REPUBLIC POLYTECHNIC

E355 : Cold Chain Management

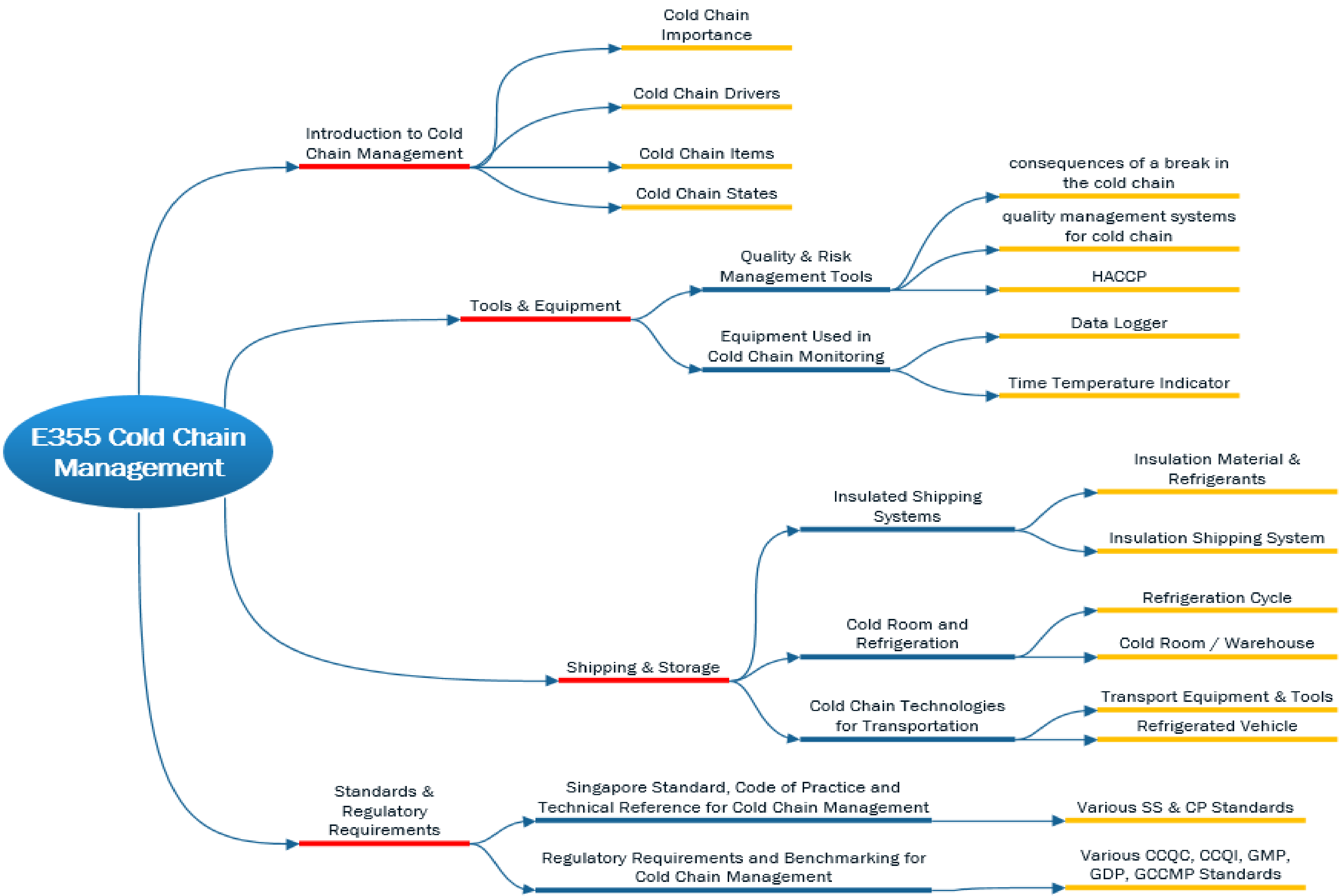
Problem 05

Keep the Cold Box “Refrigerated”

- Identify Types of Refrigerants
- Describe Functions of Refrigerant In Insulated Shipping Systems
- Conduct Experiment For Determining Melting Point of Phase Change Material (PCM)

SCHOOL OF ENGINEERING

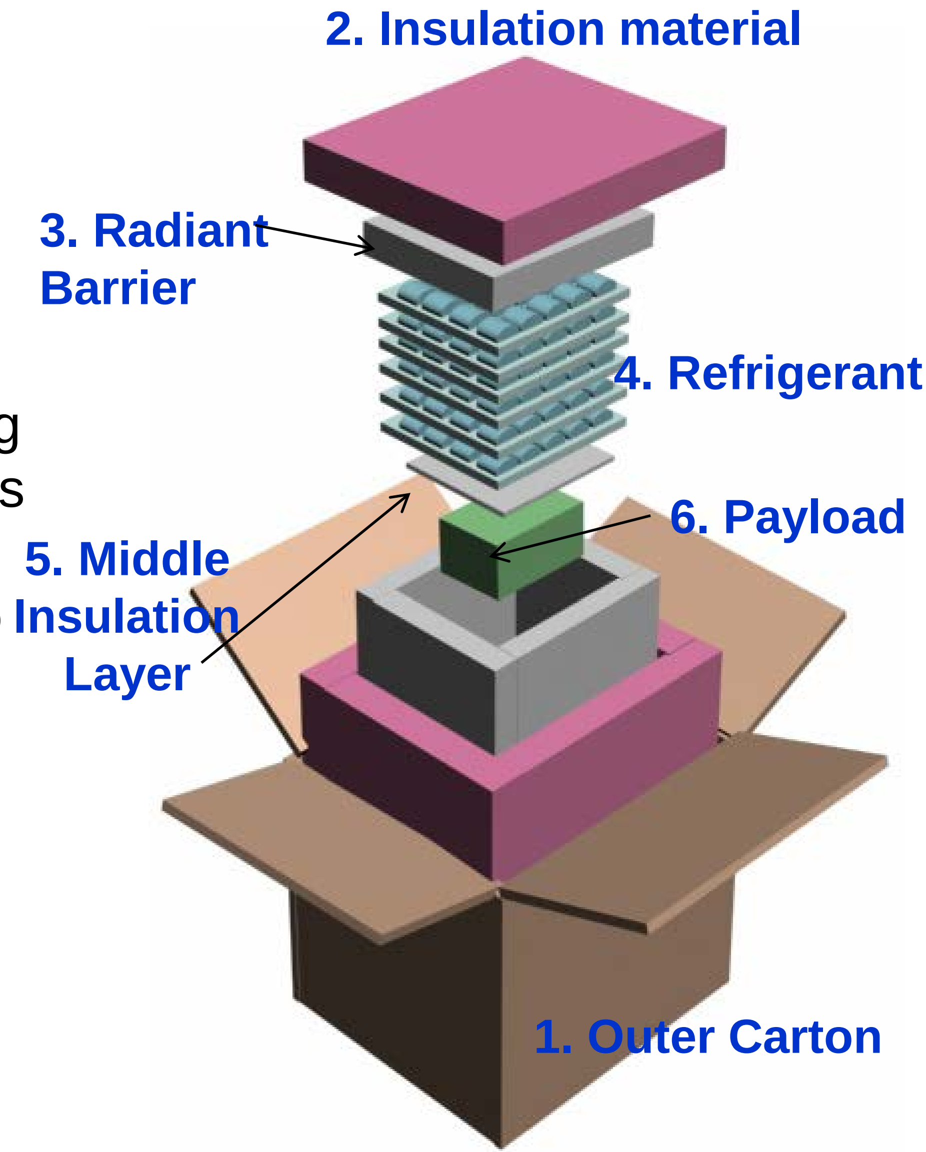
E355 Cold Chain Management - Topic Tree



Cold Chain Shipping System (Recap)

A cold chain shipping system commonly consist of the following parts:

1. **Outer Carton** – to protect and hold the items inside, labeling
2. **Insulation Material** – to minimize heat absorbed from the surrounding
3. **Radiant Barrier** – to reduce effects of radiation
4. **Refrigerant** – cooling substance to maintain internal temperature
5. **Middle Insulation Layer** – to separate the payload and the refrigerant and reduce radiation effects
6. **Payload** – product to be shipped



Refrigerant

- Refrigerants are called temperature stabilizers or Phase Change Materials (PCM), which can be formulated and conditioned at specific temperature and can be used in concert with the product and packaging to create an environment to thermally protect the product
- PCMs are materials that use phase changes (e.g. melting) to absorb or release a significant amount of latent heat at relatively constant temperatures (e.g. Ice changes phase when heated at 0^oC and is converted to water)
- Latent heat is defined as the amount of energy (heat) absorbed or released by a substance during a change in its physical state that occurs without changing its temperature

Refrigerant

- Based on different temperature requirements of the product, ambient temperature of the distribution of the package, and inner packaging constraints, a variety of different refrigerants may be used in the insulated shipper
- Some of the common refrigerants come in the form of:
  - Ice
  - Dry Ice
  - Gel Packs
  - Foam Bricks
  - Eutectic Plates

Ice

- Low cost, has high latent heat, easily available and environmentally-friendly
- Although its phase change temperature is 0ºC, storage temperature of ice is usually as low as -20ºC; thus if taken directly from freezer and placed into shipping container, it can cause product temperature to fall below 0ºC
- Ice melts to form water, which is not advisable in shipping containers, as it may leak to affect container and/or product

Dry Ice

- Can be in pellet or block form, which is actually solid carbon dioxide that sublimes to gaseous form at -78^{o}C.
- Low cost, high latent heat, easily available, do not require pre-conditioning and reduced disposal.
- Extremely cold, and may form a layer of wet ice that affects its performance.
- Requires weighing prior to shipment, unlike gel packs
- Hazardous due to gas expansion, amount of carbon dioxide gas produced takes away oxygen in the air, and cold burns if handled with bare hands.
- Regulated in usage, especially for international air shipments.

Gel Packs

- Also known as Gel Ice, and comes in metalized laminated pouches, polyethylene (PE) pouches, saddlebags and blister packs
- Generally low cost, simple and safe to use, versatile and easily available
- Require pre-conditioning subject to different distribution requirements
- Possibility of leakage in heavier packaging configurations


Foam Bricks

- Also known as Gel Bricks, are less common compared to Gel Packs, due to relatively higher costs
- The term ‘brick’ comes from its shape which is formed from a foam that is impregnated with liquid and enclosed in a plastic film (usually PE)
- Consistent shape gives a good fit in container to improve efficiency and less prone to leakage as compared to gel packs
- Not so easily available



Eutectic Plates

- Also known as Gel Bottles, Ice Packs, PCMs, Panels, and usually contained in tough high density PE bottles
- Variations include phase change temperature, latent heat capacity, physical structure, size and shape
- Ideal for rough environments and reuse, improves packing efficiency and low leakage possibility
- Generally higher cost and require pre-conditioning for different distribution requirements



To Find Amount of Refrigerant

Product Type	Product Volume (m^3)	Product Temperature (^{o} C)
Product A	0.090	+1 to +4
Product B	0.078	-15 to 0

Cold Box	Available Space For Product and Refrigerant (m^3)	Heat Penetration Rate, HPR (W/K)
CB1	0.177	0.323
CB2	0.089	0.263

Refrigerant	Weight (kg)	Length (cm)	Width (cm)	Depth (cm)	Volume (m3)	Melting Point (^{o} C)	Latent Heat (kJ/kg)
Q1	1.52	20	15	40	0.012	+2	158
Q2	1.12	20	15	40	0.012	-7	238

The phase change temperature (i.e. melting point) of the respective PCM must fall within the required product temperature range. Hence,

- Q1 to be used by Product A;
- Q2 to be used by Product B.

To Find Amount of Refrigerant

Steps to determine No of units of PCM needed per box and the number of boxes needed.

1. Melt rate of PCM

$$= \frac{(\text{Ambient temperature} - \text{Melting temperature}) * \text{HPR}}{\text{Latent heat of PCM}}$$

where

Ambient temperature = +25°C

HPR is measured in KJ/h°C

Latent heat is measured in KJ/kg

Melt rate is measured in kg/h

To Find Amount of Refrigerant

2. Weight of PCM required (kg) = Melt rate * Duration

   where duration is measured in hour

3. Units of PCM required = $\dfrac{\text{Weight of PCM Required}}{\text{Weight of Each PCM}}$

4. Roundup the units of PCM required and multiply the value by the volume of each PCM

5. Check if the sum of the total volume of PCM required and the volume of the product exceeds the available inner space for each box type

6. If it exceeds, change the PCM to one with a higher latent heat, or different shape/size

Calculation for **CB1** used with Refrigerant **Q1** for Chilled Storage (**Product A**)

1. Heat Penetration Rate, HPR = 0.323 W/°C

   1 W =3.6 KJ/h OR 1 W = 1 J/s

   Melt Rate = (25-2)*0.323*3.6/158 = 0.169 kg/h

2. Weight of PCM required = 0.169 * 48 hours = 8.125 kg

3. Units of PCM required = 8.125/1.52= 5.345

4. Actual units of PCM required = 6 units

   (round up 5.345 to nearest whole number)

5. Volume occupied by PCM = 6*0.012= 0.072 m^3

6. Allowed volume for product = 0.177 – 0.072

   = 0.105 m^3 > the volume of product Alpha 0.090 m^3 (Can Use!)

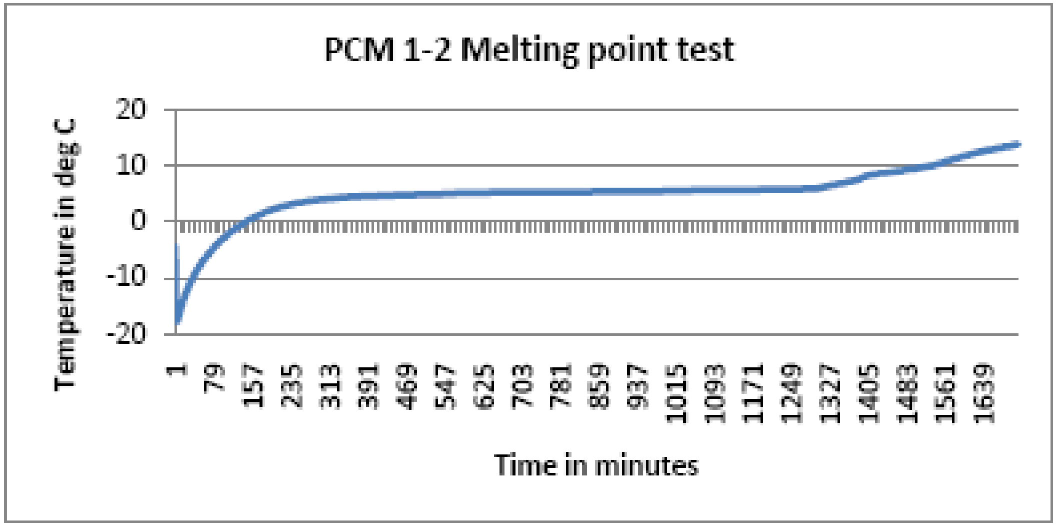
Today's Problem - Calculation

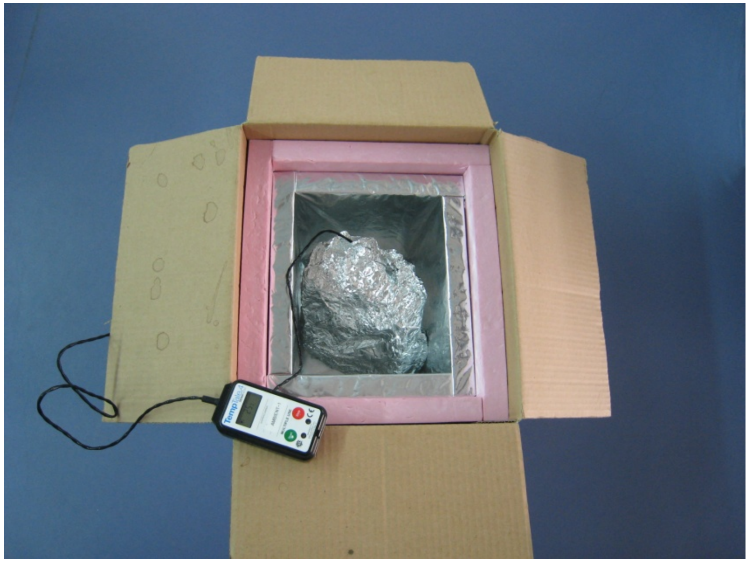
	Inner Vol [m³]	HPR [W/°C]	HPR [kJ/h°C]	Refrigerant type	Ambient temp [°C]	Melting temp [°C]	Temp diff [°C]	Weight [kg] per refrigerant	Vol [m³] per refrigerant	Latent Heat [kJ/kg]	Melt Rate [kg/h]	Weight of refrigernant [kg] required	Units of Refrigerant	Total vol of refrigerant [m³]	Allowable vol for product [m³]	
For Product A															0.090	
CB1	0.177	0.323	1.163	Q1	25	2	23	1.52	0.012	158	0.169	8.125	6	0.072	0.105	OK
CB2	0.089	0.263	0.947	Q1	25	2	23	1.52	0.012	158	0.138	6.616	5	0.060	0.029	not OK
For Product B															0.078	
CB1	0.177	0.323	1.163	Q2	25	-7	32	1.12	0.012	238	0.156	7.504	7	0.084	0.093	OK
CB2	0.089	0.263	0.947	Q2	25	-7	32	1.12	0.012	238	0.127	6.110	6	0.072	0.017	not OK

- For **Product A** refrigerant Q1 can only be used with Cold Box **CB1**
- For **Product B**, refrigerant Q2 can only be used with Cold Box **CB1**

To Find Melting Point of Refrigerant

- Freeze two pieces of the same PCMs until they are completely solid, and place a thermocouple between them, wrapping the entire setup in aluminum foil to limit heat loss
- Place the setup in an insulating container and monitor the temperature versus time graph
- The flat part of the graph will indicate the melting temperature





Today's Problem

- John needs to find out the performance of the refrigerants so that he can decide on the quantity of refrigerants to use and to see if it can fit into the boxes;
- If he wishes to try to use the other refrigerants, he must first find out the phase change temperatures, before finding out the latent heat, weight and size;
- The calculations used to determine number/volume of refrigerants to be used in each box should be further validated through simulation and qualification.

Learning Objectives

- Describe the functions of the refrigerant used in insulated shipping systems
- Recognize that different types of refrigerant is needed to keep products and different temperature ranges
- Identify the different types of refrigerant used in the industry
- Set up an experiment to determine the melting point of a given phase change material
- Compute the amount of phase change material needed to maintain temperature in a given scenario