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ABSTRACT

After slaughtering, pork carcasses should be cooled down as fast as possible to reach a core temperature of 7°C (current requirement in European regulation) before transport in order to inhibit the growth of spoilage and pathogen microorganisms. To reach this temperature, carcasses are usually loaded into chiller rooms (15-20 hours) where the rate of cooling is controlled. To reduce the logistic time from slaughter house to cutting plant, a solution is proposed by loading the product into a trailer at core temperatures higher than 7°C. However, we have to assess that such a practice will not lead to a sanitary risk when applied to real scenario. In order to answer this issue, the first step will be to study the airflow characteristics within a trailer filled with pre-chilled pork carcasses.

The objective of this study is to investigate experimentally the air velocity distribution in a reduced scale trailer filled with reduced scale carcass models under isothermal conditions. The 215 carcass models were made of polyurethane foam using a mold obtained by 3D printing based on X-ray scanner of a real carcass. The Reynold number in the experimental device is the same as in a real trailer (Re ~1.3 10^5). In this way, the airflow is similar to that observed in the real conditions. The velocity measurements have been carried out using 2D-LDV equipment (Laser Droplet Velocimetry) at different points in the symmetry plane of the filled trailer model. The analysis of the experimental results allows the understanding of the airflow magnitude and direction, thus, high and low velocity zones can be distinguished.

Keywords: refrigeration, transport, carcasses, airflow, Laser Droplet Velocimetry.

1. INTRODUCTION

Meat carcasses are highly perishable products and their quality depend on the refrigeration conditions used after slaughtering. To prevent quality loss, since 1964 in the European Union, carcasses should be chilled immediately after the post mortem inspection and kept at a constant core temperature of ≤ 7°C until the consumption. The first step of cooling in slaughterhouses intend to cool down, 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 depending on slaughterhouses. The big challenge in this step is to lower the core temperature without affecting the color, tenderness and water loss of carcasses (Létang, 1990 ; Kuitche, 1995 ; Savell et al., 2005). As a consequence of this regulation, carcasses can be stored in chilled rooms of slaughterhouses for 24-48 hours.

In France, most of the slaughterhouses are located in west part while cutting facilities are dispatched all over the country. In order to provide their clients with acceptable product quality in an acceptable delay, slaughterhouses are asking today for an easing of this regulation. Such a request has been accepted in other European countries such Italy where a national regulation has been created (DL n.286, 1994) that allows carcasses transportation before reaching the European regulatory temperature (≤ 7°C). In this case, only short and fast transportation are allowed (Kuffi et al. 2013). The Belgium Scientific Committee of the FASFC used predictive microbiology to conclude that the transport of pork carcasses at temperature above the regulatory temperature was acceptable for 2 hours of transportation if carcasses are loaded in the trailer with 9°C of surface temperature, or for 3 hours with temperatures of 7°C at the surface and 12°C in the core (Anonymous, 2004 and 2008).

Those studies have been conducted using either empirical studies or predictive microbial tests without taking into account the variability of the transportation step. The refrigerated equipment characteristics, the loading technique, the number of carcasses and the transportation duration have an important impact on the core and surface temperature evolution and as a consequence they can affect the microbial growth. In 1996, James explained that the main problem in the cold transportation is the non-uniform air distribution inside the trailer. It is thus necessary to understand the airflow pattern in the refrigerated trailer.

The objective of this experimental work is to study the airflow inside a trailer loaded with carcasses at reduced scale. This airflow is characterized by air velocity and flow direction using 2D Laser Doppler Velocimetry (LDV). The identification of zones of low air velocity leads to the information of a potential microbial risk.

2. MATERIALS AND METHODS

2.1 Experimental device

With respect to European regulation, the refrigerated trailers have the internal length of 13.3 m. In order to conduct our experiments on a reasonable dimension, a reduced scale trailer (1:3.3) has been used. In such a way, Reynolds number is the same order of magnitude of the real trailer (Re~1.3 10^5). The side wall of this trailer was made of glass to allow the measurements of internal air velocity using two-dimensional LDV (Dantec Dynamics, Flow explorer-2D). The other walls are made of wood.
As a result of the scale reduction, studied pork carcasses have been also prepared at the same scale (1:3.3). Based on X-ray scans provided by the French Pork Institute (IFIP), 3D carcass geometry has been built up and the scale has been reduced before printing both half-carcasses on polyamide structure (Figure1). The obtained structure has been used to create a silicone mold and to prepare 430 half-carcasses using expanded polyethylene. Once all the reduced scale carcasses are prepared, they have been placed into the reduced scale trailer respecting a real loading configuration observed in real pork carcasses refrigerated transport. This configuration has been approved by both French Pork Institute (IFIP) and French meat companies (Culture Viande) the partners in this work (Figure 2).

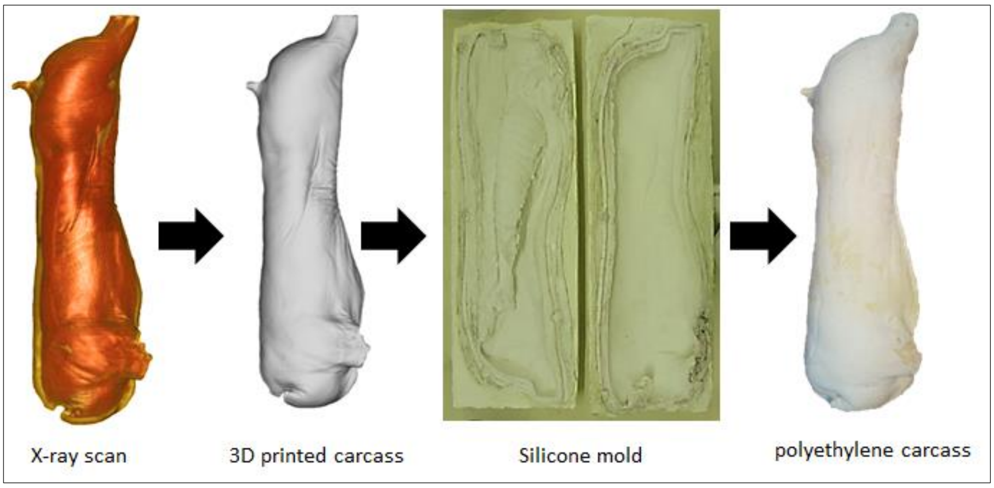

Figure 1. Steps to produce reduced scale carcasses from the X-ray scan of real pork carcass.

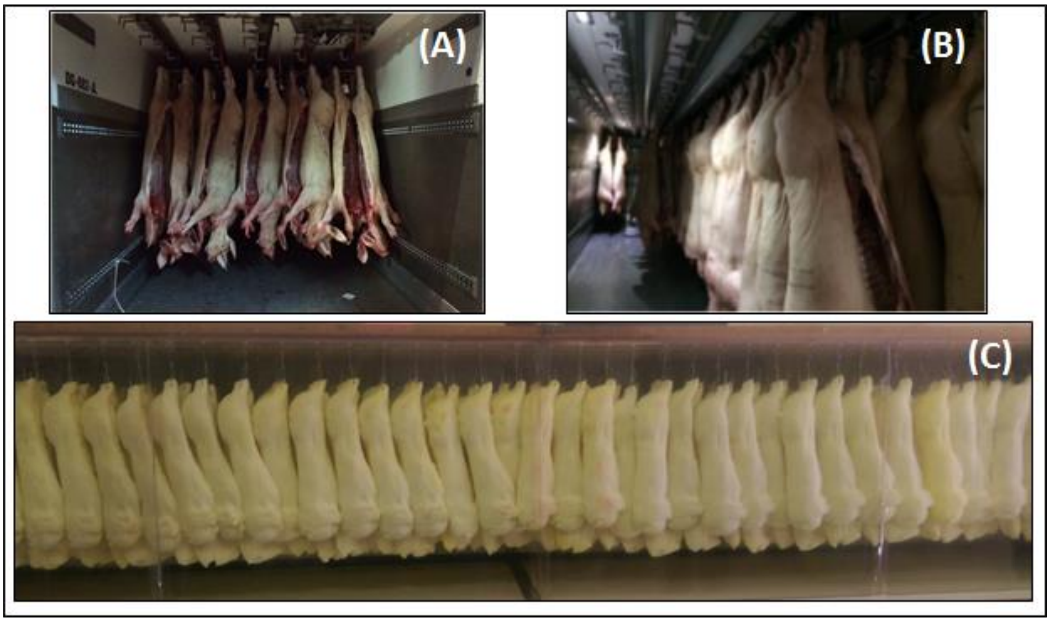

Figure 2. Photography of the selected loading configuration (A and B) and the reduced scale trailer filled with pork carcasses (C).

2.2 Velocity measurements

The measurement of the internal air velocity by LDV requires the use of a wall of glass to allow the penetration of the laser beam inside the trailer. The laser equipment was placed on a displacement system that allowed the automation and the control of the movement according to the three axes x, y and z (Figure 3).

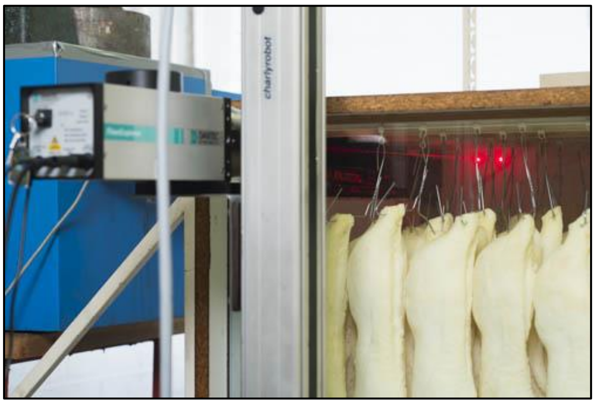

Figure 3. Measurement of air velocity above the carcass in a reduced scale trailer by Laser Doppler Velocimetry (LDV).

The air velocity was determined by measuring the displacement velocity of small particles of paraffin oil (diameter ≈ 1 µm) injected into the blowing device. Those particles are small enough to follow the air displacement inside the trailer. Thus the velocity of this tracer is considered as the air velocity.

The 2D LDV used in this study was able to show the airflow direction (sign +/-) as well as the velocity magnitude. This magnitude is represented by the mean velocity and its fluctuations of two velocity components in the trailer: U (longitudinal in x direction) and V (vertical in y direction). The device is composed of two 70 mW laser diodes emitting two laser beams at 660 nm and 785 nm, a beam-splitter, a Brag cell, a focusing and receiving lens, a pinhole arrangement to collect scattered light and a photomultiplier. Measurements were conducted in a coincidence mode where both laser beams converge in the same measure volume (0.17 mm x 2.8 mm).

In this study, measurements of velocity have been carried out in the symmetry plan (35 cm from the glass wall) of the trailer filled with carcasses over and under the carcasses as shown in Figure 4-A.

A total of 2270 measurement points were undertaken to describe the airflow pattern in the symmetry plan using Matlab (R2015a, Mathworks Inc.). Results were presented using the velocity magnitude defined by the eq. 1.

$$\|\vec{V}\| = \sqrt{V^2 + U^2} \text{ (eq. 1)}$$

In addition to this profile, measurements in 8 vertical plans at x= 50, 150, 250 and 350 cm of the reduced scale trailer length over and under carcasses (from z=0 cm to z= 35cm) and just after the inlet section were conducted (Figure 4-B). Measurements were also carried out in two horizontal plans at mid-height at the front (from x=3 cm to x=10 cm and from z=0 cm to z=35 cm) and at the rear of the trailer where no carcasses are present (from x=486 cm to x=497 cm and from z=0 cm to z=35 cm). The airflow rate was then calculated in those plans using the integral of the U velocity component (eq. 2).

$$Q = \int_x U \, dS \text{ (eq. 2)}$$

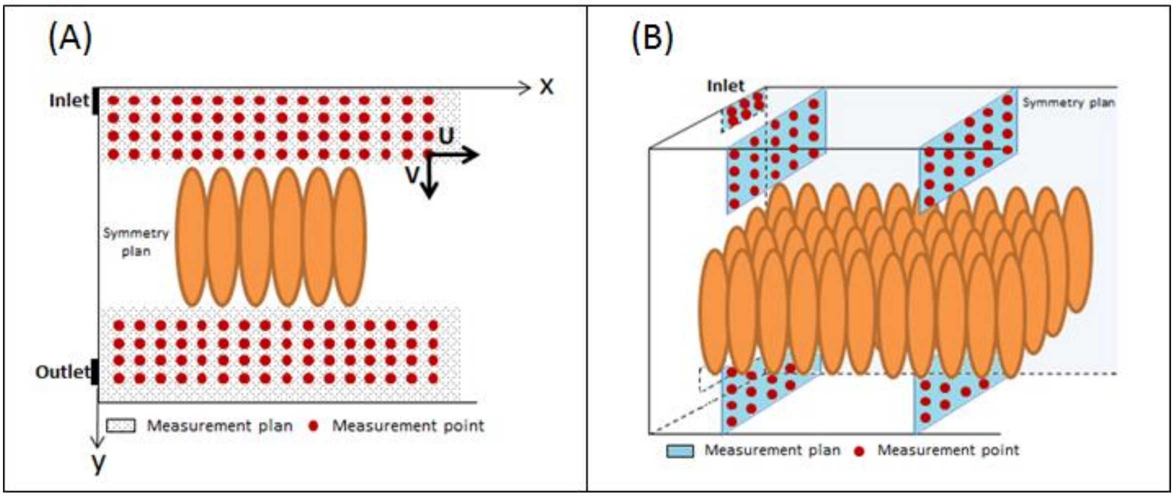

Figure 4. Graphical representation of measurement positions (A) in the symmetry plan of the trailer and (B) in vertical plans over and under carcasses.

3. RESULTS AND DISCUSION

3.1 Symmetry plan characterization

In order to illustrate the overall airflow pattern in the symmetry plan, Figure 5 shows the magnitude of the velocity obtained by LDV measurements around carcasses. The zones over and under the carcasses were expanded vertically in this graph to better highlight the velocity in those zones. Over carcasses we can see the evolution of the jet behavior.

The trailer can be divided into two main zones: the first zone from x=0 m to x=10 m and the second one from x=10 m to the end of the trailer. In the front zone (x≤10 m), the air velocity decreases from 11 $m.s^{-1}$ to 2 $m.s^{-1}$. For the rear zone (x>10 m), the air velocity decreases also from the upper part of the trailer (y=0 m) to the upper part of carcasses (y=3.6 m) where the velocity ranges from 0 $m.s^{-1}$ to 1.5 $m.s^{-1}$ corresponding to a weak airflow. Similar results have been obtained with the airflow characterization in the empty trailer (Moureh and Flick, 2005).

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Under carcasses, the trailer can also be divided into two zones: the first zone (0 m ≤ x ≤ 6 m) where the air velocities are around 2-3 m.s^{-1} and the second zone (6 m < x ≤ 13.3 m) where the air is nearly stagnant.

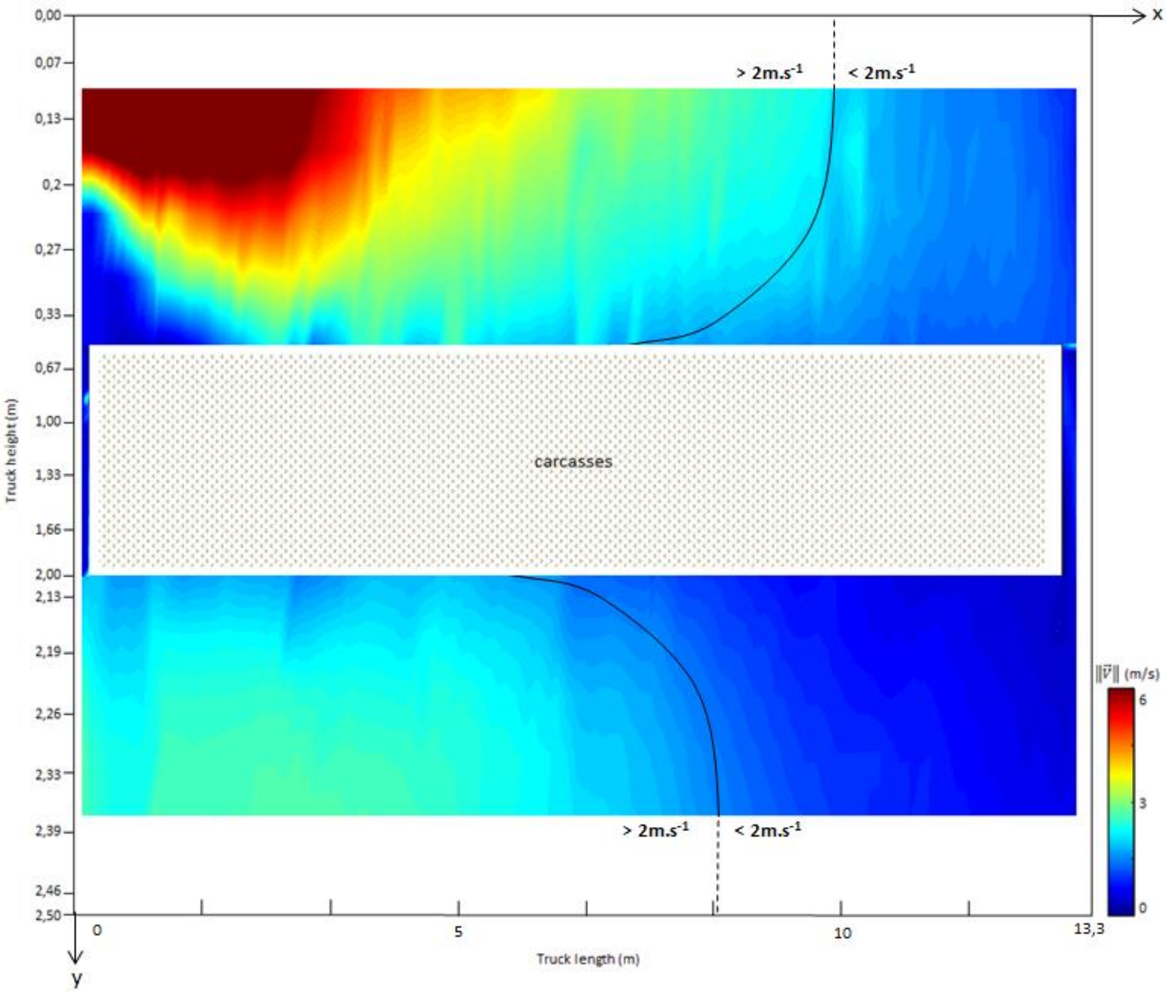

Figure 5. Velocity magnitude in the symmetry plan of the trailer filled with carcasses *(results obtained from LDV measurements and translated to the real scale of the trailer using Reynolds analogy)*.

3.2 Airflow rate estimation

Velocity measurements in the vertical plans upper and under carcasses were used to estimate the airflow rate in those regions (Figure 6). Results are shown as dimensionless airflow rate obtained by the expression of the measured airflow divided by the inlet flow (Q/Q_0).

In the two first measurements plans (x=1.66 m and x=4.99 m), the airflow rate is higher than the inlet one. This phenomenon is related to the strong blowing airflow in the inlet of the trailer. At 5 m < x< 8 m, the airflow rate decreases rapidly. Those results are similar to those obtained in the empty trailer (Zertal Ménia, 2001).

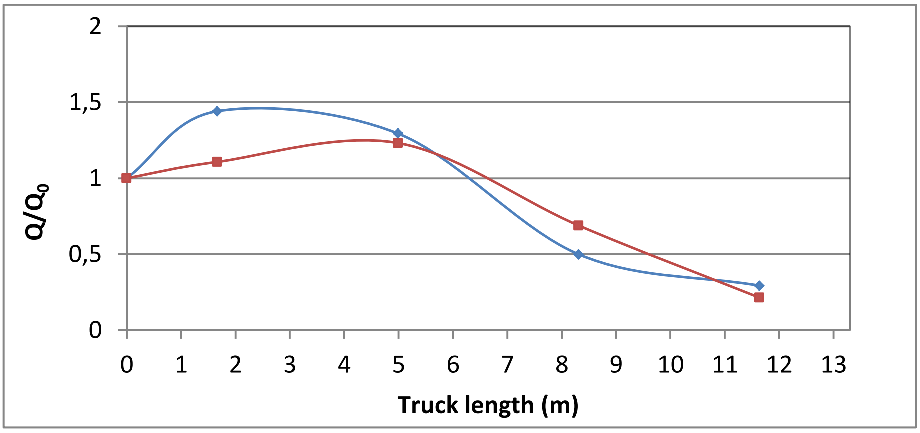

Figure 6. Dimensionless airflow rate estimation in the filled trailer *(blue)* over and *(red)* under carcasses *(results obtained from LDV measurements and translated to the real scale of the trailer using Reynolds analogy).*

Under carcasses, the airflow rate is different from the over carcasses ones. Those differences can be attributed to a circulation of the air between the carcasses volume.

3.3 Simplified model reconstruction

Based on the results obtained in (3.1.) and (3.2.), a simplified schematic airflow can be developed in the filled trailer (Figure 7). It takes into account the hypothesis of vertical and horizontal air circulations between carcasses. These circulations were estimated by the difference between upper and lower airflow rates.

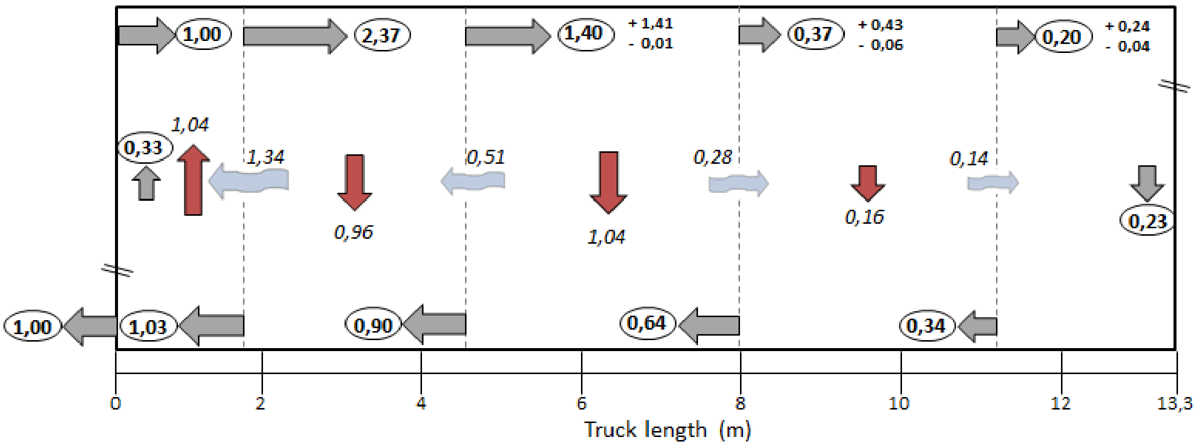

Figure 7. Simplified schematic airflow rate distribution in the symmetry plan of the filled trailer. Values represent Q/Q_0. *Bold values with grey arrow correspond to the calculated airflow; italic values with red arrow correspond to the difference between upper and down airflow; blue arrow correspond to the airflow lateral circulation.*

4. CONCLUSION

Using a reduced scale trailer filled with pork carcasses (1:3.3) with respect of the Reynolds number and a 2D LDV technique, internal flow was successfully characterized in the trailer.

A zone of low airflow has been identified in the rear part of the trailer above carcasses starting from approximately 10 m. Under carcasses the zone of low airflow is larger and extends from the back of the trailer to 6 m of length. In these zones where air is nearly stagnant, the product temperatures maintain is problematic and a potential risk of microorganism's development can be expected. The results of this study allow, on one hand, the understanding of the airflow distribution around carcasses and on the other hand, the development of the simplified model.

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