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Energy demand and environmental impacts of alternative food transport refrigeration systems

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Abstract

This paper considers the use of liquid carbon dioxide and liquid nitrogen based cryogenic refrigeration systems for temperature controlled food transport applications and provides a comparative assessment of these systems with conventional vapour compression systems driven by an auxiliary diesel engine. Two refrigerated vehicles (one rigid and one articulated), two food products (one chilled and one frozen), and three delivery schedules (long multi-drop delivery, continuous multi-drop delivery, and short delivery) are used for assessment purposes. The analysis indicates that for all cases investigated more cryogenic fluid is required for food transport refrigeration compared to the quantity of diesel. For all delivery schedules, the Well to Wheel environmental impacts of cryogenic systems will be of the same order as those of diesel driven refrigeration systems. Uncertainty of diesel and cryogenic prices in the future makes investment in cryogenic systems difficult on economic grounds alone, and the unavailability of charging infrastructure currently hinders the use of cryogenic refrigeration systems for long distance transportation.

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Keywords: Transport refrigeration; cryogenic TR systems; LCO_2; LN_2; thermal load; distribution schedule; refrigerated transport; environmental impact;

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Nomenclature

$A_{\sec tion}$	Surface area of each section [m^2]
C_p	Specific heat of the product [KJ.kg^{-1}.K^{-1}]
C_{pa}	Specific heat of the air [KJ.kg^{-1}.K^{-1}]
C_{pt}	Specific heat of the insulated body [KJ.kg^{-1}.K^{-1}]
H	Height of the door [m]
h_r	Heat of respiration of produce [kWh/kg]
V	Payload volume [m^3]
k	Thermal conductivity of the material [W.m^{-2}.K^{-1}]
m	Mass of payload [kg]
m_c	Mass of liquid cryogenic expanded [kg]
Q_{cond}	Hourly thermal load due to conduction [kWh]
$Q_{\inf il}$	Hourly infiltration load [kWh]
Q_{pre}	Hourly precooling load [kWh]
Q_{prod}	Hourly product load [kWh]
Q_{rad}	Hourly thermal load due to radiation [kWh]
Q_{resp}	Respiratory heat load [kWh]
$Q_s A^{-1}$	Sensible heat load of infiltration air per square metre of doorway [kW.m^{-2}]
$Q_{pulldown}$	Temperature pulldown load [kWh]
Q_{trans}	Hourly thermal load due to transmission [kWh]
$R_{material}$	Thermal resistance value of the insulating material
R_s	Sensible heat ratio of infiltration heat gain
T_0	Ambient temperature [K]
T_1	Desired thermostat temperature [K]
$UA_{\sec tion}$	Heat flow through each section of the vehicle
W	Width of the door [m]
x	Thickness of the material [m]
X	Conditional variable for the specific hour, '1' if the vehicle is in operation, '0' if the vehicle is not in operation
ϕ_t	Total solar radiation gain during the 24 hours period based on allowance factor
ρ_a	Air density [kg.m^{-3}]

1. Introduction

With one million transport refrigeration units (TRUs) currently operating in the EU and UK accounting for around 84,000 TRUs, the current transport refrigeration sector using diesel powered TRUs is responsible for significant greenhouse gas and particulate emissions [1]. The number of TRUs in the UK is predicted to reach 97,000 by 2025 increasing the amount of diesel that will be required to sustain the growth [2]. Articulated vehicles over 33 tonnes account for 80% of the refrigerated food transportation in the UK.

Cryogenic transport refrigeration (TR) systems using liquid nitrogen (LN$_2$) or liquid carbon dioxide (LCO$_2$) are proposed as alternatives to current diesel-powered vapour compression systems, alongside all electric TR systems [3]. Cryogenic systems offer several advantages, such as, rapid pull-down of temperature, greater load capacity, and very