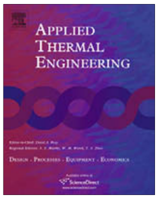
Applied Thermal Engineering 29 (2009) 1467–1477

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng



Food transport refrigeration – Approaches to reduce energy consumption and environmental impacts of road transport

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ARTICLE INFO

Article history:
Received 29 January 2008
Accepted 18 June 2008
Available online 2 July 2008

Keywords:
Refrigerated transport
CO_2 emissions
Alternative refrigeration technologies
Energy conservation

ABSTRACT

Food transport refrigeration is a critical link in the food chain not only in terms of maintaining the temperature integrity of the transported products but also its impact on energy consumption and CO_2 emissions. This paper provides a review of (a) current approaches in road food transport refrigeration, (b) estimates of their environmental impacts, and (c) research on the development and application of alternative technologies to vapour compression refrigeration systems that have the potential to reduce the overall energy consumption and environmental impacts. The review and analysis indicate that greenhouse gas emissions from conventional diesel engine driven vapour compression refrigeration systems commonly employed in food transport refrigeration can be as high as 40% of the greenhouse gas emissions from the vehicle's engine. For articulated vehicles over 33 ton, which are responsible for over 80% of refrigerated food transportation in the UK, the reject heat available form the engine is sufficient to drive sorption refrigeration systems and satisfy most of the refrigeration requirements of the vehicle. Other promising technologies that can lead to a reduction in CO_2 emissions are air cycle refrigeration and hybrid systems in which conventional refrigeration technologies are integrated with thermal energy storage. For these systems, however, to effectively compete with diesel driven vapour compression systems, further research and development work is needed to improve their efficiency and reduce their weight.

1. Introduction

The commercial food sector, including agriculture, food manufacture transport and retail is responsible for 22% of the UK's total greenhouse gas emissions. Food distribution and retail accounts for approximately one third of this, with food transport estimated to be responsible for 1.8% of total emissions [1].

Road transport refrigeration equipment is required to operate reliably in much harsher environments than stationary refrigeration equipment. Due to the wide range of operating conditions and constraints imposed by available space and weight, transport refrigeration equipment have lower efficiencies than stationary systems. This, together with increasing use of refrigerated transport arising from the much wider range of transported goods, home delivery and greater quality expectations, are placing considerable pressures on the food industry to reduce the energy consumption of refrigerated transport. The reduction in energy consumption, however, cannot compromise the temperature control of the transported food products which is governed by legislation.

EU and UK legislation covers temperature control requirements during the storage and transport of perishable foods. These regulations have been revised in early 2006 and regulation EC No. 852/2004 on the Hygiene of Foodstuffs requires 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 [2,3].

The transport of perishable food products, other than fruit and vegetables, and the equipment used for the carriage of these products is governed by an agreement drawn by The Inland Transport Committee of the United Nations Economic Committee for Europe in 1970–1971 [4]. The agreement is known as the ATP agreement and its aim is to facilitate international traffic by setting common internationally recognised standards for temperature controlled transport vehicles such as road vehicles, railway wagons and sea containers.

The ATP classifies insulated vehicles and bodies as either Normally Insulated Equipment (IN, isotherme normal: U coefficient equal or less than 0.7 $W/m^2\,K$) or Heavily Insulated Equipment (IR, isotherme renforcé: U coefficient equal or less than 0.4 $W/m^2\,K$). The overall heat transfer coefficient can be calculated from:

$$U = \frac{Q}{S}\,(\mathrm{W/m^2\,K})$$

where Q is the heat flow through the insulated walls per degree difference between the air temperature inside and outside the body (W/K) and S is the mean section of the body, which is the geometric

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doi:10.1016/j.applthermaleng.2008.06.027

mean of the inside surface area, I, and the outside surface area, O of the body. The mean section can be calculated from:

$$S = \sqrt{OI}.$$

The ATP also classifies refrigeration and heating equipment in terms of temperature control at −20, −10, 0 and +12 °C. The most common ATP classification for equipment, FRC, certifies it for all temperature classes.

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 the insulated body and the refrigeration unit have been tested by a third party and that the two have been appropriately matched [5]. An ATP certified vehicle or body could carry a single certificate that covers both the insulated body and the refrigeration unit.

The ATP certificate is valid for 6 years but can be extended by another 3 years on condition that an “in service” examination is carried out [3]. There are concerns, however, that in service testing procedures are not stringent enough and this may lead to higher energy consumption than necessary [6,7]. In the UK, the average number of ATP certificates issued in 1 year is approximately 1500. ATP certified bodies frequently operate in service for 9–12 years depending on the type of operational service impacting on the body [3].

This paper reviews technologies and approaches currently employed in food transport refrigeration and their environmental impacts. The impacts are expressed in terms of greenhouse gas emissions arising from the fuel consumption of the vehicle and refrigeration system engines and refrigerant leakage to the environment. The emissions are expressed in ‘kg CO_2 per pallet km’ which can easily be converted to kg CO_2 per kg or litre of product per km. The data presented will facilitate the determination of the carbon footprint arising from the transportation of both ambient and refrigerated food products and will contribute to the overall effort to quantify and reduce the carbon footprint of the food chain. The paper also reviews research into the development and application of alternative refrigeration technologies for transport applications that could lead to a reduction in energy consumption and environmental impacts.

2. Technologies currently in use in food transport refrigeration

2.1. Vehicles

The majority of refrigerated road transportation is conducted with semi-trailer insulated rigid boxes. In Europe the external length and width of a semi-trailer rigid box are fixed but the external height and internal dimensions can vary depending on the individual design type. These dimensions are as follows [3]:

External dimensions: 13.56 m length, 2.6 m width and 2.75 m height.
Internal dimensions: 13.35 m length, 2.46 m, width and 2.5 m height.

Many factors are considered in the design of the envelope of a refrigerated transportation unit: extremes of exterior weather conditions, desired interior conditions, insulation properties, infiltration of air and moisture, tradeoffs between construction cost and operating cost and physical deterioration from shocks and vibrations.

A rigid semi-trailer box normally 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. Another popular insulation material is extruded polystyrene. The thermal conductivity of extruded polystyrene 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. In side walls, the insulation thickness is constrained by the maximum permissible insulated vehicle width of 2.60 m and europallet dimensions. A europallet is 1.0 m deep by 1.20 m wide and the need to accommodate 2 europallets side by side means that the insulation thickness can rarely be more than 45–50 mm.

The performance of insulation materials deteriorates with time due to the inherent foam characteristics. Recent data show a typical loss of insulation value of between 3% and 5% per year which can lead to considerable rise in the thermal conductivity after a few years [6,8]. If a 5% yearly ageing is assumed, a vehicle with an initial K-coefficient of 0.4 W/m^2 K will have a K-coefficient of 0.62 W/m^2 K after 9 years of operation, resulting in a 50% increase in energy consumption and CO_2 emissions. If one considers the large number of refrigerated vehicles and containers in use worldwide, the global impact of the reduction of insulation effectiveness is considerable.

2.2. Refrigeration units

The most common refrigeration system in use for refrigerated food transport applications today is the vapour compression system. Mechanical refrigeration with the vapour compression cycle offers a wide range of options for compressor drive methods. The choice may be based on duty required, weight, noise requirements, maintenance requirements, installation cost, environmental considerations and fuel taxation. The performance and power requirements of these systems are normally assessed at full load. In reality however, transport refrigeration systems operate over a wide range of loads. To match the varying load, the refrigeration system is either switched on and off or its capacity is modulated to maintain the set temperature with a consequent reduction in efficiency. Depending on the system design envelope, the expected coefficient of performance (COP) is generally in the range between 0.5 and 1.5.

The most common drive systems for refrigerated transport vapour compression systems are [3,9]:

Vehicle alternator unit: with this method which is commonly used in small delivery vans, the vehicle engine crankshaft drives an upgraded single alternator and a 70 Ah battery. The alternator charges the vehicle battery which feeds a small refrigeration system with 12 V d.c. supply. The system can also be driven with a 230 V mains electric supply during standby.

Direct belt drive: with this system, which is used in the majority of van size vehicles, the compressor of the refrigeration unit is directly driven from the vehicle engine through a belt.

Auxiliary alternator unit: this system uses a dedicated large alternator driven by a belt from the main traction engine, generating power to drive an electric motor in the refrigeration unit. Fan motors for the heat exchangers and the control system are also fed from the alternator output. An alternative arrangement for an alternator system is to use a diesel generator system.