INTRODUCTION

This video was created to satisfy the final team project of the Flow Visualization course at CU-Boulder. Its purpose was to capture several different forms of phase change on video or time lapse and to create a compilation where they were shown in reverse. The phase changes include solid to liquid (ice and candle wax melting), liquid to gas (water boiling), and solid to gas via combustion (napkin on fire).

SETUP

The setup for these clips was very simple. The first involved a collection of ice cubes sitting on top of a clear pyrex dish that was oriented upside down. This inspired nice outward movement of the cubes as they melted and made for some nice reflections off the glass. The second clip involved a number of wax candles setup in a large skillet to which heat was applied from underneath. The third clip contained an ice cube that was placed on a heated stovetop coil. The fourth clip was a close-up of water being heated then boiling. The fifth clip involved two phase changes; first ice melting then water boiling. The final clip is a napkin that was lit with a match at its top left corner from which the flame then propagates down. All clips were shot from approximately 6-24 inches away from the subject.

FLOW DISCUSSION

There are three main fluid phenomena captured in this video: melting, vaporization, and sublimation. For this report, we will focus mainly on the melting and vaporization processes, as they are the most highlighted in the video.

Melting

In the clips where ice (or wax) is melting, the solid object exhibits heat flow inward to the system. The molecules in the solid begin to take a less structured orientation as heat excites the H_2O. For example, in the first clip, the ice is sitting at room temperature (about 68^{o} F) for two hours or so. Over that time, heat flows from the moving air around it and the pyrex container underneath it (via conduction and convection). Once the frozen water molecules have been heated to the point of melting point (32^{o} F), the cube begins to undergo a phase change. Here, as heat continues to be added, the temperature stays the same as more energy is required to promulgate the phase change. This is known as the latent heat of fusion and has a value of approximately 334 kJ/kg for water[1]. The physics behind ice melting is becoming more and more a pertinent issue as we have started to see the earth's ice caps melt at higher rates. A simple heat balance shows that with man's increased energy use, we are heating the atmosphere and in turn the oceans and ice caps.[2]

Vaporization

When heat is added to the liquid from of H_2O, we see another form of phase change. The jump from liquid to gaseous state is known as vaporization. This occurs once the temperature of the heated water reaches 212^{o} F. In this instance, the molecules become even more loosely arranged. We again see this lag in temperature increase once the water reaches boiling point as the latent heat of vaporization is the additional energy involved in this phase change. For water, this value is 2257 kJ/kg, which you'll notice is significantly higher than the latent heat of fusion value[1]. This energy has massive repercussions in the world of human energy needs. Almost all of our electricity comes from some process involving heating water to steam. In the patent for solar thermal energy processes established in 1975, we see a description of how water is heated to vapor via concentrating solar energy, then this energy can be used later as the fluid condenses and releases the energy it absorbed during heating and phase change[3].

The energy associated with phase change in general is interesting because of its applications in the world of energy. Thermal Energy Storage (TES) becomes important when there is a difference between when the energy source is available and when it is needed. There are studies being done to determine which phase-change materials would be best for such an application and how they may be utilized[4]. As the world moves forward in establishing its new energy portfolio (which will no doubt include more sustainable options), thermal energy storage capacity will be a huge piece of the final puzzle.

VISUALIZATION TECHNIQUE

In order to visualize these phase changes, I relied on good focus and lighting. There was no use of dyes or tracers of any kind. The fluids themselves acted as the medium to highlight the phenomena. Again, the melting phase change was shown with ice and candle wax, vaporization was shown with water, and sublimation was shown with a paper napkin and flame.

PHOTOGRAPHIC TECHNIQUE

The clips in this compilation were shot with both a Sony EX1R video camera (using the time lapse function) and a Sony EOS 7D still camera (using the video capture function). Since the phenomena were occurring at different speeds, some editing work was done to bring all the fluid flows into a similar realm of movement. The first clip represents approximately 2 hours of actual footage, which was then sped up to about 100x speed. The other melting clips involved the addition of heat via a stove top and therefore were only sped to about 30x. The field of view of the shots ranged from about 8 inches to 15 inches.

IMAGE EDITING

The only real editing done to this footage was some contrast manipulation and playback speed and direction. For the most part, the clips had some contrast increase (for example in the first clip to make the white ice cubes stand out against the dark background). Also, each was obviously played in reverse and then at the end, played back quickly in forward motion. All focus jumps or slight movements during the clip were done manually during the filming.

CONCLUSION

Since the beginning of the semester I have wanted to do a video like this. I actually heard the song (Spoon – "Written in Reverse") on my way home from class one day and got the idea. There is something about a day-to-day phenomena (like ice melting) that comes out so different when seen in reverse and at a much faster speed. I received a number of comments saying how the reverse time lapse keeps the viewers attention so well because you don't really know what its going to form into. I think the wax clip is the best example of that as, at first, you have no idea what you are looking at. I am very happy with how this project came out and would definitely consider doing something like this in the future with even more examples.

References

[1]The Engineering Toolbox. http://www.engineeringtoolbox.com/latent-heat-melting-solids-d_96.html

[2]Sellers, William. "A Global Climatic Model Based on the Energy Balance of the Earth-Atmosphere System." 1968. Accessed at - http://books.google.com/books?hl=en&lr=&id=lhzK1-woaiQC&oi=fnd&pg=PA125&dq=ice+caps+melting+heat+transfer&ots=Ok-MVflW1m&sig=s71cfR5KtABdIX2WzHZjOZIPYtU#v=onepage&q&f=false.

[3]US Patent 3875926 – "Solar Thermal Energy Collection System." http://www.google.com/patents?hl=en&lr=&vid=USPAT3875926&id=QSEsAAAAEBAJ&oi=fnd&dq=solar+thermal+water+vapor&printsec=abstract#v=onepage&q=solar%20thermal%20water%20vapor&f=false

[4]Syed, Tashfeen, Kumar, Sunil, Moallemi, Karim, Naraghi, Mehdi. "Thermal Storage Using Form-Stable Phase-Change Materials." Ashrae Journal. May 1997.