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COLD CHAIN TECHNOLOGY BRIEF

TRANSPORT REFRIGERATION



Acknowledgement: This Cold Chain Brief was prepared by Richard Lawton (IIR D2 Commission President), has been reviewed by Jim Curlin and Ezra Clark experts from the UN Environment OzonAction and also several experts from the IIR commissions.

IIR-UN Environment Cold Chain Brief on Transport Refrigeration



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2 The Cold Chain

Summary

This brief provides an overview of the main areas of transport refrigeration, some of the different systems used and the working fluids employed. It will go on to look at current trends in using alternative refrigerants and the direction the sector is moving in over a longer period. Future developments will be discussed along with the technical challenges facing designers as they attempt to reach the best balance between what the end user expects from a system and the framework determined by international treaties and regulations.

The “cold chain” refers to the various stages that a refrigerated product passes through, either until it is removed by a customer in a retail environment or unloaded from a delivery vehicle a few metres from its destination. From the moment a fruit or vegetable is harvested or an animal is slaughtered, the product starts to deteriorate. The deterioration of a product can be slowed by reducing the temperature at which it is stored. In fruits and vegetables, this slows down metabolic processes, which, in turn, slows spoilage. Reduced temperatures slow the growth of potentially harmful bacteria in animal products that are stored at frozen temperatures, allowing them to be shipped all over the world with minimal food safety risks. It is important that suitable temperature control be maintained from as soon as is feasible to as close as possible to consumption. From the raw materials stage to the various distribution storage facilities a commodity passes through, transport refrigeration keeps it at the temperature required to maximise storage life and quality for many days, weeks and months between cold storage facilities.

1 Introduction

Over time, the increased demand for temperature sensitive goods and the extension of shelf-life, has led to the development of diverse means of transport. This has been accompanied by technical developments designed to maintain unbroken cold chains. Transport refrigeration is by land, sea and air. Land transport being the most diverse comprise refrigerated semitrailers, containers rigid vehicles and small vans. Sea transport is now mainly refrigerated containers though entire refrigerated ships exist and significant numbers of fishing and fish processing vessels. Air transport times are short and the temperature control rudimentary.

The Cold Chain

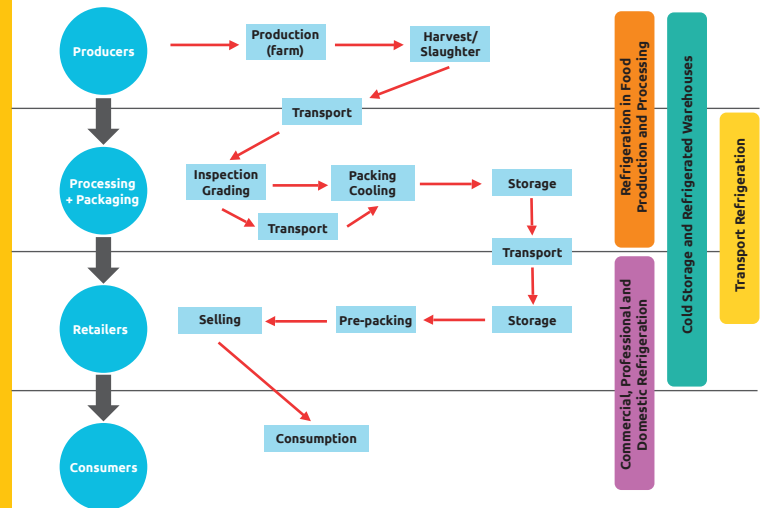


Fig.1

The cold chain is often quite complex, with foods being chilled or frozen on more than one occasion. Worldwide about 400 million tonnes of food are preserved using refrigeration. The overall volume of cold stores (refrigerated warehouses) around the globe is about 600 million m³. The IIR estimates that the total number of refrigeration, air-conditioning and heat pump systems in operation worldwide is roughly 3 billion, including 1.5 billion of domestic refrigerators. 90 million of commercial refrigerated equipment (including condensing units, stand-alone equipment and centralized systems) are operating in the world. There are also 4 million refrigerated road vehicles (vans, trucks, semi-trailers or trailers), 1.2 million refrigerated containers (reefers) and 477,000 supermarkets, with a footprint ranging from 500 to 20,000 m² in operation and where 45% of the electricity consumed is used by refrigeration equipment (IIR, 2015¹).

¹IIR, 2015. 29th Note: The Role of Refrigeration in the Global Economy.

I Fig.1: Overall cold chain with the different components

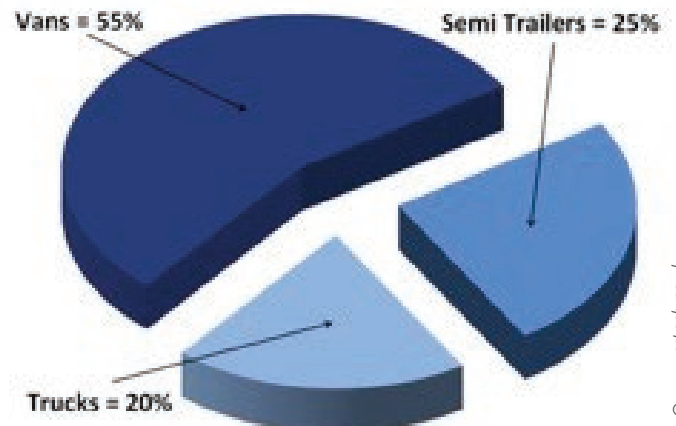
3 Overview of Transport Refrigeration

Transport refrigeration is provided by various means as the commodity is moved along the cold-chain such as from the manufacturer to a distribution centre and then to stores from where it may increasingly be delivered to a customer's home, typically in a van or small truck. Regardless of the vehicle it is preferable to ship in bulk and having only one temperature required whenever possible as this incurs the least cost and complexity.

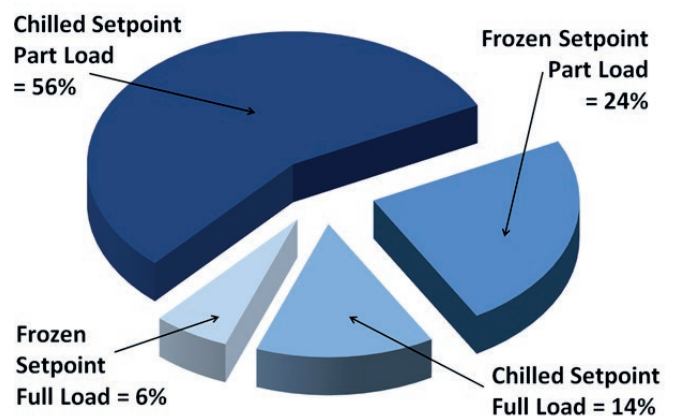
3.1. Refrigerated Vehicles

Refrigerated trucks come in many different shapes and sizes. They range from semi-trailers capable of carrying 26 - 33 fully stacked ISO pallets, commonly 1200x1000mm or 800x1200mm to smaller vehicles specially adapted by a manufacturer from standard cars or vans, sometimes in conjunction with a third party body builder who makes an insulated compartment to be mounted on the vehicle chassis, carrying only a few small cartons. The bodies of most truck and trailer refrigerated vehicles are insulated bodies of sandwich construction with an outer weatherproof protective layer, an interior frame of metal to provide structural rigidity surrounded by insulating materials and an inner protective layer. The inner protective layer often features "kick-plates" to protect against impacts from pallet-trucks and forklifts during loading/unloading as well as being equipped with various fixings. Smaller vans have the voids filled with moulded foams with mineral wool insulation around the smaller voids (Lawton *et al*, 2016²).

In the majority of developed countries such vehicles are subject to ECE/Trans/249 ("ATP") regulations (UN, 2015³) which require minimum insulation performance and heat extraction rates to ensure cold-chain integrity. There are two classes of insulation, IN and IR for frozen and chilled respectively. These correspond to heat transfer coefficients below 0.70W•m⁻²•K⁻¹ and 0.40W•m⁻²•K⁻¹. The refrigeration equipment typically delivers cold air to the top of the body and the warmed air, having been drawn through the cargo, returns lower down. Multi temperature, multi compartment vehicles and their refrigeration systems are becoming increasingly common.



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Fig.2



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Fig.3

² Lawton, A. R., Mynott, T., Rhodes, C., 2016. Performance Data of Insulated Paint on Refrigerated Equipment. p.2, IIR ICC2016, Auckland, New Zealand.
³ Cavalier, G., Devin, E., Michineau T., Vannson F. Thomas G., 2016. Ageing of Refrigerated Truck Insulation. p.2, IIR ICC2016, Auckland, New Zealand.
⁴ Cemafruid, 2015. Full load and part load reefer efficiencies for French energy certificate eligibility. <https://nr-pro.fr/app/webroot/files/types/1/TRA-EQ-11.pdf>
⁵ United Nations (UN), 2015. Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be used for such Carriage, Geneva, 978-92-1-139153-4.

Fig.2: Approximate Fleet Split (Cavalier *et al*, 2016³)
 Fig.3: Approximate Operating Mode Time Split (Cemafruid⁴)

3.2. Refrigerated Air Cargo

Air cargoes are used to transport a variety of vegetables and flowers with shorter storage lives to their destinations. Pharmaceutical cargoes are also common where cargo holds are typically kept between 15°C and 25°C (WHO, 2014⁶) with additional temperature control provided by passive or active systems. Passive systems are insulation media around the commodity which aim to reduce the influence of the surrounding air. Active systems are also packaged around the commodity but they contain refrigerants such as dry ice or phase-change materials (eutectic) to further reduce the rate at which a cargo warms or cools. Due to strict rules set by aeronautic regulatory bodies it is not viable to have refrigeration systems such as in road or container systems due to the levels of redundancy and risk minimisation required which drive costs up exponentially. Weight is also at a premium, as is space due to aerodynamic considerations when designing airplanes which are prioritised over the ability to quickly load vast amounts of cargo.



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Fig.4

3.3. Intermodal Refrigerated Containers

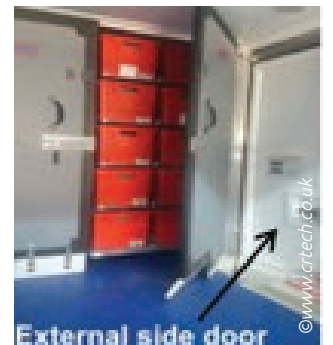
Intermodal refrigerated containers are filled with commodities at or near to the source, typically carrying either live commodities to undergo ripening before sale or frozen cargoes to be further processed by a plant based near to the destination port. They are then shipped on large container carrying vessels with voyages lasting between a few days to five or even six weeks. During the voyage, the containers on deck can be exposed to hot and humid equatorial temperatures near the equator and then experience freezing and dry conditions when crossing the northern hemisphere, for example.

Containers are made to the principles of ISO standard 1496 which stipulates dimensions and other design-critical criteria. It is important for manufacturers to ensure compatibility with equipment such as cranes, lifting trucks, transport chassis etcetera all over the world. Such containers have ISO corner castings, T-bar floors to ensure airflow (required for break-bulk stows), lock-bars on the doors, drain holes, fresh air ventilation and sophisticated microprocessor controllers. The equipment is usually removable (integral), mounted with bolts and feature forklift pockets to allow a severely damaged unit to be changed. One company produces an integrated system which is inseparable from the container. Whilst this has the advantage of reducing heat leaks, and therefore power consumption, it also means that it is not possible to replace the refrigeration system should it become heavily damaged. The overwhelming majority of containers are either 40' or 20' long with 40's being common in standard and "high-cube" varieties. Many other designs are covered by ISO 1496 however these are rarely seen.



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Fig.5



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Fig.9

- Fig.4: Over-Cab Unit
- Fig.5: Nose Mounted Unit
- Fig.6: Inside a Home Delivery Vehicle
- Fig.7: Eutectic System
- Fig.8: Insulating Cover
- Fig.9: Insulating Packaging

⁶World Health Organisation (WHO), 2014. *Temperature-Controlled Transport Operations by Road and by Air*, Technical Report Series 961. WAS/14.598 Supplement 12, Annex 9, p15, WHO Press, Geneva, Switzerland.

3 Overview of Transport Refrigeration

3.4. Intermodal Container Controlled Atmosphere and Humidity Control

Many live cargoes, such as fruits, require fresh air venting to prevent gas build-up becoming detrimental. Relative humidity control is incorporated to modern systems. As fruits metabolise they not only produce heat but also increase CO₂ and decrease O₂ levels. Some systems are available which can be retro-fitted to equipment to allow precise control of these levels. One such example is seen in Figure 14 which is installed into the evaporator access panel of a compatible system. An example is shown in Figure 13 with the evaporator access panel at the upper right side opposite the fresh air ventilation panel. The storage life of some cargoes is greatly increased with low O₂ and high CO₂ levels.

3.5. Refrigerated Trains

Intermodal containers have now largely replaced the refrigerated trains of the first half of the twentieth century. "Freezer cars" were common in America until the 1950s as they allowed access to meat that didn't require curing – a novelty at the time. The American railroads were used to haul cargoes of frozen, hung meat across the sparsely spread towns and cities. Refrigeration was achieved using only dry-ice and other simple eutectic or phase-change solutions. More recently new routes have emerged, mostly connecting Russian terminals to others in the Middle East and the Asia-Pacific region, again due to the vastness of the countries. Containers are loaded onto ISO chassis-cars and regularly carry goods between Russia and countries such as China and Iran and its Middle Eastern neighbours.

3.6. Reefer Ships

The number of reefer ships is declining in favour of container ships. Many reefer ships have four refrigerated holds and deck space and power supplies for containers. Older vessels are often refurbished to be more accommodating to containers. A side-loading system for the holds to allow simultaneous unloading of the holds and containers is one such example. Small reefer ships often dedicated freezers are employed transferring the catch from fishing vessels to their eventual markets.



Fig.10



Fig.11



Fig.12



Fig.13



Fig.14



Fig.15



Fig.16

Fig.10: Reefer Stack at a Terminal

Fig.11: Two 20' Reefers Stacked

Fig.12: HFC-134a System

Fig.13 : CO₂ System

Fig.14: Active Controlled Atmosphere System

Fig.15: Reefer Ship

Fig.16: Side Loading System

4 Current Issues and Market Trends

Whilst many people only experience refrigeration domestically, in chilled and frozen sections of supermarkets and possibly air conditioning, the cold chain to get the produce to them often goes unnoticed. Without developments in cold storage and transport throughout the production and distribution processes, the modern supermarket would look very different with many commodities imported long distances being either very expensive or unavailable.

Over the past decade, principally in developed countries the cold chain has been extended to the customer's doorstep as supermarkets and online distribution services competed for business and introduced home delivery services, increasing the amount of smaller delivery trucks in service. Global container numbers have also grown steadily as international transportation has increased between developing countries. Growth is predicted to continue especially once developing countries adopt the cold chain for local distribution but this is to be expected as the population of the planet increases and demand for foreign produce grows, together with the desire to have foods available all year round which requires imports from abroad as fruit and vegetable crops depend on seasonal weather.

As developing countries obtain suitable infrastructure to facilitate implementation of a cold chain this will drastically reduce the amount of food waste and CO₂ impact associated with food production. Simultaneously there will be an increase of the CO₂ impact of vehicles and their cooling systems and therefore informed decisions need to be made on zero ODP refrigerant and low CO₂ emitting vehicles.

5 Current Refrigerants and Potential Alternatives

Currently a large percentage of the transport market is using either HFC-134a or HFC-404A refrigerants. HCFC-22 remains common outside Europe and North America and is also used on the majority of reefer ships. There are a few other options available however they are, currently, by no means common. The GWPs are from Kuijpers and Peixoto report (2014⁷).

Although the road transport sector has been quick to adopt alternative lower-GWP gases, the container industry has been much slower due to the technical and logistical challenges of ensuring the global availability of tools and supply chain of gases. Typically road transport operates over distances of a few hundred kilometres, returning to a base to be serviced. This does not happen with containers as they spend months at sea travelling around the globe.

Road transport has been quick to migrate from HFC-404A to HFC-452A for larger truck and trailer systems. Smaller systems currently using HFC-134a will possibly move to HFC-513A or propane much as commercial refrigeration is tending to. Some propane systems currently exist, though they are not common. The container industry has yet to change, however one of the large manufacturers has introduced a CO₂ system although only relatively small numbers have been sold. So far there have been minimal impacts upon the aerospace industry due to the systems used. Alternative technologies such as cryogenics and sorption are available and may become more widespread.

Table 1: Summary of current and alternatives refrigerants

Transport Refrigeration		
Types of transport	Current higher GWP refrigerants (GWP kg•CO ₂)	Alternative lower GWP refrigerants (GWP kg•CO ₂)
Refrigerated containers, road transport, trains	HFC-134a (1360); HFC-404A (3920), HCFC-22 (1810)	R-744 (1), HFC-452A (1950); HFC-513A (573); HC-290 (5)

⁷Kuijpers, L., Peixoto R., 2014. Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, pp 54 – 57, 2014, UNEP Nairobi, Kenya.

6 Development Perspectives and Challenges

Currently both equipment manufacturers and standards committees are working to introduce systems and standards for safe operation of hydrocarbon, and other, flammable refrigerants. These have low GWPs, typically below five, although some resistance is present due to commercial interests. The marine industry is concerned about the dangers of such systems aboard vessels, particularly under deck where fires may start and spread easily. Various novel systems have been developed for road transport use which, although not yet significant in numbers, may one day mature into valid alternatives to reduce overall CO₂ equivalents.

6.1. Technical Challenges and Potentials

Equipment manufacturers have to balance safety and cost considerations within the transport industry. The cargo free-air spaces are small when stuffed, leaving potential dangers for workers opening the doors after a refrigerant leak on the evaporator section. Patent issues block much of the development of transcritical CO₂ vapour-compression cycles for transport applications leaving gas manufacturers to lead development and create new blends with low GWPs and excellent thermo-physical properties. Many blends are propene based and blended with common HFCs to produce a mid-GWP interim solution.

6.2. Related Driving Policies

Refrigeration and Air Conditioning Industry witnessed considerable development and modernization in the last 3 decades partly as result to the international environmental policies where many refrigerants that have been used efficiently for decades, are held responsible to the Ozone Layer Depletion as well as Global Warming. The phase-out of ozone depleting substances (ODSs), under the Montreal Protocol, triggered significant changes in the industry moving towards alternative refrigerants and technologies that has zero-ODP (Ozone Depletion Potential).

In October 2016, the Kigali Amendment to the Montreal Protocol brought another dimension to the mandate of the Montreal Protocol by adding the control of production and consumption of hydrofluorocarbons (HFCs) under its mandate which will have major contribution towards the fight against climate change. Control of HFCs production and consumption will add to the climate benefits already achieved by the Montreal Protocol through the phase-out of ODSs including CFCs and HCFCs. The emissions of HFCs are also listed within the group of GHGs (Greenhouse Gases) under the Climate related conventions i.e. Paris Agreement and previously the Kyoto Protocol. However, actions to specifically control HFCs emissions within the climate regime are not yet set except for reporting requirements under the UNFCCC (UN Framework Convention on Climate Change).

The refrigerant climate impact of refrigeration equipment depends on direct and indirect effects. The direct effect is from its GWP (Global Warming Potential) and amount of a refrigerant emitted to the atmosphere (either from a leak, accident, or from improper handling or disposal). The indirect effect is associated with the energy consumed during the operation of equipment which, over its lifetime, occurs as a result of the CO₂ (CH₄ to lesser extend)

produced by fossil fuel power plants, and is commonly greater than the direct effect. Minimizing direct and indirect impacts, of all types of refrigerants, emissions should be addressed through improved design, better field commissioning and maintenance practices, sound decommissioning procedures and enforcement to local relevant standards and regulations.

There are several principal organisations developing standards related to the refrigeration and air-conditioning sector. The UNEP International Standards in Refrigeration and Air-Conditioning booklet (UNEP, 2014⁸) summarises the main international standardisation organisations and provides some examples of national and regional standards organisations.

The cold chain sector is one of the most important but overlooked business segments in terms of being addressed in a holistic approach. This is because it crosscuts with different economic, social and technical areas i.e. food industry, health, refrigeration, transportation, tourism, etc. The norms and directions for cold chain technology selection that has less environmental impact, energy efficient operation and affordable economics is scattered amongst different groups and entities within the same country. In September 2015, International Community adopted the 2030 Sustainable Development Goals (SDGs) stipulating Goal #2 «Zero Hunger» as the second global goal which needs to be achieved by 2030. This automatically means the urgent need to efficiently manage the portfolios of «Food Security» & «Food Waste» which depends on the cold chain capabilities. While this goal can be noted as the main goal with direct relation to cold chain, other goals are also connected to the cold chain business i.e. Goal #3: Health and Wellbeing, Goal # 9: Industry Innovation and Infrastructure, Goal # 12 Responsible Consumption and Production as well as Goal #13: Climate Action. Therefore, the integrated approach in addressing the cold chain challenges can lead to multi socioeconomic and environment benefits.

⁸UNEP, 2014. *International Standards in Refrigeration and Air-Conditioning. An introduction to their role in the context of the HCFC phase-out in developing countries.*

Conclusions

The road and marine refrigeration industries face vastly different challenges with regard to regulatory compliance due to the global infrastructure required to keep container ships and ports working. National issues with bordering countries will have some impact on developing countries in the Middle East with regards to road transport however this will be minimal compared to the disruption faced by the owners and operators of intermodal containers. Air freight will not be significantly affected due to the stringent safety standards and risk-averse regulators of the aviation industry.

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