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Development of a new thermometer for the measurement of carcass surface temperature in slaughterhouse

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ABSTRACT

After slaughtering, pork carcasses must be cooled down in chilled rooms before transportation to prevent microbial growth. European regulation was amended and considers not only the core temperature but also the surface temperature as criteria to allow carcasses transportation. For example, pork carcasses can be shipped with a core temperature of 15°C and a surface temperature of 7°C. However, because of high variations of the environment in the slaughterhouse (air velocity, temperature…), industry and public authority face a challenge to develop a robust measurement process of the surface temperature of the carcasses.

In this study, performances of different existing surface temperature thermometer (Infrared, surface thermometer…) were evaluated in terms of accuracy and repeatability. Both cooling and heating conditions were studied. The performances of the studied devices were evaluated using a validated heat transfer model in a simple 1D configuration that uses a 1D Monte-Carlo process to evaluate the uncertainty. Results showed that existing sensors failed to properly evaluate the surface temperature of the product. A new thermometer with better performances was proposed and recommendations of the measurement process of surface temperature in cold environment are recalled.

1. INTRODUCTION

After slaughtering, the core temperature of pork carcasses is about 38-40°C while the surface temperature is around 30°C (Rossel, 2003). Pork meat is highly perishable, the refrigerating conditions after slaughtering may impact significantly its quality. Since 1964, in the European Union, the carcasses had to be cooled down to 7°C in the core before transport. The cooling process in the slaughterhouse is of major importance to limit micro-organisms growth while preserving meat organoleptic quality (Savell et al. 2005; Kinsella et al. 2006).

As hygiene improved in the meat sector, the risk of putrefaction became very low, and spoilage and pathogens micro-organisms are nowadays mostly present at the surface. For this reason, derogations to the regulation was allowed to transport pork carcasses with a core temperature above 7°C while maintaining a surface temperature of 7°C to facilitate logistic operations (European Commission n° 853/2004, European Commission 2017/1981). More precisely, for transport of less than 6h, there is no maximum temperature, for transport of more than 6h, the maximum core temperature is 15°C. In other words, the derogation to the regulation is also based on the measurement of the surface temperature. However, because of high variations of the environment in the slaughterhouse (air velocity, temperature, type of the surface, type of the device…), industry and public authority face a challenge to develop a robust measurement process of the surface temperature of the carcasses based on the existing probes of the market such as surface contact thermometer of infrared thermometers.

The objectives of this study were first to evaluate the performance of different existing technologies of the market, identify factors impacting the robustness of the measurement, and develop a new probe concept that may overcome issues relative to the surface temperature measurement and provide a robust solution for the industry and public authorities. The performances of the studied devices were evaluated using a validated heat transfer model in a 1D configuration that uses a 1D Monte-Carlo process to evaluate the uncertainty.

2. MATERIAL AND METHODS

In this section, the tested devices are first presented (section 2.1), then the different conditions under which the devices were tested are described. Finally, a modelling methodology used to evaluate the performances of the different tested devices is detailed.

2.1. Probes

(a) (b) (c) (d)

Figure 1 : Probes tested : (a) commercial contact thermometer (b) commercial Infra-Red (IR) thermometer (c) developed Surfascup Surface (d) developed Surfascup penetration

Four different probes were tested (Fig. 1), two commercial probes and two probes developed in our laboratory for this specific application. The commercial contact thermometer (testo 925) and the fast reacting contact probe, K-type thermocouples, accuracy constructor (± 0.5 °C; ± 0.3 % of the read value, manufacturer data) is a contact thermometer top on the line used in professional sector. The commercial Infra-Red, testo 835-T1 (±1°C in the range 0-99.9°C, manufacturer data), is a IR thermometer top on the line used in professional sector.

The two sensors developed at the Inrae laboratory measured temperature using T-type thermocouples, calibrated at 0, 5, 10, 15 and 25°C (thermocouple uncertainty of 0.2°C). It is important to note that these thermocouples are linked to a data logger located outside the cold room in a stabilized environment (~20°C). This way the measure is not impacted by any perturbation of the cold junction compensation of the thermocouple.

2.2. Experiments

2.2.1. Cooling in a controlled environment

During the cooling tests, experiments were conducting by placing a 0.1*0.1*0.05 m piece of meat in a polystyrene box. There was 0.05 m of polystyrene on each side of the meat, except for the top side which was in contact with ambient air. This way, the heat transfer is on one dimension. The box and the meat were placed in a cold room with controlled temperature, humidity and air velocity (0.2 m.s^{-1}).

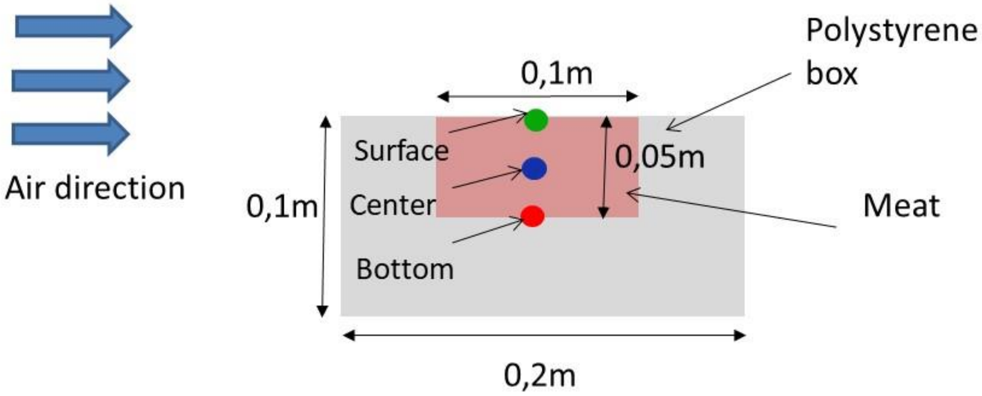


Figure 2: Configuration and dimensions of the experiments conducted during the cooling tests

2.2.2. Measurements in a non-controlled environment

In order to evaluate the impact of operating conditions such as high ventilation, temperature fluctuations or defrosting, an additional test was conducted on a real product in a cold room set at 4°C. The objective was to represent on-field conditions. The four same sensors were tested on the surface of a meat product. A thermocouple slightly inserted very cautiously under the surface was used this time as a reference. Indeed, for the real condition simulation, it was not possible to develop a model.

2.3. Modelling

2.3.1. Thermal model

The model was applied only for the cooling configuration presented in section 2.3.3. As the box was isolated by 100mm of polystyrene on all sides but the top, a one dimension model was developed using Fourier's law (Eq. 1)

$$\boldsymbol{\rho Cp \frac{dT}{dt} = \lambda \frac{d^2T}{dx^2}} \qquad \textbf{Eq. (1)}$$

A symmetry boundary condition was considered in the isolated bottom

$$-\lambda \frac{\partial T}{\partial x} = 0 \qquad \textbf{Eq. (2)}$$

Convective heat transfer was considered at the product surface, latent heat of water of the meat was also considered.

$$-\lambda \frac{\partial T}{\partial x} = h(T_{air} - T_s) + L_v \cdot \dot{m} \qquad \textbf{Eq. (3)}$$

The water evaporation rate was calculated from the concentrations of air vapor and saturated vapor at the surface temperature

$$\dot{m} = k \cdot S_w \cdot \left(C_{sat(T_{sphere})} - C_{wa}\right) \qquad \textbf{Eq. (4)}$$

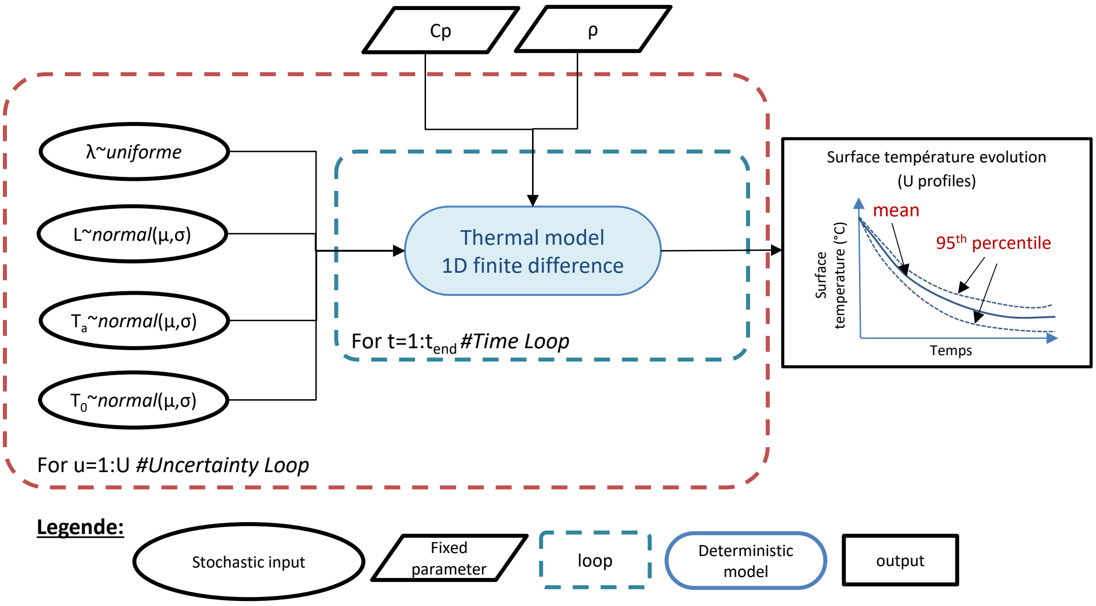
Mass transfer coefficient was determine from the convective heat transfer coefficient using the Lewis analogy.

$$k = \frac{h}{\rho_a \cdot Cp_a \cdot Le^{2/3}} \text{ with } Le = \frac{a_{diff}}{D_w} \approx 0.85 \qquad \textbf{Eq. (5)}$$

Equations were solved using FTCS (Forward Time Centered Space) method. Because of its non-linearity, an iterative process was used to solve Eq. (3)

2.3.2. Uncertainty propagation

The uncertainty was consider using a 1D Monte Carlo methodology.



Notation: λ *meat thermal conductivity* ($W.m^{-1}.K^{-1}$);
L *product thickness* (m);
T_a *air ambiant temperature* (°C);
T_0 *product initial temperature* (°C);
C_P *product thermal capacity* ($J.kg^{-1}.K^{-1}$);
ρ *product density* ($kg.m^{-3}$).

Figure 3: Uncertainty propagation modeling process (1D Monte Carlo)

3. RESULTS AND DISCUSSION

3.1. Cooling in stabilised atmosphere

3.1.1. Model validation

The Fig. 4 shows the temperature evolution of the product at three positions during cooling. Among the three positions presented (surface, center, bottom), two positions (center, bottom) are used for model validation. For all of the four probes, the model predictions (line) and its uncertainty range are covering temperature measured by the thermocouples for both (center and bottom positions). The RMSE is ranging from 0.0°C to 0.1°C (Table 1), within the thermocouple uncertainty (0.2°C). From this observation, the validity of the predicted value for the surface can be assumed. This predicted value of the surface temperature is used in the next subsection as the reference to evaluate the performance of the tested probes to measure the surface temperature of the product.

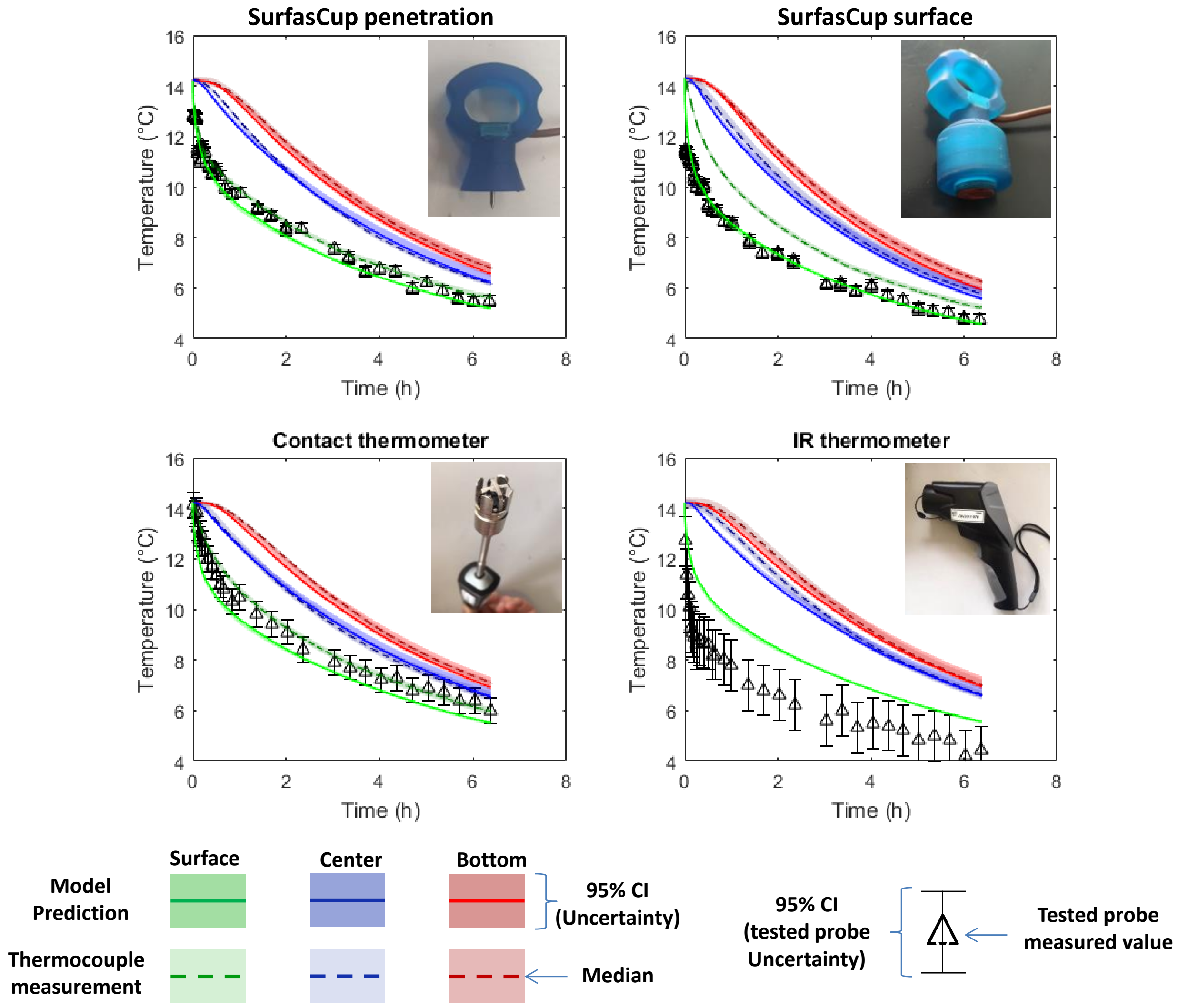


Figure 4: Product temperature evolution during cooling at three positions: surface (green), center (blue) and bottom (red), predicted values (lines), measured values using thermocouples (dashed) and measured values by the tested probe (triangles). 95th CI of the model and measurements are also represented.

3.1.2. Performance of the probes during cooling in controlled conditions.

In the Fig. 4, the surface temperature evolution is represented in green (model and thermocouples) and by the triangle (tested probe). The first observation is that the value measured by the thermocouple does not offer a good approximation of the surface temperature. Indeed, in practice, the thermocouple is slightly introduced under meat surface, assuming that the temperature measured would be a good approximation. However, the results show that this assumption is not correct. Moreover, depending on the cases, the measured temperature is very different. Using a thermocouple placed at the product surface should be used very cautiously to measure surface temperature.

Amongst the four tested probes, the best performance is obtained using the Surfascup surface and penetration, followed by the contact thermometer. The IR thermometer underestimated the surface temperature. Quantitative information of the errors are given in table 1. The two Surfascup probes RMSE are 0.2°C, the contact thermometer RMSE is 0.7°C while the IR thermometer if 3.4°C. However, during heating from 4°C to 15°C (Table 1), performances of the IR thermometer was better (RMSE = 0.5°C), performance of the Surfascup surface was also at RMSE = 0.5°C. The performance of the Surfascup penetration remained the better in comparison with the other probes (RMSE = 0.1°C)

Table 1: Root mean square error (RMSE) or the measured values and the model predictions during cooling and heating

RMSE cooling from 15°C to 4°C

	SurfaceCup penetration	SurfaceCup Surface	Contact thermometer	IR thermometer
Surface tested probe	0,2	0,2	0,7	3,4
Surface thermocouple	0,3	1,5	0,9	NA
Center thermocouple	0,0	0,1	0,0	0,1
Bottom thermocouple	0,0	0,0	0,0	0,0

RMSE cooling from 4°C to 15°C

	SurfaceCup penetration	SurfaceCup Surface	Contact thermometer	IR thermometer
Surface tested probe	0,1	0,5	1,0	0,5
Surface thermocouple	0,0	0,6	0,1	NA
Center thermocouple	0,1	0,1	0,2	0,1
Bottom thermocouple	0,0	0,0	0,0	0,0

3.1.3. Impact of penetration depth

Fig. 5 presents the evolution of the temperature of the penetration Surfascup and of the model at three positions: at the surface, at 0.5cm below the surface and at 1cm below the surface. According to the results, although the penetration probe measures 1 cm and actual sensor around 0.5cm, the measured temperature is closer to the surface temperature provided by the model as temperature at 0.5cm and 1cm. According to these results, the measurement made by the penetration sensor at 1 cm is representative of the real surface temperature.

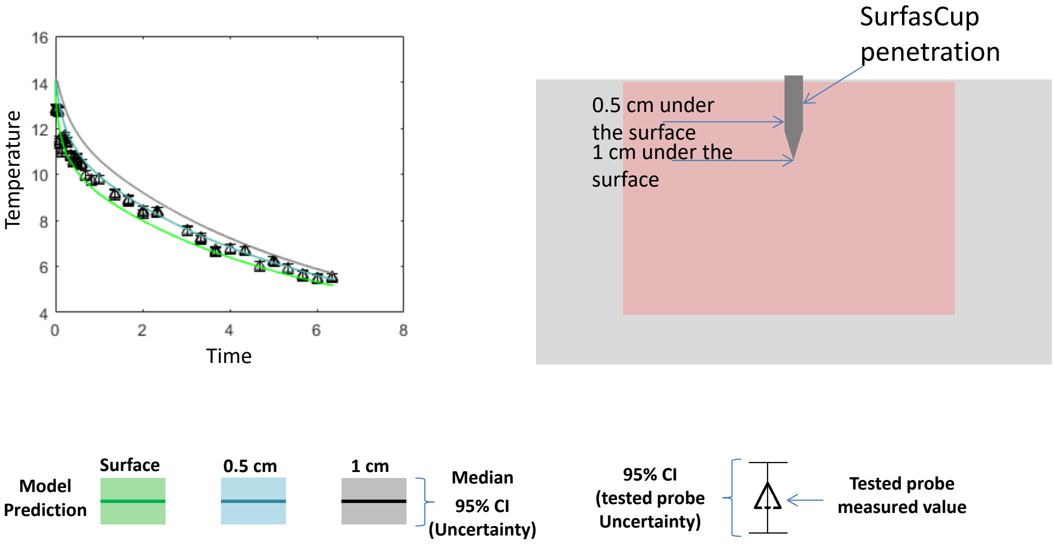


Figure 5: Comparison of temperature at the surface, 0.5 cm and 1 cm below the surface

3.1.4. Probes performance in non-controlled conditions

Fig. 6 presents the evolution of the measurement error (temperature of the thermometers tested - reference temperature). The dotted curves represent the errors of each thermometer (scale on the left). The continuous light blue (scale on the right) represents the air temperature of the disturbed atmosphere of the cold room, strongly linked to the operation of the refrigeration unit, in particular the start-up of the refrigeration unit and the defrosting.

Starting and stopping of the cold unit which impacts the ambient temperature (temperature light blue curve) causes a sudden variation in the error of the infrared thermometer (red curve) and of the contact thermometer (purple curve), while the error of both the Surfascup (green and yellow curves) remains more or less stable.

When the air temperature decreases (following the start-up of the refrigeration unit), the error of the infrared and contact thermometers increases sharply. Conversely, when the air temperature increases (following the shutdown of the cold unit or the defrost), the error decreases and approaches these of the Surfascup.

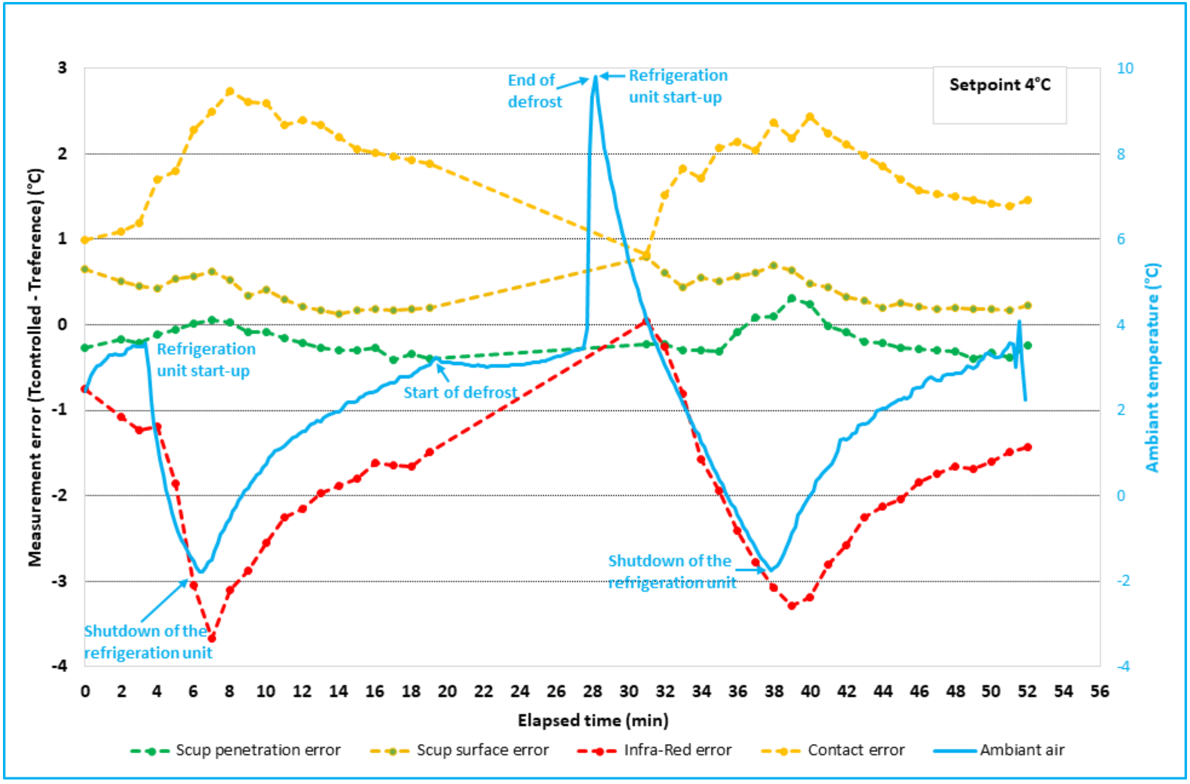


Figure 6: Variation in the measurement error (Tmeasured – Treference) for the four tested thermometers as a function of time in a disturbed environment at a set point of 4°C (measurement taken on the muscle). Reference temperature was measured using a T-type thermocouple introduced slightly under the meat surface

3.2. General discussion

The measurement of the surface temperature for meat carcasses is now a criteria for the regulation. However, public authorities and industry are facing challenge to develop a robust methodology to measure this surface temperature. In our study, two technologies were develop to measure temperature that is a good approximation of the surface temperature. The performances of those probes were better than the performances of existing probes in the market. Results showed that in both controlled and non-controlled, IR thermometer failed to offer a good approximation of the surface temperature. These results may be explained by the sensitivity of the probe (electronic components) to low ambient temperatures. Similarly, the temperature measured using the contact thermometer also showed limited performances (RMSE > 0.5°C), particularly in dynamic conditions. This result is explained the two thin slates of the contact thermometer are in contact with both the surface and the air temperature. Hence, the measurement is also impacted by the air temperature.

The two developed probes showed better performances in estimating the surface temperature as the sensor if isolated from the surrounding air. Moreover, is it important to recall that it is recommended that some precautions has to be taken to measure temperature in cold and dynamic environment. For example, handheld thermocouple technology shouldn't be used as the technology required a cold junction compensation that might be impacted in cold and dynamic condition as those encountered in agro-industry environment. As an alternative, the use of thermistance technology should be preferred. Other parameter have to be consider: maniability, response time, cross-contamination, cleaning… Finally, given the results related to the uncertainty of the measurement of food surface temperature in cold environment, the authors encourage the authorities to develop a specific standard related to the measurement of the food surface temperature in cold environment.

4. CONCLUSIONS

Surface temperature of meat carcass is a criteria to allow carcass transportation after slaughter house. However, the measurement surface temperature is subjected to various perturbations that impact the robustness and the accuracy of the result. In this study, the performances of four sensors were tested: an infra-red sensor, a contact thermometer (both commercially and used in slaughterhouses) and two sensors developed in our laboratory. Results showed that existing sensors failed to properly evaluate the surface temperature of the product. The sensors developed presented the best results. Surface temperature should be measured cautiously in slaughterhouses. To measure the temperature of food surfaces in cold environments, the authors suggest that authorities develop a specific standard.

NOMENCLATURE

C	vapour concentration (kg.m^{-3})	m	mass (kg)
Cp	thermal heat capacity (J.kg^{-1}.°C^{-1})	$\dot{m}$	mass rate of water (kg.s^{-1})
D_w	mass diffusivity of vapor in air (m^2.s^{-1})	S	surface (m^2)
h	convective heat transfer coefficient (W.m^{-2}.°C^{-1})	t	time (s)
		T	temperature (°C)
k	mass transfer coefficient (m.s^{-1})	α	thermal diffusivity (m^2.s^{-1})
L	Meat thickness (m)	λ	thermal conductivity (W.m^{-1}.°C^{-1})
L_v	Latent heat of evaporation (J.kg^{-1})	ρ	density (kg.m^{-3})

REFERENCES

European Commission (2004), Regulation amending Annex III to Regulation (EC) n° 853/2004 of the European Parliament and of the Council as regards temperature conditions during transport of meat.

European Commission (2017), Commission Regulation (EU) 2017/1981 of 31 October 2017 amending Annex III to Regulation (EC) No 853/2004 of the European Parliament and of the Council as regards temperature conditions during transport of meat.

Kinsella, K.J., Sheridan, J.J., Rowe, T.A., Butler, F., Delgado, A., Quispe-Ramirez, A., Blair,I.S., McDowell, D.A., 2006. Impact of a novel spray-chilling system on surface microflora,water activty and weight loss during beef carcass chilling. Food Microbiology. 23 (5), 483-490.

Rossel, R., 2003. Listeria monocytogenes en abattage et découpe de porc: contrôle de lacontamination environnementale des frigos de ressuage et salles de découpe. Thèse dedoctorat. Ecole Nationale Vétérinaire de Toulouse.

Savell, J.W., Mueller, S.L., Baird, B.E., 2005. The chilling of carcasses. Meat Science. 70 (3),449-459.