GLOBAL COLD CHAIN NEWS

SPECIAL REPORT: CRYOGENIC TRUCK REFRIGERATION WITH NITROGEN

Editors
Dean Stiles T: + 44 (0) 1304 228196
E: dean.stilesglobalcoldchainnews.com

Sally Nash T: + 44 (0) 1304 22819

Advertising and publishing
David Crawford T: +44 (0) 208 643 4948
E: david.crawford@globalcoldchainnews.com

Subscriptions
www.globalcoldchainnews.com
Tina Massey tel: +44(0)1326 560420
E: tina.massey@globalcoldchainnews.com

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There is a global resurgence of interest in cryogenic refrigeration using liquid nitrogen as operators look for viable alternatives to diesel powered truck refrigeration systems. We report on the latest trials of prototype systems.

Nitrogen alternative to diesel powered truck fridges

Gas suppliers such as Air Liquide and Linde Gas, and specialist refrigeration equipment suppliers such as EcoFridge, have developed systems that demonstrate in field trials that liquid nitrogen is viable alternative to diesel for truck refrigeration.
EcoFridge says its systems for trucks and trailers have performed well in trials in a cross section of operations over the last two years in Israel, South Africa, France, the UK and North America.
The company's longest 'full time' trial is 20 months with Asda, a UK Wal-Mart subsidiary. The trial involved seven semi-trailers with dual temperature systems operating at -20 and +3 degrees C.
A study by Cambridge Refrigeration Technology in the UK, commissioned by EcoFridge, compared a nitrogen-powered unit against a conventional diesel powered fridge unit and found the nitrogen system substantially better on operating costs and performance.
These findings compare with similar studies undertaken by other companies. CO2 savings as high as 88% can be made according to a study undertaken by Air Liquide that compared cryogenic and diesel refrigeration systems operating in France and the US.
On fuel alone, for every litre of diesel burned, 2.63kg of carbon is released into the atmosphere. If a diesel driven refrigeration system uses 4-litres per hour and operates for 2, 500 hours per year, 26.3 tonnes is released into the atmosphere.
When estimating the overall energy consumption from extraction to consumption, liquid nitrogen systems reduce carbon emissions by a factor of 4 according to the LCA Report, Carbon Emission Report: Energy Lifecycle Assessment in Truck Refrigeration, produced in January 2007 by MWH Global.
Governments in France, UK and California in the US have already decided to push private companies to estimate their carbon footprint. Several food retailers such as Tesco, Wal-Mart, Metro, and Casino, expect to communicate their carbon footprint on product labelling. Large companies such as Cadbury, Coca- Cola, Rhodia, and Sony have committed to reduce their CO2 emissions and actively seek low carbon alternatives in transport and refrigeration.
The Air Liquide study of transport refrigeration considered two countries, France with a low CO2 emission per kWh and the US with a high CO2 emission per kWh. For transport operations, direct CO2 emissions are calculated from a full truck delivery with the bulk ratio (average mileage per delivered volume) and taking into account leaks during filling.
The study compared the total CO2 emitted by a cryogenic cooling system using a direct injection of liquid nitrogen with the CO2 emitted by a diesel-mechanical system. The study uses a semi-trailer carrying frozen products. The carbon footprint calculation takes into account the first pull-down and cooling during shipping. Losses from door openings for the deliveries are also included. The calculation is done for a year of 300 days of 8 hours each with an average of 5 door openings per day during the year.
The calculation considers two sources of CO2 emissions for diesel-powered refrigeration: those due to diesel combustion and to leakages of refrigerants. Using liquid nitrogen eliminates these CO2 emissions and those linked to the production of liquid nitrogen are included.
The results demonstrate that cryogenic refrigerated transport has a positive impact on the environment with green house gases emissions (CO2 and refrigerants) drastically reduced says Air Liquide in the report.

Annual CO2 emissions: diesel vs liquid nitrogen in USA and France

Per vehicle	Mechanical cooling	Liquid Nitrogen Cooling	
		USA	France
Diesel			
Consumption [1]	14,470L diesel/year		
Emission factor [2]	2.94kg **eq CO2/l**		
CO2 emissions	42.5tonnes **eq CO2/y**		
Refrigerants			
Losses [3]	1.35kg/year		
Emission factor [4]	3743.4kg eq CO2/kg of liquid		
CO2 emissions	5.1tonnes **eq CO2/y**		
Liquid Nitrogen			
Consumption		89,467L LIN/y	60,837m3 LIN/y
Emission factor		0.092kg **eq CO2/m3**	0.470kg **eq CO2/m3**
CO2 emissions		28.6tonnes **eq CO2/y**	28.6tonnes **eq CO2/y**
Total CO2 emissions	47.6tonnes **eq CO2/y**	5.6tonnes **eq CO2/y**	28.6tonnes **eq CO2/y**
CO2 saving		88%	40%

The figures above relate to frozen products. For chilled products (+4°C) the result would be: 24.5 tons eqCO2/y for mechanical cooling, versus 1.1 tons eqCO2/y in France or 5.7 tons eqCO2/y in the US for cryogenic cooling with LIN. **Source: IM-WBL Carbon Footprint Air Liquide Products & Offers Dec 2007**

Notes
1 Calculation supplied by Air Liquide
2 Emission factor of diesel in kg equivalent CO2 per litre, including extraction, refining, transport and combustion
3 On average, 15% of the refrigerant is lost each year per vehicle
4 Emission factor of R404a fluid in kg eqCO2 per kg of fluid. Source: Air Liquide

Linde Gas trials cryogenic refrigeration

Pullach, Germany: Linde Gas has developed a prototype cryogenic refrigeration system called Frostcruise for truck and trailer use. The system uses liquid nitrogen in a closed system as the coolant and is on trial in the UK and in use in Malaysia with a fast-food chain.

Gist, a Linde Group temperature control distribution company in the UK is currently trialling the system on a contract with a major UK food retailer that has had previous experience of cryogenic systems in its temperature-controlled transport operations. The trial will evaluate the system and allow Linde to collect data on operating costs and CO2 savings.

The UK trial system is fitted to an 18-tonne rigid vehicle but a version for semi-trailer use will be developed soon, says Simon Handley at Linde Group. The system has chill and frozen capability.

Linde opted for a closed system to address safety issues associated with direct systems where there is a risk of operators entering the oxygen-depleted load space. The indirect system uses a heat exchanger which means there is a breathable atmosphere in the load space.

"We have developed a safe indirect system as a standardised offering," Handley said. "The system ensures temperature is controllable for required periods of time and allows for single- or multi-temperature compartments."

Apart from the low-carbon benefits of using liquid nitrogen and avoiding organic gas refrigerants, Frostcruise provides a low noise alternative to diesel-powered systems. "Frostcruise is more efficient than a mechanical diesel-powered equivalent, it is lighter and has reduced service costs," he says.

Operators need appropriate nitrogen storage facilities to refill tanks on vehicles. Typically, a minimum of five vehicles would justify the additional infrastructure costs.

One of the benefits for European operators subject to noise limits is low operational noise in comparison to diesel powered fridge units. Linde's system produces 60db so can be used in low noise areas.

The nitrogen tank takes 8 to 10-minutes to fill- designed to take about the same time to fill the diesel tank.

The rigid test truck has a 430L liquid nitrogen tank which gives 8-hours endurance chilled – 6 hours frozen – using 40 to 50L/hr chilled and 60 to 70L/hr for frozen based on data from Malaysia at 40C ambient.

APT in Europe

The transport of perishable food products, other than fruit and vegetables, and the equipment used for the carriage of these products is governed by the APT agreement drawn up by the Inland Transport Committee of the United Nations Economic Committee for Europe in 1970-1971. APT sets common standards for temperature controlled transport vehicles such as road vehicles, railway wagons and sea containers and the tests to be done on such equipment for certification purposes.

The refrigeration equipment installed on a refrigerated vehicle must also possess a valid ATP capacity report. The agreement states that new refrigeration equipment installed on a refrigerated vehicle must have a heat extraction capability at the class limit temperature of at least 1.35 times the heat transfer through the walls in a 30 °C ambient temperature and 1.75 times if the refrigeration unit was tested separately outside the vehicle to determine its effective cooling capacity at the prescribed temperature.

The ATP certificate ensures that a third party has tested the insulated body and the refrigeration unit and that the two have been appropriately matched. An ATP certified vehicle or body could carry a single certificate that covers the insulated body and the refrigeration unit. The ATP certificate is valid for six years but can be extended by another three years on condition that an 'in service' examination is carried out. There are concerns, however, that in-service testing procedures are not stringent enough and may lead to increased energy consumption.

In the UK the average number of ATP certificates issued in one year is approximately 1500. ATP certified bodies frequently operate in service for 9 to 12 years depending on the type of operational service impacting on the body.

Legislation and regulation

The UK, like other European Union member states, imposes very stringent controls on food transport specifying temperatures during the storage and transport of all perishable foods. These regulations, revised in 2006, and regulation EC No 852/2004 on the Hygiene of Foodstuffs, require manufacturers to have suitable temperature controlled handling and storage facilities that can maintain food at appropriate temperatures and enable these temperatures to be monitored, controlled and recorded. There are also specific temperature requirements for certain categories of food; examples are shown the table below. The UK has also implemented specific chill temperature control requirements for foodstuffs not covered by EC No 853/2004. These requirements apply to food which is likely to support the growth of pathogenic micro-organisms or the formation of toxins. Such food must be kept below 8 ºC unless the manufacturer recommends otherwise, but this must be based on well-founded scientific assessment of the safety of the food at the specified temperature. There are also very limited chill holding tolerance periods where product may be above the minimum but this must be consistent with food safety requirements, for example during transfer from storage depot to transport vehicle.

Transport temperature requirements of food products

Products	Temperature (oC)
Chilled Products	
Fresh fish (in ice), crustaceans and shellfish (excluding live ones)	+2
Cooked dishes and prepared foods, pastry creams, fresh pastries, sweet dishes and egg products	**+3**
Meat and cooked meats pre-packaged for consumer use	+3
Offal	+3
Poultry, rabbit and game	+4
Non-sterilized, untreated, unpasteurised or fermented milk fresh cream, cottage cheese and curd	+3
Milk for industrial processing	+6
Cooked meats other than those which have been salted, smoked, dried or sterilized	+6
Frozen Products Temperature	
Ice and ice cream	-25
Deep frozen foods	-18
Fishery products	-18
Butter and edible fats, including cream to be used for butter making	-14
Egg products, offal, rabbit, poultry and game	-12
Meat	-10

Source: Carrier Transicold Europe

Nitrogen Cryogenics - Direct vs Indirect

Field trials of nitrogen cryogenic systems demonstrate the viability of cryogenics for on-board vehicle refrigeration. Gas suppliers such as Air Liquide, Linde Gas and specialist refrigeration equipment suppliers such as EcoFridge have collected data on operating costs and fridge performance that show that nitrogen cryogenic systems are an alternative to diesel driven refrigeration systems.

Using nitrogen as a refrigerant for road trailer applications is not new: systems were available in the 1960s and in the 1980s BOC Gases marketed its Polarstream system in the United Kingdom which was used by retailer Marks and Spencer on its temperature controlled food distribution.

There are two approaches to system design: direct systems where the liquid nitrogen is released into the load space for cooling and indirect systems that use a heat exchanger with the liquid nitrogen to cool air circulated in the load space.

Nitrogen is an inert gas composing the largest part of the atmosphere so is harmless, however, in a direct refrigeration system there is risk if operatives enter an oxygen-free load space.

This is one of the reasons for Linde Gas's closed system currently on trial with Gist in the UK and later this year with a large food retailer. The system is currently used in Malaysia with a major burger chain that is shortly to increase its distribution operation with more Linde systems.

Direct systems such as that offered by EcoFridge system use a 'fail safe' to ensure that operatives cannot compromise their safety. Nitrogen is released as a refrigerant into the trailer's loading area only when the doors are closed. Should an operative become enclosed in the load space, an independently powered, illuminated press-button will instantly close the system down. As soon as the doors are opened, the oxygen analyser and warning system automatically checks the internal atmosphere and will not allow entry until the requisite oxygen level is achieved. In multi compartment trailers, each compartment has an independently powered oxygen analyser and warning system with cable and bulkhead locks to prevent access to load spaces until venting is complete.

There are pros and cons for direct and indirect systems. Indirect systems using cold air from cooled pipe work are up to 30% more costly to run since they need more nitrogen to achieve temperature for frozen product.

There are moving parts such as fans needed to circulate the cold air in the load space, which will add to maintenance costs and will mean some low noise, 60db on Linde's system.

Indirect systems take longer to pull down to set point so more standing time needed and they are slower to return to set point after each door opening.

> Direct systems require a venting period when the operator must wait for 90 - 120 seconds for the atmosphere to return to 18% oxygen inside the box before entering."

There is a high power requirement to operate fans requiring a charge source or the system cannot operate. This is an issue with deep frozen at any speed.

Continuity of temperature inside the box can be an issue as moving air will often result in some spots being warmer than others. And as with standard diesel systems, air movement is likely to cause some shrinkage and weight loss.

Temperature distribution is very consistent and more stable than that of mechanical systems, the pull down is up to 50% quicker.

On the plus side there is minimal safety risk from operatives entering an oxygen depleted load space and the benefit that product can be unloaded/loaded immediately without the need toallownitrogen gas to disperse from the confined area in the trailer/vehicle.

Direct systems, where nitrogen is released as vapour into the load space, require various safety measures to guard against personnel entering or being trapped in an area where oxygen is low or non-existent.

Direct systems require a venting period when the operator must wait for 90 - 120 seconds for the atmosphere to return to 18% oxygen in side before entering.

On the plus side, direct systems have faster pull down, faster return to set point, and less standing time. They offer more constant temperature throughout the box and there are no moving parts, thus reducing maintenance and upkeep costs and down time. There is virtually no shrinkage or weight loss, which improves value and shelf life; they are silent and there is no top freezing.

Vehicle operators using liquid nitrogen refrigeration need to run a minimum of five vehicles, and ideally larger fleets are needed to get economies of scale, in order to justify the additional infrastructure costs involved for bulk gas storage and vehicle filling points on site. Gas supply companies will provide this.

Diesel powered fridge alternatives

Transport refrigeration systems are predominantly based on the vapour compression refrigeration cycle. Articulate vehicles over 33-tonnes are responsible for over 80% of refrigerated food transportation in the UK and the refrigeration systems in these vehicles are invariably driven by auxiliary diesel engines.

To meet the requirements of the ATP agreement and satisfy the refrigeration demands over a wide range of operating conditions transport refrigeration systems are oversized by up to 1.75 times the calculated load. Fuel consumption of auxiliary diesel engines is approximately 2 l/hr, that is 8% of vehicle main engine consumption.

There are alternatives with commercially available cryogenic systems using nitrogen and CO2. Other new technologies that may have commercial application include use of the engine exhaust gas heat. Sufficient reject heat is available from the engine of articulated vehicles to drive sorption refrigeration systems at normal out of town driving conditions but insufficient heat will be available in town driving. This shortcoming can be overcome through the use of an auxiliary heat source or eutectic energy storage.

Air cycle technology has food transport applications but the main disadvantage at present is the low coefficient of performance compared to that of the vapour compression system, particularly for chilled food distribution applications, and the unavailability of off the shelf components.

Direct power generation from the heat in the exhaust of the engine to power refrigeration systems may be a promising technology for the future. Other technologies that need further investigation and consideration are stirling cycle powered systems, magnetic refrigeration and solar energy driven systems.

Nitrogen refrigeration systems in action

Germany:
Air Liquide sells a liquid nitrogen refrigeration marketed as Cryogen Trans. Cryogen Trans provides single and multi-compartment vehicles with versions available for trucks, trailers, containers and semi-trailers.
The system uses an adjustable temperature controller that sprays liquid nitrogen into the cargo bay via a spray pipe. The liquid nitrogen vaporises and displaces the oxygen from the air in the cargo bay. The heated nitrogen gas escapes to the outside via a pressure equalisation flap.
The liquid nitrogen is stored on the vehicle in a pressurised tank with working pressure of 5 bar.
The system, fully loaded weighs between 314kg and 622kg depending on vehicle and load-body type. Appropriate safety devices are fitted to load space doors to ensure the nitrogen is vented from the body before operators enter the unit.
The system is sold in Germany although the company has some test vehicles on the road in neighbouring Switzerland.
Cryotherm produces 70% of the system with valves, ventilation systems, thermal and pressure indicators bought in the market.
"The installation can be done by ourselves but most of the customers do prefer the installation done by their bodybuilder," said Dr Franz Lürken at Air Liquide Deutschland.

United Kingdom:
EcoFridge sells it system in the UK and has run an extended trial with the Asda supermarket chain, a Wal-Mart subsiduary,. Linde Gas's is trialling its Frostcruise system in the UK through BOC and Gist, both Linde Group companies. Gist is testing a prototype installation on a rigid truck on a contract with a major UK food retailer.
The retailer has had previous experience of cryogenic systems in its temperature-controlled transport operations.
The trial will allow Linde to collect data on operating costs and CO2 savings.
Simon Handley at Linde Group says: "We have developed a safe indirect system as a standardised offering,"
"The system ensures temperature is controllable for required periods of time and allows for single or multi temperature compartments."

Malaysia:
Linde Gas's Frostcruise system is in use in Malaysia with a fast food chain that plans to increase its distribution chain with more similar Linde systems.

South Africa:
Transfrig, which manufactures and supplies of its own transport refrigeration systems, sells EcoFridge's nitrogen powered transport refrigeration systems in South Africa.
Peter Solomon, managing director of Transfrig said: "EcoFridge suits truck and trailer temperature controlled transport and is highly effective both for mono and multi temperature configurations.
"The system is remarkably simple to operate, safe, economical and of course friendly to the environment – typically one EcoFridge system can save around 25 tonnes of carbon per trailer per year."

Australia:
MaxiTrans is running field trials of EcoFridge units to confirm the suitability of EcoFridge for local operating conditions and to collect data on operating benefits prior to making it available for sale.

Vehicle insulation technology

Most temperature-controlled transport is done with semi-trailers (articulated vehicles) with insulated rigid bodies.
In Europe the typical construction dimensions of a semi-trailer rigid box are are 13.56m in length, 2.6m in width and 2.75m in height with internal dimensions of 13.35m, 2.46m, and 2.5m.
Refrigerated trailer design is a compromise of many factors: extremes of exterior weather conditions, desired interior conditions, type of load, insulation properties, infiltration of air and moisture, construction cost, operating costs and physical deterioration from shocks and vibrations.
A rigid semi-trailer box usually consists of expanded foam insulation sandwiched between two external skins. Each skin consists of a few millimetres of plywood covered with a glass reinforced polyester, steel or aluminium skin. The most popular insulation is expanded polyurethane (PU) foam with cyclopentane as the blowing agent. This construction achieves a thermal conductivity in the region of 0.022 W/(m K).
Sidewall thickness is constrained by the maximum permissible insulated vehicle width of 2.60m and euro-pallet dimensions of 1m 1.20m. This construction can accommodate 2 euro-pallets side by side but insulation thickness is limited.
Another popular insulation material is extruded polystyrene. The thermal conductivity of this insulation is higher than PU foam but in floor and roof construction where there are fewer constraints for overall thickness, body builders can offset thermal losses by using thicker panels.
Roofs and floors often have 100 mm or more insulation. In sidewalls, the constraints mean the insulation is rarely more than 45-50 mm thick.
Other techniques use vacuum insulated panels. German trailer maker Krone developed a process where the insulation plate consists of pressed powder wrapped with high barrier plastic film. Air is evacuated to create the vacuum before the panel is sealed so that the vehicle body behaves like a vacuum flask.
The performance of insulation materials deteriorates with time due to the inherent characteristics of foam. Research shows a typical loss of insulation value of between 3% and 5% per year. At 5% after nine years of operation there is a 50% increase in energy consumption and CO2 emissions.
Given the large number of refrigerated vehicles and containers in use worldwide the global impact of the reduction of insulation effectiveness is large.

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Editorial Office
Dean Stiles T: + 44 (0) 1304 228196
E: dean.stilesglobalcoldchainnews.com

Marketing and Sales
David Crawford T: +44 (0) 208 643 4948
E: david.crawford@globalcoldchainnews.com

Subscriptions and Administration Office
www.globalcoldchainnews.com
Tina Massey tel: +44(0)1326 560420
E: tina.massey@globalcoldchainnews.com

Commercial Transport Publishing Limited
39a Meneage Street, Helston,
TR13 8RB, United Kingdom

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Company number: 6453302

Registered office: 6 Corunna Court, Corunna Road, Warwick CV34 5HQ, United Kingdom

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