Refrigerated Transport

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Contributor: Angelo Maiorino

The cold chain is responsible for perishable products preservation and transportation, maintaining a proper temperature to slow biological decay processes. Often the efficiency of the cold chain is less than ideal, significantly increasing food waste and energy consumption. Refrigerated transport is a critical phase of the cold chain because of its negative impact on energy consumption and greenhouse gas emissions.

Keywords: refrigerated transport ; environmental impact ; refrigeration ; renewable energies ; sustainability ; carbon dioxide ; cold chain ; vaccine ; PCM

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1. Introduction

The growing need to ensure the preservation of perishable goods (foodstuffs, pharmaceuticals or similar products), together with the widespread use of refrigeration systems since the twentieth century, has led to an ever-increasing interest in the process that is commonly called the “cold chain”. This expression indicates the path, from the producer to the consumer, followed by the products that need to be maintained at a controlled temperature. The cold chain can be divided into five main phases:

- Production/Packaging;
- Storage;
- Transport (also present among other phases);
- Sale;
- Preservation (consumer).

2. Importance of Vapor Compression Refrigeration (VCR) Units in Refrigerated Transport

Vapor Compression Refrigeration (VCR) units are the most used systems (market share of 80% [1]) in refrigeration (industrial, commercial, domestic, refrigerated transport) and air conditioning (domestic and automotive) applications. These systems are responsible for the consumption of about 15% of the world’s electrical energy and contribute about 10% to greenhouse gas emissions [1]. In particular, VCR systems cause indirect emissions, related to the production of electrical/mechanical energy for the compressor supply, and direct emissions, due to the loss of refrigerant charge that occurs over time (up to 30%/year depending on the application [2]).

Refrigerant leakage also causes a reduction in the efficiency of the refrigeration system and, therefore, an increase in energy consumption and greenhouse gas emissions [3]. The most widely used refrigerants are HydroFluoroCarbons (HFCs), which are going to be phased out of the regulation EU No. 517/2014 [4] because of their high Global Warming Potential (GWP).

Numerous studies are still underway in order to reduce greenhouse gas emissions related to refrigeration and air conditioning systems by replacing HFCs with new refrigerants [5][6]. Although direct emissions due to refrigerants with low GWP are negligible compared to the case of HFCs, the increase in energy consumption (and consequently indirect emissions) due to the loss of refrigerant charge is significant [7]. A critical review of the parameters used for the assessment of the environmental impact of RACHP (Refrigeration, Air Conditioning, Heat Pump) systems has been conducted by Mota-Babiloni et al. [8].

It is estimated that about a third of global food products is lost or wasted along the food chain before reaching the consumer [9]. Perishable food, such as fruits, vegetables, dairy products, meat and fish products, need to be kept at a controlled temperature along the entire supply chain. The low efficiency of the actually used systems can cause product waste. Significant difficulties in this regard are encountered during transport, in particular during loading and unloading operations [10]. Product transport is practiced, in most cases, on the road [10][11] by means of special vehicles having a part of the bodywork thermally insulated and equipped with systems capable of lowering the temperature inside the empty body and maintaining it at a certain value. Food waste during transportation phases can be caused by the following:

- Heterogeneity of air and food temperatures inside the refrigerated compartment, due to the type of the air delivery systems and the load patterns used;
- Increase in air and, consequently, food temperatures due to warm air infiltration that occurs during door openings in loading/unloading operations;
- Insufficient refrigeration capacity.

Further information concerning air infiltration and the temperature distribution inside the refrigerated compartments are respectively reported in Section 5.2 and Section 5.3.

Unlike static refrigeration units, refrigerated transport systems are subject to a strong variability of operating conditions (weather conditions, orientation of insulated walls, frequency of loading/unloading operations). This results in a generally lower COP than corresponding static systems [12].

The thermal load experienced by a refrigerated compartment is mainly given by:

- Transmission load, depending on the shape, size, color of the refrigerated vehicle, the stratigraphy of the insulated walls and the characteristics of the route taken;
- Infiltration load, due to the doors opening/closing cycles during loading and unloading operations;
- Respiration heat load, due to the transformation of sugar and oxygen into CO_2 e H_2O that takes place in fresh products such as fruits and vegetables.

Thermal energy sources inside the compartment also contribute to the total heat load.

The presence of a refrigeration system on a vehicle causes an increase in the engine load due to three factors: additional weight (refrigeration unit and thermal insulation), increase in the front surface and, therefore, in the aerodynamic resistance of the vehicle (due, for example, to the presence of the condenser in the case of a VCR system) and refrigeration unit power supply [13], that is usually obtained by absorbing mechanical energy from the vehicle’s internal combustion engine.

Over the years there has been an increase in the number of refrigerated vehicles circulating, due to an increase in the quantities of products transported. This has led to an increasing energy consumption by the refrigerated transport industry [12][14]. It is estimated that around 15% of global fossil fuel energy is used in the refrigerated transport sector [15]. In the case of VCR systems, the greenhouse gas emissions due to the operation of the refrigeration system, including both direct and indirect emissions, can reach 40% of the total vehicle’s engine emissions [12].

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