Freezer Container Shipping

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Summary

The project concerns the achievement of technical knowledge regarding the technical disciplines: automation (measuring and control), auxiliary systems, electrical engineering, cargo handling and refrigerating technology. Besides theoretical knowledge and management-related skills, companies require their higher qualified workers to have practical skills as well.

Problem description and problem definition

Present situation:
Nowadays on board of vessels the freezing, cooling and heating processes of cargo are done by reefers. Reefers are used for transportation of temperature-controlled cargo according to a company (2ConnectLogistics US, 2012) specialized in transportation of reefer cargo. The average power consumption of a reefer container, with a constant temperature of -18°C is 6Kw generated from generators running on diesel oil. The reefers need a lot of maintenance and therefore time from the crew on board (GDV, 2013). Reefers will maintain the temperature of the cargo stable during day and night. The reefer system is a system that has been applied for many years. However, according to a Maersk Line’s captain (Ballieux, R, 2013) the system is not efficient enough.

Nowadays 42% of the reefers are filled with frozen cargo, according to a German company (GDV, 2013). The diesel generators consume a lot of diesel oil, which provides the energy for the reefer system on board. To connect the electricity of one container, it takes 1 minute for loading and 30 seconds for discharging. While the container is on board, it will take 40 seconds for the daily check. According to Ballieux R. reason enough to think about a new energy-efficient system for the future.

- Loading: 30 sec connecting + 30 sec checking = 60 sec/container
- During the voyage: 1 x per day 100 reefers/hour
- Discharging: 30 sec x 518 containers = 15540 sec

Desired situation by Freezer container shipping:
The desired situation is an energy-efficient freezing system that will work on shore and not on the vessel. The cargo will be frozen on shore in the freezer container. The freezer containers will replace the reefer system. After loading the container, the cargo in the freezer container will stay frozen during the voyage without using energy from the vessel. It means that the freezing system will be shore based, so the crew on board is not required to keep an eye on the freezer container until the next port. With this desired situation, the crew does not have to worry about the temperatures, maintenance or anything else of the freezer containers. It all comes to the efficiency of the freezer containers and the energy-efficient freezing system on shore.

Problem definition:
Frozen cargo will warm up during the voyage without a temperature control environment such as reefers. The reefer system nowadays is energy inefficient.

Objective:
Keeping the cargo frozen in a container without using energy, holding a constant temperature on board and have an energy-efficient freezing system on shore.

After field research for the fourth sub question, the conclusion is that only insulation in the freezer container will not keep a constant temperature for a number of weeks. Therefore more research was required to answer how to preserve a constant temperature, that it will not use energy from the vessel. The conclusion is to keep a constant temperature with the magnetic freezing system in the container. To supply the magnetic system on the freezing container solar paint will be used, this paint works like normal solar panels with an efficiency of 10%. To connect all containers an electrical grid is necessary, so the inner containers with no solar energy production also can function.

The recommendations: to research the costs, a network system for controlling the temperature by warming up and cooling down and how the excess energy can be stored in batteries.
Preface

This project has been produced to develop and enhance the abilities needed for Maritime Officer. Regarding technical and nautical disciplines: automation, propulsion and auxiliary systems, electrical engineering, cargo handling and refrigeration technology. This report will involve improving the container freezing system for merchant navy. Freezer container shipping is about temperatures below zero degrees Celsius. The project only is about freezing systems, temperatures below zero degrees.

In the secondary year of the study Maritime Officer, students need to make a project about innovations in the maritime sector. We as contractors chose to improve a current maritime problem.

We decided to improve the conventional reefer system because in our opinion this system could be much more efficient with the available present technology.

The report contains the desk research and field research for the sub questions. In every sub question, the contacted outside expert advice will determine the final solutions to the problem. At the end, all the sub questions will answer our main question. Which will lead to a wide approach of the subject, “Freezer container shipping”.

We would like to express our gratitude by thanking Mrs. Van der Drift for helping and guiding us through the process. We would also thank Mr. Van Kluiven, Mr. Snoeijer and Mrs. Van der Valk for the comments, inspiration and ideas.

Rotterdam, February 14th 2014
Mathijs Ballieux, Xavier Kreft, Niels van Doorn, Robert Muilwijk and Rick Spelde.
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1. Introduction

The project concerns the achievement of technical knowledge regarding the technical disciplines: Automation (measuring and control), auxiliary systems, electrical engineering, cargo handling and refrigerating technology. Besides theoretical knowledge and management-related skills, companies require their higher qualified workers to get practical skills as well. The objective of this project is not only to produce a paper and presentation, but also to gain the knowledge and skills to apply the project-management techniques that have been studied during the Propaedeutic year and to develop the skills to do research and to organize a symposium. In project 2 and 3 the students will research the different project disciplines.

The students will set up a symposium at the end of this project. The students will make a presentation about new innovations and developments. The theme of the symposium will be Maritime Innovation. The topic for the project three and the symposium is “How can frozen cargo be transported at a constant temperature without energy usage from the vessel by freezing on the shore”.

The problem solutions are for container vessels that will carry reefers all over the world, and all the companies which are linked to frozen cargo in the maritime sector.

1.1 Problem description and problem definition

Present situation:
Nowadays on board of vessels the freezing, cooling and heating processes of cargo are done by reefers. Reefers are used for transportation of temperature-controlled cargo according to a company (2ConnectLogistics US, 2012) specialized in transportation of reefer cargo. The average power consumption of a freezer container, with a constant temperature of -18°C is 6Kw generated from generators running on diesel oil. The reefers need a lot of maintenance and therefore time from the crew on board (GDV, 2013). Reefers will maintain the temperature of the cargo stable during day and night. The reefer system is a system that has been applied for many years. However, according to a Maersk Line’s captain (Ballieux, R, 2013) the system is not efficient enough.

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Problem definition:
Frozen cargo will warm up during the voyage without a temperature control environment such as reefers. The reefer system nowadays is energy inefficient.

Objective:
Keeping the cargo frozen in a container without using energy, holding a constant temperature on board and have an energy-efficient freezing system on shore.
1.2 Project assignments

Main question:
How can frozen cargo be transported at a constant temperature without energy usage from the vessel by freezing on shore?

Sub questions:
1. How does the reefer system work nowadays?
2. Which refrigerating methods are available to freeze the containers on shore?
3. How can we optimize the energy usage to supply the freezing system on shore?
4. In what way can the container temperature be constant, so that it will not use energy from the vessel?

1.3 Project Borders

Through different research methods, the sub questions will be answered. The sub questions will give the answer to the main question that will result in the solution of the problem definition.

What has been investigated?
- How the reefer system works. Analysing maintenance, time and energy usage.
- Which energy system on shore will freeze the freezer containers.
- The most efficient energy method to supply the freezing system on shore.
- Which method can be utilized to keep the temperature constant in the freezer container during the voyage.
- Only transportation of freezer containers based on sea trade.

What has not been investigated?
- Material costs will not be investigated.
- The voyage of the container after discharging.
- No experiments.
- Temperature control by reefers for heating and cooling.
- Energy source that are not available around the port.
- World wide application of the energy efficient system.

1.4 Research methodologies

Research method:
The desk research will be analysing the problems about freezer containers and studying the literature. The literature includes freezing technology, equipment and automation. For field research companies will be contacted in different ways. Contacted companies will be providers of the insulation. Every sub question needs a unique approach for researching.

Research method sub question 1
Quantitative and qualitative, desk- and field-research. Through interviews and literature. Interview Maersk Line.

Research method sub question 2
Quantitative and qualitative, desk- and field-research. Through problem analysis. By brainstorming about the different possibilities of freezing. Advantages and disadvantages of freezing systems.

Research method sub question 3
Quantitative and desk-research and field-research. Through models, literatures and interviews. Brainstorm with the possibilities of different energy systems.

Research method sub question 4
Quantitative and qualitative desk- and field-research. Through interviews and literatures. Interviews with Trip & Co – Air cargo products and Krautz – TEMAX.
2. Project assignment

2.1 Reefer system

A freezing unit, fixed on the back of the container, does the freezing for the reefers. The freezing unit consists of an air ventilation fan and a compressor. The air ventilation fan is constantly blowing at low speed. The compressor is automated and will switch on and off to maintain the temperature between the limits. In the present situation, generators on the shore and on board power the freezing unit of the containers.

To answer the first sub question “How does the reefer system work nowadays?” a quantitative and qualitative, desk- and field-research is necessary. Through interviews and literature. Interview Maersk Line.

The reefer system works with air flow, ventilation and electricity. Currently reefers are used to freeze, cool and heat up the cargo. Maintenance hours by the experts are too high. If there are 200/300 containers on board a crewmember will spend a whole day checking the reefers temperatures on the displays.

Refrigerated containers are provided with their own refrigeration unit. This unit is attached to an electric power supply and provides a cold airflow through the container. The cold air is blown through the grills in the floor. It is a circulation system, so the air will find its way back through the container ceiling. The fan in the unit forces the air through the air-cooler. This fan also acts as the evaporator in the cold circuit and back through the grill into the cargo (see figure 1).

When pre-frozen cargo is stacked in the reefer, only air has to flow around the cargo. Only the heat that enters the insulation from outside has to be absorbed. To ensure that air can flow around the cargo and to make sure that the heat will be removed. The cargo must be arranged in the container.

The air refresh rate today is approximately 30 - 40 changes per hour when transporting frozen cargo and approximately 60 - 80 changes per hour when transporting fruit [Dr. Yves Wild, 2014] The latest reefers have variable speed fans, whereby the speed is controlled by the temperature difference between the supply air and the returning air.

The container should only be pre-frozen before loading so that the temperature outside the opened doors is approximately the same as the temperature inside the container. When the doors of a pre-frozen container are opened, water will condense on the walls, which may cause water damage to the cargo.
2.2 Refrigerating methods

Introduction

The most common freeze methods are: dry ice, freezing by nitrogen, peltier effect, magnetic freezing. There is also new technology by freezing with sound waves. All these methods can be compared to each other by the advantages and disadvantages of the different methods. For comparison a matrix is used. In the matrix characteristics are described for each freezing method together with advantages, disadvantages and applications.

The characteristics are:
- The efficiency qualities are based on the efficiency of freezing compared to the conventional system electricity usage, the capacity to freeze a certain space and the freezing temperature working range of the system.
- Low maintenance qualities are about fewer moving parts and the ease of maintenance of the system. The system needs to reduce the men-hours used to maintain. The frequency of inspecting the freezing system.
- Compact is the amount of area that the system is using related to the efficiency of the freezing system.
- Installation is the complexity of the freezing system. In general this means the system is difficult to install on board or on shore.
- Environmental friendly is based on consumption of energy and how much emissions the freezing system discharge. The higher the efficiency the more eco-friendly the system is. Is the freezing system harmful for the surroundings.
- Not hazardous means how unsafe the freezing method is for the human.

To answer the second sub question “Which refrigerating methods are available to freeze the containers on shore?” a quantitative and qualitative, desk- and field-research is required. Through problem analysis. By brainstorming about the different possibilities of freezing. Advantages and disadvantages of freezing systems.

2.2.1 Dry Ice

Dry Ice is frozen carbon dioxide, which is a natural part of our earth’s atmosphere. This is the gas that human exhale during breathing. Because of its very cold temperature of -78,5°C, dry ice is especially useful for freezing and keeping things frozen. Dry ice changes directly from a solid to a gas, this is sublimation, in normal atmospheric conditions without passing through the liquid stage. Therefore it gets the name ‘dry ice’ (Merrit, 2012).

To use dry ice as a coolant in a freezer container, different ways are possible with dry ice. The two most efficient methods of freezing the cargo in the container with dry ice is:
A double container wall full of dry ice can maintain the temperature in the container cold. The dry ice can also be added into the container combined with the cargo. It will be three times more energy efficient then water ice (H2O). Often it is combined with regular ice to save the weight of shipping and extend the cooling energy of water ice.

Advantages of dry ice:
According to Lindegroup, a company specialized in dry ice (The Linde Group, 2010).
- Odourless
- No residue
- Free of
- germs and bacteria
- Non-toxic
- Non-flammable
- Three times as cold as water ice
- Easy to handle

Disadvantages of dry ice:
- By a temperature higher than -78°C, dry ice will sublimate*.
- The amount of carbon dioxide will rise when the ice is sublimated. This is dangerous in enclosed areas.
- When dry ice sublimes, the pressure in the atmosphere will rise. Because of the air expansion the container can explode.
- Hard to store the dry ice without sublimating.

*sublimation, the transition of a substance directly from solid to gas without passing the liquid phase.

Applications of dry ice:
- Most common use is to preserve food.
- Is used by industrial purpose like shrink-proof connecting.

### 2.2.2 Liquid Nitrogen

At an extremely low temperature nitrogen turns into a liquid form, therefore liquid nitrogen. It is made by fractional distillation of liquefied air. Liquid nitrogen is a colourless liquid and it boils at -196°C. With this temperature the liquid nitrogen can freeze objects very fast. Liquid nitrogen can be stored and transported in vacuum tanks and stays good for several weeks. The liquid nitrogen is very compact and it is possible to reach very low temperatures. Therefore it is a useful freezing system.

The system works with cryophorus. This is a glass container with liquid water and water vapour (William Hyde, 1813). With this set-up, you can freeze something really fast by evaporation. A cryophorus system is made of two bulbs at each end attached to a tube of the same material (see figure 2). When liquid water is operated in the bulb and the other end is flooded into a freezing mixture (the liquid nitrogen), the pressure of the water gas will drop down during the cooling. The water will evaporate, so there will be more water vapour. With this water vapour, it is possible to cool objects really fast. Liquid nitrogen has a lot of advantages for freezing, but the disadvantages are greater. When the cargo will come into contact with liquid nitrogen, the cargo will be damaged and it will be unusable. So liquid nitrogen is not a satisfactory freezing method (Morgan, 2012).

Advantages of liquid nitrogen as freezing method:
- Non-flammable
- Liquid nitrogen is not expensive
- It is inert
- Freezing can be done very fast
- With 28 grams of liquid nitrogen it is possible to replace 22.4 litres of air
- The standard earth atmosphere contains 78% of nitrogen

Disadvantages of liquid nitrogen as freezing method:
- It is difficult to control the temperature precisely
- The cargo will be lost if there is direct contact with the liquid nitrogen
- Because of the low temperature the liquid nitrogen can cause cold burns

Applications of liquid nitrogen:
- Medical applications as cryonic preservation.
- Cooling device such as high temperature superconductor to achieve superconductivity.
- Culinary use in food preparation.
2.2.3 Peltier Effect

Sending electric current through two metals causes the Peltier effect. These two metals have a transition with each other. The movement of the current from the first metal to the second metal gives the effect of providing heat on one side. This is done by using different metals with different electron densities, N-type and P-type (see figure 3). The other side of the two metals will cool and absorb heat from for example, water. The water will be kept cool this way. The warm side of the semiconductor needs to be ventilated to remove the heat. Table 1 will show the result of a test with the Peltier effect.

The results from table 1:
250 ml water is cooled with the Peltier effect (Peltier plate: 4 cm by 4 cm (see figure 4). It takes one hour to cool the water 3.5 degrees Celsius according to Rimstar an investigation group (Rimstar Peltier Modules Thermoelectric investigator, 2011).

<table>
<thead>
<tr>
<th>Time</th>
<th>Temperature Celsius</th>
<th>Temperature Fahrenheit</th>
<th>Voltage</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>3:55pm</td>
<td>18C</td>
<td>64.4F</td>
<td>13.1V</td>
<td>3.8A</td>
</tr>
<tr>
<td>4:56pm</td>
<td>14.5C</td>
<td>58.1F</td>
<td>12.8V</td>
<td>3.66A</td>
</tr>
</tbody>
</table>

**Advantage of the Peltier effect:**
- There are no moving parts in the system, a part of the ventilation.

**Disadvantage of the Peltier effect:**
- The efficiency is only 5%.
- Cannot freeze big volumes.

**Applications of the Peltier effect:**
- Cooling electronic components and small instruments.
- Small portable cooler used for camping.
2.2.4 Magnetic freezing

Magnetic refrigeration is a freezing system that works by means of magneto caloric effect (BASF The Chemical Company, 2012). It can be used to reach very low temperatures. The magneto caloric effect is a magneto-thermodynamic phenomenon in which a change in temperature of a suitable material (gadolinium or other alloys) is caused by change in the magnetic fields. When Gadolinium’s alloys will enter magnetic fields, the temperature will rise. When it leaves the magnetic field, the temperature drops. When the material comes in a magnetic field the spin moments will become align parallel with the magnetic field lines and will heat up the isolated material of gadolinium alloys (see figure 5). When the material will be moved out of the magnetic field, the spin moments will lose their arranged order according to the movie from the U.S department of energy (U.S. Department of Energy, 2011). To perform their reorientation they absorb thermal energy that will cause a temperature drop and eventually low temperature. The efficiency of magnetic refrigeration can be as much as 50% greater than conventional refrigerator system (BASF The Chemical Company, 2013).

Description of the magnetic refrigerating (see figure 6).
1. Adiabatic magnetization: First a caloric magnetic material needs to be insulated in a box. The increasing external magnetic field (+H) causes the magnetic dipoles of the atoms to become align parallel to the magnetic field lines, thereby will the heat capacity increase $T + \Delta T_{ad}$ (Hari Krishan, 2010).

2. Isomagnetic enthalpy transfer: This added heat can be removed (-Q) by a fluid or a gas. The magnetic field is held constant to prevent the dipoles from reabsorbing the heat. Once sufficiently cooled, the magnetic fields will be removed, this will cause that the spin moments lose their arranged order (Mark W., 2012).

Advantages of magnetic freezing:
- The efficiency: 50% higher than conventional refrigerating systems. According to Hari Krishnan (Hari Krishan, 2010)
- Energy efficient usage.
- Compactness of the system.
- Reliability, due to the absence of gas the emission will be very low.
- Key factor for different types of technologies.
- Environmental friendly refrigerant.

Disadvantages of magnetic freezing:
- Expensive to build the system because of the gadolinium.

Applications of magnetic freezing:
- Replace larger vapour-compressor refrigeration.
- Future uses are for refrigeration in spacecraft.
2.2.5 Sound wave freezing

Nowadays it is almost impossible to imagine a life without refrigeration systems. Currently, cooling is primarily achieved with vapour compression systems that use a specific refrigerant to maintain the required temperature level. Even though the vapour compression system is effectively used, engineers are constantly trying to find better alternatives.

This refrigeration system is based on the principle of conversion of sound energy into thermal energy with the help of an acoustic driver system and a stack enclosed by a resonator tube, see the figure below. This system is eco-friendly since it works in an air medium (or any noble gas) and does not require any refrigerants.

The principle of the sound wave freezing system, the main components are: high frequency speakers, gas, tube, stack and heat exchangers (see figure 7). The most important part of a thermo acoustic device is the thermo acoustic stack. The stack consists of a large number of closely spaced surfaces that are aligned parallel to the resonator tube (see figure 8). The purpose of the stack is to provide a medium for heat transfer as the sound wave oscillates through the resonator tube. The standing sound wave is produced in a resonating tube. Both ends of the stack are connected to heat exchangers. Coupling the stack to a heat source or heat sink, the transfer of heat will be more efficient (Sushant Patil, 2013).

The principle of the thermo acoustic refrigerator is a freezing device that uses acoustic power to pump heat from a section of low temperature to a section of ambient temperature. Sound is a pressure wave that transfers kinetic energy from one air molecule to the next using compression and expansion of the medium. When something is compressed it gets hot, and when it expands it will cool again (Saravanan G., 2011).

The stack contains gas parcels and then the standing wave carries the parcel left and right. Temperature changes are due to gas oscillations in the stack. The left parcel rejects heat to the stack and the right parcel absorbs heat from the stack.

Advantages of sound wave freezing:
- No moving parts and therefore mechanically simple.
- Environmentally friendly refrigerants.
- Use of simple materials, low costs.
- Saves energy.
- Large range of working temperatures.
- No sliding seals or lubrication.

Disadvantages of sound wave freezing:
- Works for small containers.
- Still in project face.

Applications for sound wave freezing:
- Still being research, only one prototype.
- Can replace vapour-compressor refrigeration.
2.2.6 Matrix freezing systems

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Effeciency</th>
<th>Low Maintenance</th>
<th>Size</th>
<th>Installation</th>
<th>Environmental friendly</th>
<th>Not hazardous</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic cooling</td>
<td>++</td>
<td>+</td>
<td>+/-</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>8+</td>
</tr>
<tr>
<td>Sound wave cooling</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
<td>++</td>
<td>++</td>
<td>7+</td>
</tr>
<tr>
<td>Peltier cooling</td>
<td>--</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+/-</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Liquid Nitrogen</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>1+</td>
</tr>
<tr>
<td>Dry ice</td>
<td>+/-</td>
<td>-</td>
<td>--</td>
<td>+</td>
<td>--</td>
<td>--</td>
<td>7-</td>
</tr>
</tbody>
</table>

++ = Very good  
+ = Good  
+/− = Average  
− = Poor  
-- = Very poor

**Magnetic freezing**

- **Efficiency:** Two plusses, very high efficiency, the efficiency is 50% greater than the conventional refrigerator system according to Hari Krishnan\(^\text{14}\).
- **Low maintenance:** One plus, there are no parts that consume, only electricity has to be added to create the magnetic field.
- **Size:** Plus/minus, magnetic freezing is smaller than compressor freezing systems. Magnetic freezing can be supported in smaller and larger freezing systems.
- **Installation:** One plus, it is easy to connect this system to the old system (Conair) of the freezer containers. Instead of the conventional compressor, the magnet system can be used.
- **Environment friendly:** Two plusses, the efficiency of this freezing system is prohibitive, what makes it an eco-friendly system. And there is no pollutant refrigerant.
- **Not hazardous:** Two plusses, no moving parts in the environment and the magnetic field lines are not dangerous.

**Sound wave freezing**

- **Efficiency:** One plus, large range of working temperatures and low energy consumption.
- **Low maintenance:** One plus, no moving parts and no lubrication.
- **Size:** One plus, compact because the system can be made with three sonic speakers.
- **Installation:** Plus/minus, easy to install but the system needs special frequencies with special amplifiers.
- **Environment friendly:** Two plusses, no harmful refrigerants.
- **Not hazardous:** Two plusses, not dangerous because the sound is not hazardous and there are no moving parts.

**Peltier effect**

- **Efficiency:** Two minuses, efficiency is only 5%.
- **Low maintenance:** One plus, no moving parts, simple construction.
- **Size:** One minus, because of the low efficiency the peltier plate is not compact to freeze a big area, such as a container.
- **Installation:** One plus, very simple system. Main parts: electric wires and peltier plates.
- **Environment friendly:** Plus/minus, the freezing effect has no emissions to the environment. Besides of that, it is a low-energy usage system what makes it an eco-friendly one. On the other hand, the peltier system has a low efficiency.
- **Not hazardous:** One plus, potential high current shock.
Liquid nitrogen

Efficiency: One plus, very good freezing method but with direct contact with the cargo it will damage it.

Low maintenance: One plus, no moving parts. The system only has to be refilled with nitrogen.

Size: One minus, it is not compact because there is a need of water and nitrogen. These liquids need to be stored in large tanks.

Installation: One minus, the system will not work because liquid nitrogen boils at -196°C and the pipelines need to resist high pressures. Besides of that the system needs special mechanic parts to undergo the extreme freezing temperatures.

Environmental friendly: One plus, if nitrogen escapes the freezing system will not be hazardous to the environment.

Not hazardous: One minus, because of the extreme freezing temperatures the skin can be burned when it touches the mechanical parts of the system.

Dry ice

Efficiency: Plus/minus, it is a good freezing method but not that efficient to apply as a freezing system.

Low maintenance: One minus, dry ice sublimes at -78°C and need to be refilled after evaporation.

Size: Two minuses, because of the sublimation at room temperature, the dry ice need to be refilled. To freeze there is plenty of ice needed.

Installation: One plus, easy concept.

Environmental friendly: Two minuses, CO₂ is used to make dry ice.

Not hazardous: Two minuses, because of the extreme freezing temperatures it will create cold burns with the skin when you touch it.

Table 2 is the matrix of different freezing systems. After counting the positive and negative aspects, the magnetic freezing system is selected as the best freezing method.
2.3 Optimize the energy usage to supply the freezing system on shore.

Introduction

Energy is concerned with the deployment of advanced, clean, and sustainable energy sources and technologies. In order to optimize the energy usage for supplying the magnetic freezing system, there needs to be an eco-friendly system. For the topic of this project will use the port of Rotterdam as example only energy out of water will be used. The best way to do this is by tidal energy or osmotic power.

All the investigated energy sources can be compared to each other by the advantages and disadvantages of the different methods. For comparison a matrix is used. In the matrix characteristics are described by each energy source.

The characteristics of the energy sources are:
- The efficiency qualities are based on the efficiency of energy supply compared to the conventional energy suppliers.
- Low maintenance qualities are about fewer moving parts and the ease of maintenance of the system. The system needs to reduce the men-hours used to maintain. The frequency of inspecting the energy supplies.
- Compact is the amount of area that the system is using.
- Installation is the complexity of the energy supply system. In general this means the system is difficult to install.
- Environmental friendly is based on the eco-friendly compared to the current energy supply systems that used fossil fuels and the side effects that can harm the environment.
- Not hazardous means how unsafe the energy supply method is for a human. (all systems work with high voltage. So high voltage is not counting on the matrix)

To answer the third sub question “How can we optimize the energy usage to supply the freezing system on shore?” a quantitative and desk and field-research is needed. Through models, literatures and interviews. Brainstorm with the possibilities of different energy systems. Interview an expert.

2.3.1 Tidal-energy conversion

Tidal energy is part of the largest untapped sources of renewable energy in the world (BlueWater Company, 2013). Tidal cycles, which are mainly driven by the phases of the moon, are highly predictable and reliable. This means that it is always known beforehand how much electricity a tidal device will produce. Taking advantages of the tidal movements of the oceans and converting it into electricity which is more constant. Water will rotate the blades of a submerged turbine, which drives a generator that generates electricity. The electricity will be exported to the shore by means of a power cable. Tidal energy is a proven technology and will be
evolved during the years according to predictions from the blue water concept (BlueWater New Energy team, 2013). The bluewater farm project is made nearby the coast of Orkney, United Kingdom.

Advantages of the bluewater developments:
- Easy access, inspection and maintenance.
- Watertight deckhouse to safely accommodate vulnerable electrical equipment.
- Dry power cable connection.
- Suitable for horizontal and vertical axis turbines.
- Independent of water depth.
- Low weight eases 1 of installation.
- It will also do so when the wind is not blowing and the sun is not shining.

Disadvantages of the bluewater developments:
- Strength of tidal streams depends on position of the moon what is proportional to the energy supply.
- High costs of building the system.

Application of the bluewater development:
- Nearby the coast of Orkney, United Kingdom.

2.3.2 Ocean Mill

The Ocean mill C-energy project (Ocean Mill, 2010) was developed after 14 years of extensive research and offshore tests. The full-scale prototype as deployed in the C-Energy project has successfully proven that the Wave Rotor technology works. The results from the full-scale prototype project have confirmed that the theoretical analysis matches the full scale of site results. The performance is demonstrated, the analysis models are validated and the design tools are verified & calibrated.

Their next step is a full-scale commercial demonstration. The 1,5 MW demonstration plant, that is mounted on the Dutch storm surge barrier of the Oosterschelde.

Ocean Mill and its group partners have started with the project to install a facility for 1,5 MW of clean tidal energy power, in one of the openings of the Dutch Oosterschelde Storm Surge. The planned installation window was around the end of Q3 - 2012. The project will run for 15 years and will produce enough electricity to feed more than 1,000 homes of clean tidal power.

Their key objectives are to prove long-term durability (>10 years). Demonstration of production performance and efficiency, eliminates technical risk for projects using the Wave Rotor. Out of the C-energy project result came the following: installed capacity 1,500 kWp (3 rotors 500kWp each) and tidal streams up to 5,5 m/s. If the project would be realized on a bigger scale it could power the freezing system on shore (Ocean Mill, 2010).

The Ocean mill is divided in four main parts (see figure 10):
1. 3 Wave Rotors
2. Power Take Off modules
3. Support structure
4. Controls and E&I infrastructure

Advantages of the ocean mill:
- Environment friendly.
- Both tidal flows and waves drive the rotor.
- Relatively low rotational speed poses no threat for sea live.
- Long term durability.

Disadvantage of the ocean mill:
- Hoisting system to compensate tidal variation.
- Project state.

Application of the ocean mill:
- Mounted on the Dutch storm surge barrier of the Oosterschelde.
2.3.3 Osmotic power

Osmosis represents the difference between two water masses (freshwater and saltwater). This system can be used where river water flows into the sea. It separates fresh and salt water with a semipermeable membrane. This membrane can separate the fresh water and the solute substances, like salt. During this separation, freshwater flows to the saltwater, on the saltwater side the pressure increased. This pressure can be used as energy source. As example: the pressure at a temperature of 10°C and a difference of salt concentration of 3.5%, the theoretical pressure will be 28 bars. This technique is called “PRO” or “Pressure Retarded Osmosis”. The pressure that is formed during the separation can be used to drive a turbine who will generate electricity. The only waste product will be brackish water according to information about the osmotic power according to Brauns, .E (see figure 12).

Advantages of osmotic power:
- There will always be freshwater and saltwater.
- The only wasted product is brackish water.
- The osmotic installation can be placed near to the harbour, to prevent of using too much cable length.

Disadvantages of osmotic power:
- The membrane must be cleaned or replaced.
- The dumped waste products in the water can be a problem for the filters and membrane.
- Engineering and design problems.

Application of osmotic power:
- Osmotic power prototype at Tofte Hurum, Norway.

2.3.4 Matrix water energy

<table>
<thead>
<tr>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

Figure 12 Osmotic power system
<table>
<thead>
<tr>
<th></th>
<th>Efficiency</th>
<th>Low Maintenance</th>
<th>Size</th>
<th>Installation</th>
<th>Environment friendly</th>
<th>Not hazardous</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal energy conversion</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
<td>1</td>
</tr>
<tr>
<td>Ocean mill</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>7</td>
</tr>
<tr>
<td>Osmotic power</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
<td>4</td>
</tr>
</tbody>
</table>

+++ = Very good
+/- = Average
+ = Good
-- = Very poor

Tidal energy conversion
- Efficiency: One plus, because it will only work by tidal streams depends on position of the moon.
- Low maintenance: One plus, The low maintenance is because of the few parts, the gasket must be inspected regularly.
- Size: Two minuses, because the installation is not compact, the blades have a diameter of several meters.
- Installation: One plus, easy installation because the energy conversion is made on shore. And the whole installation is minimal weight.
- Environment friendly: One plus, because the tidal streams are used to provide energy, there is no emission, but after a leak it is possible that lubrication oil can be spilled into water.
- Not hazardous: Plus/minus, because the entire installation is hazardous for the marine navigation.

Ocean mill
- Efficiency: One plus, the installation will run for more than 15 years and will produce enough energy for 1000 homes. So it will be not any problem to supply the energy for freezing containers. Another efficient point is that the rotor will be driven by tidal flows and waves.
- Low maintenance: One plus, the rotors must be cleaned from seaweed and the moving parts must be inspected.
- Size: One plus, the system consists of three wave rotors. These rotors are vertical installed so they will not use a lot of space.
- Installation: One plus, the ocean mill is made on shore and can be easy installed if the foundation is already placed.
- Environment friendly: One plus, because the tidal streams and waves are used to provide energy, there is no emission, but after a leak it is possible that lubrication oil can be spilled in to water.
- Not hazardous: One plus, the entire installation is hazardous for the marine navigation, but because it is more compacted as the tidal energy conversion one plus is given.

Osmotic power
- Efficiency: One plus, there will always be fresh- and saltwater to supply the system. For the theoretical efficiency, see the example in the text.
Low maintenance: One plus, the maintenance consists of cleaning the filters and membrane. The turbine needs regular maintenance.

Compact: One minus, the installation using fresh- and saltwater, so there must be two inlets for the fresh- and saltwater. To supply many freezing containers an enormous membrane is necessary.

Installation: Plus/minus, the installation of the system is not difficult. The only problem is the inlet for fresh- and saltwater. Inlet pipes must be drilled to a river and the sea.

Environment friendly: Two plusses, the osmotic power system used fresh- and saltwater and the only wasted product is brackish water. The brackish water can be pumped into the sea.

Not hazardous: One plus, the osmotic reaction is not hazardous because it is a natural reaction.

Based on the matrix shown above is the ocean mill system chosen as the best energy source to feed the magnetic freezing system on the freezer container.

### 2.3.5 Freezing system on shore

Some freezing containers will not be used constantly because there is no cargo available all the time. The containers will heat up and when the cargo is available, the container must be cooled down in a short period of time. With the freezing system it is possible to freeze several containers at the same time.

This system is based on the reefer system from 30 years ago. This system was known as Conair. A huge blower blew cold air into the reefer on shore and during the voyage. Pipelines were the link between the blower and the reefers.

The cold air from the magnetic freezing system is blown into the freezing containers. An automatic control system measures the temperature in the container and will open or close the valves, which are positioned in the pipelines. The cold air is blown into the bottom side of the container (see figure 13). The air will circulate and will heat up. Hot air will levitate, because hot air is lighter than cold air. The heated air will leave the container at the top. This air will be cooled again with magnetic cooling.

![Figure 13 Connection system for the freezer containers](image-url)
2.4 Preserving a constant temperature, so that it will not use energy from the vessel

Introduction

The last sub question is about keeping the freezing containers at a constant temperature during voyage. There are many solutions, but one of the criteria is that the freezing containers will not use any energy from the vessel. These criteria can be completed by insulation, so that the insulation will keep the containers’ temperature constant for a couple of weeks. To answer this sub question “In what way can the container temperature be constant, so that it will not use energy from the vessel?” a quantitative and qualitative desk- and field-research is required. Though literatures

2.4.1 Insulation

The relative performance of different insulation on any given application can be influenced by numerous factors. The principal factors to compare the different insulations are (G. Verkerk, 2004):

- Thermal conductivity ("λ" value)
- Insulation thickness
- Density

Mineral wool
Mineral wools are capable of operating at high temperatures and exhibit good fire performance ratings when tested. Mineral wools are used on all types of pipework, particularly industrial pipework operating at higher temperatures. The thermal conductivity of mineral wool is around 0.035 - 0.043 W/mK depending on the thickness of the material. The specific density of mineral wool is 15-21 Kg/m³.

Glass wool
Glass wool is a high-temperature fibrous insulation material, similar to mineral wool, where inorganic strands of glass fibre are bound together using a binder. As with other forms of mineral wool, glass-wool insulation can be used for thermal and acoustic applications. λ = 0.040 W/mK, specific density unknown.

Rigid foam
Pipe insulation made from rigid Phenolic, PIR, or PUR foam insulation is common in some countries. Rigid-foam insulation has minimal acoustic performance but can exhibit low thermal-conductivity values of 0.021 W/(m·K) or lower, allowing energy-saving legislation to be met whilst using reduced insulation thicknesses. λ PUR & PIR = 0.026-0.035 W/mK, specific density = 30 – 60 Kg/m³.

Cellular Glass
100% Glass manufactured primarily from sand, limestone & soda ash. λ PUR & PIR = 0.036-0.060 W/mK, specific density = 105-165 Kg/m³.
Silica aerogel

Silica Aerogel insulation has the lowest thermal conductivity of any insulation. Although no manufacturer currently manufactures Aerogel pipe sections, it is possible to wrap Aerogel blanket around pipework, allowing it to function as pipe insulation. The usage of Aerogel for pipe insulation is currently limited. Aerogel, also called frozen smoke, is an insulation that has a very high efficiency. Aerogel is made out of silica gel. This is the same product as they use for glass. The liquid is removed out of the silica gel and replaced with gas. The result is a molecular structure, which has incredible strength. It is very stiff but will break easily. Insulation works on the principle of stationary air, more (stationary) air gives better insulation. Aerogel has an extremely low density (0.01 gram/cm$^3$) so will provide very good insulation.

$\lambda = 0.013-0.03 \text{ W/mK}$, specific density $= 1.1 \text{ Kg/m}^3$

### 2.4.2 Matrix of insulation

<table>
<thead>
<tr>
<th>Insulation</th>
<th>Thermal conductivity (W/mK)</th>
<th>Density (Kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral wool</td>
<td>0.035 - 0.043</td>
<td>15–21</td>
</tr>
<tr>
<td>Glass wool</td>
<td>0.040</td>
<td>48 – 70</td>
</tr>
<tr>
<td>Rigid foam (PIR &amp; PUR)</td>
<td>0.026-0.035</td>
<td>30 – 60</td>
</tr>
<tr>
<td>Cellular glass</td>
<td>0.036-0.060</td>
<td>105-165</td>
</tr>
<tr>
<td>Silica aerogel</td>
<td>0.013-0.03</td>
<td>1.1</td>
</tr>
</tbody>
</table>

From the matrix above aerogel comes out as the better insulation. It has a thermal conductivity of 0.013 W/mK and a density of 1.1 Kg/m$^3$. This means Silica aerogel is ultra-lightweight with the best insulation capacity.

For preserving a constant temperature during a certain time, insulation can help to maintain it. Only in theory will the temperature be constant for eternity. In the practical world, the greater the temperature difference from the inside and outside the more heat energy will enter the closed insulated container. According to the interviews (see appendix) with Mr. Ludo Claes from company KRAUTZ and Mr. R. Stoltz from company TRIP-CO, it is not possible to get a good result with only insulation.

To compensate for the energy lost or in other words the heat energy that enters the container. There is a need of a freezing system on board or on the container. The problem with the freezing system is the consumption of electrical energy, but the criteria are to use no energy from the vessel.

To answer the question, in what way can the containers’ temperature be constant, without using energy from the vessel. The freezer container needs insulation. This will help to keep external heat energy outside the freezer container. The insulation that is used is named aerogel, this works on the principle of stationary air. More (stationary) air gives a better insulation. Aerogel has an extremely low density (0.01 gram/cm$^3$) this means it is very lightweight. The thermal conductivity from aerogel is 0.013 W/mK. With the conductivity of the aerogel, it is possible to calculate the heat flow and the energy losses. Appropriate calculations about the aerogel can be found in the appendix. (Energy loss of aerogel)

### 2.4.3 Energy production by solar paint on board the mv Alabama

After the calculation of energy lost by the aerogel, it is necessary to compensate for the lost energy. This can be achieved by a freezing system that is placed into the freezing container. This freezing system will be the magnetic freezing system. Before the magnetic freezer unit is mounted on the container, there is energy required to power this system. The solution is an electrical grid made by the freezer containers itself. This will be done by solar energy. A new breakthrough is made in solar paint technology. This means no more solar cells, but paint that can be applied on the outside of the freezer container. If all freezing containers on board are painted with this latest technology the cargo can generate enough energy to supply the magnetic freezing system for each container.
After the calculating of the total production of energy that is generated by all the freezer containers itself, the energy usage of the freezer unit will be compared. This will show how much energy the system requires and how much energy is produced by the solar paint on the containers.

Solar paint
Quantum dots (titanium dioxide particles) to be coated with cadmium sulfide to create an generated electric power: quantum dots have a band gap that can be bridged by photons from sunlight, after which energy released when the quantum dot falls back to its ground state. If the quantum dots are dissolved in a mixture of water and alcohol, it creates a kind of paint. The efficiency of the solar paint has now reached 10% (Independent, 2011)(Futuras, 2011). For exact calculation of how much energy is produced by the solar paint see appendix. (Energy provided by solar paint)

Motor vessel of Maersk Alabama has a capacity of 1068 TEU. For the design of the solar paint system, the calculation will be based on perfect sun and weather conditions. The solar paint will be applied on 40 feet containers, in rows of eight containers, in bays of eight containers and in tiers of four containers. Only the outside standing containers surface area will be included in the calculation for the total generated power on board. Total area 40 feet container is 105.54 m² (bottom not included). During the voyage, the Maersk Alabama will only shipping 1068 freezing containers. For calculation about how much energy is produced by the solar paint see on board the MV Maersk Alabama see appendix. (Energy generated by MV Alabama)

2.4.4 Energy usage by the magnetic freezer unit

Magnetic freezing takes advantage of the phenomenon that a magnetic working material generates heat when it is exposed to a magnetic field and drops in temperature when the magnetic field is removed (the magneto caloric effect). Compared to gas freezing, magnetic freezing has the following characteristics:
- It is expected to conserve energy by operating at close to the theoretical efficiency
- It is eco-friendly since it does not use CFCs or other fluorocarbon refrigerants
- It works quietly and with little vibration since it does not use a compressor

Characteristics of magnetic freezing

<table>
<thead>
<tr>
<th></th>
<th>Newly developed system</th>
<th>Old system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic field source</td>
<td>Neodymium permanent magnet</td>
<td>Neodymium permanent magnet</td>
</tr>
<tr>
<td>Strength of magnetic field</td>
<td>1.1 tesla</td>
<td>0.77 tesla</td>
</tr>
<tr>
<td>Magnetic working material</td>
<td>Gadolinium</td>
<td>Gadolinium alloy</td>
</tr>
<tr>
<td>Heat exchange medium</td>
<td>Water and alcohol</td>
<td>Water and alcohol</td>
</tr>
<tr>
<td>Operating cycle</td>
<td>2.4 seconds</td>
<td>2.4 seconds</td>
</tr>
<tr>
<td>freezing capacity</td>
<td>540 W</td>
<td>60 W</td>
</tr>
<tr>
<td>Coefficient of performance</td>
<td>1.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Main equipment dimensions</td>
<td>H410mm × W400mm × D390mm</td>
<td>H270mm × W270mm × D430mm</td>
</tr>
</tbody>
</table>

For example a heat pump cooler operating at COP freezing (coefficient of performance) 2.0 removes 2 units of heat for each unit of energy consumed. So to compensate for the energy in the freezer container, the magnet freezer unit needs to remove 137.8 Watt to keep a constant temperature.

The energy usage for every watt the magnetic freezing system will remove 1.8 watt of energy out of the container. If the system need to remove 137.8W to keep a constant temperature this means the system uses is:
The total loss of heat energy coming in the freezer container is 138 W, the generated energy of the solar paint for each container is 397 W. The magnetic freezing system has a freezing capacity of 540 W, this means the system can handle the waste energy of 138 W. The energy usage of the freezer unit is 77 W to remove the waste energy. Conclusion is that there is enough generated energy from the solar paint for the magnetic freezer unit to remove the heat energy from the freezer container.

\[
76.5 \, W = \frac{1 \times 137.8}{1.8}
\]

2.4.5 Network system on board

Only the containers on deck, which will get sunlight, will produce energy by the solar paint. The containers in the hold and on deck, out of the sunlight, will not produce energy from the solar paint. It is important that the containers, which produce energy, are connected with the containers that will not produce energy, so the energy can be divided to the other containers.

The solution to this problem was examined in a brainstorm session. After the session, there is a cable network on the tank top and on the hatches needed on board. While the containers are loaded in the hold and on the hatches, the container will be lined with the network system. The links need to be based on the bottom and the top of the containers, so the containers are also connected to each other. The advantage of this system is that the containers are linked in the system automatically while the container is loaded. No crew is needed to connect it on board.
3. Conclusion

How can frozen cargo be transported with a constant temperature without energy usage from the vessel by freezing on shore? Answering the main question will draw up the conclusion. The main question is answered by the sub conclusion from the sub questions.

The results from sub question how reefer work nowadays is that the system is not efficient enough. With modern technology, this can be improved easily. The reefers are consuming a lot of man-hours just to maintain and connect the reefers on board.

Currently there are plenty of different freezing systems. The conclusion from the second sub question is that magnetic freezing is the best ways to freeze the containers. This is because the efficiency is 50% higher than conventional freezing systems. The easy maintained of the system helps the crew to reduce man-hours on the freezer container. The magnetic freezer unit is compact so it can be used in the container itself. The system is environment friendly and will reduce emissions.

The onshore freezing system will only work if it has a power supply. From the research of the third sub question, the Ocean mill project comes out as the supply for the magnetic freezing system on shore. This project is installed in the Dutch storm surge barrier of the Oosterschelde, nearby the port of Rotterdam. This environment friendly energy producer is an efficient on tidal streams. The system of vertical rotors is easy to maintain, compact and not hazardous for the environment. The onshore freezing system is easy to adapt on already existing systems.

After field research for the fourth sub question, the conclusion is that only insulation in the freezer container will not maintain a constant temperature for a couple of weeks. Therefore more research was required to answer how to preserve a constant temperature, that it will not use energy from the vessel. To supply the magnetic system on the freezing container solar paint will be applied. This paint works like normal solar panels with an efficiency of 10%. To connect all containers an electrical grid is necessary, so the inner containers with no solar energy production also can function. The total amount of electrical energy generated by the 538 freezer containers is $212 \, kW$ and the amount of energy for each freezer container is $397 \, W$. The heat energy that enters the container is $138 \, W$ and the magnetic freezing unit can remove $540 \, W$ of heat. The unit needs a total of $77 \, W$ of energy to remove the entering heat energy in the container.

The conclusion is that it is possible to transport cargo at a constant temperature, without energy usage from the vessel by freezing on shore, by freezer containers that are frozen onshore and on board of the vessel which produces their own energy from solar paint for the magnetic freezing unit.
Recommendations

Before this project will become reality, there is need for further research. For further research we will look to our borders again.

- Costs. During the project we did not take into account the costs. To realize any project, the costs need a lot of attention to make a profitable product. For this realization, costs of the magnetic freezing system, aerogel and the solar paint can be investigated. This can be achieved by companies who are involved by these products.

- Temperature control by reefers for heating and cooling. During the voyage, the temperature of the freezing containers can be increased by a failure of the magnetic freezing system or a leak in the insulation. There must be a failure system like a network system that can be implemented in a PC on the bridge or the control room. When the temperature of the freezing container will rise, an alarm is required. This network system can be investigated and made by a company who is specialized in automation.

- Energy storage on board. In the last sub question we calculated the loss of heat, the energy that is needed for the magnetic freezing system in the freezing container and the energy that the solar paint produce. There is a discrepancy between the energy loss and the energy that will be produced by the solar paint. The excess energy can be stored in batteries.
Appendix

Calculations

Energy loss of aerogel:
Lambda is the thermal conductivity of a material, it tells how good the material conducts heat. If the lambda is small the material will conducts heat badly. If the material conducts no heat across the material this means it insulate.

Lambda (λ) is in W/mK
The thermal conductivity from aerogel is 0,013 W/mK

The thermal conductivity can be converted into thermal resistance (Rm).
The equation is:

\[ R_m = \frac{tickness}{\lambda} \]

Thickness = insulation material aerogel is 100 mm → 0.1m.
Lambda = aerogel is 0.013 W/mK

\[ R_m = \frac{0.1}{0.013} \]

\[ R_m = 7.69 \ m^2 K/W \]

The transition resistance Rsi and Rse
Rsi is transition resistance from the material to air on the inside of the container (Coldest side)
Rse is transition resistance form the material to air on the outside of the container (Hottest side)
Rc is the thermal resistance of a flat construction.

Alfa (α) is a correction, 0.05

Rsi and Rse are standards:
Rsi = 0.13 m²K/W
Rse = 0.13 m²K/W
Alfa (α) = 0.05

\[
Rc = \frac{Rm + Rsi + Rse}{(1 + \alpha)}(Rsi - Rse)
\]

\[
Rc = \frac{7.69 + 0.13 + 0.13}{(1 + 0.05)}0.13 - 0.13
\]

\[Rc = 7.31 \text{ m}^2\text{K}/\text{W}\]

Total resistance
Rtot is the total resistance between the air of both sides.

\[Rtot = Rc + Rse + Rsi\]

\[Rtot = 7.31 + 0.13 + 0.13\]

\[Rtot = 7.57 \text{ m}^2\text{K}/\text{W}\]

Heat transmission coefficient U (W/m²K)

\[U = \frac{1}{Rtot}\]

\[U = \frac{1}{7.57}\]

\[U = 0.13 \text{ W/m}^2\text{K}\]

Qw is the heat flow through the container.

U is heat transmission coefficient.

A is the surface area of 40 feet container.

T is the temperature difference between inside and outside.

- Inside -20°C
- Outside 30°C

\[Qw = U \times A \times \Delta T\]

\[A = 12.192 \times 438 \times 2.591\]

\[A = 135.26 \text{ m}^2\]

\[Qw = 0.13 \times 135.26 \times 50\]

\[Qw = 879.19 \text{ W}\]

Energy loss

E is given in Joule (J)

U is heat transmission coefficient.

A is the surface area of 40 feet container.

GG are the ‘degree days’. The average of the Netherlands are taken: 2860

\[t \text{ is the time between freezing periods, 24 hours.}\]
\[ E = U \times A \times GG \times t \]

\[ E = 0.13 \times 135.26 \times 2860 \times 86400 \]

\[ E = 4345.03 \text{ MJ} \]

\[ E = \frac{4345.03 \times 10^6}{(365.25 \times 24 \times 3600)} \]

\[ E = 137.8 \text{ J/s} \]

**Energy provided by solar paint**

Solar panel = 250 Wp = 250 kWh / year (20% efficiency)

Solair paint = 125 Wp = 125 kWh / year (10% efficiency)

Area solar panel = 1.6269 m

\[ \text{solair paint} = \frac{125}{1.6269} \]

Solar paint = 76.83 kWh / year

Sun hours Rotterdam = 1459 hours

Solar paint = 76.83 kWh / year

\[ \text{Watt} = \frac{76.83 \text{ kWh}}{1459 \text{ hours}} \]

watt = 54 W (per m\(^2\))

**Energy generated by MV Alabama**

Dimension cargo hold MV Alabama

- Length 12.192m
- Width 2.438m
- Height 2.591m

Starboard and port sides

\[ \text{total ST PS sides area} = ((\text{length} \times \text{height}) \times (\text{rows} \times \text{tiers})) \times 2 \]

\[ \text{total ST PS sides area} = ((12.192 \times 2.591) \times (8 \times 4)) \times 2 \]

\[ \text{total ST PS side area} = 2021.7262 \]

**Topside**

\[ \text{total top area} = (\text{length} \times \text{width}) \times (\text{rows} \times \text{bays}) \]

\[ \text{total top area} = (12.192 \times 2.438) \times (8 \times 8) \text{total top area} = 1902.3421 \]

**Front side**

\[ \text{total front area} = (\text{width} \times \text{height}) \times (\text{tiers} \times \text{bays}) \]

\[ \text{total front area} = (2.438 \times 2.591) \times (3 \times 8) \]

\[ \text{total front area} = 151.6046 \]

This gives a total outside surface area of 4075.6790 m\(^2\). The sun cannot give full potential energy to all of the calculated surface area therefore only the biggest areas will be used. These are the top area with the starboard and portside areas with a total of 3924.0683 m\(^2\).
\[ \text{total generated waatpeak} = \text{total area} \times \text{watt} \]

\[ \text{total generated waatpeak} = 3924.0683 \times 54 \]

\[ \text{total generated waatpeak} = 211.8997 \text{ kW} \]

\[ \text{total 40 feet container} = \frac{1064 \text{TEU}}{2 \text{TEU}} \]

\[ \text{total 40 feet container} = 534 \text{ containers} \]

\[ \text{power for each container} = \frac{211899.6882 \text{ W}}{534} \]

\[ \text{power for each container} = 396.82 \text{ W} \]

Obtainable power for each container on board is 396.82 Watt peak.

**Interviews**

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Covers & Blankets - plastics sheeting & stretch - restrain products/ tiedown straps - Hardware - special product

**Vragen betreft isolatiemogelijkheden:**

**Wat zijn de meest gebruikte isolatie technieken voor vriezen ?**

Als het om actieve en passieve isolatie gaat geldt voor passieve isolatie dat aluminium noppenfolie het meest gemakkelijk is om mee te werken. Uiteraard zijn Dry-ice en koelelementen uit de vriezer perfecte koelmethodes alleen is dit niet altijd direct beschikbaar op de locatie. Actieve Isolatie zijn de koelcontainers die er in alle vormen en maten zijn.

**Wat zijn de verschillen in isolatie materialen voor vries- en warmte technieken.**

Voor zowel Warmte als vries
Voor beide geldt dat er geen verschil is. Isolatie houd zowel warmte als kou tegen wanneer men passieve isolatie materialen gebruikt. Uiteraard bij actieve isolatie geldt wel dat er andere technieken worden toegepast.

Is het mogelijk om met isolatie energie te behouden zonder energie verlies? Zo ja, hoe?

Ook dit is afhankelijk van externe factoren en tijdslijn. Wij zien aan de hand van test resultaten die wij ontvangen van klanten dat het verlies van energie zeer beperkt blijft wanneer met Thermo hoozen gebruikt. De eerste 12 uur zijn redelijk cruciaal. Het is daarom van belang wanneer er vriesproducten worden verstuurd dat deze in de koelruimte te bedekken met isolatie om de energie te behouden. Wanneer dit gebeurd buiten de koelruimte zal er een warmere luchtspuw aanwezig zijn ten opzichte van de goederen die gekoeld moeten blijven, hierdoor zal het energie verlies snel stijgen.

Heeft u enige ervaring met actieve isolatie? Zo ja, heeft u hier informatie over?


Dit is wat er wordt gebruikt wanneer met bv Pharma verstuurd en temperatuur gecontroleerd moet zijn bijvoorbeeld +2 - +6 graden. Dan is Passieve isolatie niet betrouwbaar genoeg. Deze containers worden door bijvoorbeeld Envirotainer geleverd.

Dit is de grootste leverancier in de luchtvaart voor actieve isolatie.

Wat zijn de laatste innovaties betreft isolatie technieken?

Wat betreft Passieve isolatie kan ik zeggen dat buiten multilayer isolatie en cool-boxes met ingebouwde zones (zie bijlage) dit op dit moment de nieuwere innovatie is. Er worden multiple layer producten op de markt gebracht van nieuw materiaal wat beter goedkoper en schoner moet zijn. Op het gebied van Actieve isolatie gebeurd er een hoop maar daar kan ik helaas niet veel over zeggen omdat het niet mijn gebied is.

Geloof u dat een 20 ft vriescontainer voor een langere periode (+/- 2 weken) een constante temperatuur kan aanhouden van ongeveer – 20 graden Celsius door middel van isolatie? Waarom wel, niet?

Een vriescontainer zegt het al, ja deze kan een constante temperatuur aanhouden van -20 graden, tenzij het buiten warmer is dan +25. Misschien begrijp ik de vraag verkeerd en bedoelen jullie een standaard 20ft container alleen met Isolatie?

Dan kan ik kort en bondig over zijn, nee met passieve isolatie niet. Uiteraard met een kanttekening; afhankelijk van de buiten temperatuur wanneer deze ook -20 is, maar -20 met passieve isolatie +/- 2 weken wordt een lastig verhaal.

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Geachte heer van Doorn,

Beste Niels,

Dank voor uw mail.
Helaas moet ik u meedelen dat het vrijwel onmogelijk is om met behulp van enkel en alleen isolatie, gedurende +/-2 weken een temperatuur van -20°C aan te houden in een zeecontainer dewelke blootgesteld staat aan warme weersomstandigheden. Elke isolatie heeft een bepaalde warmtetransmissie waardoor steeds thermische energie verloren gaat. Dergelijk project zou een mogelijke oplossing kennen als energie-generatoren zoals “phase change” elementen worden toegevoegd en dan nog dienen dergelijke grote hoeveelheden toegevoegd te worden dat dit praktisch onhaalbaar wordt.

Hiermede hoop ik u alvast goed geïnformeerd te hebben en wens u veel succes met uw verdere carrière.

Met vriendelijke groet, Mit freundlichen Grüssen, Best regards,

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References


20 Ocean Mill (2010), Harvesting power of the oceans. Information about the energy supply of Ocean Mills. Obtained on 30 November 2013 from https://sites.google.com/site/oceanmilltest/home


