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Cryogenic Boiling Experiments

Cryogenic Boiling Team 1 (aka Charlie)
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AA 322 Aerospace Laboratory II
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University of Washington
Spring 2023

To achieve long term space travel it will require a reevaluation in cryogenic propellants when boiling for a period of time. This experiment will demonstrate the behavior of immersing spheres initially at ambient conditions suddenly in liquid nitrogen, and then measuring the time-varying temperatures using thermocouples. The result will provide engineers insight on heat transfer, boiling rate, and cool down time, ultimately providing a greater understanding of cryogenic propellants and long-term space travel.

I. Introduction

A. Problem Statement / Objectives / Hypothesis

Cryogenic Boiling Team 1 aka Charlie aims to understand heat transfer and cooling properties of liquid nitrogen by measuring the temperature gradients on several sphere that will be tested on. For long term space travel to be possible, storage and transfer of cryogenic propellants like hydrogen and oxygen are crucial for mission success. The propellants are very prone to boiling off and this inevitably leads to significant loss. To help prevent this a more thorough understanding of boiling, cool down, and heat transfer characteristics are very essential. The objective is to improve the accuracy of heat transfer measurements for spheres in liquid nitrogen by addressing the inconsistency caused by the nitrogen vapor envelope surrounding the sphere. This will be achieved by measuring temperature within the same plane of the sphere's surface and comparing the results across different planes, which is anticipated to help to reduce uncertainty in the boiling data of the sphere in liquid nitrogen by determining the location least effected by changes in the violent boiling. Another way of improving the precision of the measurements is to measure varying temperature gradients throughout the sphere. The method that will be used to measure heat transfer from the change in temperature is by using the heat transfer equation I.A, which measures heat transfer using thermal conductivity and temperature gradients ($\frac{dT}{dr}$). Ultimately the objective of this experiment will be to provide improved uncertainty in the analysis of sphere quenching for use in cryogenic storage and transfer systems for long-term space missions by obtaining quantitative data on heat transfer during quenching in liquid nitrogen. The units of q will be measured in watts or joules per second, while the area will be measured in square meters.

$$q = -k\frac{dT}{dr} \tag{1}$$

B. Background

In preparation for this experiment, we were given a published report by NASA[1] This report effectively compiled studies from the past 70 years. The data from these studies shows large data fluctuations, giving rise to high levels of uncertainty. Methodology is also not always clear from study to study, nor is it consistent, so comparing results is difficult. In this experiment, team Charlie hopes to use average results from this paper as guidelines to verify our test procedure is working. The data from this report covered several geometries, sizes, and materials for quenching materials in liquid nitrogen. Our focus will be on the quenching of aluminum spheres in particular.

II. Technical Discussion of Approaches

A 25 millimeter (1 inch) aluminum sphere at room temperature will be submerged using tongs into a dewar or pot containing liquid nitrogen. Thermocouples located in holes drilled into the sphere will be used to measure the difference between the temperature at the center of the sphere and the surface temperature as the sphere adjusts to the cryogenic temperature (quenching). The thermocouples will be attached to a sensor control box which will then allow the heat flux to be calculated from the change in temperature measurements. See Figure 1 for a side-view sketch of the setup. The four different types of spheres used will be 1) have a single 0.5 inch hole 1/16 inch diameter so that a basis center temperature change can be determined for later comparison, 2) have the center measurement and three additional holes along the surface of the sphere at the same plane for identifying the orientation with the least uncertainty, 3) have the center measurement, a 0.25 inch hole for a half radius measurement, and a surface measurement, and 4) have the center measurement, .5/3 inch and 1/3 inch holes, and a surface measurement for determining the gradient with the least uncertainty (Figure 2).

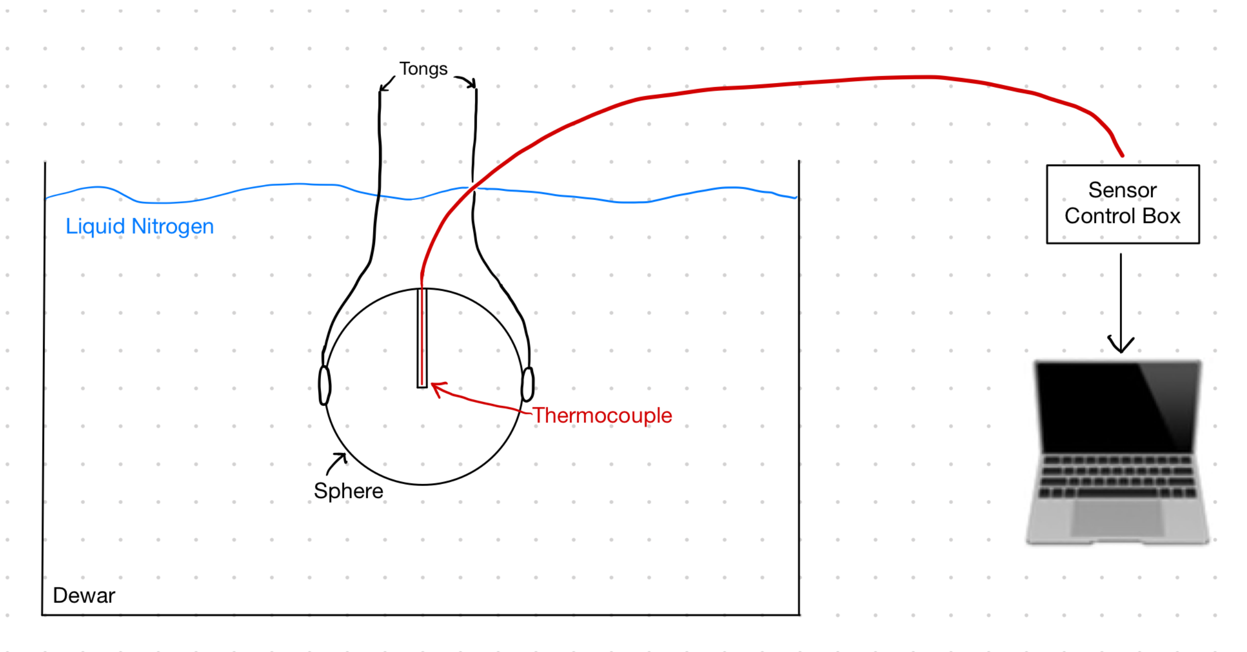


Fig. 1 Diagram of Apparatus

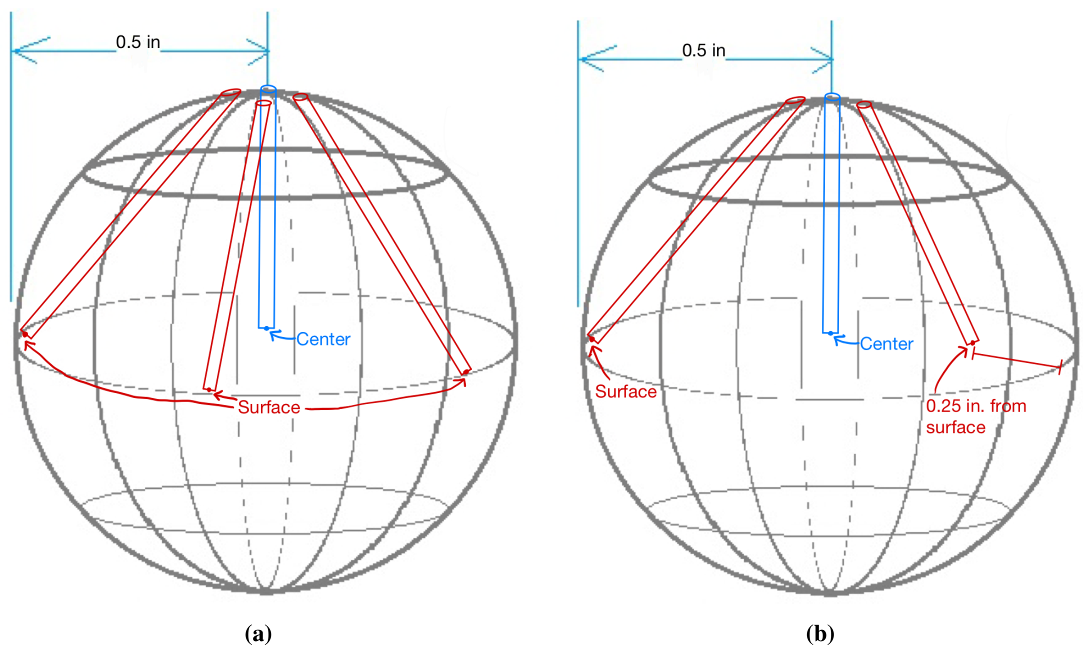
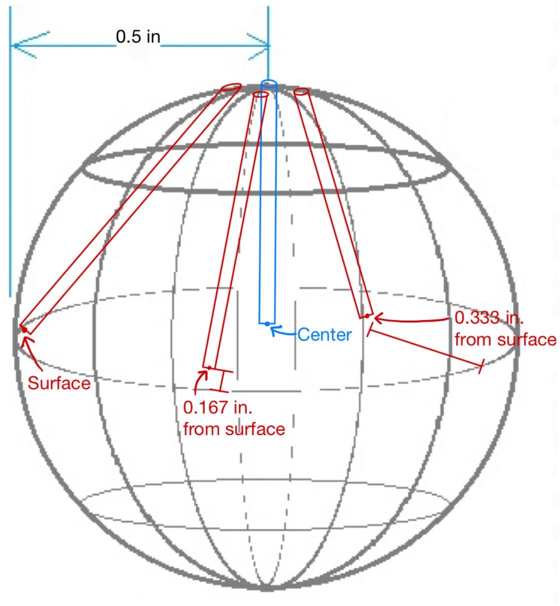


Fig. 2 Sketch of Drilled Holes for (a) Surface Locations, (b) Half Radius Gradient, and (c) One-third Radius Gradient



(c)

Fig. 2 Sketch of Drilled Holes for (a) Surface Locations, (b) Half Radius Gradient, and (c) One-third Radius Gradient

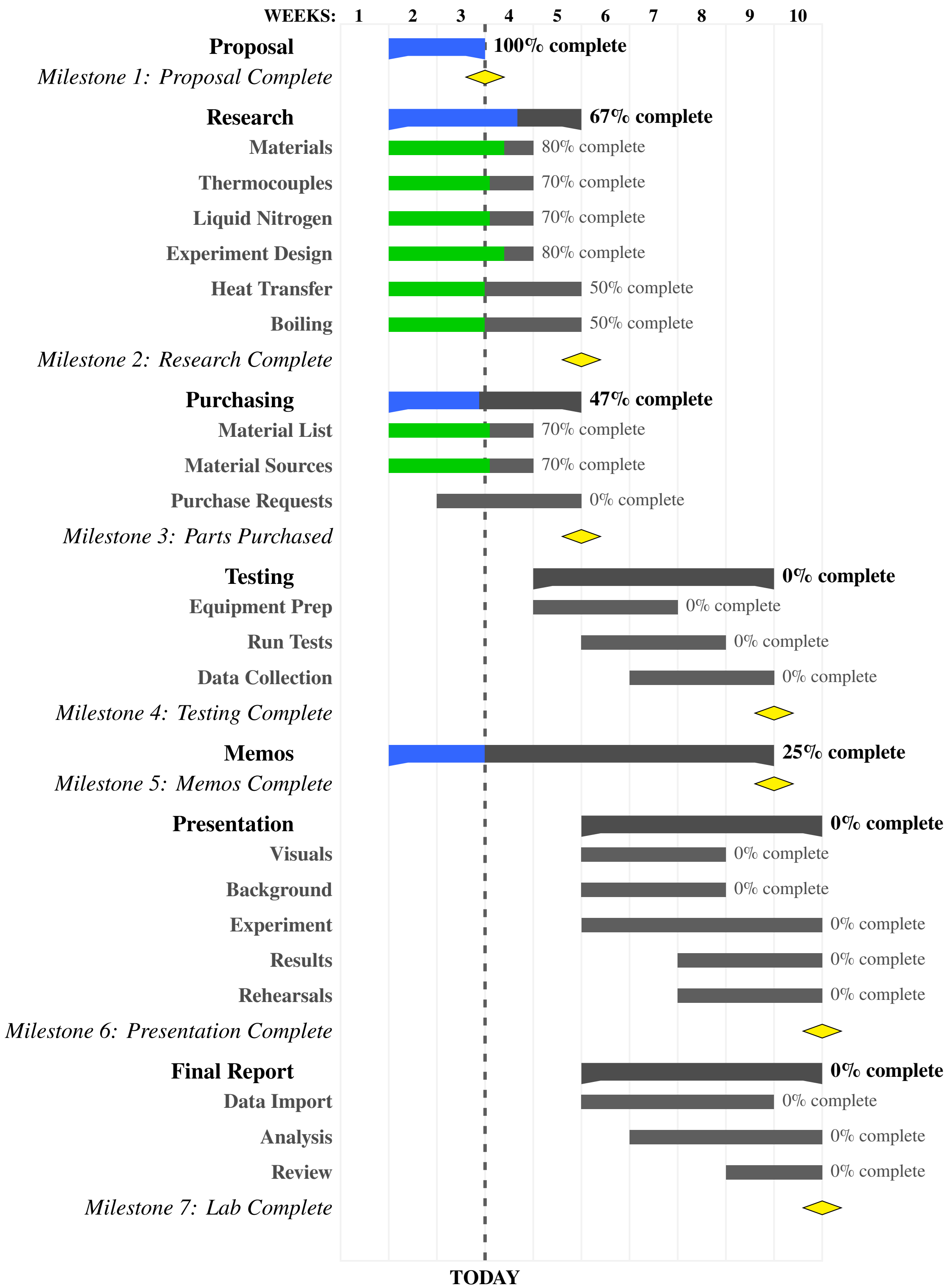
Since the temperature measurements be taken will be at cryogenic temperatures, where liquid nitrogen boils at $-195.8°C$, type T thermocouples are needed as they have an approximate range of -270 to $370°C$. However, due to this type of thermocouple being less typically used and the requirement of the diameter needing to be less than 1/16 inch, the lead time of the thermocouples is estimated to be 4 weeks. In addition, the manufacturing of the spheres with the custom holes will require a specialized drill normally used for watch making to produce the speed needed for a 1/16 inch drill bit as well as potential mill training for increased precision in creating the center temperature measurement location.

III. Project Schedule

A. Specific Roles

1) Evelyn: Facilities Liaison, Thermocouples, Experimental Design
2) Adam: Materials Research and Sourcing, Experimental Design
3) Felicity: Purchasing Officer, Heat Transfer (theory, modeling, behavior)
4) Emi: Secretary/Notes, Boiling (properties, heat flux)

B. Gantt Chart



IV. Test Plan

Five 25mm aluminum spheres will be used to measure heat transfer during the boiling of liquid nitrogen. Three T-type thermocouples will be used to measure the rate of change of temperature through each of the spheres. Holes of varying depth will be drilled in each of the spheres in order to measure the temperature at different point within which will provide a much more accurate estimate the rate of change through the material. Measurements will be taken all in the same plane to account for the effects of the vapor envelope around the sphere due to violently boiling nitrogen. Each sphere will have holes of various depths, with one only having one hole in the center in order to set a baseline for temperature at the center of the sphere. The orientation of the holes will also be varied in order to get a better idea of how the heat transfer varies at different points within the boil. Each of the spheres will be tested a minimum of 3 times, giving a total of 15 tests in all. Ideally there will be very little change between identical tests, but given the large variance in data in the NASA report provided to us it seems likely there will be changes. This may be mitigated by ensuring that the orientation of each of the spheres is exactly the same for each test.

We plan on thermocouple data acquisition through LabView, and data processing will likely be done using either Matlab or Excel.

V. Safety Considerations

- Liquid nitrogen (LN) is generally inert if untouched; however, it has the potential to cause severe burns if handled without the proper care. Skin contact with LN can result in burns, blistering, and severe frostbite injury, which can occur within seconds of exposure. Skin damage from exposure to LN may be extensive enough to require surgery or amputation. Personal protective equipment (PPE) such as safety goggles, face shields, insulated gloves, and lab coats should be worn to reduce the risk of skin injury. [2]
- As liquid nitrogen evaporates, it also displaces the oxygen in the air. If the lab space is not properly ventilated, oxygen concentrations can become dangerously low and lead to dizziness, unconsciousness, and even death. [2]
- Due to the above safety considerations, the transportation of liquid nitrogen should be done with personal protective equipment such as insulated gloves and lab coats. A dewar should be used as a safe, insulated vessel for the transportation.
- Mechanical hazards are present when using hand drills and mills. Additional training will be necessary, and safety procedures will be followed at all times along with the use of eye protection and other PPE.

VI. List of Materials and Hardware

- 4 Type T Thermocouple Probes with insulated lead wires ((item #HTTC36-T-116G-2) from Omega) (probe diameter 0.062 inch, probe length 2 in)
- 1-2 Liters of Liquid Nitrogen per test (UW Chemistry Research Stockhouse, Bagley 36)
- 5 Aluminum Spheres 25mm diameter ((item #1201B83) from Thomas Scientific)
- 1 roll of PTFE Tape (item#3AB55 from Grainger)
- 1/16th inch drill bit that will cut into aluminum (From Machine Shop)
- Cryo-dewar Pot (Machine Shop/Lab)
- Drill Press (Machine Shop)

VII. Budget Status

Description	Source	Quantity	Unit	Cost
Liquid Nitrogen	Bagley 36	15-20	Liter	$40
25mm Aluminum Ball(item #1201B83)	Thomas Scientific	5	1	$29.55
Type T Thermocouple (item #HTTC36-T-116G-2)	Omega	4	1	$45-55
PTFE Tape(item#3AB55)	Grainger	1	Roll	$0.98
			Total	$287.69

References

[1] Moore, R. C., and Hermanson, J. C., "Evaluating the Comlete Pool Boiling Curve for LIquid Nitrogen," 2019-2021.

[2] Yee, K., "Liquid Nitrogen Can Cause Severe Burns," 2021. URL `https://www.poison.org/articles/liquid-nitrogen-can-cause-severe-burns-211`.