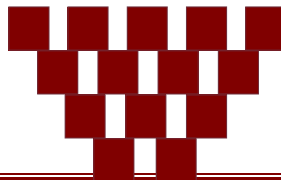


**DESIGN AND TESTING
OF INSULATED SHIPPING CONTAINERS**

PREPARED BY

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Abstract:

A wide range of products require temperature stabilization during shipping. For effective temperature control, several factors need to be taken into account which will help the manufacturer assess the best form of shipper for their product. This paper examines the three types of temperature controlled shipping systems and their relative suitability for particular types of products.

Introduction:

The purpose of this paper to inform the reader of the basics required for designing an insulated shipper to meet the needs of the product as it travels through its distribution environment. A large and growing segment of package performance testing has to do with the requirements to keep products at a certain temperature or within a certain temperature range during transit. Medical products and some electronics, for example, occasionally require a temperature controlled transit environment. This article will focus on two package types: those that keep the product frozen (below 0°C), and those that keep the product between 2°C and 8°C.

To achieve temperature stability during shipping there are three main types of insulated shipping containers to choose from: Active, Passive, and Hybrid. Let us now look at these three types of systems.

Temperature Controlled Shipping Systems:

Active shippers use a thermostatically controlled device to actively adjust the temperature inside a shipper. This can be done with refrigeration systems powered by batteries, and some even have heaters if the temperature in the package gets too low.

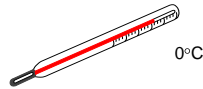
Passive systems do not actively control temperature, they rely solely on the refrigerant (phase change material PCM) packed into the shipper to remove heat. A phase change material is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa. Initially, PCMs temperature rises as they absorb heat until they reach the temperature at which they change phase. They absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase.

Hybrid systems combine active and passive systems to maintain temperature. Hybrid systems typically use a PCM that is thermostatically controlled. This article will focus only on passive systems that use PCM.

Two distinct requirements generally emerge. One involves keeping products **completely frozen** during the entire shipment cycle. The second involves keeping products **within a certain temperature band**,

typically 2°C to 8°C during shipment. In both cases, the packages must provide thermal protection and mechanical protection because of the expedited nature of the delivery process.

Keep It Frozen:



Perhaps the simplest thermal container is that required to keep a product below freezing for a minimum of 48 hours. This time period assumes 24 hour expedited shipment plus some time at the beginning and end of the cycle for the packing and unpacking process. A 72-hour performance is normally specified in order to allow for some safety margin. Conceptually, the container system consists of three primary components:

1. the exterior shipper
2. the thermally insulating medium
3. the refrigerant

The job of the exterior shipping container is to provide the mechanical integrity necessary to survive the normal bumps and jolts typical of overnight delivery distribution. Often the insulating medium helps in this regard. The important characteristic of the shipping container is that it seals the interior from air flow. Therefore it is important that the container be designed with tight seals. This means closely aligned flaps and H-pattern taping around all flap closures. A glued manufacturer's joint is also highly desirable. Avoid the use of hand holes, strapping, or crown staples for box sealing. For smaller containers of perhaps 2 cu. ft. capacity or less, 32 ECT (200 lb. burst) C-flute containers of an RSC design work well. For larger containers, double-wall corrugated is recommended.

The insulation is made of light density expanded polystyrene (EPS), Polyurethane (PUR), or Vacuum insulated panels (VIPs) or semi-rigid foam materials. Remember that the best insulating medium is an absolute vacuum and therefore, the closest we can approximate this from a theoretical standpoint, the better the insulation will be. Therefore, light density materials will work better for insulating than heavier densities of the same material. The material must be closed cell or be lined with a polyethylene sheet or similar in order to restrict airflow. When air becomes very cold, it is also very heavy and will easily escape through any opening in the bottom of the container, even through small passages of open cell foam material.

The thickness of the insulating material is a function of many things, including the thermal mass of the internal specimen, the amount of refrigerant used, the thermal resistance of the insulating material, and the amount of time that the container must maintain sub-zero conditions.

R = Thermal Resistance

If you know the R value (thermal resistance) of the insulating material, a reasonable estimate of the wall thickness can be obtained. If you are unsure of the R value, a good place to start is with 2-inch thick insulating medium. For those applications with a large thermal mass or high amounts of refrigerant, a one-inch thick insulation may be sufficient. For critical applications or for those with low thermal masses, a 3-inch thick wall may be required. The testing of the container system described later on will determine the exact requirements. Regardless of the wall thickness, the most critical element of the thermal design is that no air gaps exist in the container system. As stated previously cold air will act as a fluid and will flow out of any holes in the bottom of the container just as water will flow from a bucket with a hole in it. In fact, it is a good test for a thermal container to fill it with water to make sure that no leaks occur.

Since the orientation of the shipping container cannot be guaranteed during shipment, especially express overnight shipment, it is critical to pay attention to how the top of the container is insulated. Some designs will utilize an open cell flexible urethane as the top insulating medium. When a container like this is shipped on its side or inverted, the cold air inside will escape through the open cell urethane material and vastly reduce the thermal performance of the container. It is highly recommended that the top insulating plug be made of a closed cell material and that the fit between the plug and the container be as tight as is practical.

The Colder the Better...

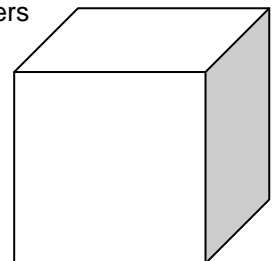
The refrigerant normally used for an application such as this is frozen carbon dioxide (dry ice). It has a freezing point of approximately -90°C and it maintains a temperature of -78°C as it sublimates (changes from a solid directly to a gas) and is available in 1-inch thick slabs or in pelletized format. It dissipates as gaseous carbon dioxide and will therefore build up pressure in the container if the container is completely sealed. It's important, therefore, to check the compatibility of the product with carbon dioxide gas and to allow for venting.

Because of the extremely cold temperature of the refrigerant, **thermal stratification** of the air in the container will occur. WESTPAK has measured as much as a 40°C temperature differential between the bottom and top air space in a dry ice refrigerated container. Because the orientation of the container cannot be guaranteed throughout shipment, it is essential that the refrigerant charge be split between the top and bottom of the container. This will also reduce temperature stratification.

For most applications, dry ice charge of approximately 3-4 lbs. per cubic foot of volume per 24 hours of shipment, would be a good place to start. This assumes a 2-inch thick insulating wall. For thinner wall sections or very light thermal mass in the product, more dry ice will be necessary. Conversely, for thicker wall sections or higher product thermal mass, less dry ice will be required. Also note that pelletized dry ice will dissipate faster and result in a colder product temperature than will the same material in a slab form.

Note that refrigerants other than dry ice are also used. These include wet ice (frozen water), gel pack and get bricks (same material used in gel pack applied to a foam in order to keep a specific shape). The most popular is "gelled" water often referred to as a "**gel pack**". When compared to dry ice, gel packs cannot reach the same temperature dry ice can, nor does gelled ice absorb as many BTU's per pound as dry ice will. However, gel packs are reusable, relatively inexpensive, and do not give out gas during the thawing process.

In addition to the thermal protection for the product, some means must be developed to provide the mechanical or physical protection for the product in the interior of the insulated container itself. For example, if a product is shipped with dry ice slabs, top and bottom, some means must be provided to keep the dry ice from injuring the product during an impact. Open cell foam materials or some other form of intimate wrap is often utilized around the product for this purpose. Other containers provide a nifty little slot in which the refrigerant, either dry ice or gel packs, can be located. In whatever fashion this is done, it must be remembered that the refrigerant can potentially harm the product during an impact. This is especially true when the product gets near -90°C , which generally makes most products rather brittle.



Keep it Cool:

The second general type of requirement often found in insulated shipping containers is the necessity to keep a product (often blood-related) between 2°C and 8°C. Freezing will definitely injure the product, or package (some rubber stoppers used in blood storage vials become brittle at temps below 2°C and sterility is compromised) and temperatures above 8°C will cause rapid tissue damage or a decrease in product efficacy.

2°C to 8°C = OK

The requirements of the container system can be analyzed in terms of the three basic components studied earlier. These include: (1) the outside shipping container, (2) the insulating medium, and (3) the refrigerant.

The external shipping container requirements are similar to those described earlier. The necessity to tightly seal the container is less critical in this application, because the temperatures are not as cold. However, the integrity of the container or its resistance to impacts is more important, because containers of this type often are used to ship biological specimens which may be classified as bio-hazards under the DOT (Department of Transportation) requirements.

The insulation material in these containers is the same as that described earlier. The requirements for insulation, however, tend to be more severe based on the narrower temperature range in which the container must operate. The thickness of the insulating medium depends largely on a variety of factors, including the R value of the material and the thermal mass of the contents. However, it is rare to find wall thicknesses less than 2-inches for most common insulating materials.

Sometimes thermally reflective materials, such as foil or metalized film, are placed on either side of the insulating medium in order to help with the insulating process. As a practical matter, remember that metallic surfaces reflect heat, not cold. Therefore, it makes the most sense to put a metalized layer on the exterior of the insulating medium. Since this is almost always facing the inside of the corrugated box, it has little chance to reflect much thermal energy. Therefore the best place for a thermally reflective material is on the exterior of the shipping container itself. Unfortunately, this is also the most difficult place to put it.

The refrigerant used for this type of application is almost always “gel packs” or “gel bricks”. In its simplest form, this material is a combination of water and kelp (seaweed). This combination is placed in a sealed poly bag and frozen. When completely frozen, these gel packs will absorb lots of thermal energy at approximately the same temperature; namely, their phase change temperature as they change from a solid to a liquid. The addition of the kelp forms a gelatin which keeps the refrigerant from leaking when the bag is punctured. A trick for usage in this application is to have a phase change temperature on the refrigerant that is slightly above the freezing point of water. This would give the gel packs the ability to absorb lots of thermal energy without freezing the product nearby. This is especially important in applications where the product itself has a relatively low thermal mass.

Thermal stratification within the insulated cavity will occur with this container design just as that described earlier. The solution is the same; namely, place refrigerant packs above and below the product as a minimum. Sometimes surrounding the product is an option, and in other cases, layering the product between gel packs is another option. If the gel packs have a phase change temperature of 0°C or lower,

it's important to pre-condition them above their phase change temperature in order to avoid freezing the product.

Assuming that gel packs are pre-conditioned **above** their phase change temperatures, it will require in general about 5 lb. of gel pack material per cubic foot of refrigerated capacity per 24 hours as a starting position. One-inch wall thickness on the insulation will double the amount of refrigerant needed, and 3-inch thick insulation will cut it in half on most container designs.

The material utilized for the top plug to seal the top of the container is not as critical as is the case with the frozen container design. The reason is that the density of the air in this case is not as low, and its ability to seep through cracks and open cells in insulating foam materials is reduced. However, the container itself is much more sensitive to heat loss through convection or air flows and therefore greater care must be taken to provide proper sealing of the container. For some applications, it may be cost effective to wrap the insulated container or the product itself in a poly bag in order to help seal it from convection air flow.

Test It:

Two primary physical tests are necessary on a refrigerated container design. One is mechanical and the other is thermal. Mechanical tests are further broken down into those involving hazardous materials and those which are not.

For hazardous material shipment, the most severe test involves freefall impacts from a height of 48-inches. Orientations of the impacts included one on each of four flat surfaces (top, bottom, side, and end) plus one base corner impact. The container must also be able to withstand a top-load compression test based on the gross weight of the container and its intended stack height. The exterior box used in the shipping container design must be able to withstand a moisture resistance test which generally utilizes a COBB test procedure. Finally, the container must be able to withstand a vibration input typified by ASTM D999, Method A, although testing itself is not required.

For shipment of non-hazardous material, **a shipping performance procedure** such as ASTM D4169 is generally a good idea. Other procedures such as the ISTA Procedure 1A will also do a good job of determining package performance.

The **thermal performance** of insulated shipping containers is verified by first attaching thermocouple probes, resistance temperature detectors (RTD's) or transducers to critical elements of the product after all components are preconditioned at the required temperatures. Monitoring the refrigerant packs is also a good idea in order to determine when they dissipate or no longer provide thermal cooling.

The container should then be closed, sealed, and placed in an environmental test chamber and subjected to a temperature profile that duplicates the anticipated range of temperatures during shipment. It is generally a good idea to test more than one container and to have containers arranged in different orientations other than just base down. WESTPAK generally recommends testing containers in the base-down and top-down orientations in order to determine the effect of orientation on the thermal performance.

The temperature profiles used during the chamber test should reflect both summer and winter extreme conditions. For example, summer extreme conditions are normally tested by utilizing a 24-hour cycle of 40°C at the high end and 20°C at the low end. Perhaps four hours at each temperature extreme with an 8-hour ramp between the extremes provides for a good range and cycle of tests. For a winter test profile, the high temperature of 23°C and low of 0°C provides a reasonable range. Similar temperature dwells and transition rates would occur. Total test duration of 72 to 96 hours is recommended even if the container is intended for overnight delivery distribution. The extended time will give the engineer some idea of the latitude built into the container design as far as thermal protection is concerned.

Prior to conducting the test, all components must be pre-conditioned at their intended conditions. If gel packs are utilized, they should be conditioned for a minimum of 24 hours at the condition intended, either below their transition freezing point or above that point. The product itself must be conditioned as well as the shipping container if it is intended to function that way in the real environment. That is to say, some products are conditioned in their insulated shipping container prior to shipment before the refrigerant packs are installed. If this is the case, then the insulated shipping container must also be conditioned prior to starting the test.

For actual shipment, temperature indicators are available which will change colors depending on the maximum temperature reached during shipment. Some of these are relatively inexpensive and are a good way to provide a check of the container design during actual field shipment.

Summary:

In summary, there are 3 steps that need to be taken when designing your insulated shipper. First determine within what temperature range the product needs to be kept. Second, choose the insulating material and type of refrigeration. Thirdly, design and build your insulated shipper. And finally, test the system to make sure it can meet the demands of your distribution environment.