REFRIGERATION SYSTEM FOR THE TRANSPORTATION OF LIVE SHRIMP WITHOUT WATER

By

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ABSTRACT

The objective of this project was to evaluate parameters in a refrigeration system to transport live shrimp without water. The decisive parameters that worked like decision factors in the selection of the refrigeration system were among others: determination of the system's thermal load; modeling of the thermal load in a thermal nets system; simulating conditions according to real ones; selection and acquisition of the refrigeration system that best adapts to the specific necessities, and finally the practical confirmation of the selected refrigeration system's effectiveness. According to these parameters, was possible to find a refrigeration system in stock market that met the necessary characteristics for the transportation of live shrimp without water, and with it was be made the required trials to corroborate the system functionality, which showed satisfactory results and for that reason can be potentially acceptable in the market physic as that economically, since represent a inversion according with the actual market value exportation and shrimp sale.

RESUMEN

El objetivo de este proyecto es evaluar parámetros en un sistema de refrigeración para transportar camarones vivos sin agua. Los parámetros o factores que actuaron como determinantes en la selección del sistema de refrigeración son entre otros: la determinacion de la carga termica del sistema; el modelaje de la carga térmica en un sistema de redes termicas; la simulacion de acuerdo a las condiciones similares a las reales; la selección, adquisicion del sistema de refrigeración que más se adapte a las necesidades y por último la comprobación práctica de la efectividad del sistema de refrigeración seleccionado. De acuerdo a estos parámetros, se pudo encontrar un sistema de refrigeración existente en el mercado que cumple con las características necesarias para el transporte de camarón vivo sin agua y con el cual se realizaron las practicas requeridas para corroborar su funcionalidad que arrojó resultados satisfactorios y por ende potencial aceptabilidad en el mercado tanto física como económicamente, ya que representa una inversión que esta acorde con los valores del mercado actual de exportación y venta de camarones.

DEDICATION

Many people come to mind when having to choose someone special to whom I can dedicate this accomplishment to somebody. However, there is one being, and one being alone, who I can mention without hesitation and with great joy in my heart. It is to God to whom I dedicate this work as an offering to that who is my Lord and Savior, who has given me my existence and with it all the marvels of the life. But more than a dedication this is a thank you for all that He has done in me, for all the blessings he has bestowed upon me by offering me His love and with it the all the wisdom, courage and perseverance that have helped me climb this step in the ladder of my life and that will help me go even farther. For all that You have given me, Thank You God.

I would also like to dedicate this work to my parents, my sisters, Tony, Lyle, Belkys, my new family, my partners, my professors, my relatives and my beautiful son, Jayson. They mean everything to me. I thank them for being with me in the good times and the bad, and most of all because during those “bad times”, they have shown me who my true friends are. May God bless each and every one of them, and allow me to be with you for the rest of my life.

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Love, Janneth.

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CHAPTER I

INTRODUCTION

With its tropical climate, ubiquitous water supply, and vast tracks of land, certains agricultural industries have become important pillars of the Puerto Rican economy, such as, poultry, pork, beef and coffee industries. However, other areas have near or total dependence on imported products to meet local demand. The most glaring example is its requirement to import over 95% of the seafood consumed. Even though fish and shellfish production for 1994 to 1996 was varied to some extent, from 2.7 to 3.7 million pounds (Matos 1997), it has drastically dropped from when it averaged some 6.3 million pounds from 1979 to 1982 (Collazo and Calderon 1988). Aquaculture has been the fastest growing food production system for the past decade, with an average compound growth rate of 9.6% since 1986 compared to the 3.1% annual growth rate for terrestrial livestock meat and 1.6% for capture fisheries. (Dudley-Cash 1998). However, considering that almost one-fourth of the 3.8 million inhabitants of Puerto Rico have to rely on government funds for their food purchasing abilities (Torres-Gotay 2000) successful local production of a high value food commodity, such as shrimp, would be highly limited without developing external markets.

The transportation of live shrimp was consided important because it would demonstrate that an industry could be developed on the island to produce and export commodities although it has limited local market to support its development. In addition, it would allow the industry to fill a market niche available without competing against the frozen shrimp producers that are dominated by countries in the Far East. It was necessary to develop a refrigeration system that would meet the requirements to reach the highest shrimp survival rates during the transportation process. Previous studies determined optimal handling, temperature and atmospheric conditions for the live shipping of shrimp in a water free environment (Ruilova Dávila 1994; García Rodríguez 2001). The main focus of this manuscript is to present a plan for the transportation of live shrimp in a water free environment to develop external markets for this food commodity.

CHAPTER II

LITERATURE REVIEW

There are a great number of techniques for the transportation of seafood that have been developed to increase the useful life and improve the quality of the product. Although not many experiments have been carried out concerning the transportation of live without water, there have been some experiments aimed to determine the right package, oxygen level, and consumption of CO_2. According to European Patents, some patents have been reported in Tokyo (Yoshida 1999), where a system for the transportation of live fish is being developed for the Mitsubishi Gas Chemical Company using a humidity permeable package inside which produces oxygen and uses CO_2 absorbent materials. The method was quite safe and cost efficient and during the last years it has been one of the most utilized transportation methods in eastern countries, especially Japan.

Many companies are dedicated to design more convenient methods for the transportation of live fish and they have evaluated different methods of containers, aerators and CO_2 absorbers. All have the same goal: to improve the product's quality. However, the difference between their projects and this one is that none of them have designed systems for the transportation of live organisms without water (Johnson 1988).

In 1904, the U.S. Fisheries Commission began studies to determine the best method of transporting live fish. In 1988, SILKSTREAM designed a system for the transportation of live fish, which is now used almost worldwide (SILKSTREAM 1998). It consists of while transporting the fish, maintaining a flat and continuous movement, so that the fish do not come in contact with any rough or hard surface, therefore, reducing the stress. Although these systems for fish transportation are submerged in water, the information can be used as a comparative parameter for our study.

In Norway, Jarle Tveiten Transport developed a system for transportation of live fish, which decreased the stress, mortality, oxygen consumption and energy costs (Rimmer y Franklin 1997).

There are some requirements (Jong 1996) regarding the transportation of aquatic organisms (import or export), as established by the following agencies and organizations:

- Air Transport Association of America
- National Fisheries Institute
- Federal U.S. Agencies
- U.S. Public Health Service
- U.S. Department of Agriculture
- U.S. Department of Transportation

At an international level the regulations are enforced by the following agencies:

- U.S. Department of Treasury
- U.S. Department of Commerce

The transportation of biological material among countries is regulated by the following organizations:

- International Postal Union
- International Civil Aviation Organization (ICAO)
- International Maritime Organization (IMO)

These organizations establish important transportation guidelines such as:

- The package design must provide security to maintain the desired temperature and it must be simple enough so that it can leave the airport as soon as possible.
- The equipment should be sufficiently refrigerated and/or isolated to resist exposure to high temperatures and long trips.
- The packages should be transported in special vehicles or systems to minimize movement and leakage possibilities.

- All safety conditions and features of the system should be specified.
- The product should be pre-cooled when packaged to preserve low temperatures as long as possible and to slow down the metabolism in live animals.
- Aeration should be given to live animals to guarantee the product survival.

Many companies have developed refrigeration systems for transportation, and most of them uses refrigeration by compression. This is one of the better known techniques worldwide. However, most literature refers to land transportation in trucks or boxcar systems which in many cases are not specifically designed for products that required refrigeration and are only manufactured following standard commercial needs. There are also non conventional systems, for example, refrigerated transportation system using solar energy and developed by the University of Southampton (Bahaj 1998), has revolutionized the refrigeration industry by being innovative and economical in terms of energy consumption. There is a wide range of articles that offer information on conventional refrigeration, however they don't apply to the system developed in this study. This study will explore an alternative to conventional refrigeration.

Froese (1997) found that tropical fish adapt very well to temperatures between 22-30ºC while death occurred at temperatures between 15-18ºC in a experiment conducted on live fish transportation in Styrofoam® bags. Froese's (1997) results determined that the use of this type of bag and the increase in insulation turned out to be more appropriate and cost efficient than refrigeration. In addition, the aquaculture centre located in Trondheim, Norway has studied the transportation of tropical fish species, monitoring stress and behavior under different conditions, but always in water (Iversen 1998).

Many studies have been carried out with *Macrobrachium rosenbergii* to determine the culture characteristics of this shrimp species (García Pérez 1993). A study was conducted at the University of Puerto Rico, Mayaguez Campus to determine the effects of storage temperature on live shrimps under absence water and to select the best conditions to transport live shrimps and offer a high quality product to the market (Harper y Kubarik 2000). However, the study did not select the best conditions to transport live shrimps, so, the main goal of this study was to complete the transportation process of live shrimp in absence of water.

CHAPTER III

MATERIALS AND METHODS

The energy balance method was used to model the total thermal load at a single point. In order to do this, all possible forms of heat transference for the system in question must be utilized. These possible heat transference forms are presented in Figures 1 and 2.

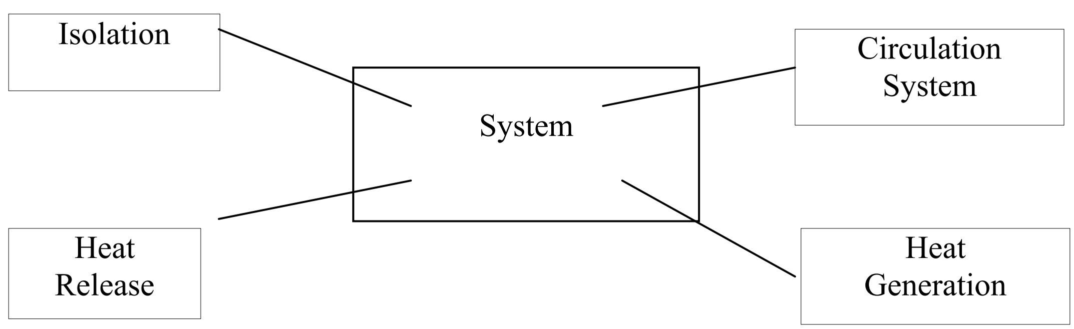


Figure 1. Differents forms of heat transference in the system

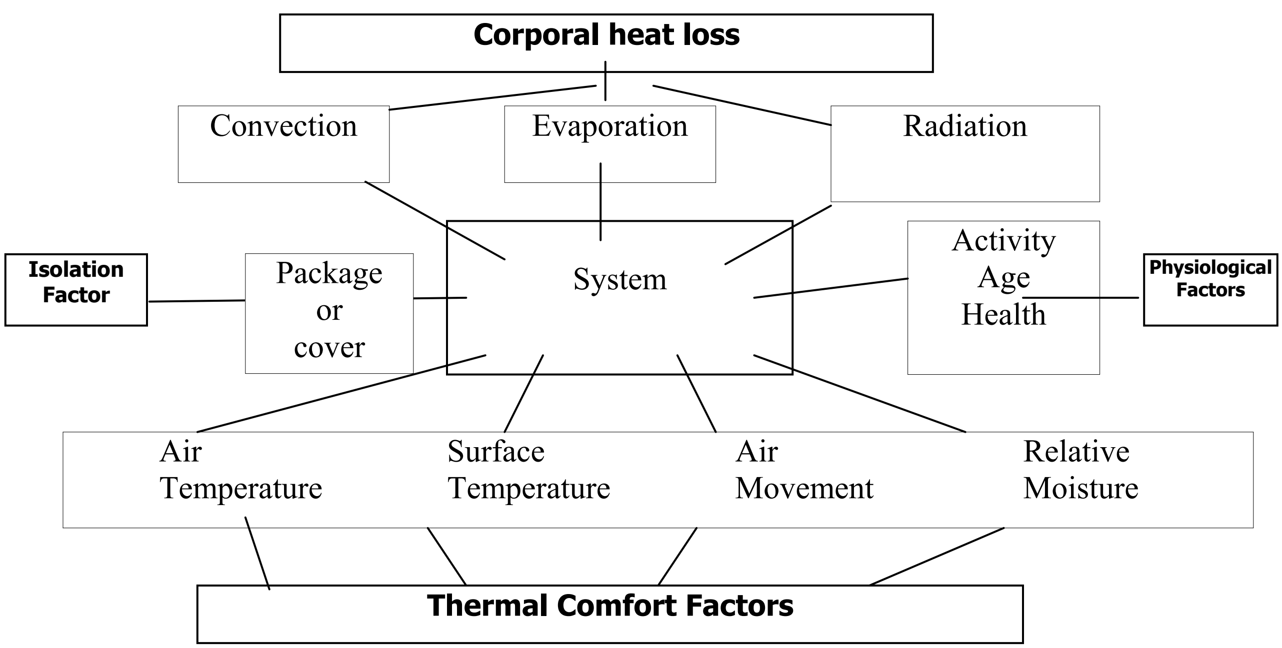


Figure 2. Factors that influence the system's heat transference

The following equiation was used to determine the Total Load at a single point of a refrigeration system (Mitalas 1983):

Total load = Wall load + Air change load + Product load + Metabolic activity load + Radiation load + Water evaporation load

The thermal nets method described by Rabl and Kreider (1998) was used to determine the system's thermal load and during model the simulation. The thermal net model is useful to explain the important concepts of the time constant of the system and provides a tool to estimate the heating and cooling rates of the system (McMaQuiston and Spliter1992).

The thermal net diagram approaches the system like one composed of a finite number of parts called nodes (N) which are presumed to be isothermal. To model the exchange of heat, the nodes are connected by resistances, forming a thermal net. The neighboring nodes are directly joined by conduction, convection, or radiation. The heat flow between neighboring nodes is given by:

$$Qn'\text{-}n = \frac{Tn' - Tn}{Rn'n}$$

Where:

Qn'-n : Thermal loss between n' and n.

Rn'n : Resistance between n' and n.

Tn': Temperature in n'.

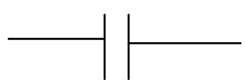
Tn : Temperature in n.

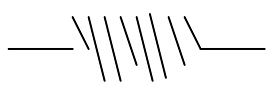
In addition, there may also be an entrance of direct heat Qn to the node n, from a source of heat, such as solar radiation, light, or by electric resistance heating. If the heat capacity of the n node is designated by Cn and its temperature is designated by Tn, assuming that Cn is constant, the rate of heat change stored in the n node, is CnTn, and according to the first law of thermodynamics, this can be equal to the total rate of heat input. Then the n node's heat balance is a first order differential equation in Tn.

$$CnTn = \sum_{n'=1}^{n} \frac{Tn' - Tn}{Rn'n} + Qn$$

If Tn'-Tn is positive, the heat flow from n' to n makes a positive contribution to Tn. In many cases, a given node can interact directly with just a relatively small number of nodes.

The previous equations, one for each node, form a system of a first order N differential equations with unknown N and the temperature of the Tn node. By analogy with electric circuits, this is useful in the representation of thermal nets through diagrams where:


represents a capacitance, C


represents a resistance, R

The temperature T is analogous to voltage and heat flow Q is analogous to current.

There is a 1 on 1 correspondence between the diagram and the group of equations of a thermal net. The diagrams are easier to understand, but the equations are needed to find the solution. With the diagrams drawn, equations can be easily written. There is a differential equation for each node, which at the end looks like this: Cn * dT = (a - bT) dt; after the variables are grouped, we have:

$$\boxed{\frac{dT}{a - bT} = \frac{dt}{Cn}}$$

Where:

dT : Diferential of Temperature

dt: Diferential of time

a and b: Constants

T: Temperature

Cn: Metabolic activity load

This is then an ordinary differential equation from which multiple similar equations originate for the different chosen nodes. There are many procedures available for the simultaneous solution of these equations in books as well as software formats. For example, Ordinary Differential Equation Solver is one of these computer programs, developed by different companies like POLYMATH®, MATHCAD®, Mathematics for Macintosh®, etc. However, Quick basic 4.5®, a program that adapts to the specific necessities of this study and is also user-friendly for people with limited programming knowledge, and it was used in the model simulation to determine the refrigeration system. However, the availability of such systems in the market as well as the cost were considered.

For the experimental corroboration, the Market Standard Dimensions System was rented to verify if the theoretical data resembled the current operation of the system. The approximate cost of the project was calculated as: (1) the refrigeration equipment was selected, (2) all the economic conditions that could affect the shrimps transportation were verified, (3) the experimental part of the study was developed and (4) a small statistics analysis was conducted with the data obtained to observe tendencies on the influence of the positions and amount the refrigerant to maintain the desired temperature.

CHAPTER IV

4. RESULTS

4.1. Selection of the refrigeration system.

4.1.1. LD-30 Container. Initially all companies that transport live organisms using refrigeration were analyzed. This analysis found a company, "Envirotainer", that had a container useful for this project (Figure 3). The design was analyzed (Figure 4), and calculations of thermal load at a point, modeling for thermal nets, simulation and total load were done. When the theory phase ended and it was decided to use this system economic problems appeared and it was not possible do it. Another system had to be developed.

Every calculation was performed for the two types or containers, evaluated. The calculations for the LD-30 are presented in Appendix A.

Figure 3. LD-30 Container

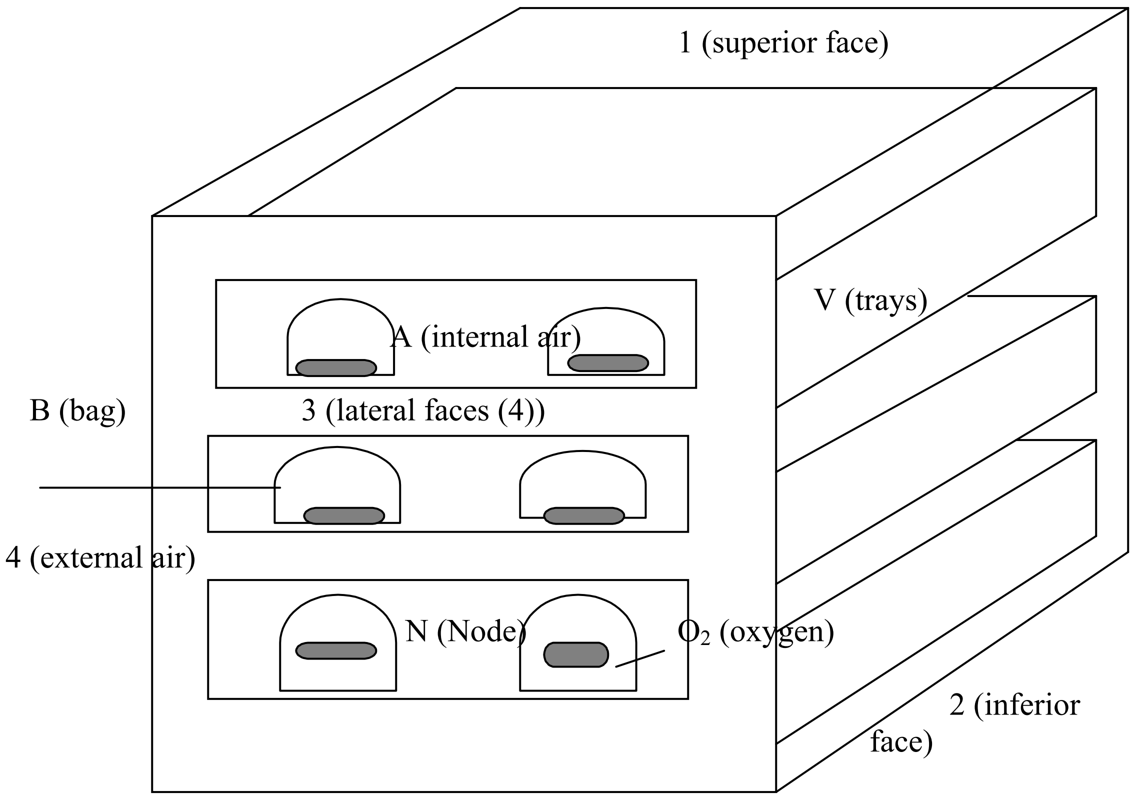


Figure 4. Frontal view of LD-30 container

4.1.2. Foam container.

The system chosen for this project was a container designed for the storage and transportation of live lobsters. It was designed by Rose Seafood Industries, Inc., and it had been redesigned several times to improve the animals comfortability. The last design was registered in United States with the patent number 5,218,923 (LaRosa 1993). This container has three sections to accomodate the shape of the lobster bodies and to provide a convenient location for the refrigerant, as shown in Figure 5.

TECH PAK SOLUTIONS

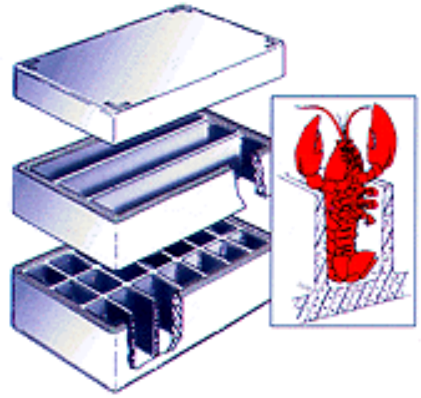


Figure 5. Foam Container

The original system underwent some modifications to adapt it to the shrimps transportation needs. The intermediate compartment, used to accommodate the lobsters claws, was eliminated, leaving the system with only two compartments, the base and the cover. The multiple internal divisions were reduced to only four equal sections. To sustain the refrigerant, a layer of foam was placed over the four sections covering them completely to provide support and to prevent the direct penetration of cold, since previous experiments showed that it may affect the system's operation and shrimp survival. The location of this one-inch thick layer of foam is shown Figure 6:

Figure 6. Foam layer location

The refrigerant used was provided by TechPak Solutions® (Techpak 1996), and it is made with ingredients included in the USDA GRAS list. This refrigerant has similar properties to water, and is ideal for any use in the transportation of food requiring cooling (Figure 7).

Figure 7. Refrigerant

4.1.2.1.Determination of the system's thermal load at a level of a single point.

Initially, it was necessary to define the system to be used for the determination of the thermal load. Thus the space initially chosen for the modeling of the thermal load was the one that covered the area where the shrimps were initially were placed, as shown in Figure 8.

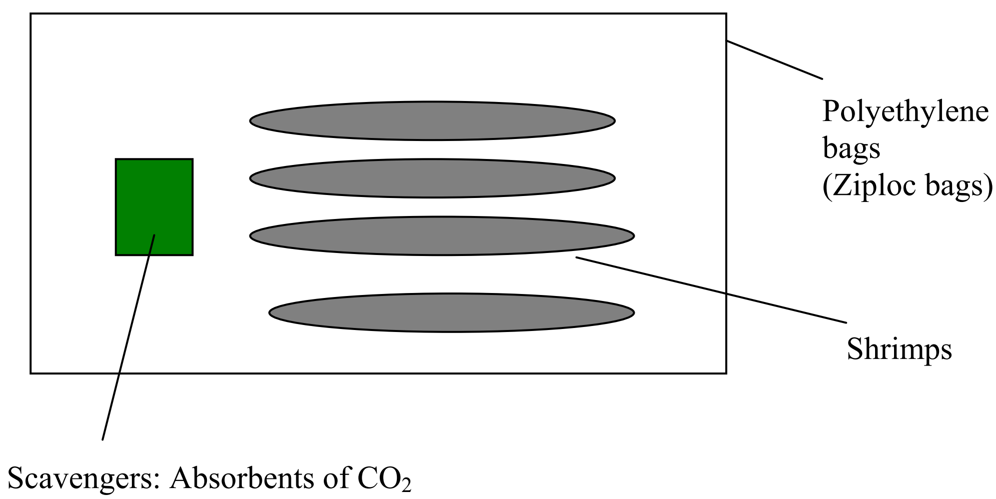


Figure 8. Initial chosen system

The system consisted of the following parameters:

- Walls: constituted by the sides of the bags, which are made of polyethylene. The bags were provided by Cryovac Company. The bag used were the PD-961 type.
- Occupants: live shrimp were placed inside these bags without water and a small paper bag, containing a CO_2 scavengers.
- Desired internal conditions: the appropriate atmosphere for the shrimps survival for 24 hours, as previously determined by Harper and Kubaryk (2000) has to have a high content of oxygen; the temperature of the whole system should remain constant, with an almost exact value of 15ºC because temperature fluctuations can affect the survival of the shrimp (García Rodríguez 2001).

According to the total load equation, each parameter was calculated (see appendix B for calculations) and gave the following results:

Wall Load (Q_{Wall})	= 3.7279 BTU/hr
Air Change Load ($Q_{Air\ change}$)	= 0 BTU/hr
Product Load ($Q_{Product}$)	=5.86 BTU/hr
Metabolic Activity Load ($Q_{Metabolic\ activity}$)	= 2.3728 BTU/hr
Radiation Load ($Q_{Radiation}$)	= 0 BTU/hr
Water evaporation Load ($Q_{Water\ evaporation}$)	= 0 BTU/hr
== == == == == == == == == == == == ==	================ =
Total Load (Q_{Total})	=11.96 BTU/hr

4.1.2.2. Modeling of the system's thermal load and generation of a dynamic model by thermal nets.

A frontal view of the refrigeration apparatus is presented in Figure 9. A two nodes were used for the system, utilizing shrimp (node 1) and frame (node 2) for the generation of a general dynamic model by thermal nets (Figures 10 and 11). The shrimp node (Figure 10) was affected by the frame and the external surrounding it. The frame node (Figure 11) was affected in the same way.

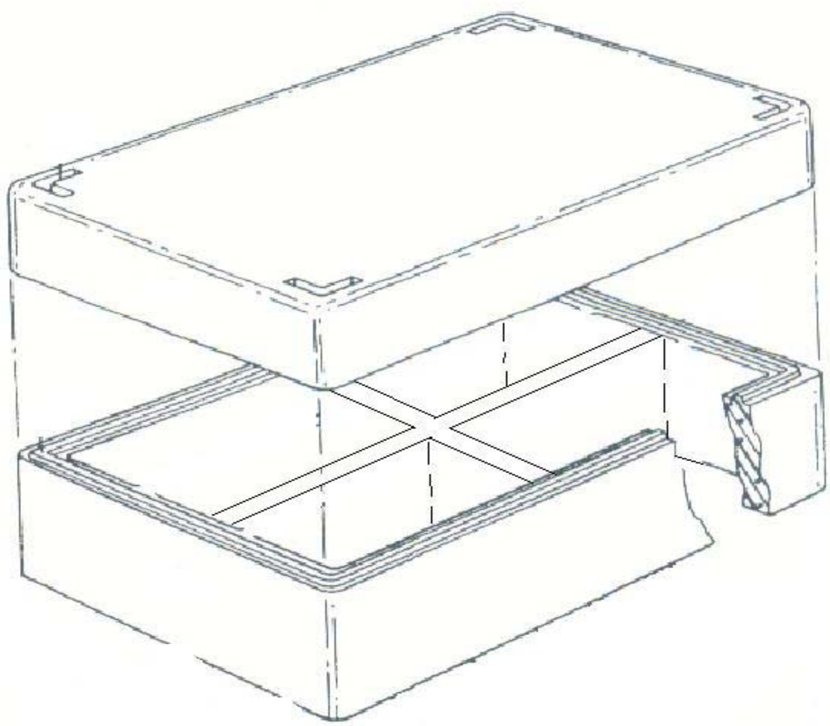


Figure 9. Frontal view of the refrigeration apparatus

Assumptions in the modeling:

- Not including contact resistance.
- Not considered radiation resistance.
- Assuming free convection inside the bag by O_2.
- Assuming free convection inside the container by air.
- The Bag and Foam resistances are by conduction.
- The shrimp resistance is assumed like similar to frozen fish resistance (conductive).
- The refrigerant is in freezing point at 0ºC not over-freezed.

Node 1: shrimp

Node 2: frame

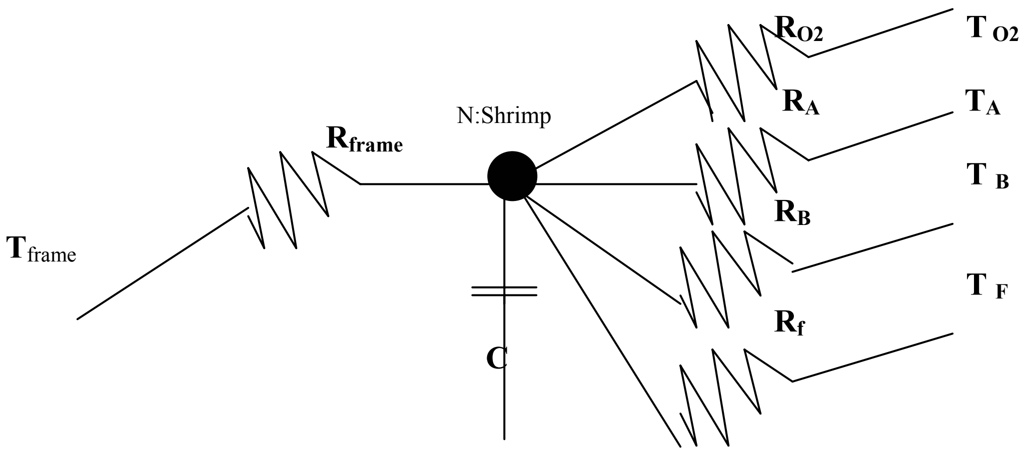


Figure 10. Node 1 (shrimp) thermal net diagram

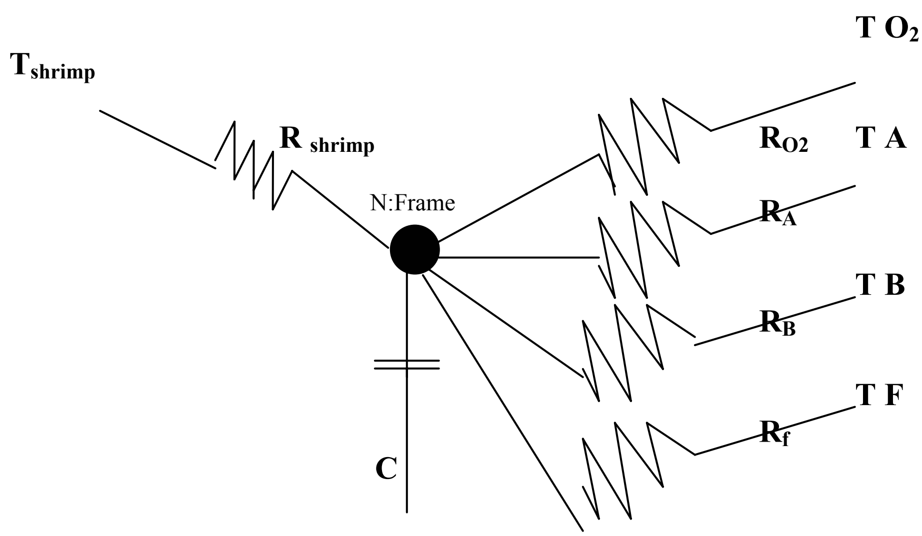


Figure 11. Node 2 (shrimp) thermal net diagram

T: Temperature
R: Resistance
C: Metabolic activity
N:Node
O2: Oxygen
A,B, and F: Conditions rounding the Node.

After grouping the variables, there are two ordinary differential equations: one for shrimp (eq. 1) and one for the frame (eq. 2):

$$(1)\quad \frac{dT_{shrimp}}{a - bT_{shrimp}} = \frac{dt}{Cn_{shrimp}}$$

$$(2)\quad \frac{dT_{frame}}{a - bT_{frame}} = \frac{dt}{Cn_{frame}}$$

Appendix C contains the derivations for both equations.

4.1.2.2.1. Simultaneous solution of differential equations

All the constant values that integrate the differential equations must be established as simple as possible to make the equation useful for simultaneous solution programs. The two equations for the two nodes to be solved are:

$$(1)\quad \frac{dT_{shrimp}}{\boxed{\dfrac{T_{frame}}{23.55907} + 199.072\ \text{BTU/hr}} - (3.4169\ \text{BTU/hr°F})^{*}\ T_{shrimp}} = \frac{dt}{Cn_{shrimp}}$$

$$(2)\quad \frac{dT_{frame}}{\boxed{\dfrac{T_{shrimp}}{0.03787} + 199.0972\ \text{BTU/hr}} - (29.7801\ \text{BTU/hr°F})^{*}T_{frame}} = \frac{dt}{Cn_{frame}}$$

See Appendix D for calculations.

There are many procedures available for solving equations simultaneously in books, as well as, software formats. For example, Ordinary Differential Equation Solver is one of these computer programs, developed by several different companies. POLYMATH 5® was used to solve these equations (Table 1).

POLYMATH 5.0 Results
No title 10-10-2002

Calculated values of the DEQ variables

Variable	initial value	minimal value	maximal value	final value
t	0	0	12	12
T1	59	58.938518	59	58.938518
T2	89	54.539823	89	54.539824
A	199.072	199.072	199.072	199.072
B	0.0424465	0.0424465	0.0424465	0.0424465
C	3.4169	3.4169	3.4169	3.4169
D	1.05	1.05	1.05	1.05
W	26.406126	26.406126	26.406126	26.406126
X	199.0972	199.0972	199.0972	199.0972
Y	32.1863	32.1863	32.1863	32.1863
Z	0.048847	0.048847	0.048847	0.048847

ODE Report (RKF45)

Differential equations as entered by the user
[1] d(T1)/d(t) = ((B*T2) + A - (C*T1))/D
[2] d(T2)/d(t) = ((W*T1) + X - (Y*T2))/Z

Explicit equations as entered by the user
[1] A = 199.072
[2] B = 1/23.55907804
[3] C = 3.4169
[4] D = 1.05
[5] W = 1/0.03787
[6] X = 199.0972
[7] Y = 29.7801
[8] Z = 0.048847

Independent variable
variable name : t
initial value : 0
final value : 12

Precision
Step size guess. h = 0.000001
Truncation error tolerance. eps = 0.000001

General
number of differential equations: 2
number of explicit equations: 8
Elapsed time: 1.1574 sec
Data file: C:\Documents and Settings\FSC\My Documents\JANNETH\ULTIMOSDATOS.pol

Table 1. Polymath program output for the foam container

Figure 12 shows results about the simulation. T1 represents the shrimp temperature. It is maintained uniform during the experiment time as expected.

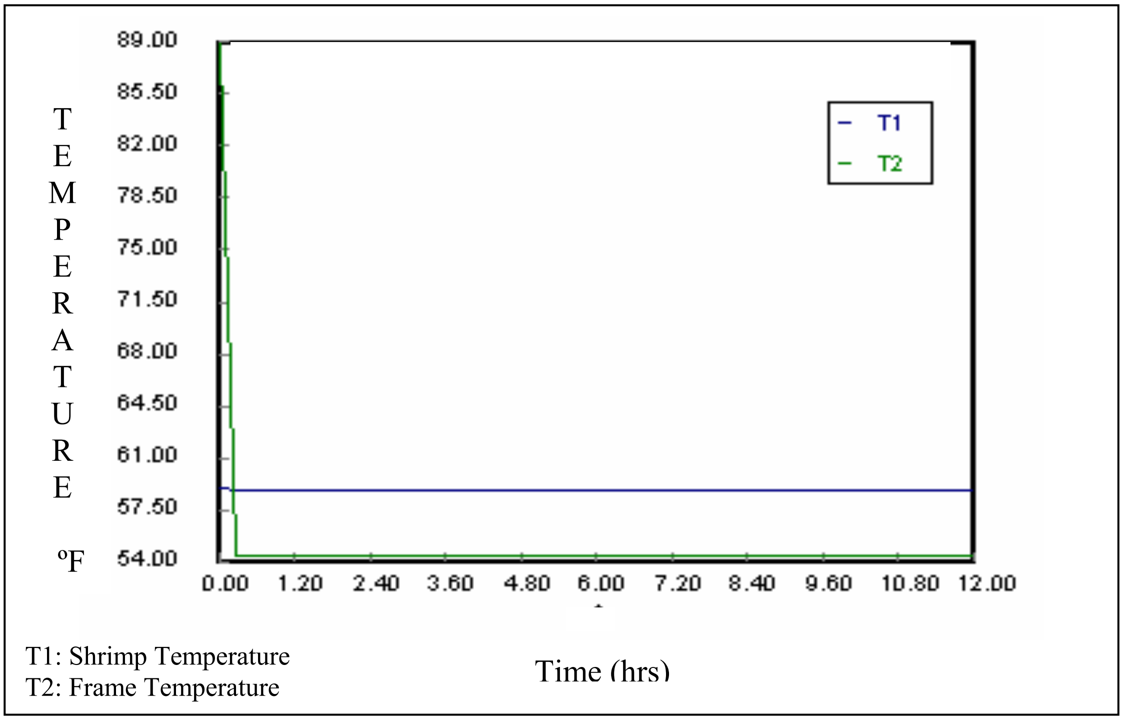


Figure 12. Temperature modeling graph

4.1.2.3. Determination of total thermal load.

The total thermal load of the system was determined so that the inside temperature of the system could be maintained at the desired range. It was desired that the inside temperature of the system remain at the optimum level for the shrimps survival (15ºC) (García Rodríguez 2001).

The refrigeration technique to be used in a cargo plane depend on the pre-cooling conditions, quick handling, and short time of exposure to adverse conditions. Because the shrimps are to be transported live, they have defined limitations in terms of the conditions they can tolerate. The shrimp breathing process during shipment utilizes energy and produces carbon dioxide. These changes affect the shrimps survival and cannot be stopped, but they can be decreased extending the period of successful transport.

The shrimps survival is directly affected by a time-temperature relationship and can decrease significantly with only a few hours of exposure to unfavorable high or low temperatures (Harper and Kubaryk 2000). In this case, maintaining the temperature of the shrimps' environment at 15ºC is a decisive factor.

Commercial cargo planes operate with cabins divided in passenger compartments and cargo compartments, and each one of them has a simple air system to control the occupants' comfort. In the case of perishable cargo, such as shrimps, they must be packed in isolated, pre-cooled containers. Cargo planes' air conditioning systems are capable of maintaining a 40ºF temperature at 30000 feet and a 30ºF temperature at 40000 feet in the cargo compartment on a hot day (ASHRAE 1994).

The critical condition for the isolation and the refrigeration system designs for the container load is the time that the container spends at the airport exposed to the sun's heat, waiting to be transported. Figure 13, 14 and 15 show temperature, humidity and pressure changes at different altitudes. Assuming an environment temperature of 100ºF for downtime at the airport, the average wall temperature on the outside of an unpainted metal container is about 115ºF.

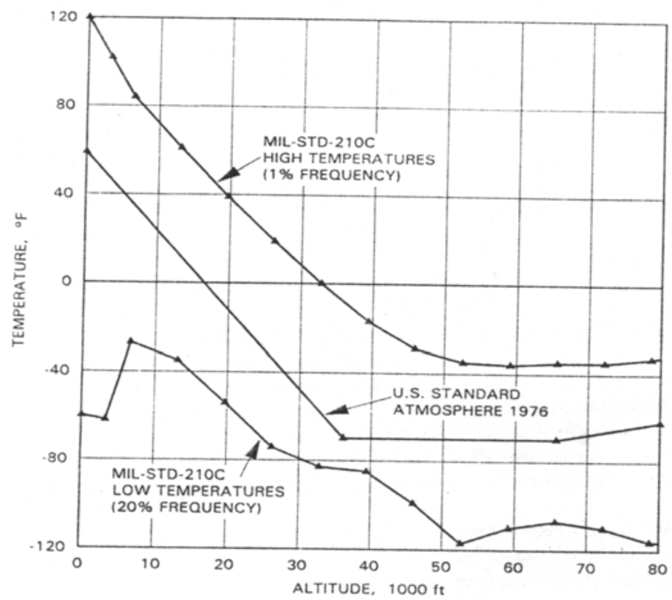


Figure 13. Profile of typical ambient temperature design for heat, standard, and cold days (ASHRAE 1995)

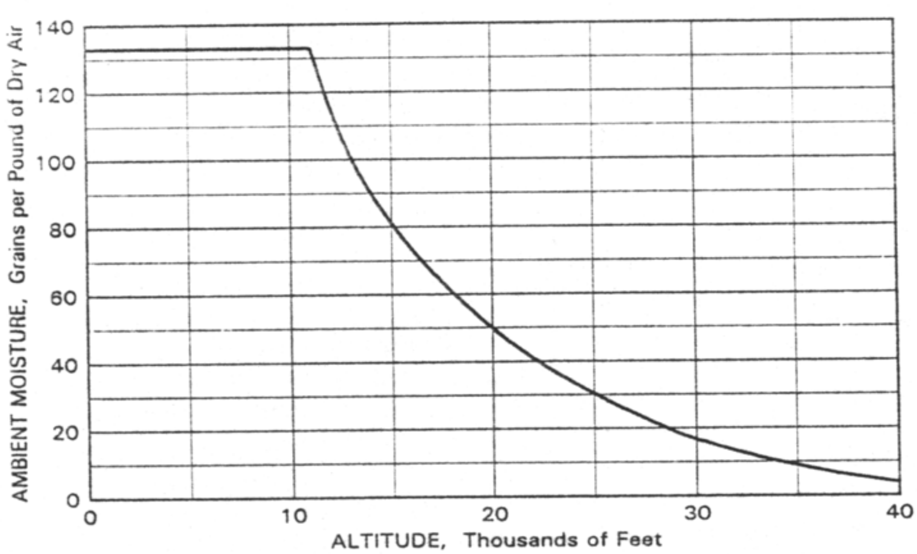


Figure 14. Air humidity content at various altitudes. (ASHRAE 1995)

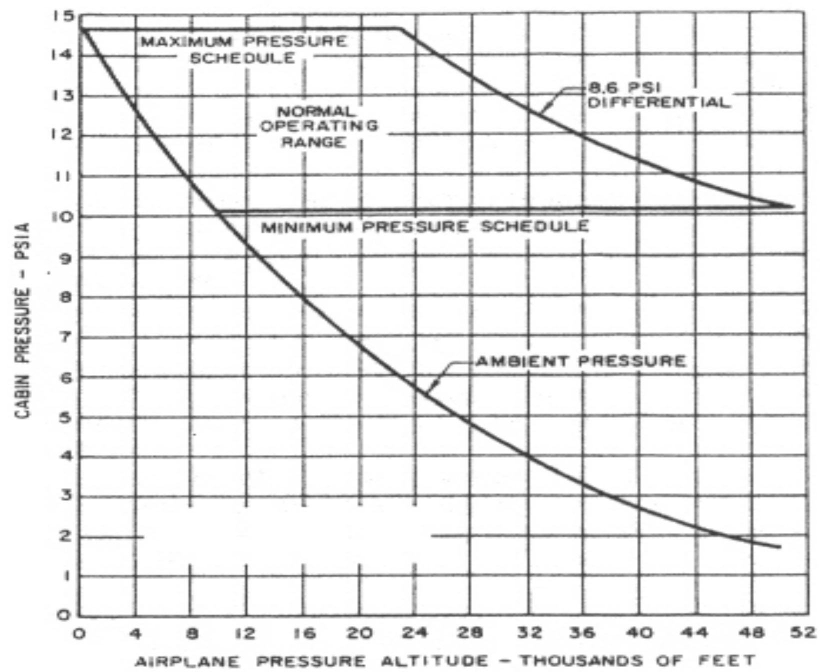


Figure 15. Variation in atmosphere pressure with altitude. (ASHRAE 1995)

Cargo planes generally designed for commercial airlines can maintain altitudes from 5000 to 7000 feet, with equivalent cabin pressures in a normal operation range. Airplanes flying above 10000 feet must be equipped with an oxygen system for the passenger compartment in the event of a loss of pressure and can also affect the thermal load.

To calculate the thermal load of the system, the total thermal load of a single bag of shrimps, indicated in section 4.1.2.1 of this manuscript, should be kept in mind. However, as it is assumed that the desired temperature (15ºC) is reached internally, the different thermal loads do both are canceled out.

The environment surrounding the system, which will be referred as External load (Qext), and is influenced by the load conditions inside the load compartment (where the container will be transported). The conditions inside the load compartment, established by the Code of Federal Regulations (U.S.) and by the Federal Aviation Regulations (FARs), are the following:

For commercial cargo plane operation between 5000 and 7000 feet:

Pressure: 11.5 PSIA

Cargo compartment temperature: 100ºF

External container wall temperature: 115ºF

The $R_{thermal}$ equation is derived from the thermal load. It is equal to temperature difference among the thermal conductivity and is the sum of external convection conductivity plus conductive conductivity plus internal convection conductivity:

$$Q_{ext} = \frac{T_{compartment} - T_{internal\ system}}{R_{thermal}}$$

$$R_{thermal} = \frac{1}{\text{External conduction conductivity} + \text{convective conductivity} + \text{Internal conduction conductivity}}$$

$$R_{thermal} = \frac{1}{h_{half\ compartment} * As + (k*As)/\delta + h_{internal\ system} * As}$$

Where:

$R_{thermal}$ = Resistance thermal

h = air convective coefficient

As = container's superficial area

k = material's thermal conductivity

δ = material's thickness

Because of the external conditions were unknown in the airplane and airport, from the literature (ASRHAE 1994) was finded, for design conditions in refrigerations systems applied to air transport, that is possible to assume an environment temperature of 100ºF for downtime at the airport, and the average wall temperature on the outside of an unpainted metal container as 115ºF. This was used like base in the assumptions and after that were made the calculations for real conditions in this system.

Extreme conditions	Real Conditions
$h_{compartment}$ = 0.047104321 BTU/(hr*ft^2*ºF)	$h_{compartment}$ = 0.04844395 BTU/(hr*ft^2*ºF)
$h_{internal\ of\ the\ system}$ = 0	$h_{internal\ of\ the\ system}$ = 0

See Appendix E for calculations.

As = 6.3625 ft^2
δ = 0.1146 ft
k = 0.0161781 BTU/(hr*ftºF)

Thus,

- Extreme conditions

$$R_{thermal} = \frac{1}{(0.047104321 * 6.3625) + (0.01617 * 6.3625)/0.1146}$$

$$R_{thermal} = \frac{1}{0.2997 + 0.897745} = \frac{1}{1.197446}$$

$R_{thermal}$ = 0.8351105 (hr*ºF)/BTU

$$Q_{ext} = \frac{T_{compartment} - T_{internal\ system}}{R_{thermal}}$$

$$Q_{ext} = \frac{(100 - 59)\,ºF}{0.8351105\ (hr*ºF)/BTU}$$

Q_{ext} = 49.09529936 BTU/hr

$Q_{TOTAL} = Q_{internal}$ + Q ext

Q_{TOTAL} = 0 + 49.09529936

Q_{TOTAL} = 49.09529936 BTU/hr = 49 BTU/hr

- Real conditions

$$R_{thermal} = \frac{1}{(0.04844395 * 6.3625) + (0.01617 * 6.3625)/0.1146}$$

$$R_{thermal} = \frac{1}{0.308196795 + 0.897745} = \frac{1}{1.197446}$$

$$R_{thermal} = 0.829227417 \text{ (hr*ºF)/BTU}$$

$$Q_{ext} = \frac{T_{compartment} - T_{internal\ system}}{R_{thermal}}$$

$$Q_{ext} = \frac{(79 - 59)\text{ºF}}{0.8292 \text{ (hr*ºF)/BTU}}$$

$$Q_{ext} = 24.1188359 \text{ BTU/hr}$$

$$Q_{TOTAL} = Q_{internal} + Q\ ext$$

$$Q_{TOTAL} = 0 + 24.1188359$$

$$Q_{TOTAL} = 24.1188359 \text{ BTU/hr} = 24 \text{ BTU/hr}$$

This value represents the system's total heat transference, meaning that 49 BTU/hr and 24 BTU/hr must be removed respectivelly to guarantee the desired internal temperature (15ºC). Thus the refrigeration system must be capable of removing, at least, 49 BTU/hr and 24 BTU/hr . In the case of the container used in our study, the refrigeration system are well-known (gel packs) and use substances that by means of its latent heat of fusion produces the necessary degree of heat absorption to prevent temperature change. According to the heat transfer principles, we have the following equation:

$$Q_{TOTAL} = m_{refrigerant} * \lambda_{refrigerant}$$

Where:

M = refrigerant mass

λ = Latent heat fusion of the refrigerant

In our case, Q_{TOTAL} emitted by the system should be equal to the Q_{TOTAL} that the refrigerant must absorb. Thus we have an energy balance.

$$Q_{TOTAL\ \text{emitted by the system}} = Q_{TOTAL\ \text{absorbed by the refrigerant}}$$

From this equivalence, it was found the quantity of refrigerant to guarantee the desired temperature:

$$Q_{TOTAL\ \text{emitted by the system}} = m_{refrigerant} * \lambda_{refrigerant}$$

$$m_{refrigerant} = \frac{Q_{TOTAL\ \text{emitted by the system}}}{\lambda_{refrigerant}}$$

- **Extremal conditions:**

$$m_{refrigerant} = \frac{49\ \text{BTU/hr}}{144\ \text{BTU/Lb}}$$

$$m_{refrigerant} = 0.3402\ \text{Lb/hr} * 24\ \text{hr} = 8.16\ \text{Lb} = 8\ \text{Lb}$$

- Real conditions:

$$m_{refrigerant} = \frac{24\ \text{BTU/hr}}{144\ \text{BTU/Lb}}$$

$m_{refrigerant}$ = 0.1663 Lb/hr * 24 hr = 3.99 Lb = 4 Lb

Using global energy balance at steady state is possible determine the amount of mass required, in this case simply is assumed that the system act as the phase change material (gel ice) and that all the heat coming in from the shrimps plus the heat coming from the outside through the thermal resistance is equal to the heat required for phase change.

$Q_{refrigerant} = Q_{shrimp} + \cancel{Q_{outside}}^{\,0}$

$Q_{refrigerant} = Q_{shrimp}$

$Q_{refrigerant}$ = m * Cp * Delta T

$Q_{refrigerant}$ = Cn * Delta T

$Q_{refrigerant}$ = (1.05 BTU/ºF + 0.048847BTU/ºF)*(79 – 59)ºF

$Q_{refrigerant}$ = 21.97694 BTU

$m_{refrigerant}$ * $Lamda_{refrigerant}$ = 21.97694 BTU

$m_{refrigerant}$ = 21.97694 BTU / $Lamda_{refrigerant}$

$m_{refrigerant}$ = 21.97694 BTU / 144 BTU/Lb*hr

$m_{refrigerant}$ = 0.1526 Lb/hr * 24 hr = 3.66 Lb

$m_{refrigerant\ two\ equations}$ = 4 Lb

$m_{refrigerant\ global\ energy\ balance}$ = 3.66 Lb = 91.57% value close within reasonable percentage.

4.1.2.4. Simulation.

To easily determine the total load and the quantity of refrigerant, a computer program was designed using Quick-Basic 5.1 (Appendix F). A program output of the total load is shown in Table 2.

```
+------------------------------------------------------------------- +
¦ * * * * * * * * * * * * * * * * CONVECTIVE COEFFICIENTS CALCULATION ***************¦
+------------------------------------------------------------------- +
°F SYSTEM TEMPERATURES

EXTERNAL TEMPERATURE....................... = 79
DESIRED INTERNAL TEMPERATURE............... = 59
GRPR..................................... = 7.260975E+08
Num...................................... = 23.72415

External convective coefficient........... = .0471043
Internal convective coefficient........... = 0
Container height (in feet)................... = 0.5
Container width (in feet).................. = 1
Container length (in feet).................... = 1.7875
Superficial area (feet^2).................. = 6.3625
Container thickness (in feet).................. = 0.1146
Thermal resistance...................... = .8351103
```

```
+------------------------------------------------------------------- +
¦ * * * * * * TOTAL HEAT LOAD AND REFRIGERANT QUANTITY * * * * * * * * * * * * ¦
+------------------------------------------------------------------- +



TOTAL HEAT LOAD (BTU/Lb)............... = 23.94893


REFRIGERANT QUANTITY (Lb).................. = 3.991489
SHRIMPS PER BAG......................... = 2
SHRIMPS PER CONTAINER..................... = 8
CONTAINER'S APPROXIMATE WEIGHT (Lb)............. = 7

DO YOU WISH TO PROCESS OTHER DATA? (Y/N):
```

Table 2. Total load program output

4.3. Refrigeration system validation.

4.3.1. Procedure without shrimps

4.3.1.1. Materials:

- According to our literature review, the specific heat of shrimps is approximately 3.73 Kj/KgºK. This value can be simulated with a 13.25% saline solution. 26.5 gm of salt were added to 100gm of water to simulate the presence of two shrimps. This solution was pre-cooled to 15ºC which is the optimum temperature to get highest shrimps survival.
- 4 polyethylene bag of 27.25 cm long 15.35 cm wide were used for the refrigerant.
- The bags containing the refrigerant were weighed; to obtain the calculated weight. The refrigerant in the bags was completely frozen.

4.3.1.2. Assembling the container.

- The polyethylene bags were placed in each section of the container.
- Saline water was placed inside each bag.
- Oxygen was injected into each bag
- Each polyethylene bag was closed with wire ties to prevent oxygen leaks.
- The foam layer was placed over the bags.
- The refrigerant substance bags were placed over the foam layer as described previously.
- The container was completely closed to prevent temperature interchange with its surrounding.

4.3.1.3. Experimentation.

This phase began when the container was closed. The time factor determines the effectiveness of the experiment because, in this case, the time-temperature relationship was the main factor for evaluation, since our goal was to achieve a constant temperature throughout time.

The closed container was stored for 24 hours. The internal temperature was monitored. After 24 hours the polyethylene bags were removed from the container. The bags containing the refrigerant substance were refrozen. The experiment was repeated.

4.3.1.4. Data collection method.

A temperature meter which took measurements in predetermined time intervals by means of a computer program was used to collect the internal temperature data. This meter measured and recorded the temperature, interpreted then and organized the results in a chart format The records were for the period from September 24 to October 31, 2002 (Appendix G).

4.3.1.5. Results.

Different refrigerant positions and amount were evaluated to corroborate the experimental data and to determine the best refrigerant substance position to keep the temperature constant or as close to 15ºC (range ± 1ºC). See Table 3 for the arrangement.

Date	Refrigerant position	Lb refrigerant	Average $T_{minimun\ in\ container}$ (ºC)	Average $T_{average\ in\ container}$ (ºC)	
25-Sep		2.7	8.51	12.93	Not foam used
25-Sep		3.7	12.86	13.79	Foam and 60ºF ext
26-Sep		3.0	9.74	11.52	Foam and 60ºF ext
26-Sep		3.0	13.05	14.86	Foam and 60ºF ext
30-Sep		3.0	5.98	18.96	Foam and 80ºF ext
01-Oct		3.0	16.38	18.64	Foam and 80ºF ext
02-Oct		4.0	11.93	15.64	Foam and 80ºF ext
03-Oct		3.0	12.82	18.9	Foam and 80ºF ext
04-Oct		4.0	14.31	16.16	Foam and 80ºF ext
07-Oct		4.0	9.01	10.25	Foam and 60ºF ext
07-Oct		4.1	12.25	13.85	Foam and 60ºF ext
08-Oct		3.2	13.27	15.46	Foam and 60ºF ext
08-Oct		2.8	13.24	15.94	Foam and 60ºF ext
09-Oct		3.1	11.58	13.91	Foam and 60ºF ext
09-Oct		3.0	12.33	13.85	Foam and 60ºF ext
10-Oct		3.0	13.7	15.27	Foam and 60ºF ext
10-Oct		3.0	13.45	14.87	Foam and 60ºF ext
29-Oct		3.0	12.32	13.88	Foam and 60ºF ext
29-Oct		3.0	12.73	14.94	Foam and 60ºF ext
30-Oct		3.1	11.30	13.84	Foam and 60ºF ext
30-Oct		3.0	12.75	15.20	Foam and 60ºF ext
31-Oct		3.0	12.72	14.93	Foam and 60ºF ext
31-Oct		3.0	13.61	15.09	Foam and 60ºF ext

Table 3. Summary of experiment without shrimps

			Average		
Date	Refrigerant position	Lb refrigerant	$T_{minimun\ in\ container}$ (ºC)	$T_{average\ in\ container}$ (ºC)	
4 oct		4.0	14.31	16.16	Foam and 60ºF ext
7 Oct		4.0	10.63	12.05	Foam and 60ºF ext
8 Oct		3.0	13.25	15.70	Foam and 60ºF ext
9 Oct		3.0	11.95	13.88	Foam and 60ºF ext
10 Oct		3.0	13.57	15.07	Foam and 60ºF ext
29 Oct		3.0	12.52	14.41	Foam and 60ºF ext
30 Oct		3.0	12.02	14.52	Foam and 60ºF ext
31 Oct		3.0	13.16	15.01	Foam and 60ºF ext
Average		3.2	12.68	14.60	

Table 4. Summary by date for the same position

Then

Lb refrigerant substance $\longrightarrow$ $S^2 = 0.22$, $S = 0.47$ and CV= 14.69%

$T_{minimun\ average}$ $\longrightarrow$ $S^2 = 1.314$, $S = 1.15$ and CV= 9.04%

$T_{average}$ $\longrightarrow$ $S^2 = 1.5851$, $S = 1.26$ and CV= 8.62%

S^2 : Variance

S: Standard deviation

xi: each run

X: average of run

CV: coefficient variation

Because this project was only observational in nature for the refrigeration system's validation, the results obtained suggest tendencies on the influence of the positions and amount of the refrigerant to maintain the desired temperature, Based on the results (Table 3) it was decided that the horizontal arrangement (Table 4), placing four bags of refrigerant containing the same weight of refrigerant had a temperature distribution close to 15ºC according with the data obtained from each datalogger placed in the compartments of the container. Based on the theoretical results (Section 4.1.2.3 in this manuscript) on the amount of refrigerant to be used, the results observed suggest that 3 to 4 pounds of the refrigerant maintained an acceptable temperature.

Figure (16) shows the temperatures inside vs temperature desired (15ºC) for the same position of refrigerant (four bags horizontally). Is possible to observe that average temperature in the differents dates was close to 15ºC. The minimum and average temperatures was too low in October 7th and the minimum temperature in anothers dates was near to 12ºC that is a little low for shrimp survivors if the exposition time is extent. The figure (16) allow appreciate that temperature in the container keep not constant along all the experiment time (24 hours).

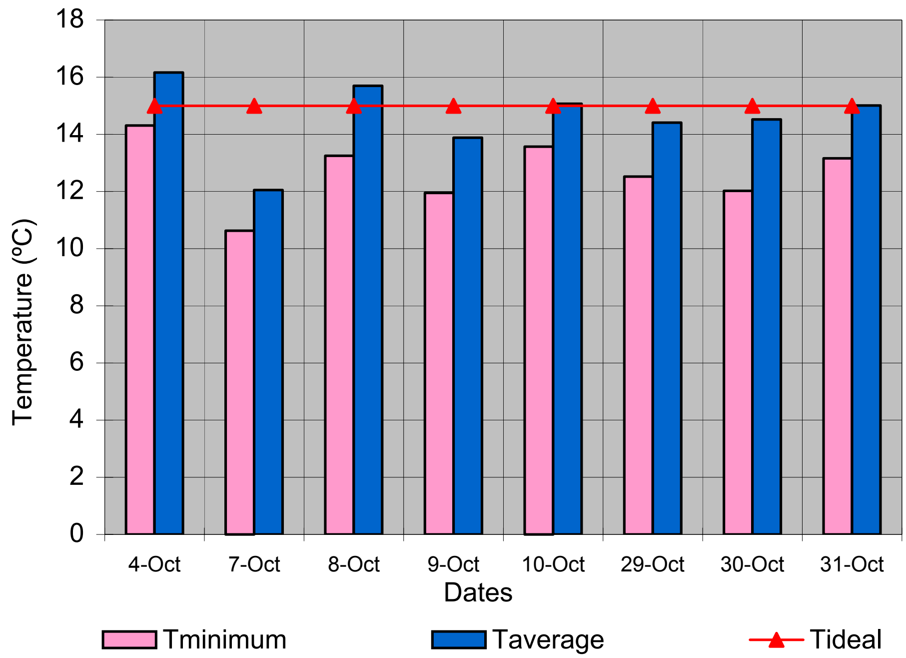


Figure 16. Temperatures inside the container

Figure (17) shows how the amount of refrigerant used (3 and 4 pounds) not change significantly the temperature inside the container. Is possible with this results say that values of 3 to 4 pounds of refrigerant keep the average temperature close to desired (15ºC) and the difference is not too high. It show that theorical data obtained previously is the amount of refrigerant that need be used in this system experimentally.

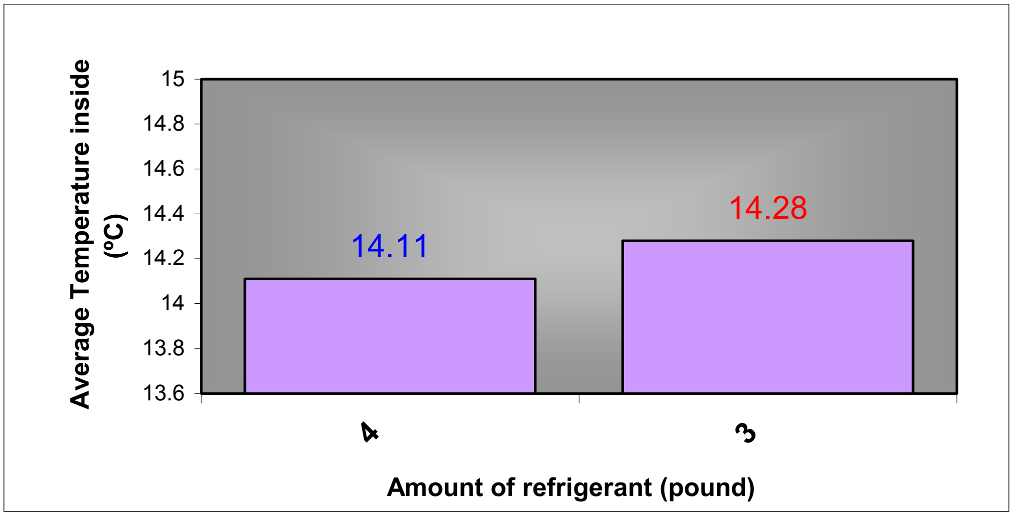


Figure 17. Temperatures vs amount refrigerant

4.3.2. Procedure with the shrimps

4.3.2.1. Materials.

- The shrimps were handled carefully to avoid stress. The shrimps were obtained at the Aquaculture Station in Lajas, Puerto Rico, where they are cultured in ponds until they reach adult size. They are seined and harvested to use for studies. For our experiment, the shrimp were transported with water in a Styrofoam® cooler to the university laboratory in Mayaguez. They were held for 24 hours in a container with 10 liters of water and 100 grams of salt, that was aerated. After this they were fed the afternoon before shipment and placed in a 15ºC aerated water bath for approximately 15 minutes.
- The CO_2 scavengers containing 1.5 grams of sodium hydroxide and 1.5 grams of calcium hydroxide were prepared and placed in a porous bag (Harper and Kubarik 2000). The bag was sealed and taped at the interior superior part of the shipping bag.
- Four polyethylene 27.25 cm x 15.35 cm bag were made.
- The bags containing the gel ice were weighed and were used frozen.
- A full oxygen tank and ties for each bag were obtained.

4.3.2.2. Assembling the container.

- The polyethylene bags were placed in each section of the container.
- Two shrimps were placed in each bag.
- Oxygen was injected into each bag.
- Each polyethylene bag was closed with wire ties to prevent oxygen leaks.
- The foam layer was placed over the bags.
- The gel ice bags were placed over the foam layer as described previously.
- The container was closed to preserve the insulation effect.

4.3.2.3. Experimentation.

The container was left undisturbed for 24 hours. After that the shrimps' survival was verified. This was done by placing the shrimps in containers with 10 liters of water and aerators. After a period of recovery and adaptation to the new environment the live shrimp were counted. The temperature inside the container was monitored throughout the experiment. The foam layer and the container were cleaned and dried to avoid cross contamination.

4.3.2.4. Data collection method.

A datalogger measured and recorded the temperature each 15 seconds, and interpreted and organized the results in a chart format. The experiment was done November 1 and 2 2002 (Appendix H).

4.3.2.5. Results.

The statistical results suggested for position and amount of gel ice were used. Three repetitions were done with live shrimp. Data from these experiments is shown in Table 5.

Date	Refrigerant position	pounds refrigerant	% Num. Survivors	$T_{\text{minimun in}}$ container °C	$T_{\text{average in}}$ container °C	
01-Nov		3.0	62.5	14.07	16.17	Foam and 60ºF ext
01-Nov		3.1	50	14.65	17.34	Foam and 60ºF ext
01-Nov		3.1	50	14.65	17.58	Foam and 60ºF ext
02-Nov		3.0	50	14.13	17.07	Foam and 60ºF ext
02-Nov		3.0	50	13.53	16.03	Foam and 60ºF ext
02-Nov		3.0	62.5	15.45	17.99	Foam and 60ºF ext
Average			**54.17**			

Table 5. Summary of results of experiment with shrimps

Then

Lb refrigerant $S^2 = 4*10\text{-}3$, S = 0.1 and CV= 2.1%

Survivors $S^2 = 0.3$, S = 0.5 and CV= 12.2%

$T_{\text{minimun average}}$ $S^2 = 0.4$, S = 0.7 and CV= 4.6%

T_{average} $S^2 = 3.1$, S = 1.75 and CV= 10.3%

Variations in the number of survivors may be due to different factors, such as: the life stage of each animal, weight, variations in external temperature. Additionally the minimum and average temperature was higher than the saline solution experiments.

4.4. Study of system's market viability.

The total cost obtained summarized in the Table 6 represents the cost of one containers with shrimp. Obviously, if large quantities of these materials is used, the cost would be considerably less than $21.80, making this alternative to transport alive shrimp much more profitable.

Other factors, such as handling and transportation, which in turn depend on other factors such as shipping destination, type of transportation, and quantity of production increase cost of the total production and the prices fluctuate. For example, Arrow Air Cargo gave us an $80.00 cost of transportation from San Juan to Miami for a unit. The cost of considerably larger shipment would be an additional $0.35 per pound. This shows how costs are diminished when quantities are increased. However, shipping these containers to Miami is not the same as shipping them to a city like Baltimore, because there are no direct flights from San Juan to Baltimore. In that case, the containers would have to be shipped to Miami and, from there, be transported in trucks to the final destination. There are obvious differences in the containers' shipment depending on their destinations. The project's market viability can also be seen by the product demand and competition.

- United States Imports 82% of the shrimp consumed (Shrimp market report 2002) and is the major importing country controlling 41% of market

Sales prices vary with species and depending on the producing country but currently they fluctuate between $6.19 and $6.70 per kilogram consumed (Shrimp market report 2002).

These are the main reasons that make the potential production and the shrimp export marketing so promising for Puerto Rico Industry. If we find the best possible way to have a live product in a competitive market, it would be possible to export large quantities and then it would sustain local production. Local shrimp production has been supported, as was also supported in this study by PRIDCO (Puerto Rico Industrial Development Company), to improve the local production and commercialization of shrimp in Puerto Rico.

RAW MATERIAL	Quantity per container	Value per unit	Total value
Shrimp	8	\$2.82	\$22.56
Container	1	\$4.44	\$4.44
Refrigerant	3 lb	\$0.42	\$1.26
Bags	4	\$0.15	\$0.60
Foam	1.8244 ft^2	\$0.40	\$0.73
Oxygen	0.0406 ft^3	\$0.21	\$8.57*10^{-3}
Calcium Hydroxide	6 gr	\$2.00*10^{-3}	\$0.01
Sodium Hydroxide	6 gr	\$0.02	\$0.10
Tea bags	4	\$0.01	\$0.02
Ties	4	\$0.00	\$0.00
TOTAL			\$29.77

Container's approximate weigh = 7 Lb

Table 6. Container costs analysis

CONCLUSION

The purpose of this study was to determine a refrigeration system for the transportation of live shrimps without water. The different types of transportation for similar systems were researched. Two types of containers that fulfilled the requirements for this particular system were found. These containers were used to establish their individual heat load at a level of a single point and their total heat load at a theoretical level. This study also determined which of the two types of containers would be most viable from an economic point of view.

The two containers were studied through the determination of the thermal load in a single point, and the modeling of the system's thermal and total loads.

After an analysis that revealed economic difficulties due to a lack of funds for the project, the Styrofoam® container, which uses the refrigerant substance as a means to keep its contents cold, was selected. It was found that this type of container meets the transportation requirements in an easy and economic way. Still, this does not mean that this was the best system for transportation, since an analysis can predict that the LD-30 container can control temperature factor better due to its design. However, the chosen container comes close enough to the desired temperature values, as shown by the experiment.

Although this study focused on the selection of the refrigeration system, the available funds limited this selection. The higher costs of rent and availability for experimentation of the LD-30 container meant that selecting the Styrofoam® container, was a decision made because of economic factors. This does not mean the LD-30 would not be a good mechanism of transportation.

Another limitation of this study during the experimental phase with the shrimps was that the shrimps had not the same stage and weight. Not being able to select the shrimps the uncontrol of these characteristics could have a direct effect on the obtained data. Another factor that could affect the results was not the problem to maintain a constant external temperature because the laboratory's air conditioner was not working properly. In addition to this, the lack of sufficient funds made impossible repeat the experiment several times with the animals to have the appropriate replications.

The small economic analysis of the study allows us to suggest that in the United States, who imports 82% of the shrimp consumed, there is a large potential market. This indicates demand for Puerto Rico's shrimp production. This would, in turn, generate an increase in the local production and have a positive effect on the state's economy. This project should be profitable and promising in the near future.

RECOMMENDATIONS

All the objectives of this study were fulfilled. However, results do not allow determination, that the system selected was in fact the best transportation system for the shrimps. Therefore, it is recommended that future research study all possible forms of transportation.

This study (transportation of live aquatic animals) may represent the first step in a very important field of study for the economy of Puerto Rico and United States. The container used could be improved. Its use could be expanded become widely known in the sea food industry as a safer and a more reliable way to transport. This would help product distribution and exporting capacity of Puerto Rico.

It would also be interesting to develop a technique to control the container internal temperature and determine the optimum distribution in the interior. Future experiments should use animals having the same life stage, sex and weight to limit the variables.

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APPENDIX A

Calculations for LD-30container

I. Determination of the system's thermal load at a level of a single point.

- Wall load:

  $Q = A * U * \Delta T$

  Where:

  Q = Wall load (BTU/hr)

  A = System area (ft^2)

  U = Heat transference coefficient ($BTU/hr.ft^{2o}F$) of the bag (polyethylene).

  ΔT = System temperature change.

  $A = 26.82\ cm * 27.94\ cm = 749.35\ cm^2$

  $A = 749.35\ cm^2 * (1pulg/2.54\ cm)^2 * (1\ pie/12\ pulg.)^2$

  $A = 0.8066\ pie^2$

  $U = 0.46\ BTU/hr\ pie^{2o}F$, obtained from the table A2.2 from the book Heating and Cooling of Buildings.

  ΔT = Texterior – T desired interior

  T exterior = 25ºC = 77ºF

  T desired interior = 15ºC = 59ºF

  ΔT = 18ºF

  $Q_{wall} = 0.8066\ pie^2 * 0.46\ BTU/hrpie^{2o}F * 18^oF$

  $Q_{wall} = 6.6786\ BTU/hr$

- Air change load:
  $Q_{air\ change} = m * (ho - hi)$

  Where:

  m = Mass of air that enters the space in 24 hours

  ho = External air enthalpy

  hi = Internal air enthalpy

This heat is zero since the package was assumed to be waterproof, and because the atmosphere inside the package was formed exclusively of oxygen, so there was no possibility of air exchange with the outside air.

$Q_{air\ change} = 0$

- Product load:

  $Q_{product} = m * Cp * \Delta T$

  m = Product mass

  Cp = Product specific heat = 3.6 Kj/KgºC

  ΔT = Product temperature change

  m = 85.83 gm/shrimp * 2 shrimp/bag

  m = 171.66 gm/bag = 0.17166 Kg/bag aprox.

  $Q_{product}$ = 0.17166 Kg/bolsa*3.6 Kj/KgºC(25-15)ºC

  $Q_{product}$ = 6.18 Kj * (24/24 hr) = 6.18 Kj

  $Q_{product}$ = 6.18 Kj/hr * (1 BTU/1.055 Kj)

  $Q_{product}$ = 5.86 BTU/hr

- Metabolic activity load:

  Given by the shrimp’s internal heat due to its breathing (metabolism).

  $Q_{metabolic\ act}$ =350 Kj/Kg*0.17166 Kg/bag* (1/24 hr)*(1BTU/1.055 Kj)

  $Q_{metabolic\ act}$ = 2.3728 BTU/hr

- Radiation load:

  It was assumed that there is no radiation load because the bags was not exposed to sun or any type of radiation in this case.

  $Q_{radiation} = 0$

- Water evaporation load: Zero

Total load = Wall load +
Air change load +
Product load +
Metabolic activity load +
Radiation load +
Water evaporation load

Total load =	Wall load	= 6.6786 BTU/hr
	Air change load	= 0 BTU/hr
	Product load	=5.86 BTU/hr
	Metabolic activity load	= 2.3728 BTU/hr
	Radiation load	= 0 BTU/hr
	Water evaporation load	= 0 BTU/hr
	== == == == == == == == == == == == == == == == == == == =	
	Total load	=14.9114 BTU/hr

II. Modeling of the system's thermal load and generation of a dynamic model by thermal nets.

Thus, we have one ordinary equation for each node:

$$(1)\ \frac{dT_{shrimp}}{a - bT_{shrimp}} = \frac{dt}{Cn_{shrimp}}$$

$$(2)\ \frac{dT_{frame}}{a - b_{frame}} = \frac{dt}{Cn_{frame}}$$

II.1. Simultaneous solution of differential equations

The value of Cn is given by the shrimps' metabolic rate found in work No. 1, designated metabolic activity load, given in units of BTU/ºF

Cn_{shrimp} = 1.05 BTU/ºF

The values of *a* and *b* should also be evaluated in the following way:

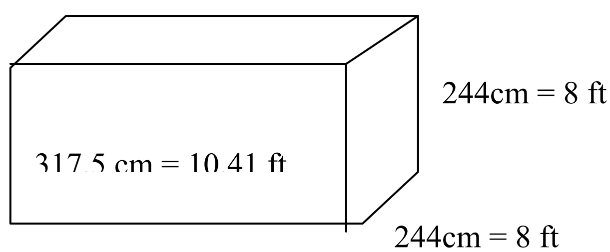
$$a = \frac{T_{frame}}{R_{frame}} + \frac{T_{O2}}{R_{O2}} + \frac{T_A}{R_A} + \frac{T_B}{R_B} + \frac{T_V}{R_V}$$

$$b = \frac{1}{R_{frame}} + \frac{1}{R_{O2}} + \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_V}$$

Conductivity data:

Air	= 0.0141 BTU/(hr.ft^2.ºF)
O_2	= 0.0141
Steel	= 26.2
Polysterene	= 0.20

Equipment data:



Example of calculations of R:

Based on the calculation carried out for the oxygen inside the bag, we have that;

$$K_{O2} = 0.0141 \frac{BTU}{ft^2 * hr} * 0.8066\ ft^2$$

K_{O2} = 0.01137 BTU/ºF*hr

R = 1 / K_{O2}

R = 1 / 0.01137 BTU/ºF*hr = 87.95 hr*ºF/BTU

And so on for all parts of the system.

In the case of external air areas, internal air areas and tray area percentages were assumed an area percentage occupied by the internal materials was taken into account. Therefore, the following was done in each case:

- external air area = equipment area + 40% equipment area
- internal air area = equipment area + 20% equipment area
- area trays = 60% equipment area

Sistem Part	**Temperature (ºF)**	**Area (ft^2)**	**Conductivity (BTU/ºF*hr)**	**Resistence (hr*ºF/BTU)**
Frame	87	461.12	12081.3440	8.2772*10-5
(O_2) Oxygen inside bag	59	0.8065	0.01137	87.9362
(V) Trays	59	276.67	7248.8064	13.7953*10-5
(A) Air inside equipment	59	553.3440	7.8021	0.128170
(B) Bag	59	0.8065	0.1613	6.1996

Table H-1. Summary of conductivities and thermal resistances LD-30

Node 1: shrimp:

Procedure to calculate *a* and *b*:

$$a = \frac{T_{frame}}{8.2772*10^{-5}} + \frac{59}{87.93} + \frac{59}{13.7953*10^{-5}} + \frac{59}{0.1281} + \frac{59}{6.1996}$$

$$a = \frac{T_{frame}}{8.2772*10^{-5}} + 428150.0921 \text{ BTU/hr}$$

$$b = \frac{1}{8.2772*10^{-5}} + \frac{1}{87.93} + \frac{1}{13.7953*10^{-5}} + \frac{1}{0.1281} + \frac{1}{6.1996}$$

b = 19338.2048 BTU/hr°F

Node 2: frame:

Procedure to calculate *a* and *b*:

$$a = \frac{T_{shrimp}}{0.03787} + \frac{59}{87.93} + \frac{59}{13.7953*10^{-5}} + \frac{59}{0.1281} + \frac{59}{6.1996}$$

$$a = \frac{T_{shrimp}}{0.03787} + 428150.0921 \text{ BTU/hr}$$

$$b = \frac{1}{0.03787} + \frac{1}{87.93} + \frac{1}{13.7953*10^{-5}} + \frac{1}{0.1281} + \frac{1}{6.1996}$$

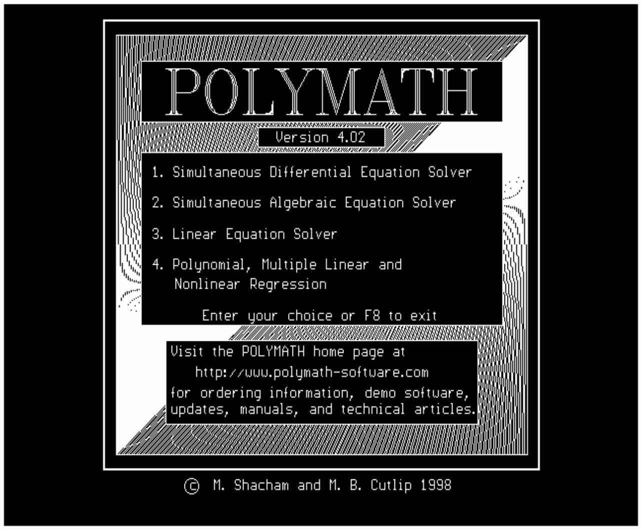
b = 7283.2195 BTU/hr°F

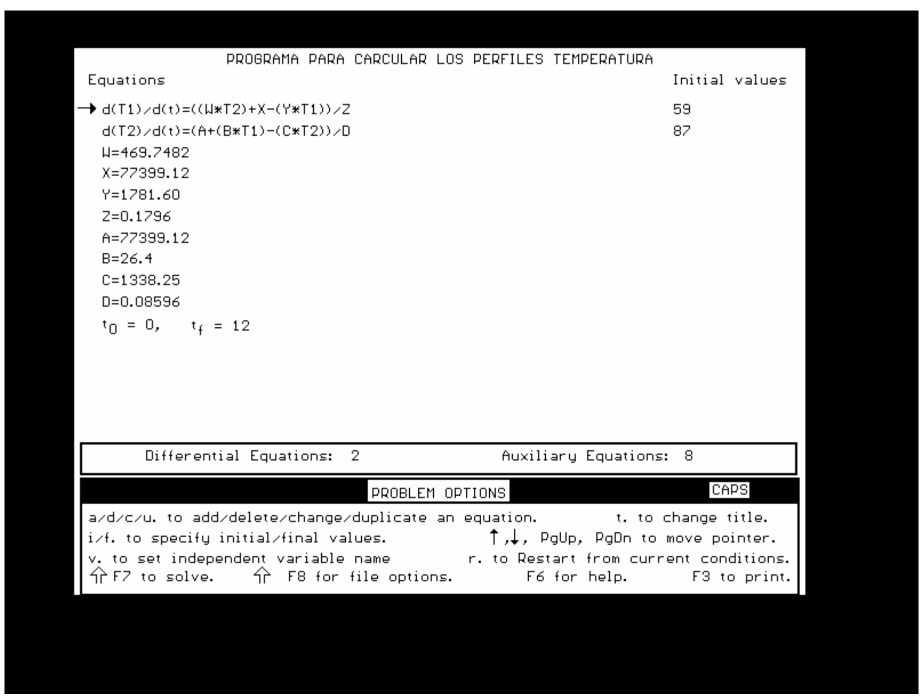
The two equations to be solved are as follows:

$$(1)\quad \frac{dT_{shrimp}}{\boxed{\dfrac{T_{shrimp}}{0.03787} + 428150.0921\ \text{BTU/hr}} - 7283.2195\ \text{BTU/hr}\ ^{\circ}\text{F}\ T_{shrimp}} = \frac{dt}{Cn_{shrimp}}$$

$$(2)\quad \frac{dT_{frame}}{\boxed{\dfrac{T_{frame}}{8.2772 * 10^{-5}} + 428150.0921\ \text{BTU/hr}} - 19338.2048\ \text{BTU/hr}\ ^{\circ}\text{F}\ T_{frame}} = \frac{dt}{Cn_{frame}}$$

POLYMATH 5 was used to solve these equations, as shown:


POLYMATH
Version 4.02
1. Simultaneous Differential Equation Solver
2. Simultaneous Algebraic Equation Solver
3. Linear Equation Solver
4. Polynomial, Multiple Linear and Nonlinear Regression
Enter your choice or F8 to exit
Visit the POLYMATH home page at
http://www.polymath-software.com
for ordering information, demo software, updates, manuals, and technical articles.
© M. Shacham and M. B. Cutlip 1998

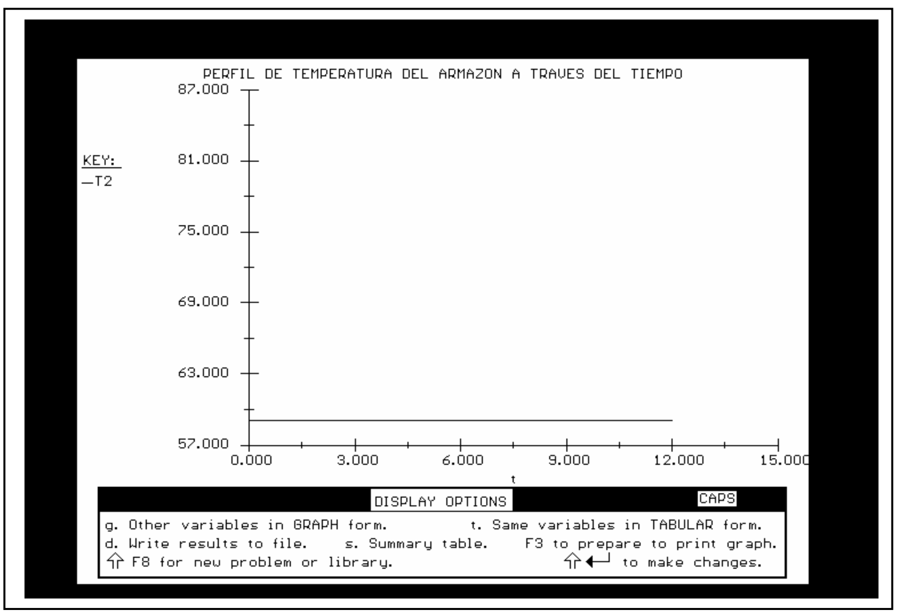

PROGRAMA PARA CARCULAR LOS PERFILES TEMPERATURA
Equations
Initial values
d(T1)/d(t)=((W*T2)+X-(Y*T1))/Z
59
d(T2)/d(t)=(A+(B*T1)-(C*T2))/D
87
W=469.7482
X=77399.12
Y=1781.60
Z=0.1796
A=77399.12
B=26.4
C=1338.25
D=0.08596
t0 = 0, tf = 12
Differential Equations: 2
Auxiliary Equations: 8
PROBLEM OPTIONS
CAPS
a/d/c/u. to add/delete/change/duplicate an equation.
t. to change title.
i/f. to specify initial/final values.
↑,↓, PgUp, PgDn to move pointer.
v. to set independent variable name
r. to Restart from current conditions.
F7 to solve.
F8 for file options.
F6 for help.
F3 to print.

RESUMEN DE SALIDA DEL PROGRAMA PARA LOS PERFILES DE TEMPERATURA

Variable	Initial value	Maximum value	Minimum value	Final value
t	0	12	0	12
T1	59	61.0333	58.9999	58.9999
T2	87	87	59	59
W	469.748	469.748	469.748	469.748
X	77399.1	77399.1	77399.1	77399.1
Y	1781.6	1781.6	1781.6	1781.6
Z	0.1796	0.1796	0.1796	0.1796
A	77399.1	77399.1	77399.1	77399.1
B	26.4	26.4	26.4	26.4
C	1338.25	1338.25	1338.25	1338.25
D	0.08596	0.08596	0.08596	0.08596

DISPLAY OPTIONS CAPS

t. Results in TABULAR form. g. Results in GRAPHICAL form.
d. Output results to DOS file. F3 to print this summary table.
⇧ F8 for new problem or library. ⇧↵ to make changes.



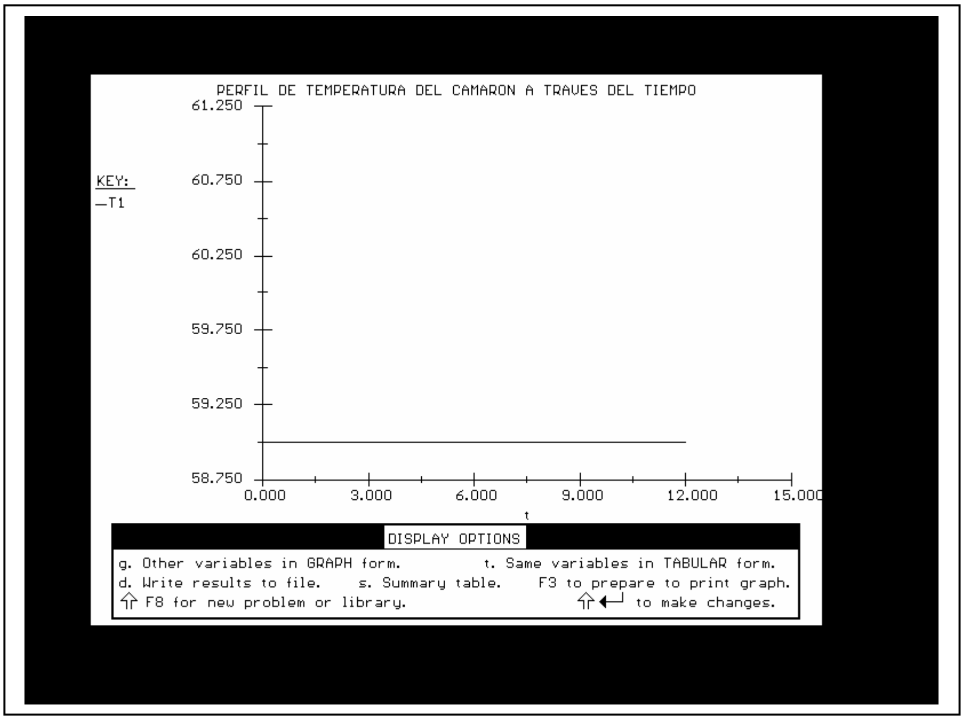


Figure 18. Polymath program output for LD-30 container

III. Determination of total thermal load.

D = 8 ft

Pr = 0.71

Tf = (100+115)ºF/2 = 107.5ºF

Cp = 0.241618 BTU/lbmºR

k = 0.015884 BTU/(hr*fte*ºR)

ρ = 0.054507 lbm/ft^3

μ = 0.0468327 lbm/ft*hr

ΔT = 15ºF

β = 107.5+460 = 567.5ºR

$$GrPr = \left[\frac{(8)^3(0.054507)^2(4.17*10^8)(15/567.5)}{(0.0468327)^2} \quad \frac{(0.241618)*(0.0468327)}{0.015884} \right]$$

$GrPr = 5445730922$

$$Num = \frac{0.527}{[1 + (1.9/0.71)^{9/10}]^{2/9}} (5445730922)^{1/5}$$

$Num = 35.49728913$

$h_m = N_{um} * (k/D)$

$h_m = 35.49728913 * (0.015884/8)$

$h_{compartment\ environment} = 0.070479867$ BTU/(hr*ft^2*ºF)

$h_{system\ (internal)} = 0$

$$R_{thermal} = \frac{1}{h_{compartment\ enviroment} * As + (k*As)/\delta + h_{system\ (internal)} * As}$$

$As = 53.3632$ ft^2

$\delta = 0.0164$ ft

$k = 26.2$ BTU/(hr*ftºF)

$$R_{thermal} = \frac{1}{(0.070479867*53.3632) + (26.2*53.3632)/0.0164 + (0.220465446 * 53.3632)}$$

$R_{thermal} = 1.17279365*10-5$ (hr*ºF)/BTU

$$Q_{ext} = \frac{T_{\text{compartment environment}} - T_{\text{system (internal)}}}{R_{\text{thermal}}}$$

$$Q_{ext} = \frac{(100 - 59)^{\circ}F}{1.17279365*10\text{-}5\ (hr*^{\circ}F)/BTU}$$

Q_{ext} = 3495926.157 BTU/hr

$Q_{TOTAL} = Q_{internal} + Q\ ext$

Q_{TOTAL} = 702.9 + 3495926.157

Q_{TOTAL} = 3496629.057 BTU/hr

IV. Simulación of the system.

The designed programs are presented next:

PROGRAMA PARA CALCULAR CARGA TERMICA EN UN PUNTO

```
CLS
SCREEN 2, 0
WINDOW (0, 0)-(320, 200)
LINE (16, 11)-(319, 199), , B
LINE (17, 12)-(318, 198), , B
'COLOR 0, 2
LINE (16, 11)-(319, 199)
LINE (16, 100)-(319, 100)
LINE (100, 20)-(300, 70), 1, BF
LINE (40, 120)-(180, 180), 1, BF
LOCATE 6, 19: PRINT "JANNETH OSPINA CORTES"
LOCATE 20, 36: PRINT " MODELAMIENTO DE CARGA TERMICA "
A$ = INPUT$(1)
CLS (2): SCREEN 0
1 CLS : COLOR 3
INICIO:
LOCATE 1, 6
PRINT ╔══════════════════════════════════════════════════════════════╗
LOCATE 2, 6
PRINT "?*************** PROPIEDADES FISICAS DEL SISTEMA ******************?
LOCATE 3, 6
PRINT ╚══════════════════════════════════════════════════════════════╝
PRINT
LOCATE 5, 6: INPUT "COEFICIENTE DE TRANSFERENCIA DE CALOR (U) (BTU/hr.pie2.?) = ", U

LOCATE 7, 8: PRINT " DIMENSIONES DE LA BOLSA EN CENTIMETROS "
LOCATE 9, 8: INPUT "LARGO.....................................= ", LB
LOCATE 10, 8: INPUT "ANCHO.....................................= ", AB

LOCATE 12, 20: PRINT " TEMPERATURAS DEL SISTEMA EN ? "
LOCATE 14, 8: INPUT "TEMPERATURA EXTERIOR.......................= ", Text
LOCATE 15, 8: INPUT "TEMPERATURA INTERIOR DESEADA...............= ", Tint
LOCATE 16, 8: INPUT "MASA DE AIRE QUE ENTRA EN 24 HORAS (Lbs/hr)= ", M
LOCATE 17, 8: INPUT "ENTALPIA DEL AIRE EXTERIOR (Btu/lbs).......= ", HO
LOCATE 18, 8: INPUT "ENTALPIA DEL AIRE INTERIOR (Btu/lbs).......= ", HI
LOCATE 19, 8: INPUT "MASA DEL PRODUCTO EN Kg/Bolsa..............= ", MP
LOCATE 20, 8: INPUT "CALOR ESPECIFICO DEL PRODUCTO (Kj/Kg.?)...= ", CP
LOCATE 21, 8: INPUT "PERDIDA DE AGUA POR EVAPORACION EN (Kg. H2O/hr)...= ", PW
A$ = INPUT$(1)
CLS (2): SCREEN 0
QP = (LB * AB / 30.48 ^ 2) * U * (Text - Tint)
QCA = M * (HO - HI)
QPROD = (MP / 24) * (CP / 1.055) * (Text - Tint) / 1.8
QACT = 350 * (MP / 24) / 1.055
QRAD = 0
QAG = ((1 / 1.055) / (1.5 / 3600)) * PW
LOCATE 3, 6
PRINT "╔══════════════════════════════════════════════════════════════╗
LOCATE 4, 6
PRINT "?******** RESULTADOS DE CARGAS PARCIALES Y TOTAL EN BTU/HR ********?
LOCATE 5, 6
```

```
PRINT ╚══════════════════════════════════════════════════════════════════════╝
PRINT
LOCATE 7, 8: PRINT "CARGA DE PAREDES....................... = ", QP
LOCATE 8, 8: PRINT "CARGA POR CAMBIO DE AIRE............... = ", QCA
LOCATE 9, 8: PRINT "CARGA DEL PRODUCTO..................... = ", QPROD
LOCATE 10, 8: PRINT "CARGA POR ACTIVIDAD METABOLICA......... = ", QACT
LOCATE 11, 8: PRINT "CARGA POR RADIACION.................... = ", QRAD
LOCATE 12, 8: PRINT "CARGA POR EVAPORACION DE H20........... = ", QAG

QTOT = QP + QCA + QPROD + QACT + QRAD + QAG

LOCATE 14, 8: PRINT "CARGA TOTAL............................ = ", QTOT

LOCATE 20, 8: PRINT "DESEA PROCESAR OTROS DATOS? (S/N): ";
INPUT RESP$

IF RESP$ = "S" THEN
  CLS (2): SCREEN 0
  GOTO INICIO:
  ELSE IF RESP$ = "s" THEN CLS (2): SCREEN 0: GOTO INICIO:
ELSE
  CLS (2): SCREEN 0
  GOTO FIN:
END IF

FIN:

END
```

Note: Commands written in Spanish are not translated because they would be inefficient in English.

PROGRAM CARRT OUT THE MODELING OF THE SYSTEM'S THERMAL LOAD WTIH EDITED DATA ON THE SYSTEM'S PROPERTIES AND PHYSICAL DIMENSIONS

```
CLS
SCREEN 2, 0
WINDOW (0, 0)-(320, 200)
LINE (16, 11)-(319, 199), , B
LINE (17, 12)-(318, 198), , B
'COLOR 0, 2
LINE (16, 11)-(319, 199)
LINE (16, 100)-(319, 100)
LINE (100, 20)-(300, 70), 1, BF
LINE (40, 120)-(180, 180), 1, BF
LOCATE 6, 19: PRINT "JANNETH OSPINA CORTES"
LOCATE 20, 36: PRINT " MODELAMIENTO DE CARGA TERMICA "
A$ = INPUT$(1)
CLS (2): SCREEN 0
1 CLS : COLOR 3
REM DATOS DE RAZON METABOLICA
CP = .9494
M = .1892
RO = 488.8109
CPS = .1195
REM DATOS DE CONDUCTIVIDAD (BTU/HR.PIE2.øF)
CA = .0141
CO = .0141
CS = 26.2
CPOL = .2
REM DIMENSIONES DE LA BOLSA EN PIES
LB = .9166
AB = .8799
REM DIMENSIONES DEL EQUIPO EN PIES (LARGO, ANCHO, ALTO Y ESPESOR)
L = 10.41
AN = 8!
AL = 8!
DX = .0164
INICIO:
LOCATE 4, 6
PRINT ╔════════════════════════════════════════════════════════════════════╗
LOCATE 5, 6
PRINT "Ç***************** TEMPERATURAS DEL SISTEMA EN øF *****************Ç"
LOCATE 6, 6
PRINT ╚════════════════════════════════════════════════════════════════════╝
PRINT
LOCATE 8, 8: INPUT "TEMPERATURA DEL ARMAZON (Tarm).............=", TARM
LOCATE 9, 8: INPUT "TEMPERATURA DEL CAMARON (Tcam).............=", TCAM
LOCATE 10, 8: INPUT "OXIGENO EN LA BOLSA (TO2)..................=", TO2
LOCATE 11, 8: INPUT "AIRE INTERNO DENTRO DEL EQUIPO (TA)........=", TA
LOCATE 12, 8: INPUT "BOLSA (TB).................................=", TB
LOCATE 13, 8: INPUT "BANDEJAS (TV)..............................=", TV

ATOT = 2 * (L * AN + L * AL + AN * AL)
```

```
ABOL = LB * AB

Z = CP * M
W = CS * ATOT
X = TO2 * ABOL * CO + TA * 1.2 * ATOT * CA + TB * CPOL * ABOL + TV * CS * .6 * ATOT
Y = CS * ATOT + ABOL * CO + 1.2 * ATOT * CA + CPOL * ABOL + CS * .6 * ATOT

A = TO2 * ABOL * CO + TA * 1.2 * ATOT * CA + TB * ABOL * CPOL + TV * CS * .6 * ATOT
ACAM = .8 * ABOL / 3
B = 1 / (.176118 * ACAM)
C = B + ABOL * CO + 1.2 * ATOT * CA + ABOL * CPOL + CS * .6 * ATOT
D = RO * CPS * ATOT * DX
T2 = -(A + B * X / Y) / (B * W / Y - C)
T1 = (W * T2 + X) / Y


A$ = INPUT$(0)
CLS (2): SCREEN 0

LOCATE 3, 6
PRINT "╔══════════════════════════════════════════════════════════════════╗
LOCATE 4, 6
PRINT "Ç************************ R E S U L T A D O S *********************Ç"
LOCATE 5, 6
PRINT "╚══════════════════════════════════════════════════════════════════╝
PRINT
LOCATE 8, 15: PRINT "W= ", W
LOCATE 9, 15: PRINT "X= ", X
LOCATE 10, 15: PRINT "Y= ", Y
LOCATE 11, 15: PRINT "Z= ", Z
LOCATE 13, 15: PRINT "A= ", A
LOCATE 14, 15: PRINT "B= ", B
LOCATE 15, 15: PRINT "C= ", C
LOCATE 16, 15: PRINT "D= ", D
LOCATE 17, 15: PRINT "T1 (Camar¢n) = "; T1
LOCATE 18, 15: PRINT "T2 (Armaz¢n) = "; T2

LOCATE 22, 8: PRINT "DESEA PROCESAR OTROS DATOS? (S/N): ";
INPUT RESP$

IF RESP$ = "S" THEN
  CLS (2): SCREEN 0
  GOTO INICIO:
  ELSE IF RESP$ = "s" THEN CLS (2): SCREEN 0: GOTO INICIO:
ELSE
  CLS (2): SCREEN 0
  GOTO FIN:
END IF
FIN:
END
```

Note: Commands written in Spanish are not translated because they would be inefficient in English.

PROGRAM CARRT OUT THE MODELING OF THE SYSTEM'S THERMAL LOAD WTIHOUT EDITED DATA ON THE SYSTEM'S PROPERTIES AND PHYSICAL DIMENSIONS

```
CLS
SCREEN 2, 0
WINDOW (0, 0)-(320, 200)
LINE (16, 11)-(319, 199), , B
LINE (17, 12)-(318, 198), , B
'COLOR 0, 2
LINE (16, 11)-(319, 199)
LINE (16, 100)-(319, 100)
LINE (100, 20)-(300, 70), 1, BF
LINE (40, 120)-(180, 180), 1, BF
LOCATE 6, 19: PRINT "JANNETH OSPINA CORTES"
LOCATE 20, 36: PRINT " MODELAMIENTO DE CARGA TERMICA "
A$ = INPUT$(1)
CLS (2): SCREEN 0
1 CLS : COLOR 3
INICIO:
LOCATE 1, 6
PRINT ╔══════════════════════════════════════════════════════════════════╗
LOCATE 2, 6
PRINT "Ç***************** CARGA POR ACTIVIDAD METABOLICA *****************Ç"
LOCATE 3, 6
PRINT ╚══════════════════════════════════════════════════════════════════╝
PRINT
LOCATE 5, 8: INPUT "Cp PARA EL CAMARON (BTU/Lb.øF)...........= ", CP
LOCATE 6, 8: INPUT "MASA EN LIBRAS (de un camar¢n)...........= ", M
LOCATE 7, 8: INPUT "DENSIDAD DEL ACERO (Lbs/Pie3)............= ", RO
LOCATE 8, 8: INPUT "Cp PARA EL ACERO (BTU/Lbs.øF)............= ", CPS
PRINT
LOCATE 10, 6
PRINT ╔════════════════════════════════════════════════════════════════╗
LOCATE 11, 6
PRINT "Ç************ DATOS DE CONDUCTIVIDAD (BTU/HR.PIE2.øF) *************Ç"
LOCATE 12, 6
PRINT ╚════════════════════════════════════════════════════════════════╝
PRINT
LOCATE 14, 8: INPUT "C. AIRE..................................= ", CA
LOCATE 15, 8: INPUT "C. OXIGENO...............................= ", CO
LOCATE 16, 8: INPUT "C. STEEL.................................= ", CS
LOCATE 17, 8: INPUT "C. POLYSTERENE...........................= ", CPOL
LOCATE 19, 6
PRINT "╔═══════════════════════════════════════════════════════════════╗
LOCATE 20, 6
PRINT "Ç***************** DIMENSIONES DE LA BOLSA EN PIES ****************Ç"
LOCATE 21, 6
PRINT ╚═══════════════════════════════════════════════════════════════╝
PRINT
LOCATE 23, 8: INPUT "LARGO....................................= ", LB
LOCATE 24, 8: INPUT "ANCHO....................................= ", AB
```

```
A$ = INPUT$(0)
CLS (2): SCREEN 0
LOCATE 2, 6
PRINT "╔══════════════════════════════════════════════════════════════════════╗
LOCATE 3, 6
PRINT "Ç***************** DIMENSIONES DEL EQUIPO EN PIES *****************Ç"
LOCATE 4, 6
PRINT ╚══════════════════════════════════════════════════════════════════════╝
PRINT
LOCATE 6, 8: INPUT "LARGO......................................= ", L
LOCATE 7, 8: INPUT "ANCHO......................................= ", AN
LOCATE 8, 8: INPUT "ALTO........................................= ", AL
LOCATE 9, 8: INPUT "ESPESOR (DELTA X)..........................= ", DX
LOCATE 12, 6
PRINT "╔══════════════════════════════════════════════════════════════════════╗
LOCATE 13, 6
PRINT "Ç***************** TEMPERATURAS DEL SISTEMA EN øF *****************Ç"
LOCATE 14, 6
PRINT ╚══════════════════════════════════════════════════════════════════════╝
PRINT
LOCATE 16, 8: INPUT "TEMPERATURA DEL ARMAZON (Tarm).............= ", TARM
LOCATE 17, 8: INPUT "TEMPERATURA DEL CAMARON (Tcam).............= ", TCAM
LOCATE 18, 8: INPUT "OXIGENO EN LA BOLSA (TO2)..................= ", TO2
LOCATE 19, 8: INPUT "AIRE INTERNO DENTRO DEL EQUIPO (TA)........= ", TA
LOCATE 20, 8: INPUT "BOLSA (TB).................................= ", TB
LOCATE 21, 8: INPUT "BANDEJAS (TV)..............................= ", TV

ATOT = 2 * (L * AN + L * AL + AN * AL)

ABOL = LB * AB

Z = CP * M

W = CS * ATOT

X = TO2 * ABOL * CO + TA * 1.2 * ATOT * CA + TB * CPOL * ABOL + TV * CS * .6 * ATOT

Y = CS * ATOT + ABOL * CO + 1.2 * ATOT * CA + CPOL * ABOL + CS * .6 * ATOT


A = TO2 * ABOL * CO + TA * 1.2 * ATOT * CA + TB * ABOL * CPOL + TV * CS * .6 * ATOT

ACAM = .8 * ABOL / 3

B = 1 / (.176118 * ACAM)

C = B + ABOL * CO + 1.2 * ATOT * CA + ABOL * CPOL + CS * .6 * ATOT

D = RO * CPS * ATOT * DX

T2 = -(A + B * X / Y) / (B * W / Y - C)

T1 = (W * T2 + X) / Y
```

```
A$ = INPUT$(0)
CLS (2): SCREEN 0

LOCATE 3, 6
PRINT ╔══════════════════════════════════════════════════════════════════╗
LOCATE 4, 6
PRINT "Ç************************ R E S U L T A D O S **********************Ç"
LOCATE 5, 6
PRINT ╚══════════════════════════════════════════════════════════════════╝
PRINT
LOCATE 8, 15: PRINT "W= ", W
LOCATE 9, 15: PRINT "X= ", X
LOCATE 10, 15: PRINT "Y= ", Y
LOCATE 11, 15: PRINT "Z= ", Z
LOCATE 13, 15: PRINT "A= ", A
LOCATE 14, 15: PRINT "B= ", B
LOCATE 15, 15: PRINT "C= ", C
LOCATE 16, 15: PRINT "D= ", D
LOCATE 17, 15: PRINT "T1 (Camar¢n)= "; T1
LOCATE 18, 15: PRINT "T2 (Armaz¢n)= "; T2

LOCATE 22, 8: PRINT "DESEA PROCESAR OTROS DATOS? (S/N): ";
INPUT RESP$

IF RESP$ = "S" THEN
  CLS (2): SCREEN 0
  GOTO INICIO:
  ELSE IF RESP$ = "s" THEN CLS (2): SCREEN 0: GOTO INICIO:
  ELSE CLS (2): SCREEN 0
  GOTO FIN:
END IF
FIN:
END
```

Note: Commands written in Spanish are not translated because they would be inefficient in English.

APPENDIX B

Calculation for the foam Container

Calculations to determine the shrimps' thermal load at a level of a single point

- Wall load:

  $Q = A * U * \Delta T$

  Where:

  Q = Wall load (BTU/hr)

  A = System area (ft^2)

  U = Heat transference coefficient (BTU/(hr ft^2 ºF)) for material of which the bag is made (polyethylene).

  ΔT = System temperature change.

  $A = 27.25 \text{ cm} * 15.35 \text{ cm} = 418.2875 \text{ cm}^2$

  $A = 418.2875 \text{ cm}^2 (1 \text{ inch}/2.54 \text{ cm})^2*(1 \text{ ft}/12 \text{ inch})^2$

  $A = 0.4502 \text{ ft}^2$

  U = 0.46 BTU/hr ft^2ºF, taken from Chart A2.2 of *Heating and Cooling of Buildings*.

  $\Delta T = T_{exterior} - T_{interior\ (desired)}$

  $T_{external} = 25ºC = 77ºF$

  $T_{interior\ (desired)} = 15ºC = 59ºF$

  $\Delta T = 18ºF$

Q_{walls} = 0.4502 ft^2 * 0.46 BTU/(hr ft^2 ºF) * 18ºF

Q_{walls} = 3.7279 BTU/hr

- Air change load:

  $Q_{air\ change}$ = m * (ho - hi)

  Where:
  m = Mass of air that enters the space in 24 hours
  ho = External air enthalpy
  hi = Internal air enthalpy

This heat is zero since the package was assumed to be waterproof, and because the atmosphere inside the package consisted exclusively of oxygen whith was no possibility of exchange with the outside air.

$Q_{air\ change}$ = 0

- Product load:

  $Q_{product}$ = m * Cp * ΔT

  m = Product mass
  Cp = Product specific heat
  ΔT = Product temperature change

  m = 85,83 g/shrimp * 2 shrimp/bag
  m = 171.66 g/bag = 0.17166 kg/bag aprox.

  Cp is found in data of experiments carried out for fish in *Refrigeration on Fishing Vessels*, and has a value of 3.6 Kj/Kg ºC

$Q_{product}$ = 0.17166 Kg/bolsa*3.6 Kj/(Kg ºC)(25-15)ºC

$Q_{product}$ = 6.18 Kj * (24/24 hr) = 6.18 Kj

$Q_{product}$ = 6.18 Kj/hr * (1 BTU/1.055 Kj)

$Q_{product}$ = 5.86 BTU/hr

- Metabolic activity load:
  Given by the shrimp's internal heat due to its breathing (metabolism).

  $Q_{\text{metabolic act}}$ = 350 Kj/Kg*0.17166 Kg/bag* (1/24 hr)*(1BTU/1.055 Kj)

  $Q_{\text{metabolic act}}$ = 2.3728 BTU/hr

- Radiation load:
  It assumed that there was no radiation load because the bags will not be exposed to sun or any type of radiation in this case.

  $Q_{radiation} = 0$

- Water evaporation load:
  First of all, the shrimp's loss of water due to evaporation must be assessed by means of experimentation because there is no reliable data. The data is obtained through the difference in weight measured at different times during the process of keeping the shrimp alive without water for 24 hours at 15ºC. This procedure was carried out from April 4 to April 6 2001, and, according to the data obtained, there was no observed water loss. However, this experiment was repeated one week later to corroborate the results and no weight loss was found due to water evaporation.

Total load = Wall load +
Air change load +
Product load +
Metabolic activity load +
Radiation load +
Water evaporation load

Total load =	Wall load	= 3.7279 BTU/hr
	Air change load	= 0 BTU/hr
	Product load	=5.86 BTU/hr
	Metabolic activity load	= 2.3728 BTU/hr
	Radiation load	= 0 BTU/hr
	Water evaporation load	= 0 BTU/hr
	== == == == == == == == == == == == == == == == == == == =	
	Total load	=11.9607 BTU/hr

APPENDIX C

Modeling of the system's thermal load and generation of a dynamic model by thermal nets

After determining the Node 1 diagram, we can proceed to determine the N node equation as follows:

$$CnTn = \sum_{n'=1}^{n} \frac{Tn' - Tn}{Rn'n} + Qn$$

Qn, was assumed to be zero since there was no other source of heat, such as solar radiation, light, or heat for the shrimp (N).

Therefore:

$$CnTn = \left[\frac{T_{frame} - T}{R_{frame}} + \frac{T_{O2} - T}{R_{O2}} + \frac{T_A - T}{R_A} + \frac{T_B - T}{R_B} + \frac{T_f - T}{R_f} \right]$$

T = variable in function of time to generate the differential equation.
The differential equation of first order is then obtained:

$$Cn_{shrimp} \frac{dT_{shrimp}}{dt} = \left[\frac{T_{frame} - T}{R_{frame}} + \frac{T_{O2} - T}{R_{O2}} + \frac{T_A - T}{R_A} + \frac{T_B - T}{R_B} + \frac{T_f - T}{R_f} \right]$$

To solve it, the following procedures must be carried out:

$$Cn_{shrimp}\, dT_{shrimp} = \left[\frac{T_{frame} - T}{R_{frame}} + \frac{T_{O2} - T}{R_{O2}} + \frac{T_A - T}{R_A} + \frac{T_B - T}{R_B} + \frac{T_f - T}{R_f} \right] dt$$

Regrouping:

$$Cn_{shrimp}\, dT_{shrimp} = \left[\frac{T_{frame}}{R_{frame}} + \frac{T_{O2}}{R_{O2}} + \frac{T_A}{R_A} + \frac{T_B}{R_B} + \frac{T_f}{R_f} \right.$$

$$\left. - \frac{T}{R_{frame}} - \frac{T}{R_{O2}} - \frac{T}{R_A} - \frac{T}{R_B} - \frac{T}{R_f} \right] dt$$

Canceling T we have:

$$Cn_{shrimp}\, dT_{shrimp} = \left[\frac{T_{frame}}{R_{frame}} + \frac{T_{O2}}{R_{O2}} + \frac{T_A}{R_A} + \frac{T_B}{R_B} + \frac{T_f}{R_f} \right.$$

Constant terms

$$\left. - T \left[\frac{1}{R_{frame}} - \frac{1}{R_{O2}} - \frac{1}{R_A} - \frac{1}{R_B} - \frac{1}{R_f} \right] \right] dt$$

Replacing the constant terms to simplify the equation:

$$a = \frac{T_{frame}}{R_{frame}} + \frac{T_{O2}}{R_{O2}} + \frac{T_A}{R_A} + \frac{T_B}{R_B} + \frac{T_f}{R_f}$$

$$b = \frac{1}{R_{frame}} + \frac{1}{R_{O2}} + \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_f}$$

The differential equation is then:

$$Cn_{shrimp} * dT_{shrimp} = (a - bT_{shrimp})\, dt$$

Grouping the variables we then have:

$$\boxed{\frac{dT_{shrimp}}{a - bT_{shrimp}} = \frac{dt}{Cn_{shrimp}}}$$

This is the ordinary differential equation (1).

After determining the Node 2 diagram, we can proceed similarly to determine the N_2 node equation as follows:

$$CnTn = \sum_{n'=1}^{n} \frac{Tn' - Tn}{Rn'n} + Qn$$

Qn, is assumed to be zero since there is no other source of heat, such as solar radiation, light, or heat for the shrimp (N).

Therefore:

$$CnTn = \sum_{n'=1}^{n} \frac{Tn' - Tn}{Rn'n} + Qn$$

$$Cn_{frame}Tn_{frame} = \left[\frac{T_{O2} - T}{R_{O2}} + \frac{T_A - T}{R_A} + \frac{T_B - T}{R_B} + \frac{T_f - T}{R_f} + \frac{T_{shrimp} - T}{R_{shrimp}} \right]$$

T = Variable in function of time to generate the differential equation.

The differential equation of first order is then obtained:

$$Cn_{frame}dTn_{frame} = \left[\frac{T_{O2} - T}{R_{O2}} + \frac{T_A - T}{R_A} + \frac{T_B - T}{R_B} + \frac{T_f - T}{R_f} + \frac{T_{shrimp} - T}{R_{shrimp}} \right] dt$$

To solve it, the following procedures should be carried:

$$CnaTna = \left[\frac{T_{O2}}{R_{O2}} - \frac{T}{R_{o2}} + \frac{T_A}{R_A} - \frac{T}{R_A} + \frac{T_B}{R_B} - \frac{T}{R_B} + \frac{T_f}{R_f} - \frac{T}{R_f} + \frac{T_{shrimp}}{R_{shrimp}} - \frac{T}{R_{shrimp}} \right]$$

Regrouping:

$$CnaTna = \left[\frac{T_{O2}}{R_{O2}} + \frac{T_A}{R_A} + \frac{T_B}{R_B} + \frac{T_f}{R_f} + \frac{T_{shrimp}}{R_{shrimp}} \right.$$

$$- \frac{T}{R_{O2}} - \frac{T}{R_A} - \frac{T}{R_B} - \frac{T}{R_f} - \frac{T}{R_{shrimp}} \Bigg] dt$$

Canceling T we have:

$$CnTn = \left[\frac{T_{O2}}{R_{O2}} + \frac{T_A}{R_A} + \frac{T_B}{R_B} + \frac{T_f}{R_f} + \frac{T_{shrimp}}{R_{shrimp}} \right.$$

Constant terms

$$\left. T \left[- \frac{1}{R_{O2}} - \frac{1}{R_A} - \frac{1}{R_B} - \frac{1}{R_f} - \frac{1}{R_{shrimp}} \right] \right] dt$$

Replacing the constant terms to simplify the equation:

$$a = \frac{T_{O2}}{R_{O2}} + \frac{T_A}{R_A} + \frac{T_B}{R_B} + \frac{T_f}{R_f} + \frac{T_{shrimp}}{R_{shrimp}}$$

$$b = \frac{1}{R_{O2}} + \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_f} + \frac{1}{R_{shrimp}}$$

The differential equation is then:

$Cn * dT = (a - bT)\ dt$

Grouping the variables we then have:

$$\boxed{\frac{dT_{frame}}{a - bT_{frame}} = \frac{dt}{Cn}}$$

This is the ordinary differential equation (2).

APPENDIX D

Simultaneous solution of differential equations

The equations for the two nodes are:

$$(1)\quad \frac{dT_{shrimp}}{a - bT_{shrimp}} = \frac{dt}{Cn_{shrimp}}$$

$$(2)\quad \frac{dT_{frame}}{a - bT_{frame}} = \frac{dt}{Cn_{frame}}$$

For the equation (1), the Cn_{shrimp} , *a* and *b* are calculated as follow:

The value of Cn is given by the shrimps' previously and denominated metabolic activity load (given in units of BTU/ºF).

Cp = 3.63 KJ/KgºC = 0.8598 BTU/LbºF

m = 85.83 gm = 0.1892 lb

Cn = 0.8598 BTU/LbºF * 0.1892 lb

Cn_{shrimp} = 1.05 BTU/ºF

$Cn_{frame} = \rho * Cp * As * \Delta X$

ρ = Density

Cp = Specific heat

As = Superficial area

ΔX = thickness

Cn_{frame} = 0.048847 BTU/ºF

Procedures to calculate a and b:

Conductivity data:

Air = 0.0141 BTU/(hr.ft^2.º F)

O_2 = 0.0141

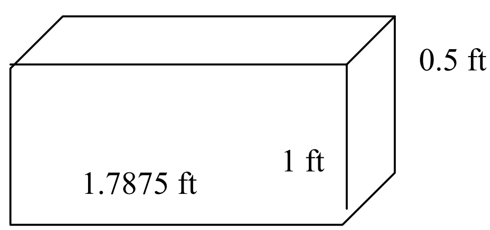
Polyurethane foam = 0.04245

Polyethylene bag = 2.082

Polysterene foam = 0.0161781

Shrimp = 0.03787 (taken like frozen fish standard data)

Equipment data:



Example of calculations of R:

Based on the calculation carried out for the oxygen inside the bag, we have:

$$K_{O2} = 0.0141 \frac{BTU}{ft^2 * hr\ ºF} * 0.4502\ ft^2$$

$K_{O2} = 6.34782*10^{-3}$ BTU/ºF hr

$R = 1 / K_{O2}$

R = 157.5343 hr ºF/BTU

And so on to calculate the conductivity and resistance for all parts of the system.

In the case of external air areas, internal air areas and tray area percentages assumed an area percentage occupied by the internal materials was taken into account. Therefore, the following was done in each case:

- External air area = equipment area + 40% equipment area
- Internal air area = equipment area + 20% equipment area
- Area trays = 60% equipment area

System part	**Temperature (ºF)**	**Area (ft^2)**	**Conductivity (BTU/ºF*hr)**	**Resistance (hr*ºF/BTU)**
Frame	89	2.12	0.04245	23.55907
(O_2) Oxygen inside bag	59	0.4502	6.34782	157.5343
(F) Foam	59	1.8244	2.4056	0.415687
(A) Air inside equipment	59	1.7875	0.0252	39.6766
(B) Bag	59	0.4502	0.9373	1.06687

Table H2. Summary of conductivities and thermal resistances

Node 1 (shrimp):

Hence, *a* and *b* are determined as follow:

$$a = \frac{T_{frame}}{23.55907} + \frac{59}{157.5343} + \frac{59}{0.415687} + \frac{59}{39.6766} + \frac{59}{1.06687}$$

$$a = \frac{T_{frame}}{23.55907} + 199.0972 \text{ BTU/hr}$$

$$b = \frac{1}{23.55907} + \frac{1}{157.5343} + \frac{1}{0.415687} + \frac{1}{39.6766} + \frac{1}{1.06687} + \frac{1}{0.415687}$$

b = 3.4169 BTU/hr°F

Node 2 (frame):

Procedure to calculate *a* and *b*.

$$a = \frac{T_{shrimp}}{0.03787} + \frac{59}{157.5343} + \frac{59}{0.415687} + \frac{59}{39.6766} + \frac{59}{1.06687}$$

$$a = \frac{T_{shrimp}}{0.03787} + 199.0972 \text{ BTU/hr}$$

$$b = \frac{1}{0.03787} + \frac{1}{157.5343} + \frac{1}{0.415687} + \frac{1}{39.6766} + \frac{1}{1.06687}$$

b = 29.7801 BTU/hr°F

The two equations to be solved are the following:

$$(1)\quad \frac{dT_{shrimp}}{\boxed{\dfrac{T_{frame}}{23.55907} + 199.072\ \text{BTU/hr}} - 3.4169\ \text{BTU/(hr ºF)} * T_{shrimp}} = \frac{dt}{Cn_{shrimp}}$$

$$(2)\quad \frac{dT_{frame}}{\boxed{\dfrac{T_{shrimp}}{0.03787} + 199.0972\ \text{BTU/hr}} - 29.7801\ \text{BTU/(hr ºF)} * T_{frame}} = \frac{dt}{Cn_{frame}}$$

APPENDIX E

Convective coefficient of air calculations

The convective air coefficient is calculated in function of the existent environmental conditions such as pressure, altitude, temperature and moisture under which the shrimps transportation is carried out. For this, it is necessary to use an equation that calculates the convective air coefficient as a function of these conditions. Available literature indicates the best equation is the Nusselt equation:

$$h_m = N_{um} * (k/D)$$

$$Num = \frac{0.527}{[1 + (1.9/Pr)^{9/10}]^{2/9}} (GrPr)^{1/5}$$

$$GrPr = \left[\frac{D^3\rho^2 g(\Delta t/\beta)}{\mu^2} \quad \frac{c\mu}{k} \right]$$

hm = convective coeficient

Num = Nusselt number

D = Correction factor in Nusselt equation

Pr = Prandt number

Tf = temperature promedium

Cp = specific heat

k = conductivity

ρ = density

μ = viscosity

ΔT = deference of temperature

β = correction of temperature

Gr = Grandt number

g = gravity

The convective coefficient into the compartment environment was calculated as follow:

- Extremal Conditions:

$$GrPr = \left[\frac{D^3\rho^2 g(\Delta t/\beta)}{\mu^2} \quad \frac{c\mu}{k} \right]$$

D = 8 ft

Pr = 0.71

Tf = (100+115)ºF/2 = 107.5ºF

Cp = 0.0241618 BTU/LbmºR

k = 0.015884 BTU/(hr*ft*ºR)

ρ = 0.054507 Lbm/ft^3

μ = 0.0468327 Lbm/ft*hr

ΔT = 20ºF

β = 107.5+460 = 567.5ºR

$$GrPr = \left[\frac{(8)^3(0.054507)^2(4.17*10^8)(20/567.5)}{(0.0468327)^2} \quad \frac{(0.0241618)*(0.0468327)}{0.015884} \right]$$

GrPr = 726097456.3

$$Num = \frac{0.527}{[\,1 + (1.9/0.71)^{9/10}]^{2/9}} \; (726097456.3)^{1/5}$$

$$\mathrm{Num} = \frac{31.18958515}{1.314676}$$

Num = 23.72416105

$h_m = N_{um} * (k/D)$

$h_m = 23.72416105 * (0.015884/8)$

$h_{compartment\ environment} = 0.047104321$ BTU/(hr*ft^2*ºF)

- Real Conditions:

$$GrPr = \left[\frac{D^3\rho^2 g(\Delta t/\beta)}{\mu^2} \quad \frac{c\mu}{k} \right]$$

D = 8 ft

Pr = 0.71

Tf = (79+56)ºF/2 = 67.5ºF

Cp = 0.0241618 BTU/LbmºR

k = 0.015884 BTU/(hr*ft*ºR)

ρ = 0.054507 Lbm/ft^3

μ = 0.0468327 Lbm/ft*hr

ΔT = 23ºF

β = 107.5+460 = 567.5ºR

$$GrPr = \left[\frac{(8)^3(0.054507)^2(4.17*10^8)(23/567.5)}{(0.0468327)^2} \quad \frac{(0.0241618)*(0.0468327)}{0.015884} \right]$$

$$GrPr = 835012074.7$$

$$Num = \frac{0.527}{[1 + (1.9/0.71)^{9/10}]^{2/9}} (835012074.7)^{1/5}$$

$$Num = \frac{32.07370765}{1.314676}$$

$$Num = 24.3966$$

$$h_m = N_{um} * (k/D)$$

$$h_m = 24.3966* (0.015884/8)$$

$$h_{compartment\ environment} = 0.04844395\ BTU/(hr*ft^2*{}^oF)$$

The convective coefficient in the interior of the system ($h_{system\ (internal)}$) was calculated and estimated as zero, because internally the system should have the same temperature, hence

$\Delta T = 0$

APPENDIX F

Programs for simulation of foam container

```
CLS
SCREEN 2, 0
WINDOW (0, 0)-(320, 200)
LINE (16, 11)-(319, 199), , B
LINE (17, 12)-(318, 198), , B
'COLOR 3, 3
LINE (16, 11)-(319, 199)
LINE (16, 100)-(319, 100)
LINE (100, 20)-(300, 70), 1, BF
LINE (40, 120)-(180, 180), 1, BF
LOCATE 6, 19: PRINT "JANNETH OSPINA CORTES"
LOCATE 20, 36: PRINT " DETERMINACION DE CARGA TERMICA TOTAL"
LOCATE 21, 36: PRINT " Y CALCULO DE CANTIDAD DE REFRIGERANTE"
A$ = INPUT$(1)
CLS (2): SCREEN 0
1 CLS : COLOR 3
INICIO:
LOCATE 3, 6
PRINT "╔══════════════════════════════════════════════════════════════════════╗ "
LOCATE 4, 6
PRINT "╟**************** CALCULO DE COEFICIENTES CONVECTIVOS***************╟"
LOCATE 5, 6
PRINT "╚══════════════════════════════════════════════════════════════════════╝"
PRINT
LOCATE 6, 6: PRINT " TEMPERATURAS DEL SISTEMA EN °F "
LOCATE 8, 6: INPUT "TEMPERATURA EXTERIOR......................= ", Text
LOCATE 9, 6: INPUT "TEMPERATURA INTERIOR DESEADA..............= ", Tint
GRPR = 2.0603015# * 10 ^ 10 * ((Text - Tint) / 567.5)
LOCATE 10, 6: PRINT "GRPR.................................... = ", GRPR
Num = .400859 * GRPR ^ (1 / 5)
LOCATE 11, 6: PRINT "Num..................................... = ", Num
hm = Num * (.015884 / 8)
LOCATE 13, 6: PRINT "Coeficiente Convectivo externo........... = ", hm
LOCATE 14, 6: PRINT "Coeficiente Convectivo interno........... = ", 0
LOCATE 15, 6: INPUT "Altura container (pie)................... = ", Al
LOCATE 16, 6: INPUT "Ancho container (pie).................. = ", An
LOCATE 17, 6: INPUT "Largo container (pie).................... = ", lg
Asup = ((Al * An) * 2) + ((An * lg) * 2) + ((Al * lg) * 2)
Area = Al * lg
LOCATE 18, 6: PRINT "Area superficial (pie^2.................. = ", Asup
LOCATE 19, 6: INPUT "Espesor container (pie)................. = ", Ro
Rtermica = 1 / ((hm * Asup) + ((.01617 * Asup) / Ro))
LOCATE 20, 6: PRINT "Resistencia térmica...................... = ", Rtermica
Qtotal = (Text - Tint) / Rtermica
A$ = INPUT$(1)
CLS (2): SCREEN 0
LOCATE 7, 6
PRINT "╔══════════════════════════════════════════════════════════════════════╗ "
LOCATE 8, 6
PRINT "╟****** CARGA CALOR TOTAL  Y CANTIDAD REFRIGERANTE  ****************╟"
LOCATE 9, 6
PRINT "╚══════════════════════════════════════════════════════════════════════╝"
PRINT
LOCATE 13, 8: PRINT "CARGA DE CALOR TOTAL (BTU/Lb)............... = ", Qtotal
Mrefrigerante = (Qtotal / 144) * 24
LOCATE 16, 8: PRINT "CANTIDAD REFRIGERANTE (Lb).................. = ", Mrefrigerante
LOCATE 17, 8: PRINT "CAMARONES POR BOLSA......................... = ", 2
LOCATE 18, 8: PRINT "CAMARONES POR CONTAINER..................... = ", 8
LOCATE 19, 8: PRINT "PESO APROXIMADO CONTAINER (Lb)............. = ", 5
LOCATE 21, 8: PRINT "DESEA PROCESAR OTROS DATOS? (S/N): ";
INPUT RESP$

IF RESP$ = "S" THEN
  CLS (2): SCREEN 0
  GOTO INICIO:
  ELSE IF RESP$ = "s" THEN CLS (2): SCREEN 0: GOTO INICIO:
ELSE
  CLS (2): SCREEN 0
  GOTO FIN:
END IF

FIN:

END
```

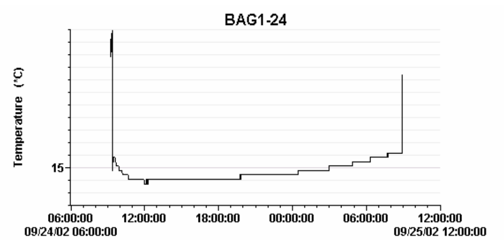
Note: Commands written in Spanish are not translated because they would be inefficient in English.

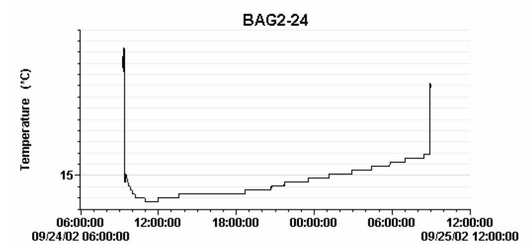
APPENDIX G

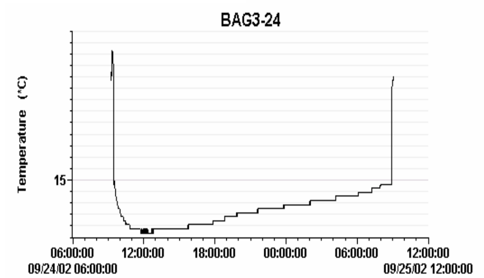
Results of experiment without shrimps

Date: September 24/02 **Container No. 2**

Refrigerant substance position: Lb refrigerant substance: 4.059

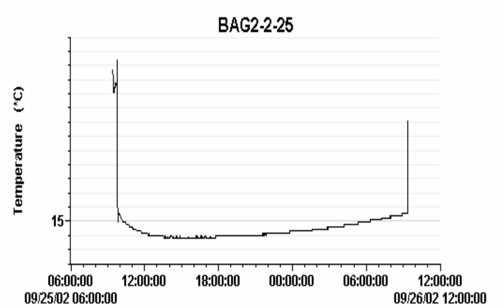


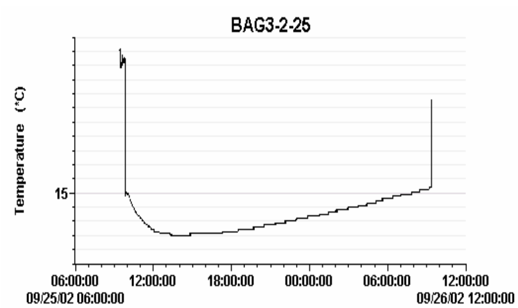


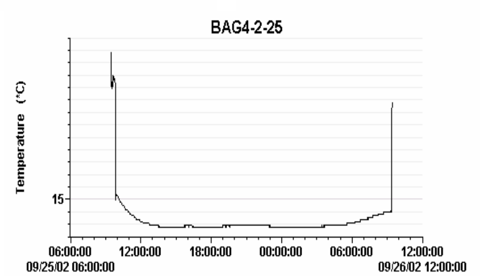


Date: September 25/02 **Container No. 2**

Refrigerant substance position: Lb refrigerant substance: 3.67

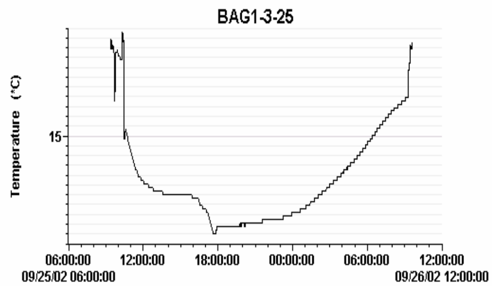


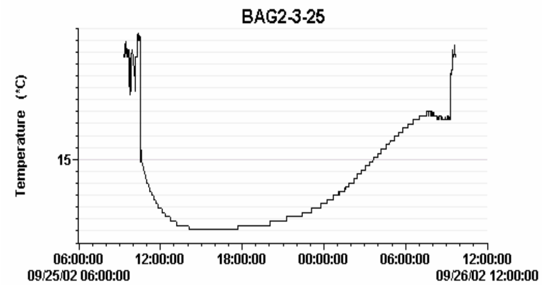


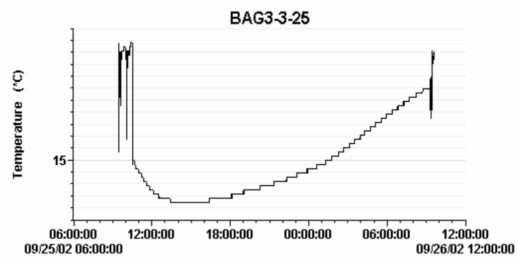


Date: September 25/02 **Container No. 3**

Refrigerant substance position: Lb refrigerant substance: 2.66

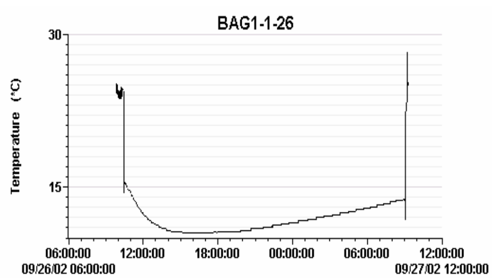


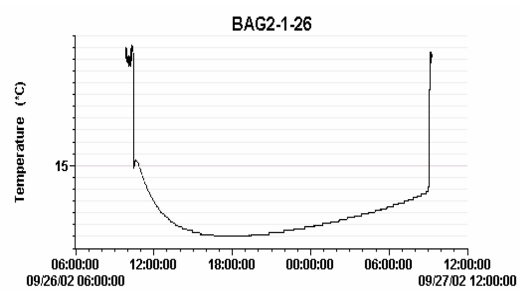


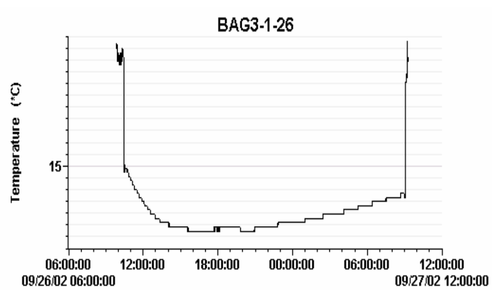


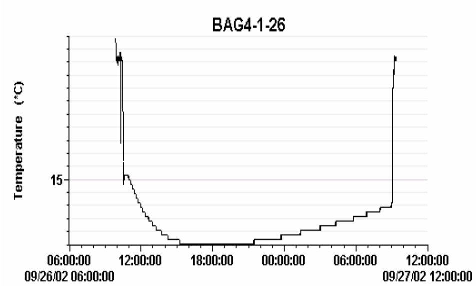
Date: September 26/02 **Container No. 1**

Refrigerant substance position: Lb refrigerant substance: 3.02





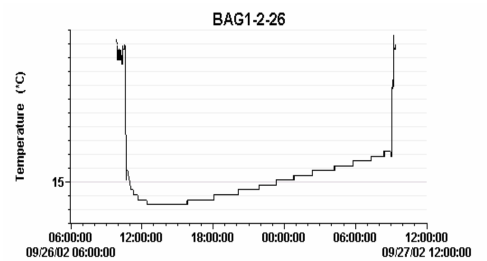


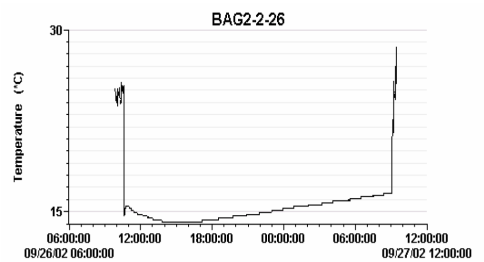


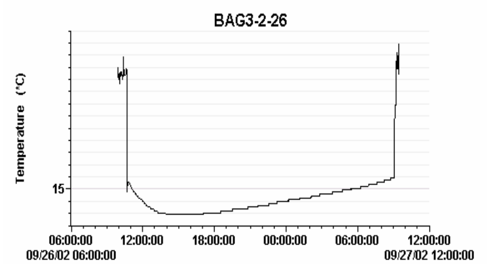
Date: September 26/02 **Container No. 2**

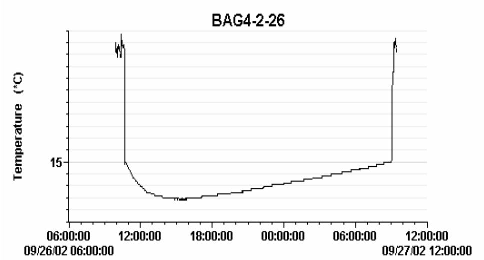
Refrigerant substance position:

Lb refrigerant substance: 3.03





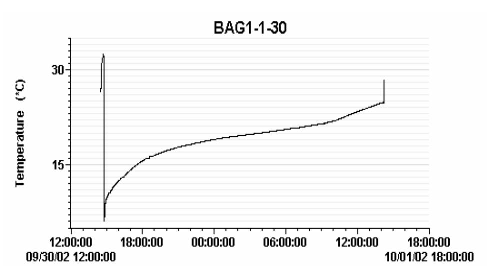


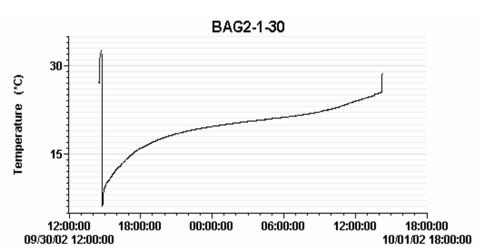


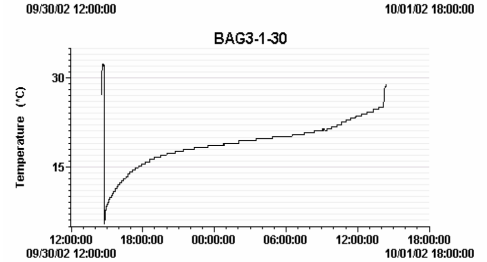
Date: September 30/02 **Container No. 1**

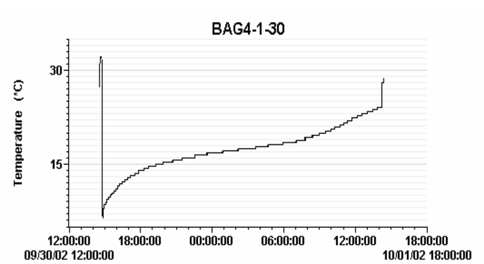
Refrigerant substance position:

Lb refrigerant substance: 3.01





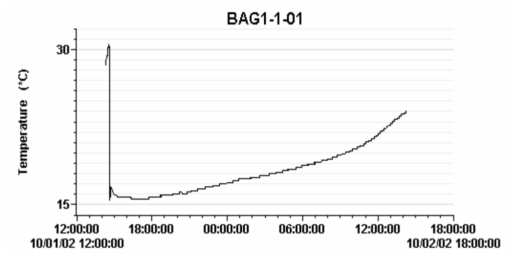


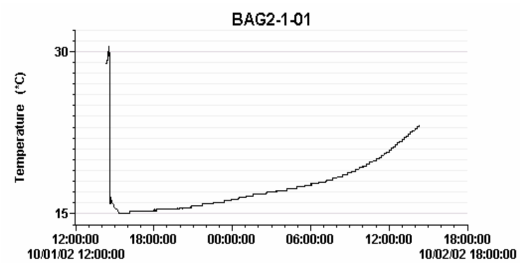


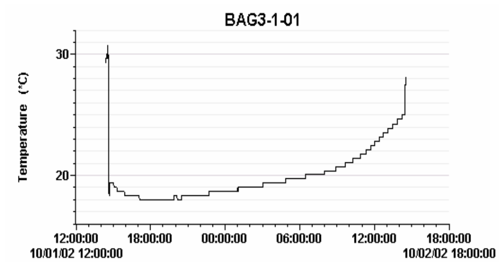
Date: October 1/02 **Container No. 1**

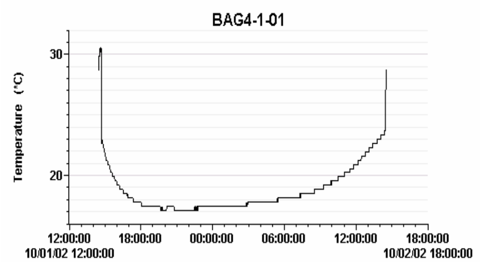
Refrigerant substance position:

Lb refrigerant substance: 3.05





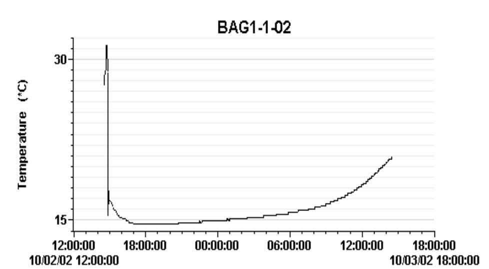


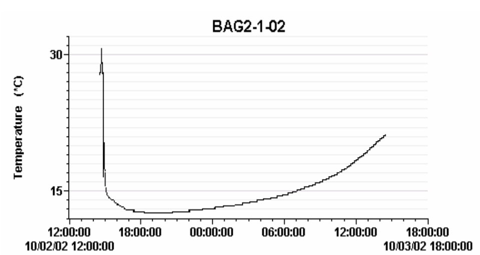


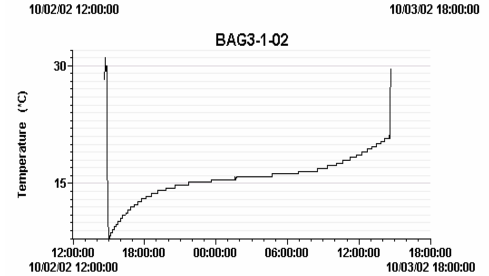
Date: October 2/02 **Container No. 1**

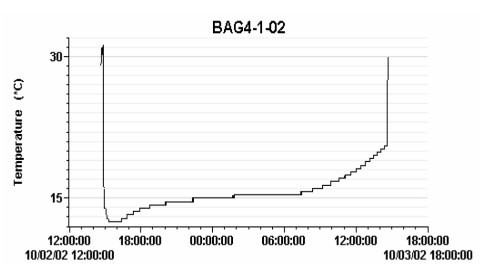
Refrigerant substance position:

Lb refrigerant substance: 4.03



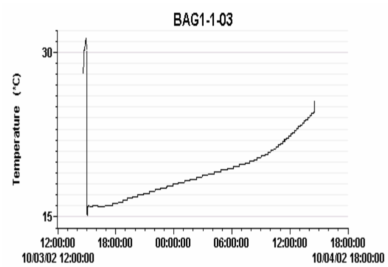


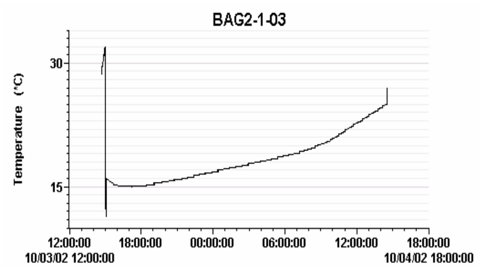


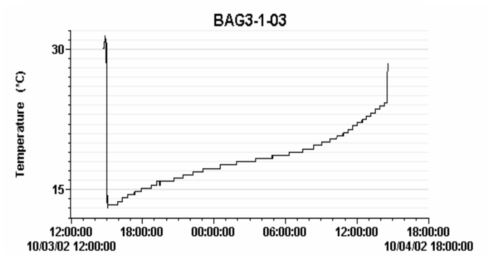


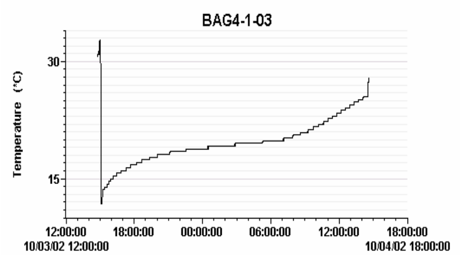
Date: October 3/02 **Container No. 1**

Refrigerant substance position: Lb refrigerant substance: 3.02



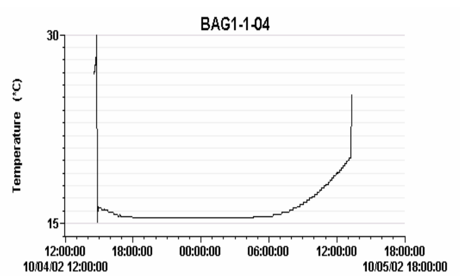


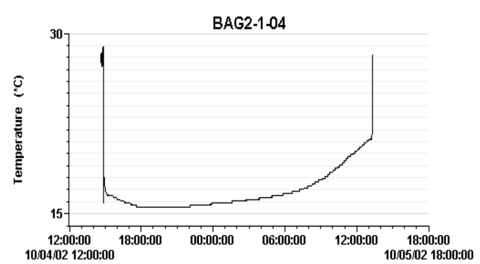


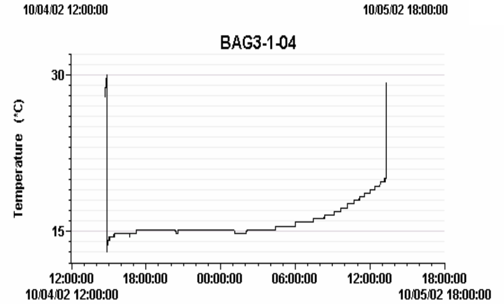


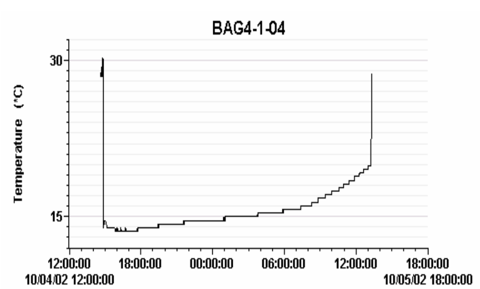
Date: October 4/02 **Container No. 1**

Refrigerant substance position: Lb refrigerant substance: 4.03



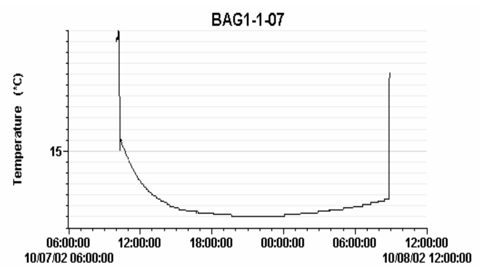


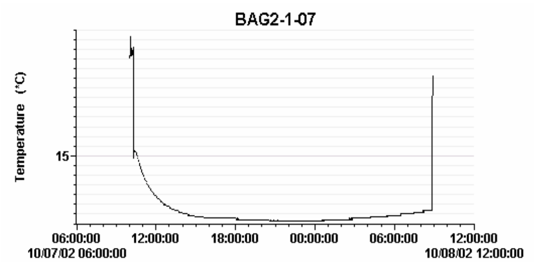


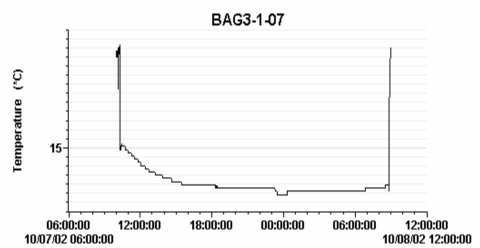


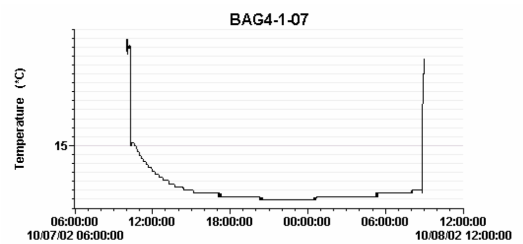
Date: October 7/02 **Container No. 1**

Refrigerant substance position: Lb refrigerant substance: 4.06



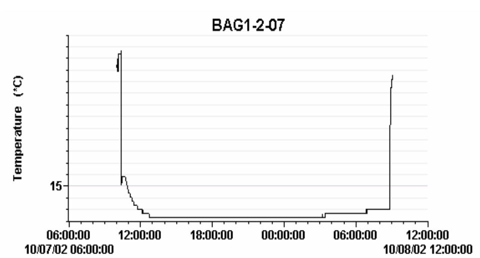


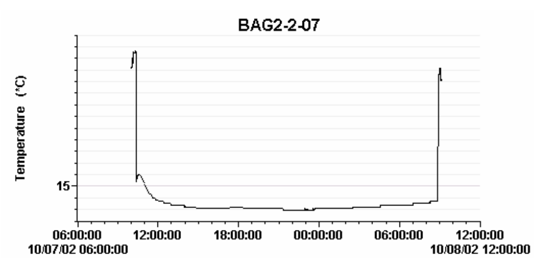


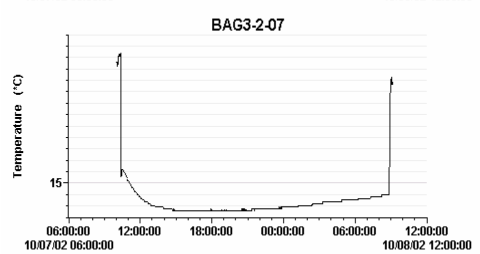


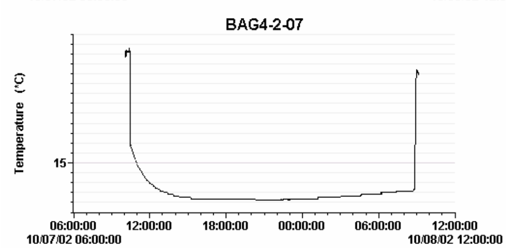
Date: October 7/02 **Container No. 2**

Refrigerant substance position: Lb refrigerant substance: 4.07



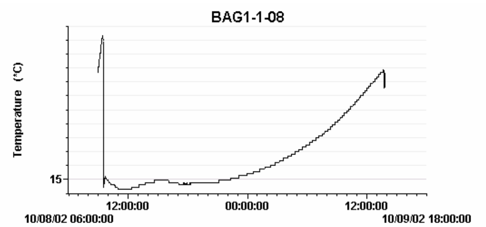


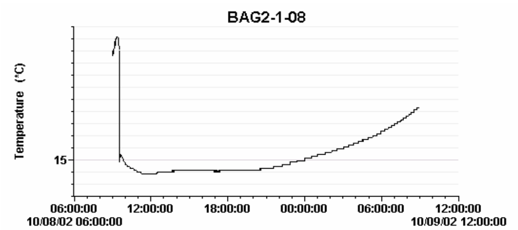


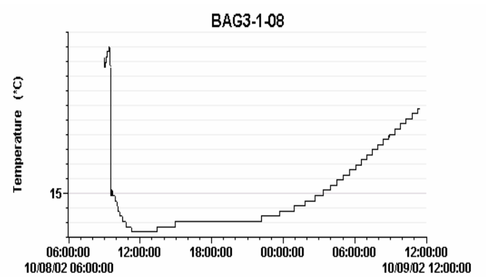


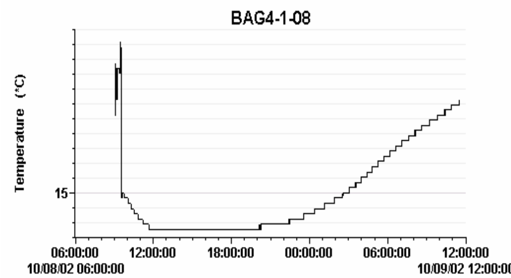
Date: October 8/02 **Container No. 1**

Refrigerant substance position: Lb refrigerant substance: 3.20



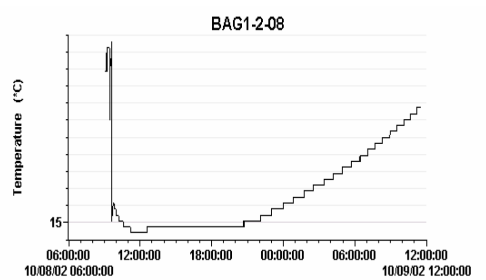


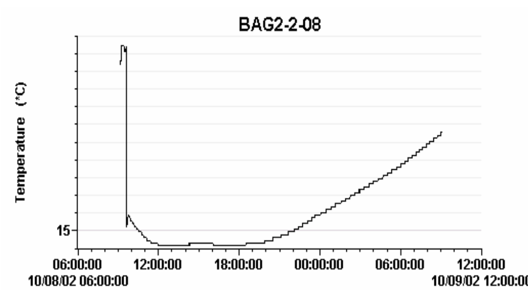


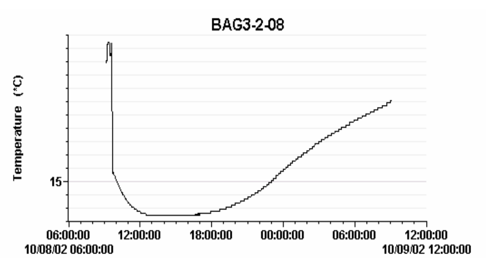


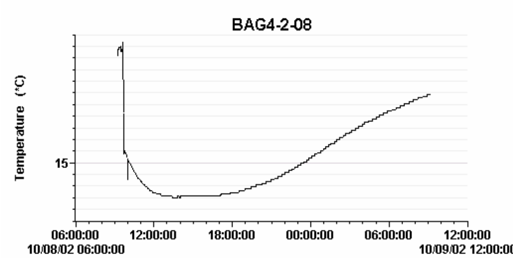
Date: October 8/02 **Container No. 2**

Refrigerant substance position: Lb refrigerant substance: 2.76



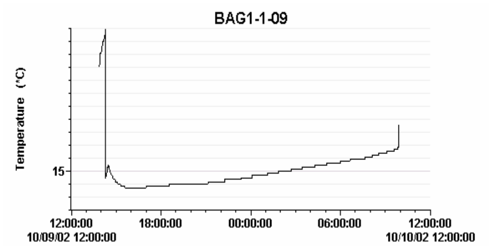


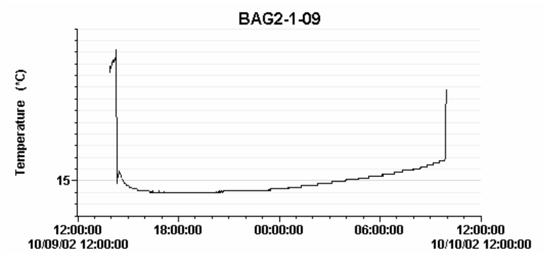


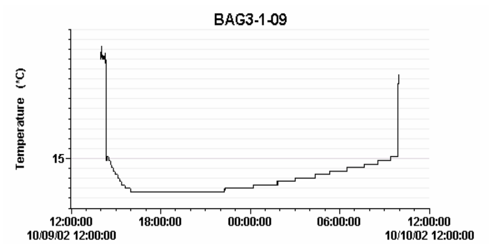


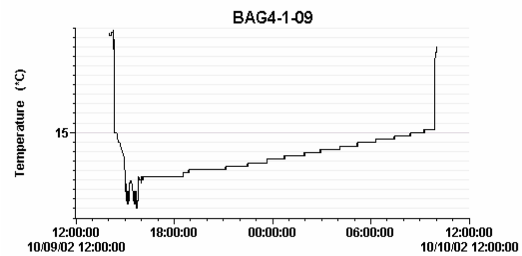
Date: October 9/02 **Container No. 1**

Refrigerant substance position: ___ ___ Lb refrigerant substance: 3.08



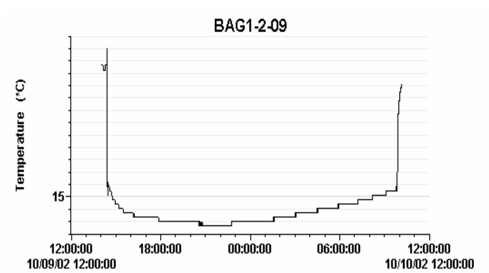


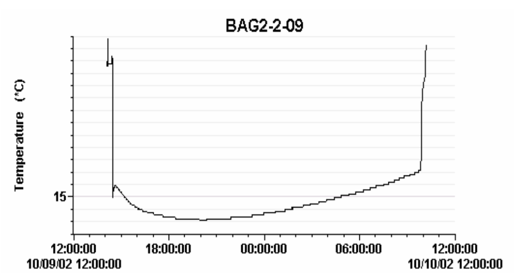


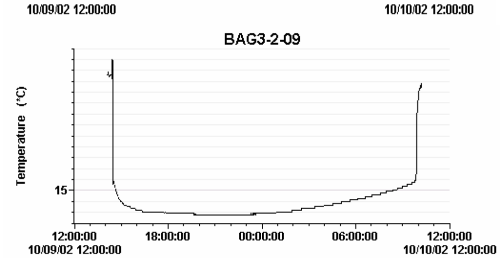


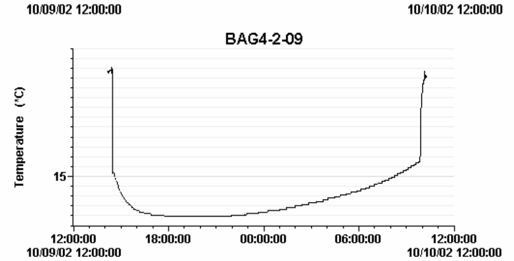
Date: October 9/02 **Container No. 2**

Refrigerant substance position: ___ ___ Lb refrigerant substance: 3.02



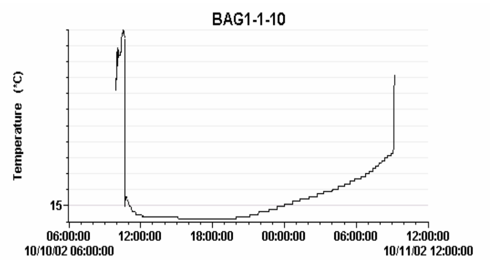


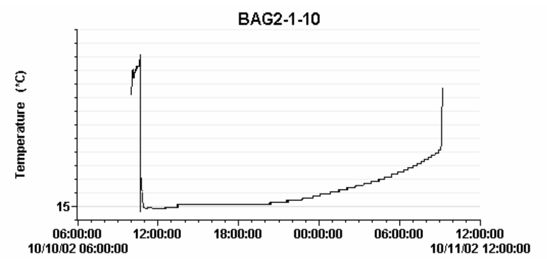


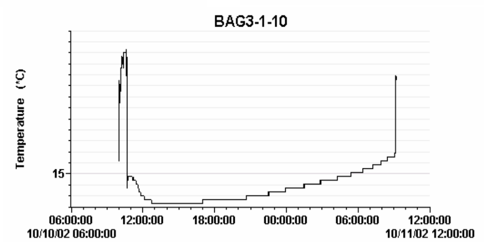


Date: October 10/02 **Container No. 1**

Refrigerant substance position: ___ ___ Lb refrigerant substance: 2.96

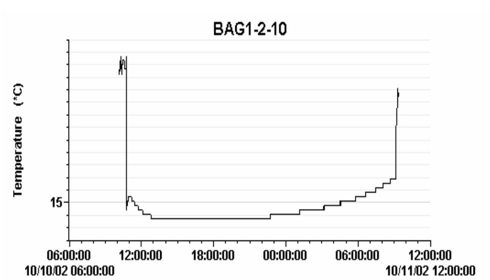


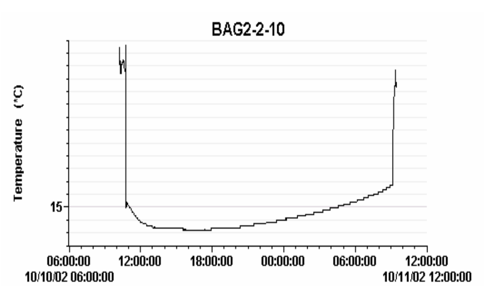


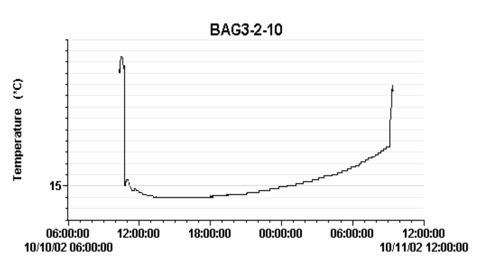


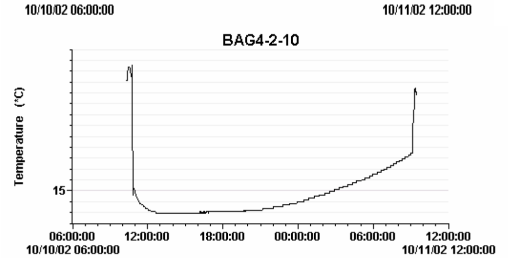
Date: October 10/02 **Container No. 2**

Refrigerant substance position: ___ ___ Lb refrigerant substance: 3.0





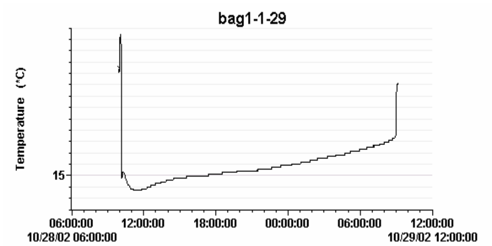


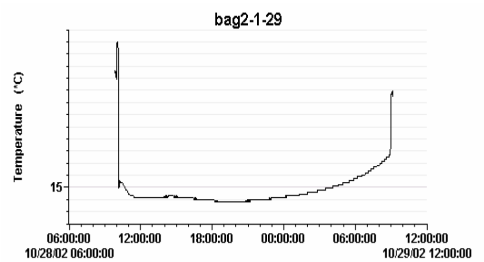


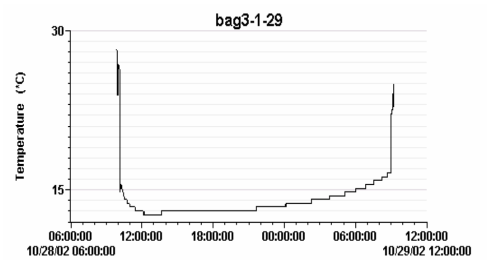
Date: October 29/02 **Container No. 1**

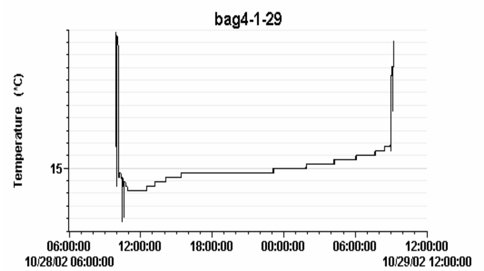
Refrigerant substance position: ___ ___

Lb refrigerant substance: 3.02





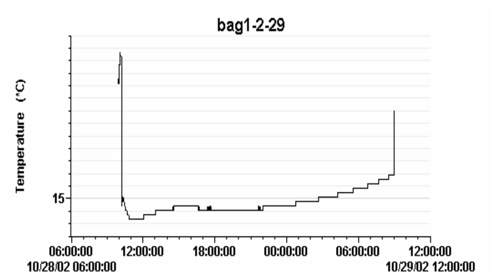


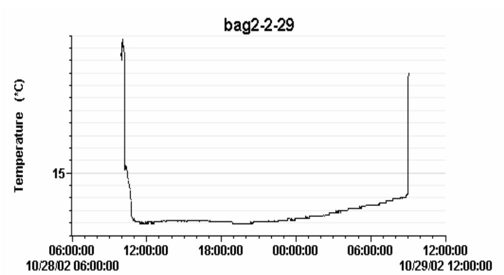


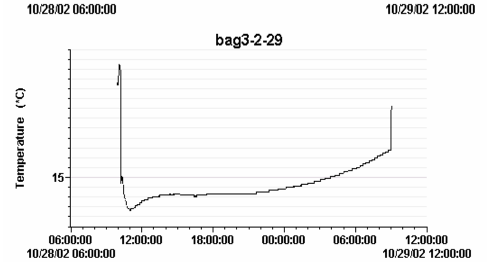
Date: October 29/02 **Container No. 2**

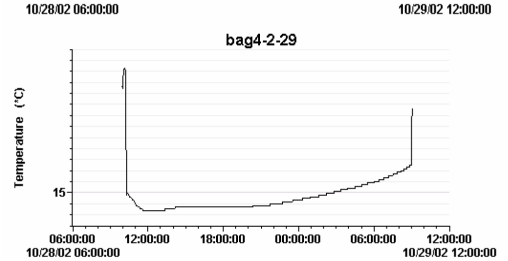
Refrigerant substance position: ___ ___

Lb refrigerant substance: 3.0



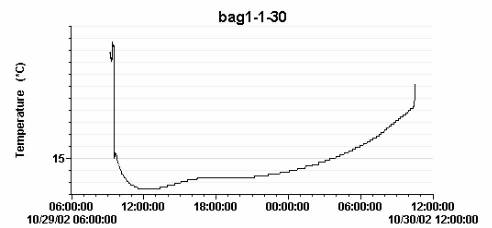


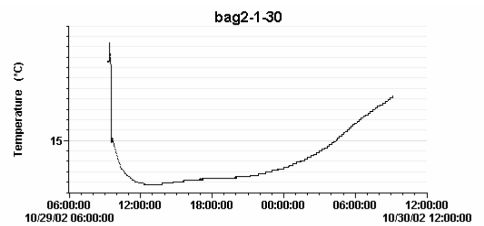


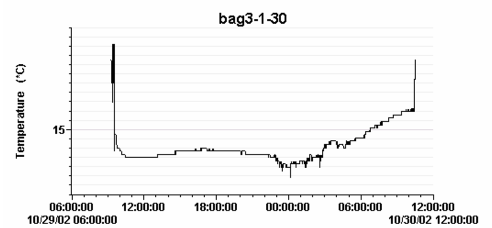


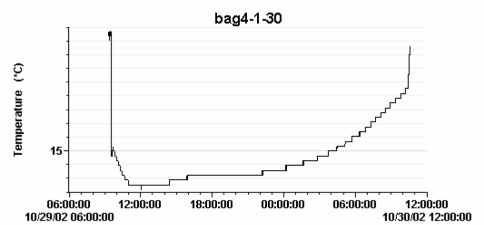
Date: October 30/02 **Container No. 1**

Refrigerant substance position: ___ ___ Lb refrigerant substance: 3.02



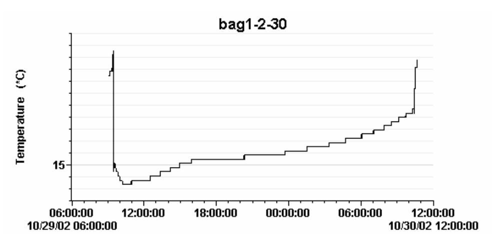


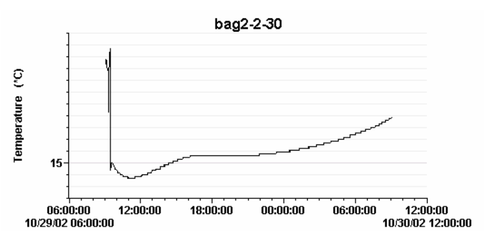


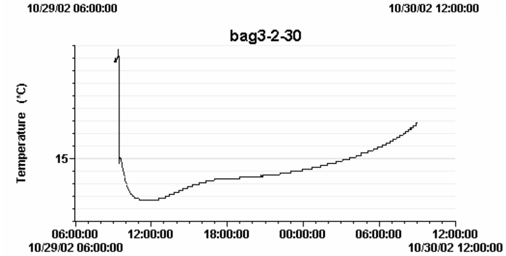


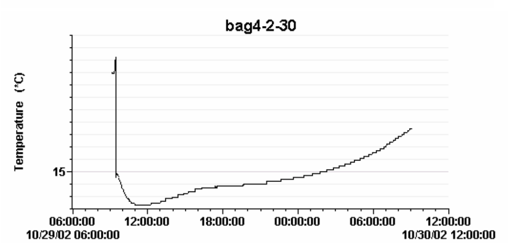
Date: October 30/02 **Container No. 2**

Refrigerant substance position: ___ ___ Lb refrigerant substance: 3.0



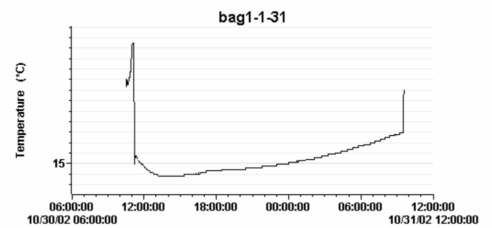


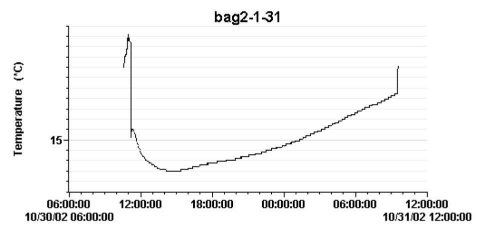


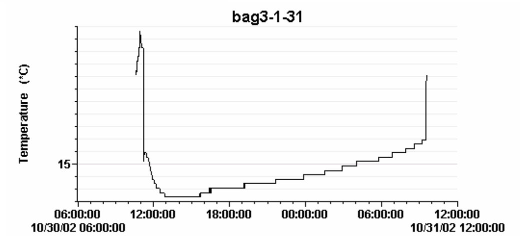


Date: October 31/02 **Container No. 1**

Refrigerant substance position: Lb refrigerant substance: 3.02

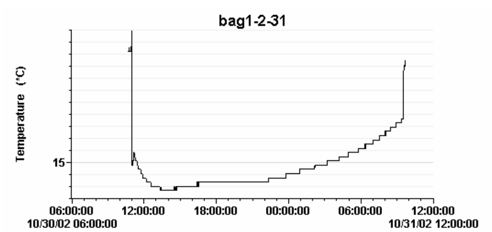


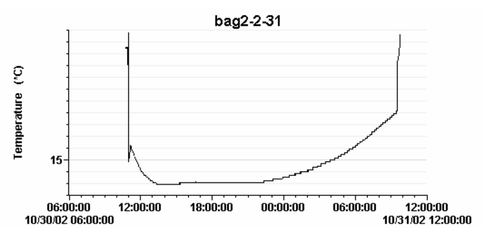


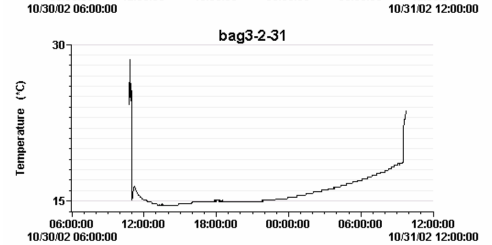


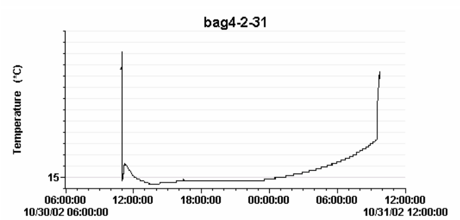
Date: October 31/02 **Container No. 2**

Refrigerant substance position: Lb refrigerant substance: 3.0









APPENDIX H

Results of experiment with shrimps

Date: November 1/02

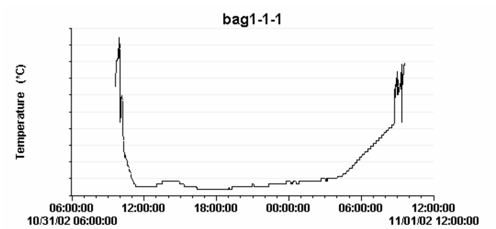
Container No. 1

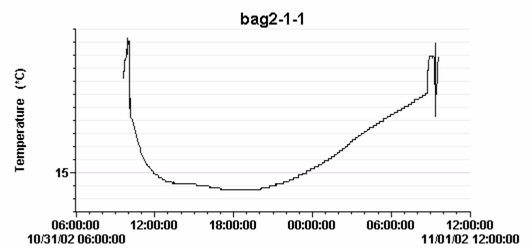
Refrigerant substance position:

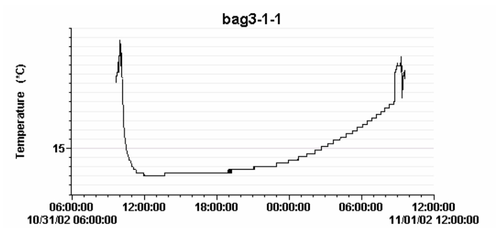
Lb refrigerant substance: 3.03

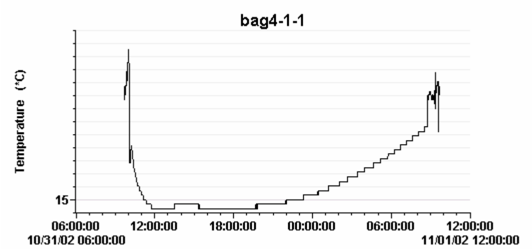
Shrimps per container: 8

No. survivors: 5









Date: November 1/02

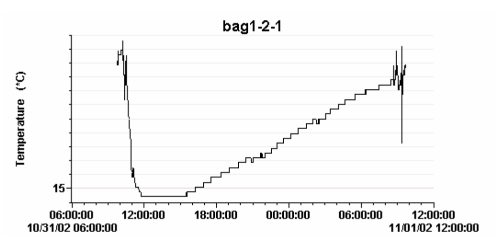
Container No. 2

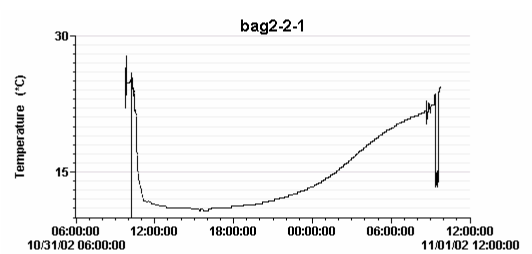
Refrigerant substance position:

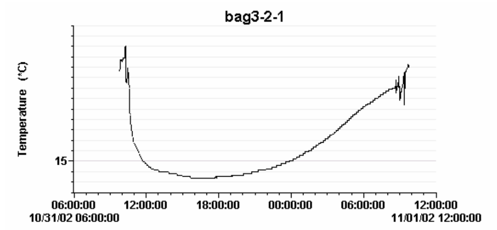
Lb refrigerant substance: 3.05

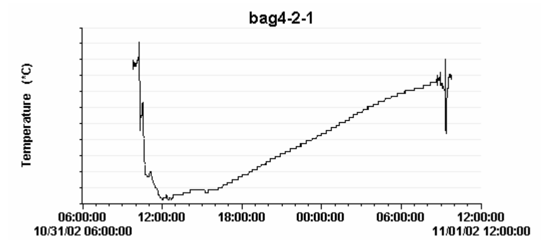
Shrimps per container: 8

No. survivors: 4






bag3-2-1
Temperature (°C)
15
06:00:00
10/31/02 06:00:00
12:00:00
18:00:00
00:00:00
06:00:00
12:00:00
11/01/02 12:00:00


bag4-2-1
Temperature (°C)
06:00:00
10/31/02 06:00:00
12:00:00
18:00:00
00:00:00
06:00:00
12:00:00
11/01/02 12:00:00

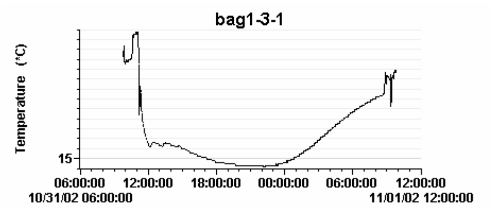
Date: November 1/02 **Container No. 3**

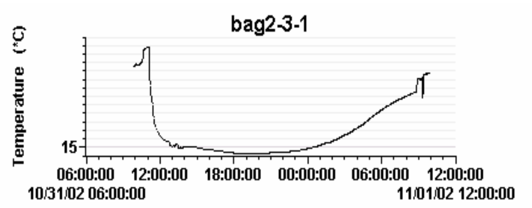
Refrigerant substance position:

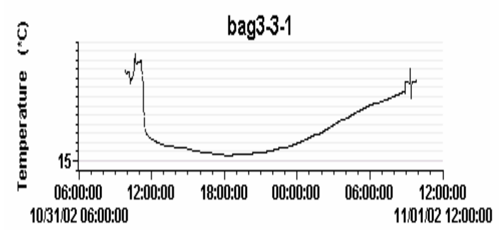
Lb refrigerant substance: 3.08

Shrimps per container: 8

No. survivors: 5







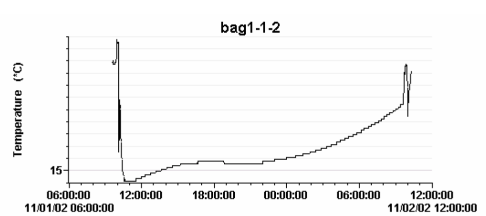
Date: November 2/02 **Container No. 1**

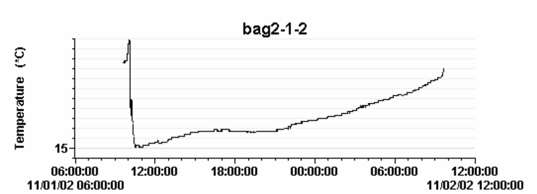
Refrigerant substance position:

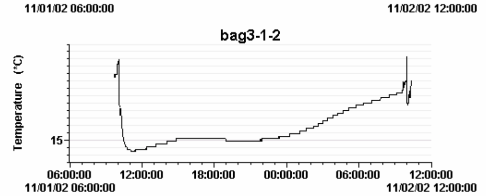
Lb refrigerant substance: 3.0

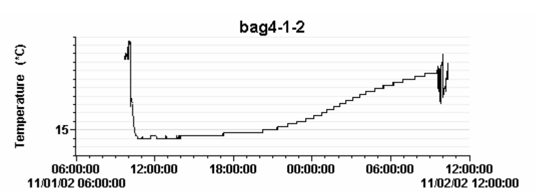
Shrimps per container: 8

No. survivors: 4









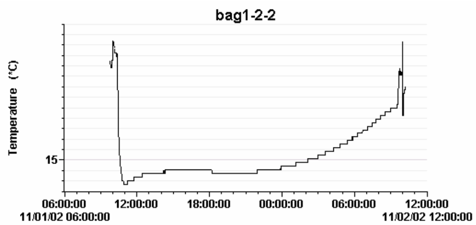
Date: November 2/02 **Container No. 2**

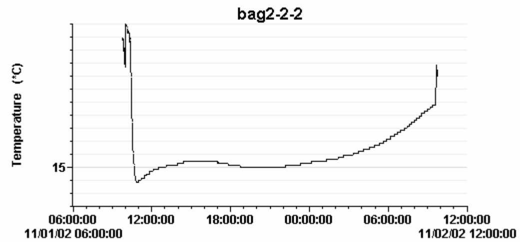
Refrigerant substance position: __ __

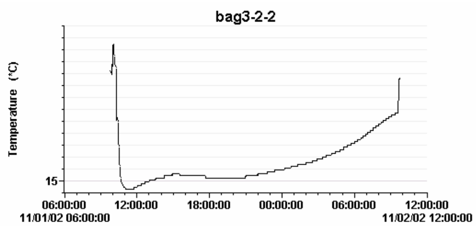
Lb refrigerant substance: 2.96

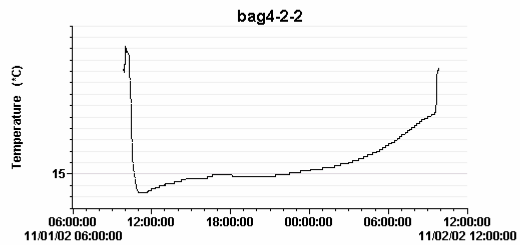
Shrimp per container: 8

No. survivors: 4









Date: November 2/02 **Container No. 3**

Refrigerant substance position: __ __

Lb refrigerant substance: 3.02

Shrimps per container: 8

No. survivors: 5