International Journal of Refrigeration 88 (2018) 337–346

Contents lists available at ScienceDirect

International Journal of Refrigeration

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

Experimental characterization of airflow inside a refrigerated trailer loaded with carcasses

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ARTICLE INFO

Article history:
Received 30 August 2017
Revised 5 January 2018
Accepted 9 January 2018

Keywords:
Refrigerated transport
Pork carcasses
Airflow
Laser droplet velocimetry

ABSTRACT

After slaughtering, pork carcasses should be cooled down in chilled rooms (for 15–20 h) as fast as possible to reach a core temperature of 7 °C before transport to inhibit the growth of spoilage and pathogenic microorganisms. To reduce the time interval between slaughtering and the cutting plant, an alternative solution involving the loading of carcasses with core temperatures higher than 7 °C directly into trailers has been proposed. However, whether or not such a practice will lead to a sanitary risk has to be assessed.

Experimental investigation was carried out in order to characterize airflow distribution in a reduced-scale trailer loaded with reduced-scale polyurethane carcass models. Velocity measurements were conducted using 2D-LDV all around the carcasses. This made it possible to deduce the flow pattern and the order of magnitude of the velocity inside the region occupied by the carcasses.

Caractérisation expérimentale de l'écoulement d'air à l'intérieur d'une remorque frigorifique chargée de carcasses

Mots-clés: Transport frigorifique; Écoulement de l'air à travers des carcasses de porc; Vélocimétrie laser doppler

1. Introduction

Meat carcasses are highly perishable products and their quality depends on the refrigeration conditions used after slaughtering. To prevent quality loss, since 1964 in the European Union, carcasses must be chilled immediately after the post-mortem inspection and kept at a constant core temperature below 7 °C until consumption. The first step in the cooling process in slaughterhouses is designed to lower, as fast as possible, the core temperature of carcasses to prevent the growth of undesirable microorganisms (Kinsella et al., 2006; Savell et al., 2005). Different techniques, e.g. using air or spray chilling, are used, and differ from one slaughterhouse to another. The main challenge in this step is to lower the core temperature without affecting the color, tenderness and water content of carcasses (Létang, 1990; Kuitche et al., 1995; Savell et al., 2005). As a consequence of this regulation, carcasses can be stored in the chilled rooms of slaughterhouses for 15–20 h.

During this operation, heat conduction occurs within the carcass, while heat and water exchanges take place at the air-product interface. These phenomena vary with time and depend on the air parameters. For instance, the temperature difference between the air and the carcass surface affects the heat and moisture fluxes which are also affected by the airflow characteristics (velocity and turbulent intensity) (Mirade et al., 2002). Thus, different studies have been conducted in order to characterize experimentally the airflow distribution inside chilled rooms, to suggest solutions enabling the control of the chilling parameters and to minimize the weight loss of carcasses by means of different modeling approaches (Mirade and Picgirard, 2001; Mirade 2007).

In France, most slaughterhouses are located in the western regions, while cutting facilities are located all over the country. In or-

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https://doi.org/10.1016/j.ijrefrig.2018.01.005
0140-7007/

Nomenclature

R_e	Reynolds number
ρ_m	air density [kg.m^{-3}] in the reduced-scale trailer
ρ_r	air density [kg.m^{-3}] in the real-scale trailer
V_m	air velocity [m.s^{-1}] in the reduced-scale trailer
V_r	air velocity [m.s^{-1}] in the real-scale trailer
L_m	characteristic length [m] of the reduced-scale trailer
L_r	characteristic length [m] of the real-scale trailer
μ_m	air dynamic viscosity [kg.m^{-1}.s^{-1}] in the reduced-scale trailer
μ_r	air dynamic viscosity [kg.m^{-1}.s^{-1}] in the real-scale trailer
L	trailer length [m]
x^*	dimensionless length (x/L)
Q	calculated airflow rate [m^3.h^{-1}]
Q_0	inlet airflow rate [m^3.h^{-1}]
Q^*	dimensionless airflow rate (Q/Q_0)
u	longitudinal velocity [m.s^{-1}]
v	vertical velocity [m.s^{-1}]
$\bar{u}$	time-averaged longitudinal velocity [m.s^{-1}]
$\bar{v}$	time-averaged vertical velocity [m.s^{-1}]
ε	porosity
A	normal section [m^2]
G_r	Grashoff number
β	coefficient of thermal expansion of air
g	gravity acceleration [m.s^{-2}]
ΔT_r	temperature difference between wall of the real trailer and internal air [°C]
ΔT_m	temperature difference between wall of the reduced scale trailer and internal air [°C]

der to provide their clients with acceptable product quality within an acceptable delay, slaughterhouses are now asking for an easing of this regulation. Such a request has been accepted in other European countries, for example in Italy where a national regulation has been created (DL n.286, 1994) and allows carcass transportation prior to the reaching of the European regulatory temperature (≤7 °C). In this case, only brief transport is allowed (Kuffi et al., 2013). The Belgium Scientific Committee of the FASFC used predictive microbiology to conclude that the transport of pork carcasses at temperatures above the regulatory temperature was acceptable for 2 h if carcasses are loaded in the trailer at a surface temperature of 9 °C, or for 3 h with a surface temperature of 7 °C and a core temperature of 12 °C (Anonymous, 2004 and 2008).

However, those studies were conducted using either empirical studies or predictive microbiological tests without taking into account the variability of the transportation step. The refrigerated equipment characteristics, the loading technique, the number of carcasses and the duration of transportation exert an important impact on the airflow pattern and as a consequence, an impact on the core and surface temperature evolution that could affect microbial growth. Non-uniform air distribution inside the trailer was identified by James (1996) as the main problem in refrigerated transport. It is thus necessary to understand the airflow pattern in refrigerated trailers loaded with carcasses.

The airflow distribution in refrigerated trailers used for meat carcass transportation is challenging because of the high length to height ratio, the compact loading and the small air spaces between carcasses. Cold air is blown at the top front of the trailer and warm air return at the bottom. Low air velocity and high product temperature are often observed at the rear (near the doors) and may lead to a sanitary risk. On the contrary, high air velocity and low air temperature at the front may lead to partial product chilling injury

Fig. 1. Photo of a refrigerated trailer with 5 rails loaded with pork carcasses as the studied configuration.

(Savell et al., 2005). To avoid these problems, certain trailers are equipped with air distribution ducts to allow airflow to reach the rear. To our knowledge, no relevant studies have been conducted on the airflow distribution in a trailer loaded with carcasses. The lack of data can be explained by the difficulty encountered when conducting direct measurements of the velocity and airflow rate in such a complex geometry. In order to overcome the complexity when using a real-scale trailer, several studies have been conducted on a reduced-scale trailer loaded with reduced-scale food pallets (Moureh and Flick, 2005, 2004; Moureh et al., 2002, 2009; Tapsoba et al., 2006, 2007). In such studies, the main focus was to analyze the airflow distribution in order to optimize the ventilation efficiency and as a result the refrigeration efficiency within the refrigerated space.

The objective of this experimental work was to study the airflow inside a reduced scale trailer loaded with reduced-scale carcasses arranged in two configurations (with and without air distribution ducts) using 2D Laser Doppler Velocimetry (LDV). From measurements all around the carcasses, the flow pattern inside the region occupied by those obstacles can be estimated and the zones of low air velocity (where a potential microbial risk could occur) can be identified.

2. Materials and methods

2.1. Experimental set-up

The studied transport configuration (number of rails and carcasses, layout) was chosen with respect to the most common conditions encountered in the long-distance transport of pork carcasses (Fig. 1), as observed by our partners, French Pork Institute (IFIP) and French meat companies (Culture Viande).

In this configuration, the refrigerated trailer had an internal length of 13.3 m and could be loaded with 215 pork carcasses. In order to hang the carcasses, the trailer was equipped with 5 rails (Fig. 1).

To conduct our experiments using reasonable dimensions, a reduced-scale trailer with a ratio of reduced-scale to real-scale of 1:3.3 (745 × 757 × 4000 mm) was used. In such a manner, the Reynolds number remained the same in both full-size and reduced-scale trailers.

$$Re_m = Re_r$$