Buoyancy

Through Dry Ice

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The objective of this assignment was to jump in and become familiar with flow visualization techniques via hands on experiences. For this assignment, buoyancy was chosen as the focus. Dry ice was placed within a glass with varying temperatures of water added to produce different effects. Many people are familiar with the effects of adding dry ice to water, most notably the formation of fog or condensed water particles or water crystals. The objective of the experiment was to go more in depth with observations and study the results of adding dry ice to water.

Dry ice is the term given to solid-state carbon dioxide coined by Prest Air Devices in 1925 [5]. To form, liquid carbon dioxide is withdrawn from a tank and placed within a porous bag to evaporate at a normal pressure. The porous material allows for the passing of air and water molecules removing them from the carbon dioxide. The carbon dioxide quickly expands and evaporates and in the process cools some of the carbon dioxide to -78.5^{o}C creating a solid "snow". This same process can be seen around the nozzle of a carbon dioxide fire extinguisher following its use. This snow is then compressed together producing desired shapes [5]. For this study a 30kg block of dry ice was obtained from the local grocery store. The blog was broken down into smaller chunks varying in dimensions and size. For this photo the chunk of dry ice was 284.3 grams.

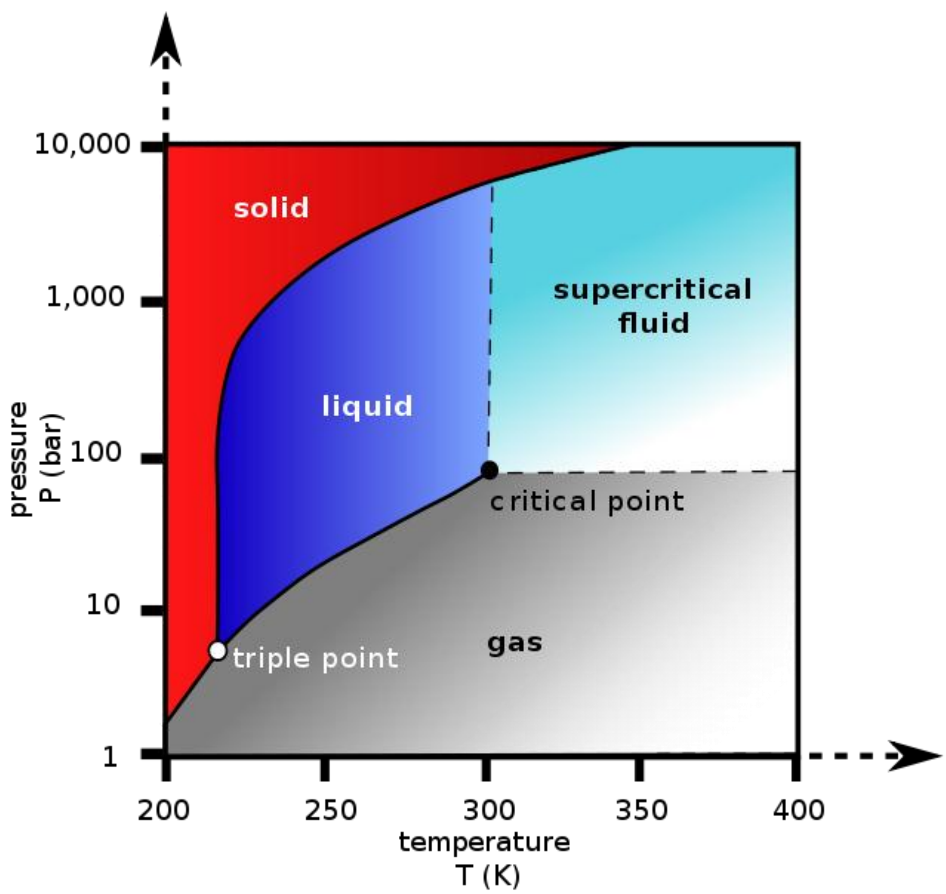

Figure 1. Three Phase Diagram for Carbon Dioxide [1].

The apparatus consisted of 500ml glass (16.9 oz.) of dimensions 6.35 x 13.63 cm. The chunk of dry ice was then placed at the bottom of the glass prior to adding water. The water used was approximately 60.3°C before being added to the glass.

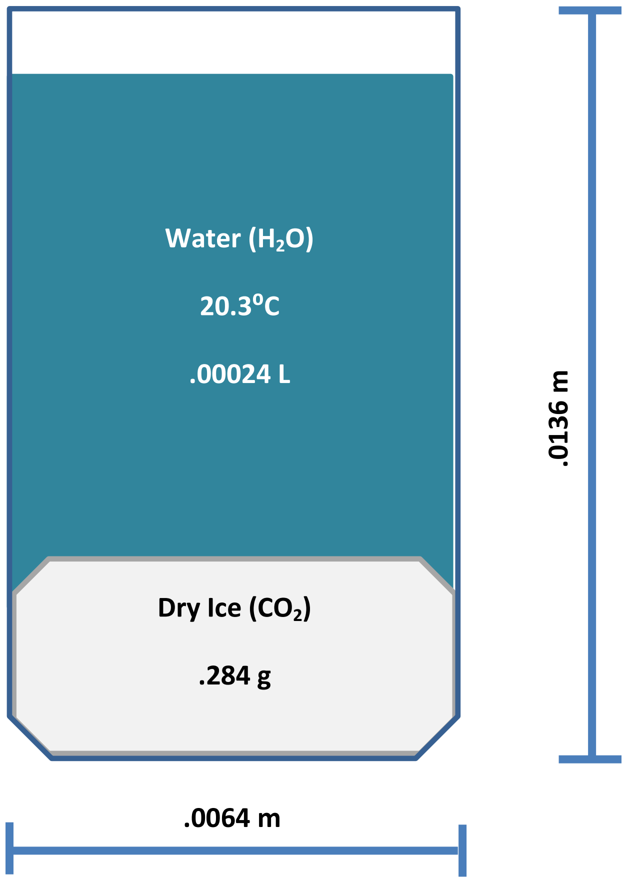

Figure 2. Sketch of Experiment Apparatus.

Immediately as the water is added sublimation of the carbon dioxide begins as it undergoes a solid-gas transformation. At this stage the carbon dioxide gas flows along the dry ice in bubble streams, coming into contact with other streams s released from different sections of the dry ice. These bubble streams combine to form several streams of large carbon dioxide bubbles. Simultaneously, the water cools quickly and small water droplets and ice crystals begin forming within each bubble producing fog. This occurs until the the water cools below its' dew point[4], approximately 9.2°C on January 28, 2011 when the photo was taken [6]. In addition to condensing within the bubbles, the water begins to freeze to the the dry ice block. When observed post photo major features such as cracks and gaps had been filled with ice while points and areas that had jutted out had evaporated away[6]. These two areas experience the largest exposed surface areas and therefore are more susceptable to convective heat transfer which varies linearly with surface area. Pointed areas would have more surface area exposed to water with less mass to store heat and thus would evaporate quicker . Crevaces would have more surface area exposed to fluid but have the entire mass of the dry ice to conduct heat and thus a larger mass produces a larger heat capacity[4].

$$\dot{Q} = HA\Delta T \qquad Rate\ of\ Heat\ Transfer^{[4]}$$

$$Q = mc_p\Delta T \qquad Heat\ Capacity^{[4]}$$

Where Q and Qdot are the Heat capacity[J] and heat transfer rate[J/s] respectively, c_p is the specific heat[J/kg*^{o}C], ΔT is the temperature difference [^{o}C], A is the surface area [m^2], m is the mass [kg] ,and H is the convective heat transfer coefficient [W/m^{2o}C][4].

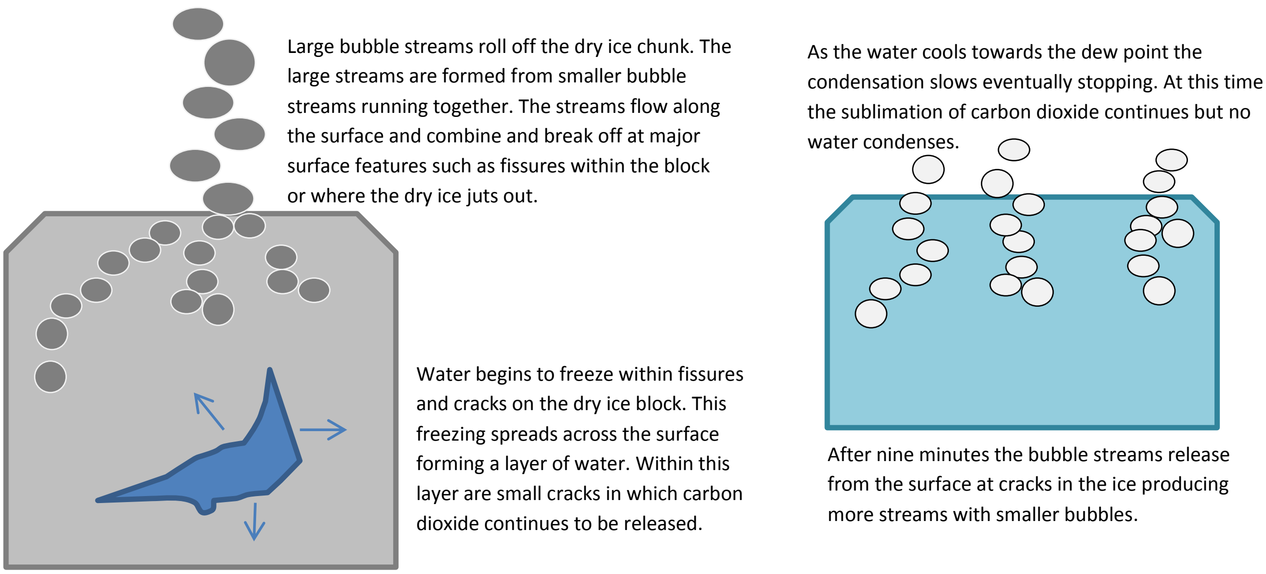

Figure 3. Depiction and description of the two types of flow seen within the experiment.

At both times the driving force of the bubbles is bouyancy. The buoyant force is characterized as the net upward hydrostatic pressure force acting upon an object submerged, or partially submerged in a fluid. In this experiment the object is the carbon dioxide gas produced when water, at much higher temperatures, reacts with dry ice. This force is produced by the increase in pressure with an increase in depth [3].

Treating the bubbles like discs, the forces at the top and bottom of the bubble are characterized by

$$F_{Top} = \rho_f gSA$$

$$F_{Bottom} = \rho_f gA(S + h)$$

Where F_{Bottom} and F_{Top} are the bottom and top forces [N], ρ_f is the fluid density[kg/m^3], g is the gravitational accelleration [9.81 m/s^2], A is the cross sectional area [m^2] of the bubble perpendicular to F_{Bottom} and F_{Top}, S is the distance [m]from the surface of the fluid to the top of the bubble and h is the height of the bubble[m] [1] .

$$F_{Buoyant} = \rho_f gS(A+h) - \rho_f gSA = \rho_f ghA = \rho_f gV$$

V=hA is the volume [m^3]. This volume can be replaced with 4/3πr^3, and more correctly modeled as a sphere. $P_f gV$ is the weight [N] of the fluid whose volume is occupied by the volume. Therefore the Bouyant force is equal to the weight of the displaced liquid. This is known as Archimedes principle. For floating bodies, the category this experiment falls into,

$$F_B(N) = W(N) = \rho_f gV_{Submerged} = \rho_{average,object} gV_{Total}$$

Where $V_{Submerged}$ [m^3] and V_{Total} [m^3] are the submerged and total volumes Rearranging for ratios of volumes and ratios of densities produces[1]

$$\frac{V_{Submerged}}{V_{Total}} = \frac{\rho_{average,object}}{\rho_f}$$

The submerged fraction of a floating body is equal to to the ratio of the average density to density of the fluid. It then follows that when the density of the object (bubble in this case) is less than the fluid density the object will float or rise within the fluid. This is easily seen when comparing the density of water, 1000 kg/m^3, and carbon dioxide gas,1.95 kg/m^3 at standard temperature and pressures[1][3].

The Photo was taken looking from the bottom of the class upward and taken once the water temperature fell below 9^{o}C since no condensation occurred, reducing visual interference from the fog. A black background was used along with the flash from the camera to produce contrast and bring out the outline of the bubbles. An Iso of 800 was used at a length of 7cm from the bottom of the glass. An f value of 3.5 was chosen. Utilizing photo shop the black backdrop was cleaned up using the clone stamp tool. Additionally the curves tool was utilized to increase contrasts between the black and whites. The sharpen tool was utilized to create sharper lines and details. In this photo I like the sharpness and contrast. If retaken I would square and center the image better and raise the camera slightly to catch the bubbles rolling off the dry ice more.

[1] Carbon dioxide pressure-temperature phase diagram showing the triple point of carbon dioxide." *Webster's Online Dictionary*. Web. 8 Feb 2011. <http://www.websters-online-dictionary.org/definitions/carbon%20dioxide?cx=partner-pub-0939450753529744%3Av0qd01-tdlq&cof=FORID%3A9&ie=UTF-8&q=carbon%20dioxide&sa=Search#922>.

[2] Cengel, Y.A., and J.M. Cimbala. *Fluid mechanics: fundamentals and applications*. International. New York, New York: McGraw-Hill, 2006. 89-90. Print.

[3] Cheung, F.E., and M. Epstein. "Two-phase gas bubble-liquid boundary layer flow along vertical and inclined surfaces." *Nuclear Engineering & Design*. 99.1 (1987): 93-100.

[4]*Convective Heat Transfer*. The Engineering ToolBox, n.d. Web. 79 Feb 2011. <http://www.engineeringtoolbox.com/convective-heat-transfer-d_430.html>

[5]"Dry Ice Fog." *Dry Ice Information*. N.P., 10 Dec 2010. Web. 5 Feb 2011. <http://citationmachine.net/index2.php?reqstyleid=1&mode=form&reqsrcid=MLAWebDocument&more=yes&nameCnt=1>.

[6] "National Weather Service-Data." *National Weather Service*. National Weather Service, 28 Jan 2011. Web. 9 Feb 2011. <http://www.nws.noaa.gov/climate/getclimate.php?wfo=bou>.