Effect of Increasing Thermal Mass on Chamber Temperature Stability within Ultra-Low Freezers in Bio-Repository Operations

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Abstracts

Stability and consistency of temperatures throughout specimen storage units is critical to the long-term viability and uniformity of those specimens for research. Empty freezers react differently to changes in air temperature, caused by opening the door, than do full freezers holding many frozen samples. This is especially important in those facilities that prefer to use upright models over chest-style units. This study was undertaken to explore and quantify the impact that increased thermal mass has on the ability to maintain chamber temperatures within specifications throughout an ultra-low freezer, following typical stresses on the unit. Frozen water jugs were used to provide increased mass within the freezers. Open door and power failure stress tests were conducted on upright ultra-low freezers from three manufacturers, under four different thermal mass conditions: empty chamber, top half of chamber full, lower half of chamber full, and full chamber. Eleven thermocouples placed throughout the unit were used to map fluctuations in the unit during each test. Results indicate that increased thermal mass had both positive and negative implications on repository operations. Understanding these implications and applying them to standard operating procedures can improve bio-repository operations.

Introduction

Cost considerations are driving the need to maximize storage density in bio-repository operations. One of the simplest ways to accomplish this for -80°C storage is to preferentially select freezers with upright configuration over those with chest-style configurations. However, it has long been known that there is a downside to this decision; chamber temperatures within upright units quickly warm when the door is opened because the colder, denser air falls to the floor. Stability and consistency of temperatures throughout specimen storage units is critical to the long-term viability and uniformity of those specimens for research.

If the decision is made to use upright freezers for specimen storage, what can be done to minimize the downside of this selection and stabilize chamber temperatures during normal operations and access? Anecdotally, one knows that empty freezers react differently to changes in air temperature, caused by opening of the door, than full freezers. Can increasing the thermal mass within an upright unit stabilize chamber temperature when the unit is accessed? What ramifications are there to increased mass during abnormal situations? For example, how do freezers containing high-thermal mass respond during a power outage?

This study was undertaken to explore and quantify the impact that increased thermal mass has on the ability to maintain chamber temperatures within specifications throughout an ultra-low freezer, following typical stresses on the unit. Frozen water jugs were used to provide increased mass within the freezers. Stress tests were conducted on upright ultra-low freezers from three manufacturers to provide data representing a spectrum of products and to, provide an initial look at the role that door configuration or controller probe position may play. The units were tested under four different thermal-mass conditions: empty chamber, top half of chamber full, lower half of chamber full, and full chamber. Thermocouples placed throughout the unit and next to the freezer controller probe monitored changes in temperature during the tests. This poster presents data from all the open door and power failure tests.

Methods and Materials

Three different makes and models of freezers were used to determine the response of chamber temperatures to increasing thermal mass. These units were placed side by side and each test was performed on the three models simultaneously.

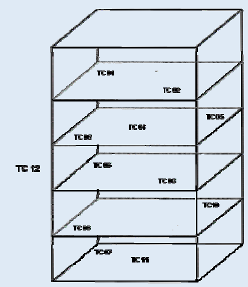
Two-and-a-half gallon water jugs of 6”x12”x9.25” dimensions, pre-cooled to -80°C were used to provide increased thermal mass. Jugs, roughly the size of a standard 16-box, ultra-low freezer rack fit well across each freezer shelf. Thermal-mass configurations studied were: empty chamber, lower half full of ice, Upper Half Full of Ice, and entire chamber full of ice.

Freezer Name	Capacity (cu. ft.)	No. Inner Doors	No. of Shelves	Ice Jugs per Shelf	Ratio of Ice to Capacity of Unit	Location of controller probe
A	23	5	5	4	.29	Back left lower shelf
B	28	2	5	5	.325	Middle shelf back left
C	24.4	5	5	5	.342	Lower shelf back right

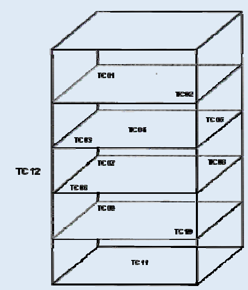
Table 1. Freezer Configuration

A Kaye Validator model 2000 equipped with 36 thermocouples was used to map changes in temperature across the freezer chambers. Data were collected using a standard laptop interfaced with the Kaye Validator. Thermocouples were calibrated against an NIST standard prior to testing. Eleven thermocouples were threaded into each unit via access ports and placed strategically throughout the unit. Thermocouple number seven (TC7) was placed adjacent to the controller probe for the unit. Thermocouples were secured within sample boxes placed on the shelf to ensure that they remained stationary during testing. The twelfth thermocouple for each unit was adhered to the back of the unit to track the ambient temperature during the test.

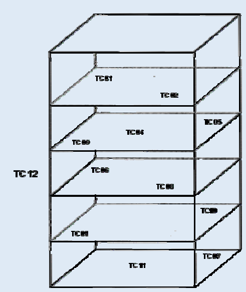
Freezer set point was -80°C and all units were running within this specification prior to beginning the study. Two tests: All Doors Open and Power Failure were performed on each unit at each thermal-mass configuration. Tests were repeated three times. For the open door test, all outer and inner doors were opened for 4.0 minutes and then closed. Recovery time was determined to be the time it took for the last interior thermocouple to return to -70°C. For the power failure test, the unit was unplugged and temperatures were monitored. When the last interior thermocouple reached 70°C power was restored to the unit. Recovery time was determined to be the time it took for the last interior thermocouples to return to -70°C.



Freezer A: Thermocouple Placement



Freezer B: Thermocouple Placement

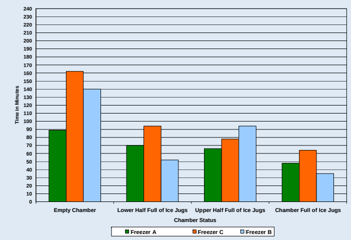


Freezer B: Thermocouple Placement

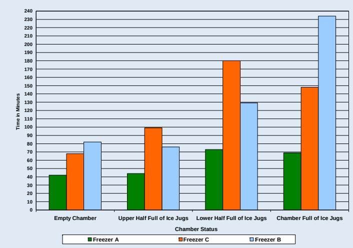
Discussion

Open Door Test: Graphs indicate that the average recovery times for all units were much less when chambers were filled with ice jugs than when they were empty. The greatest impact was seen in the unit with the largest capacity. Thermal mass in the upper part of the chamber has a more positive effect than mass in the lower part of the chamber as one expected since colder air is denser and will sink and cool the area below.

Power Failure Test: Graphs indicate that average recovery times for all units were much greater when chambers were filled with ice jugs than when they were empty. This reflects the fact that during an extended power outage all of the mass in the unit warms at the same time. Whereas the short duration of a door opening is not long enough to significantly raise the temperature of the mass within the unit, but primarily effects the temperature of the air within the chamber. The power outage results again showed that recovery was faster for partially filled units when the thermal mass was concentrated in the upper part of the unit.



Recovery Times : Open Door Test



Recovery Times : Power Failure Test

Conclusion

Increasing thermal mass stabilizes temperatures within upright model ultra low freezers. Water jugs of appropriate size and shape are effective in helping to maintain optimal chamber temperatures during normal operations and access. As expected the greatest benefit is seen in units with the highest thermal mass, i.e. units full of frozen material. On the other hand this increased thermal mass can delay recovery times following a significant power outage as the unit must work harder to cool the increased mass that has warmed uniformly.

The decision to use ice filled jugs to increase thermal mass within upright units will depend on various operational factors such as how often units are accessed, how quickly they fill, available space and equipment to pre-cool and store frozen jugs, emergency response protocols etc. At a minimum Biorepositories using upright ultra-low freezers for specimen storage should fill the units from the top down.

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