U-3ARC TRAINING WEBINAR N°41

Mobile Refrigeration

April 26, 2025

Refrigerated Transport: From Past to Innovation.

- Why is refrigerated transport essential?
- History
- Techniques and Technologies
- Classification
- Operating
- Principle Standards and Regulations
- Maintenance and Servicing

Why is refrigerated transport essential?

1. Storage of perishable goods

- **Food:**
  - Fresh products (meat, fish, fruits, vegetables, dairy products) require a controlled temperature to prevent bacterial growth and enzymatic reactions.
  - Example: Meat must be kept between **0°C and 4°C**, frozen foods at **-18°C**.
- **Medicines and Vaccines:**
  - Some medicines (insulin, antibodies) and vaccines (e.g., Pfizer/BioNTech against COVID-19, stored at **-70°C**) lose their effectiveness without a strict cold chain.
  - A temperature breach can render an entire batch unusable, threatening lives and resulting in financial losses.

Why is refrigerated transport essential?

2. Reduction of food waste

Key figures:

According to the FAO, 30% of the world's food is wasted, partly due to poor logistics.

Refrigerated transport extends the shelf life of products (e.g., milk can be stored from 6 hours to 7 days at 4°C).

Economic impact:

Reducing waste means optimizing production and distribution costs.

Example: Developing countries lose up to 50% of their crops due to a lack of cold chain.

Why is refrigerated transport essential?

3. Health and Economic Issues

Public Health:

Improper temperature conditions can lead to food poisoning (e.g., Salmonella, Listeria).

For vaccines, a break in the cold chain can compromise entire vaccination campaigns.

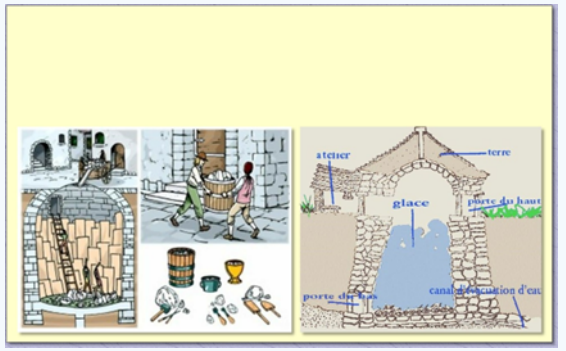
Global Economy:

The global refrigerated transport market is worth $20 billion (2023) and enables transcontinental trade (e.g., export of mangoes from Kenya to Europe).

The pharmaceutical and agri-food sectors are entirely dependent on this technology.

Historical

Origins and Key Developments



1. Precursors (before the 19th century)

- **Natural methods**: Use of transported natural ice (e.g., ice blocks for shipping), evaporative cooling, or saline solutions.
- **Limitations**: Dependence on climatic conditions, short distances, high costs

2. Industrial Revolution (19th century)

- **1820–1870**: First mechanical systems using ether, ammonia, or CO_2 (William Cullen, Charles Tellier).
- **1877**: Carl von Linde invents the industrial refrigerator, allowing continuous cooling without ice.
- **Rail transport**: Refrigerated wagons for beer (1873) and meat (1903), with cork and ice insulation.

3. 20th century: Rise of road and maritime transport

- **1938**: Invention of mobile refrigeration units by Thermo King (trucks).
- **1950s–1960s**: Refrigerated shipping containers ("reefers") with integrated systems revolutionized global trade.
- **Regulation**: ATP agreement (1954) to standardize international refrigerated equipment.

Historical

Modern Innovations and Challenges

1. Key Technologies

- **Smart Control**: IoT sensors to monitor temperature, humidity, and traceability in real time.
- **Hybrid Systems**: Solar- or hydrogen-powered refrigeration to reduce the carbon footprint.Eco-Friendly
- **Refrigerants:** Transition to propane (R290) or CO_2 to replace high-GWP gases.

2. Challenges and Solutions

- **Integrated Cold Chain**: Optimization of refrigerated warehouses, intermodal transportation (sea/rail/road).
- **Training**: Specialized programs for logisticians and technicians (e.g., OTTC course in South Africa).
- **Sustainability**: Pilot projects for electric trucks and enhanced insulation standards (e.g., test chamber in South Africa).

3. Future Perspectives

- **Autonomous Containers**: Self-powered systems with AI to adjust parameters during the journey.
- **Zero Emissions Goal**: Adoption of Alternative Fuels and Improvement of Overall Energy Efficiency

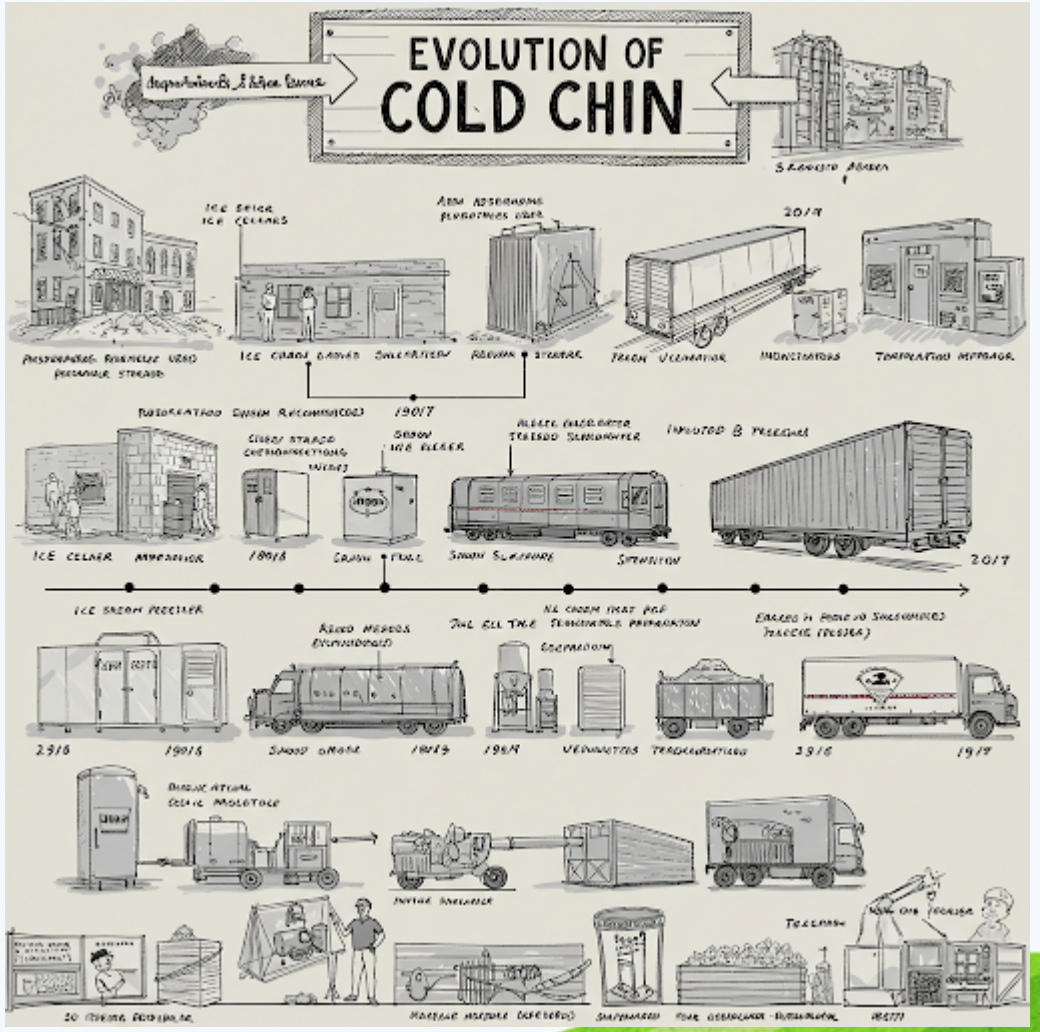
Historical

Historical Synopsis (Optional)
Key Developments at a Glance

Timeline :

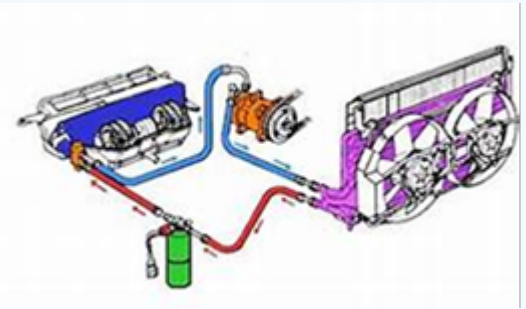
Before 1800: Natural Ice and Salting.
1834: Perkins Machine.
1870: Refrigerated Railcars.
1940: Mobile Refrigeration.
1960: Shipping Containers.
2020s: IoT and Sustainability.

A history marked by technical innovation and adaptation to global needs.



Techniques and Technologies

Types of Refrigeration Systems
Technologies at the Heart of Refrigeration



1. Mechanical System (Vapor Compression):
Principle: Closed cycle with compressor, condenser, expansion valve, and evaporator.Fluids: Refrigerants (e.g., R-452A to reduce environmental impact).
Advantages: Effective for continuous refrigeration (e.g., long-distance trucks).

2. Cryogenic System:
Liquefied gases: Liquid nitrogen (-196°C) or CO_2 (-78°C).Use: Rapid cooling (e.g., transport of frozen products).
Advantages: Silent, zero direct emissions.

3. Eutectic System:
Principle: Cold accumulation via plates containing a water-salt mixture (phase-changing).
Use: Short deliveries (e.g., urban deliveries of fresh produce).

Techniques and Technologies

Equipment Used
Equipment Adapted to Every Need

Vehicle Types:
Refrigerated Trucks: Capacity from 2 to 20 tons, temperatures from -30°C to +12°C.
Shipping Containers: ISO standards (20'/40'), energy-independent (e.g., Maersk).
Multimodal Trailers: Rail-road compatible to reduce carbon footprint.

Insulation:
Polyurethane Foam: Thickness 60-100 mm, thermal conductivity ≤ 0.025 W/m K.
VIP (Vacuum Insulated Panels): 5x better insulation than foam, used for vaccines (-70°C).

Techniques and Technologies

Temperature Control
Precision and Technological Innovation

IoT Sensors:

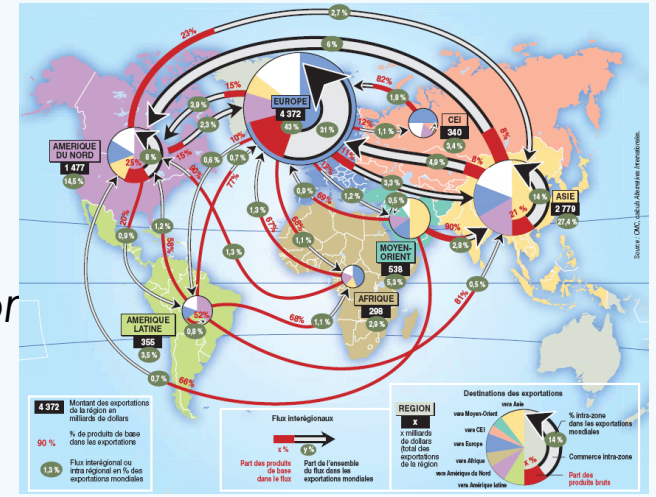
Real-time monitoring via LTE or satellite networks (e.g., Monnit, Controlant).
Alerts in the event of thresholds being exceeded (SMS, email).
Blockchain: Immutable traceability (e.g., Pfizer vaccine tracking).

Automation:

Self-regulating systems (e.g., Danfoss ADAP-KOOL).
Dynamic adjustment based on outside temperature (e.g., +35°C → enhanced cooling).

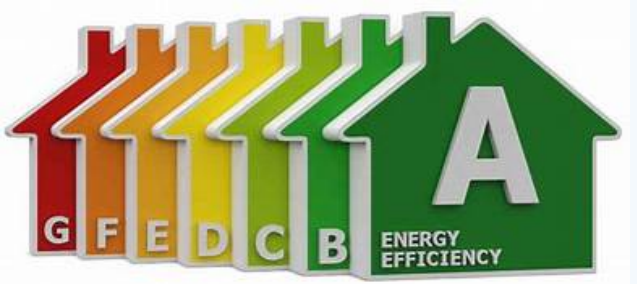
Techniques and Technologies

Use Cases
From Field to Fork, from Lab to Patient



Food:
Meat: Production line at 0-4°C (prevents the growth of E. coli).Dairy: Transpor
probiotics.Exotic Fruits: Ethylene control (e.g., bananas at 13°C).

Pharmaceuticals:
Vaccines: Logistics at -70°C (Pfizer) or 2-8°C (AstraZeneca).
Biological Drugs: Transportation under liquid nitrogen (e.g., gene therapies).



Key Innovations (Optional)
Towards Sustainable and Smart Refrigeration
Natural Refrigerants: Transcritical CO_2 (reduces carbon footprint by 30%).
Renewable Energy: Electric trucks equipped with lithium-ion batteries (e.g., Tesla Semi).
Predictive AI: Anticipates breakdowns (e.g., compressor vibration analysis).

Classification

Temperature control system

Insulated truck:

No refrigeration unit.
Insulated walls to limit heat exchange.
Ideal for short trips (<80 km) or temporary temperature maintenance (e.g., fruits and vegetables).

Refrigerated truck:

Equipped with a mechanical refrigeration unit to generate cold.
Adjustable temperatures (e.g., between -20°C and +12°C).
Used for long distances or frozen products.

Refrigerated truck:

Non-mechanical refrigeration system (e.g., dry ice).
Allows the temperature to be lowered without an engine.

Heated truck:

Maintains a high temperature (up to +20°C).
Used for heat-sensitive products (e.g., medications).

Classification

By capacity and size

Light commercial vehicles:
Gross Vehicle Weight (GVW) ≤3.5 tonnes.
Volume: 1.5 to 9 m³.
E.g., vans for SMEs or local deliveries.

Refrigerated trucks:
GVW ≤7 tonnes.
Volume: 8 to 17 m³.
Suitable for regional transport (e.g., dairy products).

Heavy goods vehicles:
GVW ≤26 tonnes.
Volume: 26 to 50 m³.
Used for transporting large volumes over long distances.

Semi-trailers:
GVW ≤38 tonnes.
Volume up to 85 m³.
Ideal for international freight or bulk deliveries (e.g., frozen goods).

Classification

By crate configuration

Single-temperature:
A single temperature zone in the crate.
E.g., ice cream transport (-18°C).

Multi-temperature:
Partitions to create multiple compartments with distinct temperatures (e.g., +4°C for meat and -18°C for frozen foods).
Represents 30% of sales in France

Specialized:
Meat racks: equipped with hanging rails for hanging meat quarters.
Specialized for flowers: ventilated shelves to preserve flowers.
Pharmacy crates: strict humidity control.

Classification

Temperature Classes (ATP)

Vehicles are approved according to the Agreement on the International Carriage of Perishable Foodstuffs (ATP):

Class A: *0°C to +12°C (fresh products).*

Class B: *-10°C to +12°C (mixed products).*

Class C: *-20°C to +12°C (frozen products).*

Classes D, E, F: *temperatures below 0°C, -10°C, or -20°C.*

- Ice cream - 20°C
- Frozen or deep-frozen fish, mollusks, and crustaceans - 18°C
- Frozen products - 18°C
- Frozen butter - 10°C
- Other frozen products -12°C
- Red offal +3°C
- Butter +6°C
- Game +4°C
- Milk in tanks +4°C
- Industrial milk +6°C
- Refrigerated dairy products +4°C
- Meat and meat products (except red offal) +7°C
- Poultry and rabbits +4°C

Classification

Other specific features

Energy systems:

Refrigeration units powered by diesel engines, batteries, or mains electricity
Innovations: Liquid CO_2 or fuel cells to reduce environmental impact

Regulations:

Mandatory ATP inspections at 6, 9, and 12 years
Blue "FRCX" marking indicating the class and validity

Operating principle

Mechanical compression system (most common)

Principle : Thermodynamic cycle based on the compression and expansion of a refrigerant.

Key components:

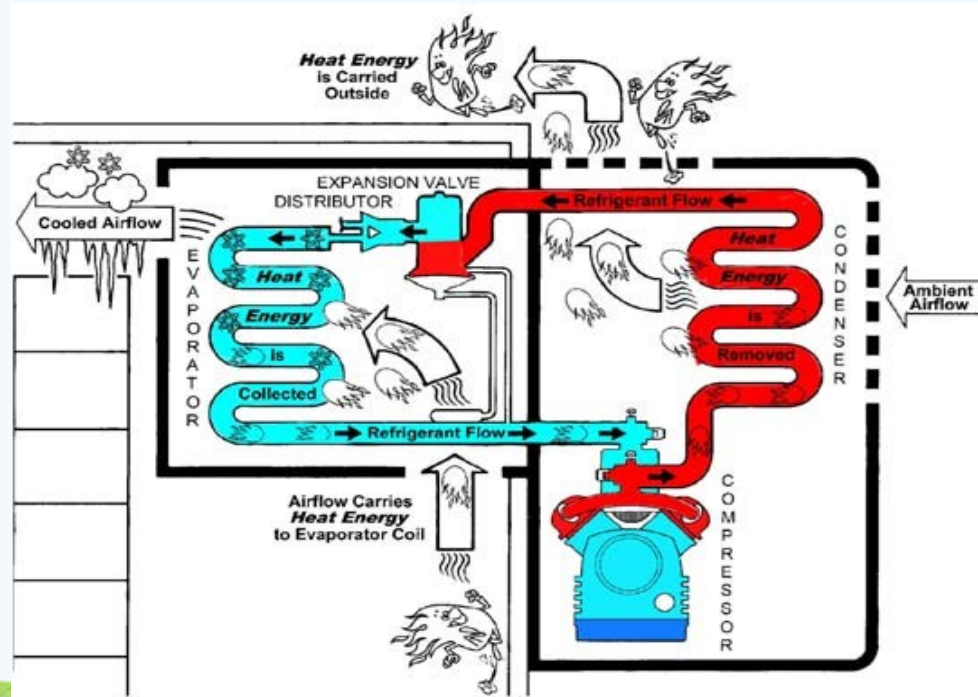
- **Compressor:** Powered by the diesel engine or a battery.
- **Condenser:** Dissipates heat to the outside.
- **Evaporator:** Absorbs heat from inside the refrigerant body.
- **Refrigerant:** R-452A (environmentally friendly) or ammonia (effective but toxic).

Operation:

- **The refrigerant is compressed (hot gas).**
- **It passes through the condenser to become liquid.**
- **Expansion via an expansion valve → rapid cooling.**
- **The evaporator captures residual heat from the refrigerant body.**

Advantages:

- **Precise temperatures (-30°C to +20°C).**
- **Long battery life (operates even with the engine off).**
- ***Disadvantages:***
- **High energy costs.**
- **Environmental impact of fluids (except CO_2 models).**



Operating principle

Cryogenic System (Liquid Nitrogen or CO_2)

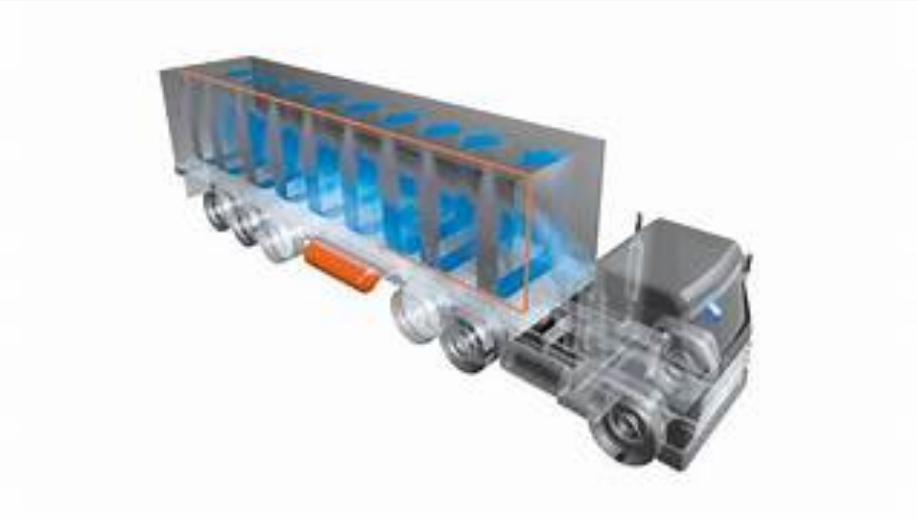
Principle : Use of liquefied gases at very low temperatures to generate cold.

Key Components:

- ❑ Insulated tank (liquid nitrogen at -196°C or CO_2 at -78°C).
- ❑ Controlled Vaporization System.

Operation:

- ❑ The gas is vaporized in the tank.
- ❑ The liquid → gas phase absorbs heat (instant cooling).



Advantages :

- ❑ Quiet (no compressor).
- ❑ Environmentally friendly (no direct emissions).

Disadvantages:

- ❑ Limited autonomy (depends on the tank).
- ❑ High refill costs.

Operating principle

Eutectic Plate System

Principle: Cold storage via plates containing a eutectic mixture (water + salts).

Components :

- ❑ Plates filled with eutectic solution (phase changing at -20°C).
- ❑ Refrigeration unit to recharge the plates (at night, for example).

Operation :

- ❑ The plates are "charged" with cold via an external unit.
- ❑ During transport, they release the cold by slow melting.

Advantages :

- ❑ No energy consumption during transport.
- ❑ Ideal for noise-sensitive areas (nighttime deliveries).

Disadvantages :

- ❑ Limited battery life of 12-24 hours.
- ❑ Additional weight.

Operating principle

Battery-electric system

Principle : Refrigeration unit powered by lithium-ion batteries.

Components *:*

- ❑ Electric motor.
- ❑ High-capacity battery (100-200 kWh).
- ❑ Fast-charging system.

Operation *:*

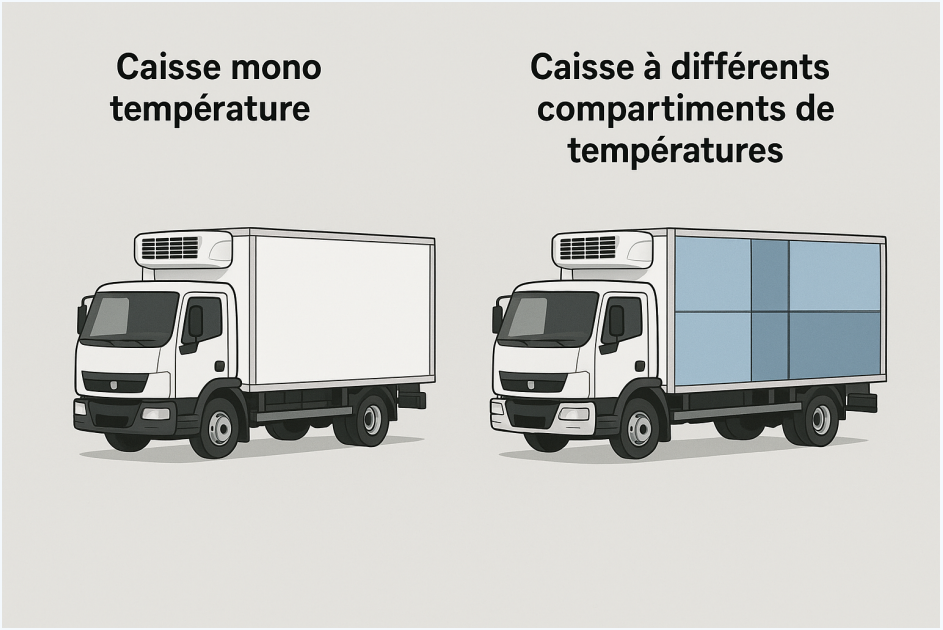
- ❑ The compressor is driven by an electric motor (no diesel).
- ❑ Battery rechargeable via mains power or regenerative braking.

Advantages *:*

- ❑ Zero emissions (ideal for city centers).
- ❑ Reduced maintenance costs.

Disadvantages *:*

- ❑ Limited autonomy (8-10 hours continuous).
- ❑ High initial investment.



Operating principle

Hybrid system (diesel + electric)

Principle : Combination of a diesel refrigeration unit and a battery.

Operation *:*

- ❑ Electric mode for stops (engine off).
- ❑ Diesel mode while driving.

Benefits *:*

- ❑ 30% reduction in fuel consumption.
- ❑ Complies with anti-pollution standards (e.g., ZFE zones).

Operating principle

Absorption system (thermal energy)

Principle *:* Use of heat (gas or hot water) to generate cold.

Components *:*

- ❑ Ammonia/water solution.
- ❑ Heat generator (e.g., exhaust pipe).

Operation *:*

- ❑ The heat separates the ammonia (gas) from the water.
- ❑ The ammonia condenses, then expands to produce cold.

Advantages *:*

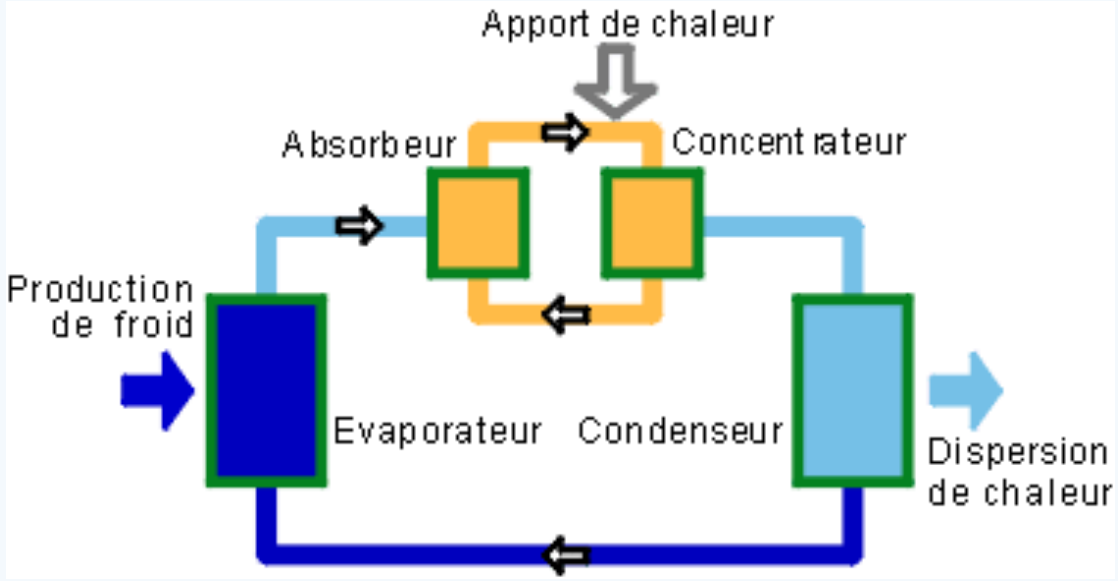
- ❑ Low power consumption.
- ❑ Suitable for long journeys.

Disadvantages *:*

- ❑ Lower efficiency than compression systems.
- ❑ Large footprint.

Applications *:*

- ❑ Tank trucks for sensitive chemicals.



Operating principle

Comparison of systems

Type	Min. Temperature	Autonomy	Coût	Sustainability
Compression	-30°C	Illimitée	High	Medium
Cryogenic	-60°C	8-12h	Very high	High
Eutectic plates	-25°C	12-24h	Moderate	Medium
Electric	-20°C	8-10h	Very high	High

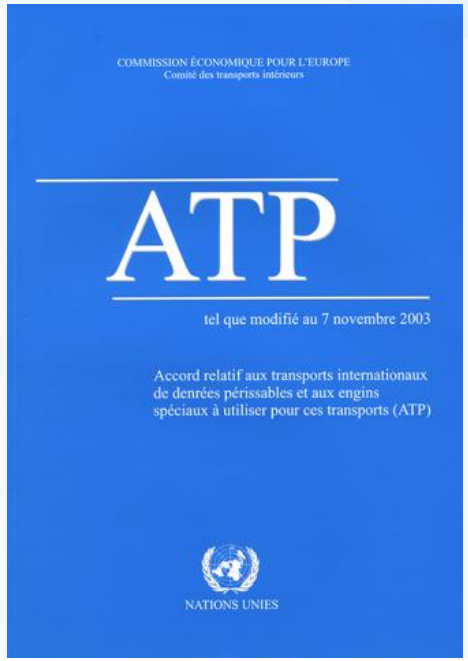
Standards and Regulations

International Standards
Global Frameworks to Ensure Safety

ATP Agreement (Transport of Perishable Goods):
Effective in 1970, regularly revised (latest version: 2023).
Defines technical standards for vehicles (insulation, equipment).
Temperature classes: A (-20°C to +12°C), B (≤ -10°C), etc.

HACCP (Hazard Analysis and Critical Control Point):
Preventive method for identifying risks (e.g., cold breakage).
Mandatory in the EU and the United States for perishable goods.

Example: Temperature monitoring every 15 minutes (HACCP) + ATP certification for trucks.



Standards and Regulations

Regional Rules
Local Adaptations, Universal Requirements

European Union:

Regulation (EC) No. 852/2004: Incorporates HACCP and requires enhanced traceability (e.g., digital logbook).
Directive 2021/382: Allergen control and temperature management.

United States (FDA):

FSMA (Food Safety Modernization Act): "Prevention is better than cure.“
Guidelines for Pharma: Vaccines stored at 2-8°C (e.g., Moderna), with a tolerance of ±3°C for 24 hours.

Standards and Regulations

Certifications
Committed to excellence

ISO 22000 :

International standard for food safety management systems.
Requires a "farm-to-fork" approach.
Adopted by 35% of global refrigerated logistics providers (source: ISO Survey 2022).

Good Distribution Practices (GDP) :

Guarantees the integrity of pharmaceutical products (e.g., no breakage of refrigeration).
Mandatory annual audit (e.g., random warehouse inspections).

Standards and Regulations

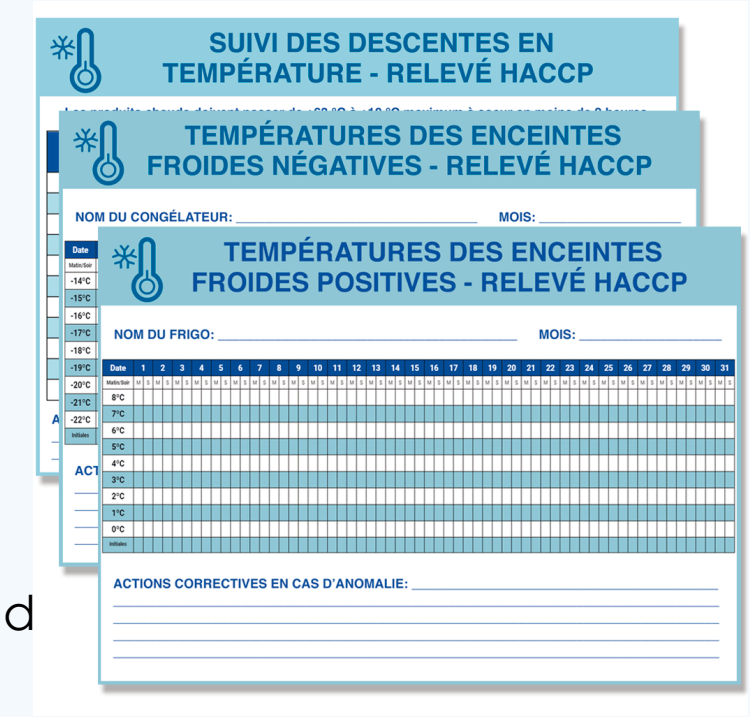
Controls and Sanctions
Vigilance and Consequences

Customs Inspections:
Verification of ATP certificates, temperature readings, sensor calibration.
Example: 10% of trucks inspected upon import into the EU (2023 report).

Sanctions :
Fines of up to €500,000 (EU) or $1 million (FDA) for non-compliance.
License suspension (e.g., pharmaceutical company in India in 2022).

Case Study (Optional)
Spoiled Meat Scandal (Brazil, 2017)

Facts: Transport without ATP → contaminated meat exported to the EU and China.
Consequences :
Loss of $1.5 billion for the Brazilian sector.
Strengthening of ATP controls in European ports.



Maintenance and Upkeep

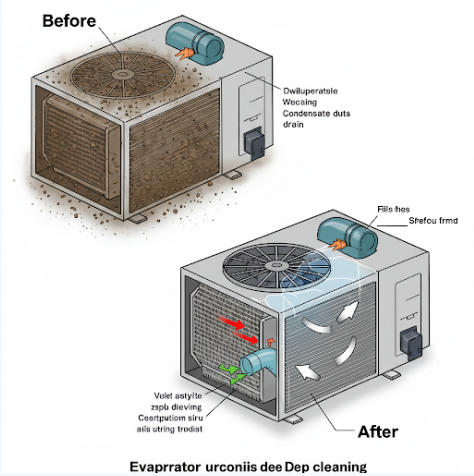
1. Mechanical Compression Systems (Most Common)

- **Compressor :**
  - Regularly check the oil level and belt tension.
  - Clean the air filters and check for abnormal vibrations
- **Condenser :**
  - Clean the fins (clean with compressed air or a fresh water jet).
  - Check for refrigerant leaks.
- **Evaporator :**
  - Regularly de-ice if excessive icing occurs.
  - Inspect drains for blockages.
- **Refrigerant :**
  - Check the level and pressure (recharge if necessary with a gas that meets environmental standards, e.g., R-452A, R-744).
  - Check for leaks with a halogen or UV detector.
- **Thermostat and Sensors :**
  - Calibrate to ensure a stable temperature (check deviations with an external thermometer).
  - Replace the batteries in wireless systems.

1) Panneau supérieur de ventilation pour le renouvellement d'air frais. À l'intérieur se trouvent : Ventilateur d'évaporateur n ° 2, capteur de température de dégivrage (DTS)
2) Panneau d'accès. À l'intérieur se trouvent : Ventilateur d'évaporateur n°1, vanne de détente électronique (EEV), thermostat de terminaison de la chaleur (HTT)
3) Prises pour élévateurs à fourche
4) Panneau de commande
5) Écran de l'appareil
6) Clavier
7) Réceptacle de surveillance à distance (si équipé)
8) Interrupteur marche-arrêt (ST)
9) Compresseur
10) Panneau d'accès pour capteur de température de soufflage (STS) / capteur d'enregistrement de soufflage (SRS)
11) Sonde de température ambiante (AMBS)
12) Échangeur de chaleur de l'économiseur
13) Étiquette d'options
14) Plaque signalétique de l'unité
15) Câbles et prises électriques
16) Emplacement de l'autotransformateur (si équipé)
17) Hélice condenseur

Maintenance and Upkeep

2. Cryogenic Systems (CO_2 or Liquid Nitrogen)



Evaprrator urconiis dee Dep cleaning

- **Cryogenic Tanks :**

Inspect walls for corrosion or microcracks.
Test safety valves and seals

- **Safety :**

Train operators on the risks of burns and asphyxiation.
Check gas leak detectors in the loading area.

- **Recharge :**

Use certified suppliers for refilling cryogenic fluids.
Store tanks in ventilated areas away from heat.

Maintenance and Upkeep

3. Eutectic Systems (Cold Storage Plates)

❑ **Eutectic Plates:**

- Check the integrity of the plates (no cracks or corrosion).
- Check the concentration of the eutectic solution (adjust if necessary).

❑ **Recharge :**

- Connect the system to the mains for 8 to 12 hours for complete freezing.
- Ensure that the electrical heaters are functioning properly.

❑ **Insulation :**

- Inspect the joints between the plates and the truck structure.

Maintenance and Upkeep

4. Electrical Systems (Battery or Hybrid)

❑ **Batteries :**
- Check battery life and charge/discharge cycles.
- Clean terminals to prevent oxidation.

❑ **Generator:**
- Change oil and filters at the recommended intervals.
- Test starting under real-world conditions.

❑ **Wiring :**
- Inspect high-voltage cable insulation to prevent short circuits.

Maintenance and Upkeep

General Maintenance Practices

- **Daily Inspection:**
  Monitor temperatures before and after loading.
  Check door seals (door seal test with a piece of paper)

- **Cleaning :**
  Disinfect the truck interior with non-corrosive products.
  Avoid ice or standing water buildup.

- **Documentation :**
  Keep a maintenance log with service dates, fluid levels, and interventions.
  Record temperatures for traceability (HACCP/ISO requirements).

Key trends and technological innovations

Sustainability
Green vehicles for responsible refrigeration

Warehouse automation:
Autonomous robots for loading (e.g., AutoStore).Gains:
+25% productivity, -15% waste (McKinsey).

Blockchain and Traceability
Transparency and Digital Trust

How it Works :
Each step (production, transportation, delivery) is recorded in a tamper-proof log.
Example: Walmart traces mangoes in 2 seconds vs. 7 days previously.

Applications :
Pharma: Guarantee vaccine integrity (e.g., Moderna with SAP).
Food: Identify sources of contamination in real time.

«Tomorrow's cold will be smart, or it won't be. »

شكرا

Merci

Thanks

Gracias

Obrigado