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Get Wet Assignment

MCEN 4151-001

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Whirlpool Simulation

Every body of land is surrounded by a larger body of water. One of the unique phenomenons that tends to happen in flows is commonly known as whirlpools. Merriam-Webster [4] defines a whirlpool as any water moving rapidly in a circle which produces a depression in the center into which the floating objects may be drawn. The video captures the whirlpool phenomenon as a function of time given a step input to the system.Overall, the intent here is to recreate the whirlpool, let it dissipate with time, and use a high frames per second camera to capture the fluid dynamics of the system.

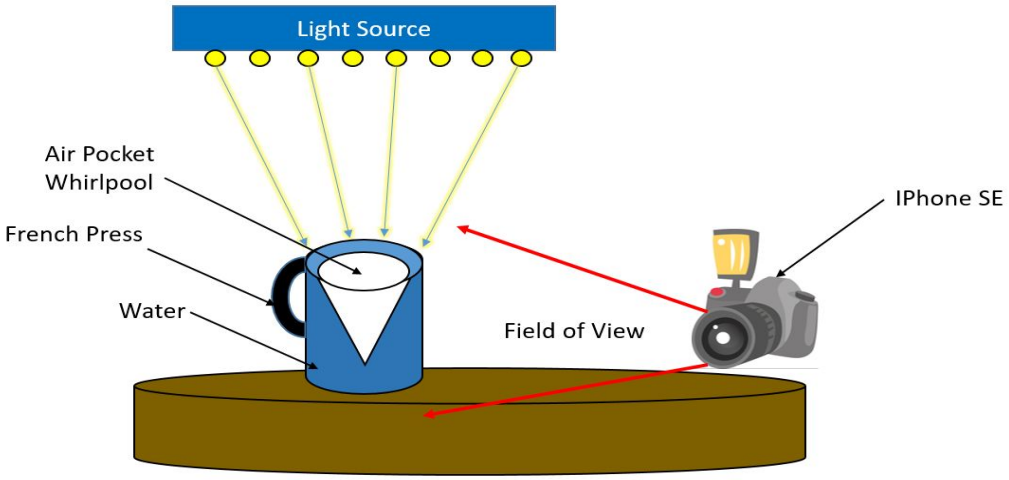

Fig 1. The apparatus set up after the spoon is removed from the french press

The apparatus is composed of a small reservoir of water in a french press with a diameter of 0.0889 meters. At the fluids steady state rest, a perturbation is developed by a spoon approximately 0.1016 meters in depth of the fluid. The standard size spoon is rotated clockwise from the top to bottom reference frame at a tangential velocity of about 60 meters per second.

After the initial input rotational motion of the spoon from the force of a human hand, turbulent flow begins to induce a vortex. As the input acts as a step input (over a period of time being on and then off), the vortex causes a downward force into the fluid. Eventually, a steady state equilibrium flow is achieved when the inward force, due to gravitational pressure, is equal and opposite to the centrifugal force of the deepest point of the vortex. The centrifugal force is an outward force experienced on a particular body when rotating about an axis. The equation is described as follows:

$$F_c = \frac{MV^2}{R} \qquad \textbf{Equation 1}$$

It is seen that the tangential velocity V, particle mass M, and the radius of the vortex R can describe the centrifugal force experienced on a water molecule as the radius changes as a function of the depth of the fluid. The reason the radius becomes smaller is due to the energy input of the system and the strength of the opposing forces from gravity. Internal forces on water molecules, at any point from the pressure cause by gravity, increases with the depth of the particle position from the surface of the fluid. More of the fluid exists above a deeper molecule, therefore a force created by higher volumes of mass above a point will continue to grow in magnitude on a point analysed in a body fluid has more fluid above it. It is the same as the pressure in air decreases with increasing altitude, as there is less air mass stacked above for gravity to act on. The vortex is now classified as a whirlpool and has an irrational vortex flow. According to Oxford Dictionaries [1], an irrational vortex is one in which a body of water without a continuous external force is acting on the vortex and the tangential velocity in proportion to the radius R. In this case, the fluid has an initial step input to create the whirlpool

with an external force, but after the external force is removed, the whirlpool begins to dissipate and lose energy over time. The tangential velocity begins to slow down, and the force from gravitational pressure overcomes the whirlpools deepest point in the fluid. Eventually, the system runs out of energy and is overcomed by gravity. This is represented in the pressure related to two points in the bernoulli formula:

$$P + \tfrac{1}{2}\rho V^2 + \rho g H = C \qquad \textbf{Equation 2}$$

P is the static pressure, the second term is the dynamic pressure, and the third term is the gravitational pressure [2]. Taking the difference of the pressure at from one point to another results in a pressure gradient. Reynolds number holds an important value to the type of flow the system impedes. In this case the system does not have flow in the direction orthogonal to the diameter vector of the glass so the standard pipe equation for reynolds number can not be used. The reynolds number formula associated with length is as follows:

$$R_e = \frac{\rho V L}{\mu}, \quad L = 2\pi R \qquad \textbf{Equation 3}$$

Rather we can treat the fluid as a point based system a single particle and get an approximation by assuming one full revolution of the particle is the circumference of the diameter of the whirlpool. Since the whirlpool has a different diameter relating to its depth we will calculate the reynolds number at the top of the whirlpool where the diameter is largest. Using the density and viscosity of water along with a 60 meters/second velocity and R is 0.045 meters. The result is $R_e = 18416$ where $R_e > 4000$ is considered turbulent Flow. Since the flow itself is a vortex and appears uniform in magnitude and direction it really is not clear if this reynolds number is appropriate for scientific analysis. This information was including for a general purpose to the reader.

The environment of the video was taken inside a house against a white background (paper towels). Lighting for the scene was a fluorescent light bulb placed above the apparatus. To

create visuals for the art of the fluid, two food dye colors were used. A single red food dye drop was applied near the edge of the french press while a blue food dye drop was used near the center. The goal was to create aesthetics, but also show the deviation in the fluids rotational motion as a function of the radius of the vortex.

Slow motion of the video was done using an Iphone SE which is a digital camera. This camera has a 120 or 240 frames per second rate depending on 1080 or 720 megapixels, Miller[3]. The camera was propped vertical up against a backboard roughly 20 cm from the object. A field view of 16 inches was obtained. Since the fluorescent light bulbs were used as a light source, the camera was able to capture the frequency of the bulbs. Originally, this was supposed to be an art piece used to describe the reliance we have on energy (coffee in this case of the french press). It became apparent that the flickering of the lights diminished the quality of the visualization of the fluid itself. Openshot software video effects were used to reduce this problem. Negative values of the pixels were used to create unique coloring of the video and flip the flickering exposure from the light. Contrast was increased 15 percent to create darker regions of the fluid, and an 8 percent increase in saturation made the food dye color more distinct.

The image reveals the effects of Bernoulli's formula [equation 2], and shows that a pressure gradient is created within the vortex that keeps the particles flowing in a rotation about an axis. The bubbles that are created in the bottom of the whirlpool by the spoon show how these particles are spun in a pressure gradient- causing the bubbles, in this case, to never leave the whirlpool and rise to the surface. In the future, a large clear bowl should be used to get a better visual of the food dye across the radius. In addition, the lighting used should be natural or non-modulated light bulbs to avoid the flickering of the lights captured by a 120 frames per second camera.

References

[1] "vortex". *Oxford Dictionaries Online (ODO)*. Oxford University Press. Retrieved 9-21-2018

[2] http://www.grc.nasa.gov/WWW/K-12/airplane/bern.htm Retrieved 9-21-2018

[3] Miller, Chance (March 30, 2016). "First iPhone SE teardown reveals mainly 5s/6s parts inside, but a few surprises too". *9to5Mac*. Retrieved 9-21-2018

[4] https://www.merriam-webster.com/dictionary/whirlpool Retrieved 9-21-2018