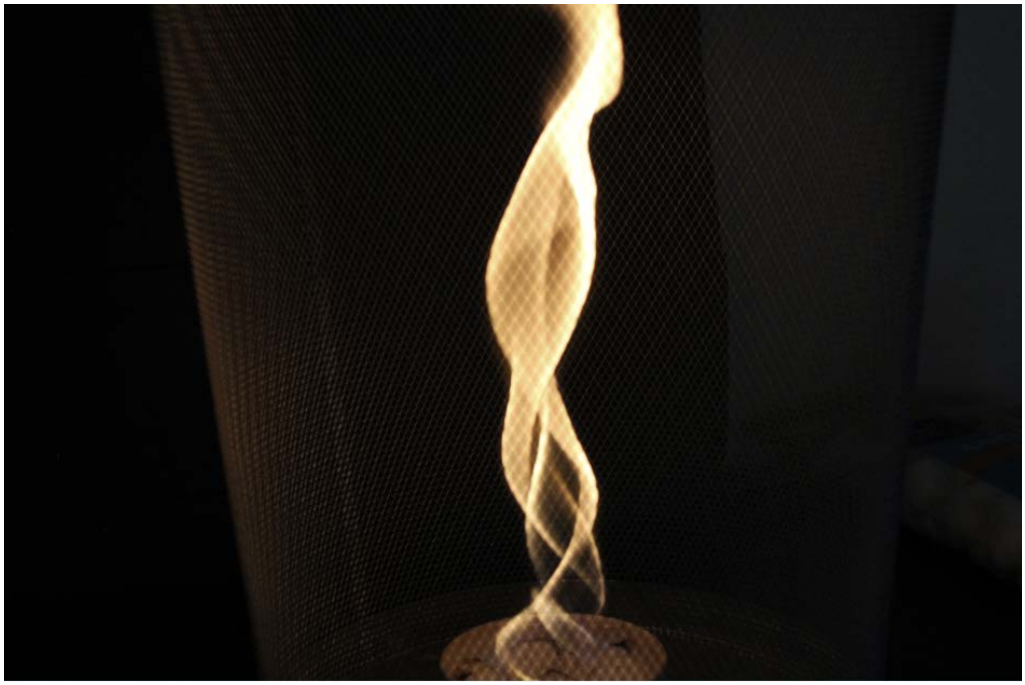

Figure 2: Original

Figure 3: Edited

Reference:

[1]. Fire Tornado
https://www.stevespanglerscience.com/lab/experiments/fire-tornado/

[2]. Howard W. Emmons, "*The Fire Whirl*", Division of Engineering and Applied Physics, Harvard University (1967)

[3]. Keng Hoo Chuah, "*The prediction of flame heights and flame shapes of small fire whirls*", Proceedings of the Combustion Institute 31 (2007) 2599 - 2606

[4]. D.G. Akhmetov, N.V. Gavrilov, "*Flow Structure in a Fire Tornado-Like Vortex", DOKLADY PHYSICS Vol. 52 No. 11, 2007*