# AIR FLOW CHARACTERISTICS IN A CHILLER FOR PORK OFFALS AND COOLING CONSEQUENCES

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## SUMMARY

In chillers the velocity and temperature of the air flowing around the products determine their temperature and weight loss kinetics and thus the process efficiency. These kinetics themselves can affect bacterial growth and meat tenderness. In practice, air circulation is often overlooked while it seems economic advantages could be gained in systems where air flow would be well managed.

The experiments were carried out in an industrial continuous air chiller designed for cooling pork offals from 40°C to 4°C in 2 hours. A box containing a small data logger was suspended from the overhead conveyer and moved through the chiller with the products. Thermocouples and 'hot wire' type anemometers were used to measure continuously (1) the properties of the air flowing around the products and (2) the core and surface temperatures in the livers.

The air velocity variations along the conveyor at different heights from the floor were analysed. The average air velocity was about 2.4 m/s but values ranging from 0.3 m/s to 9 m/s were recorded. The fast changes observed were explained by the arrangement of the fans. Histograms of the velocities derived from 1500 measurements show that the median is the best indicator of the average conditions. The shape of the temperatures kinetics measured in the livers was different from that commonly obtained under constant conditions. The main variations in the air velocity accounted for this difference. In addition, air flow directions and velocities were measured at many locations of one section of the chiller. Uneven air distribution was evidenced, especially a part of the flow was diverted along the walls and the floor.

## INTRODUCTION

In the meat industry, after slaughter, carcasses and offals are chilled most of the time by air. The chilling kinetics, i.e temperature and weight loss kinetics, affect the cost of the process : (1) chillers dimensions depend on chilling times and (2) weight loss represent the main part of the operating cost. Chilling kinetics also affect product quality because biochemical changes which determine final meat tenderness, and bacterial growth are temperature dependent.

It is well established that air velocity strongly affect the chilling kinetics. But in industrial chillers little is known about the velocity of air flowing around the products, and its fluctuations. In practice, air circulation is often overlooked in design and operation of chillers

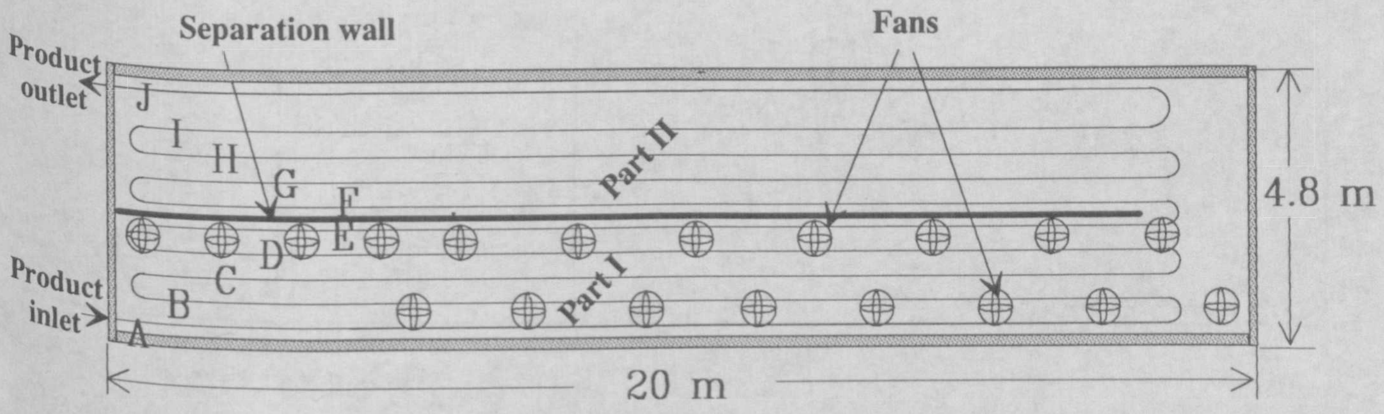


Figure1.a : Diagram of the chiller (topview )

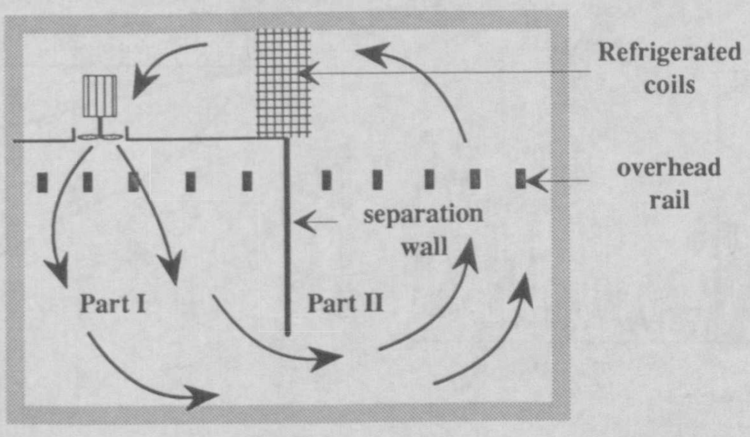


Figure 1.b : Diagram of the chiller (cutaway view)

while it seems that economic advantages could be gained in systems where air flow would be well managed. This prompt us to investigate the actual chilling conditions in industrial plants. This paper reports on the measurement procedure and on typical results obtained in one chiller.

## MATERIAL AND METHODS

A diagram of the chiller 4,8 m x 20 m x 3,4 m h. is given in figure 1.a. The chilling tunnel was divided in two parts by a plastic wall from 0.7 m to 2.4 m above the floor. The refrigerated coils were situated above this wall and disposed over the whole length of the chiller. In the first part (part I), the air was blown from the ceiling to the floor by 20 fans placed in the ceiling in 2 rows ; their individual power was 0.75 kW. In the second part (part 2), the air circulated as it is shown in a diagrammatic form in figure 1.b ; then it was cooled by passing trough the refrigerated coils.

The red offals from each pork carcass - heart, kidneys, lungs, spleen and liver - were suspended to a hook of an overhead monorail chain conveyor; the distance between 2 hooks was 0.30 m. The throughput of the slaughter line was 360 pork per hour.

Automatic measurements were carried out by placing a small data logger, Solomat MPM 4000, into a plastic box which was suspended to the conveyor in place of the offals. This data logger was connected to thermocouples and hot wire type anemometers. At the end of a trial, the data were transferred to a computer for analysis ( up to 10000 data can be recorded ).Two kind of trial were performed : (i) the air temperature and velocity around the offals were recorded every 8 s, i.e every 24 cm, (ii) chilling kinetics of livers, which have the highest commercial value, were measured in parallel with the air properties; the core temperature and the temperature a few millimetres below the surface were recorded every 1 min in 3 livers.Preliminary observations showed that the air circulation was mainly 2-dimensional. Thus, to visualise the air circulation, the air velocity and direction were measured at many locations of one section in the middle of the chiller. The air direction was evaluated by putting a piece of audio tape of 10 cm length in the flow. On account of oscillations due to turbulence the error was estimated to be +/- 30 angular degrees.

## RESULTS

The sensitive part of the anemometers was a small ball of 0.3 mm in diameter maintained at a constant temperature of about 80°C. This kind of probe is commonly used in the food industry because it provides a signal which depends on the air velocity irrespective to the

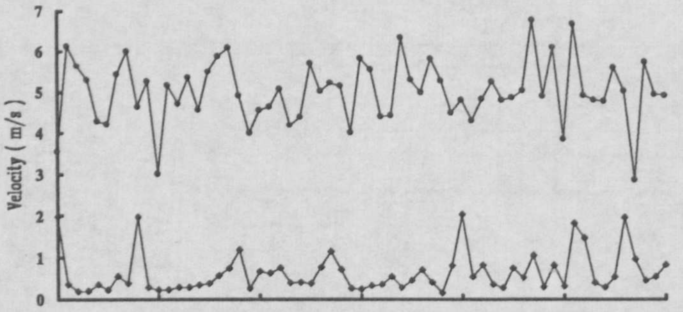


FIGURE 2 : Variations of air velocity at 2 locations in part II.

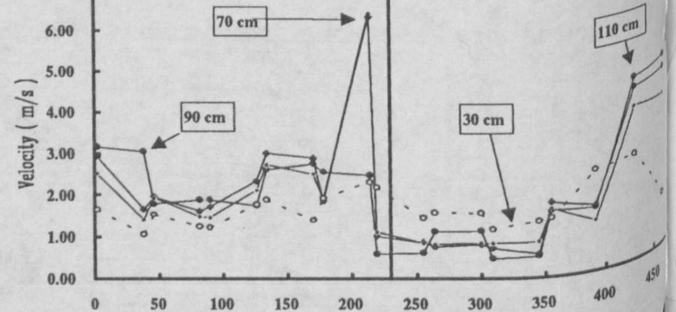


FIGURE 4 :Variations of the average air velocity at different heights from the floor.

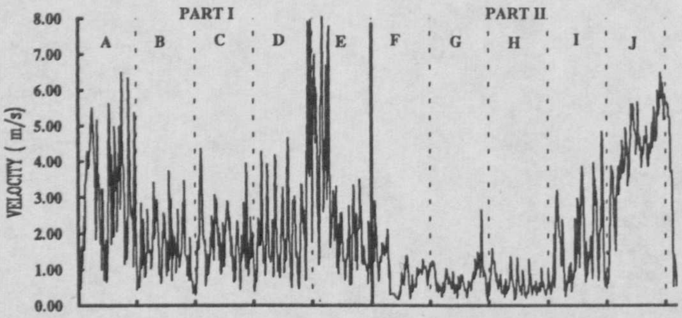


FIGURE 3 :Results of automatic velocity measurements.

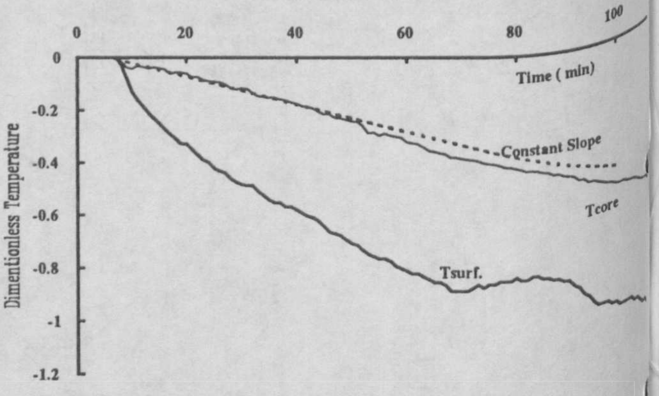


FIGURE 5 :Evolution of the logarithm of the dimensionless temperatures in a liver ( 1.7 kg ).

direction of the air flow. However the difference between the probe and the air temperature also affect the signal. Consequently, the anemometers were calibrated for different air temperatures in a laboratory wind tunnel designed for that aim. (Peyrin et al, 1992).

No difference was found between the values delivered by the anemometers and the actual values of the air velocity at 20°C. But the former were 12 % and 25 % greater than the latter at 10°C and 5°C, respectively. These figures demonstrate that care must be taken in using hot wire type anemometers in chillers.

The air velocity recorded at two different points in part II are plotted versus time in figure 2. These results illustrate the unsteady nature of the flow in industrial plants, as already shown in a dryer and in a chilling room (Daudin and Kondjoyan,1991). Thus, to improve the reproducibility, the average air velocities were calculated from 60 measurements taken in 2 min.

The average air velocity recorded at several points did not differ significantly when the chiller was full of offals or empty. It was therefore assumed that the air circulation was almost not affected by the product, probably because of the low loading density;.

Whatever the trial, the air temperature was about 2.5°C with slight variations lower than +/- 1°C. However, the maximum of these variations exactly corresponded to the side containing the openings ( product inlet and outlet), and the minimum to the opposite side. This phenomenon is certainly due to warm air coming from the slaughter line through the openings. When it is more accentuated it can affect significantly the energy consumption and the chiller efficiency ; for example, in a similar chiller, variations over the range -1°C to 6°C were recorded.

Automatic velocity measurements provided a good reproducibility. Results of a typical run are given in Figure 3 : the air velocity was recorded at 90 cm from the floor, which corresponded to the level where the livers circulated. The transfer time on one line was about 11 min. In part I, the air velocity varied rapidly from 0.3 to 9 m/s , certainly because of the succession of the fans along the rail ; the average was 2.3 m/s and the standard deviation was 1.5 m/s. This situation was also observed in the other chillers studied and can be considered as typical of what products undergo when they are conveyed under fans in continuous chillers. In part II, rapid fluctuations were also noted but it was clear that they superimposed on slow variations of the " average " velocity. These slow variations, which also existed in part I, was mainly due to the position of the lines relatively to the rows of fans. Thus, the average value of the velocities measured by the automatic procedure, at a constant distance from the lines were calculated. The results obtained at four different levels from the floor are given in figure 4. In part I, expect along the walls, the average velocity didn't vary very much. In part II, air velocities at 0.7,0.9 and 1.1 m from the floor, were lower than 1m/s under the lines F, G and H but very high under the lines I and J ; velocities at 30 cm from the floor were rather different : higher, close to the separation wall, and lower near the opposite wall. The drop in temperatures in a liver of 1.5 kg weight presented in figure 5 illustrate the thermal consequences of this uneven air distribution. In theory, when a product is cooled with air having constant air velocity and temperature, the slope of the logarithm of the dimensionless temperature (T-Tair)/(Tinitial-Tair) at one location is constant after a short while ( Cleland, 1990). In fig 5 there was a change in slope , particularly marked below the surface , when the livers come into part II because of the lack of ventilation. There was a change again at the beginning of line F when the air velocity increased.

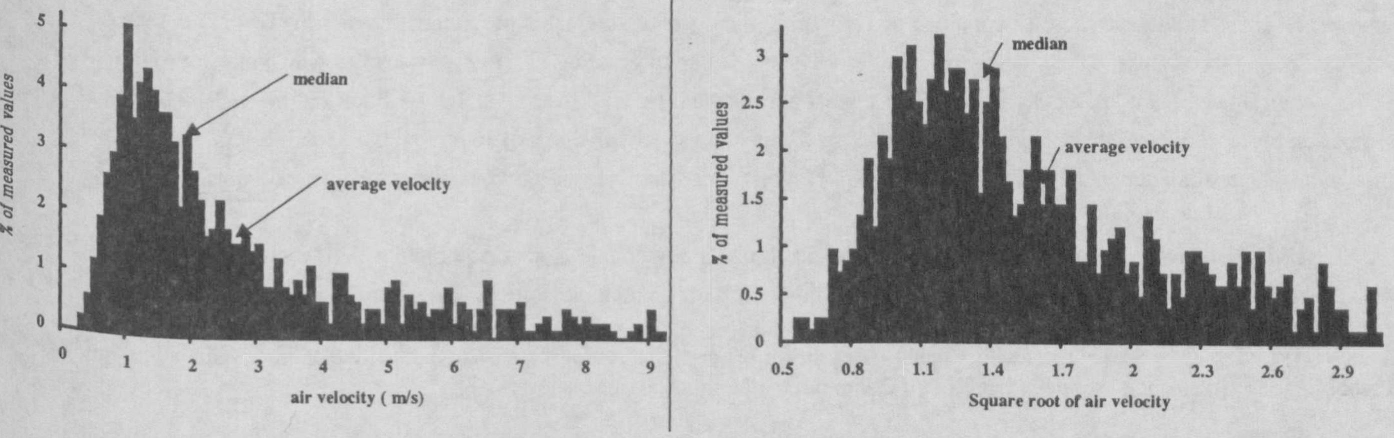
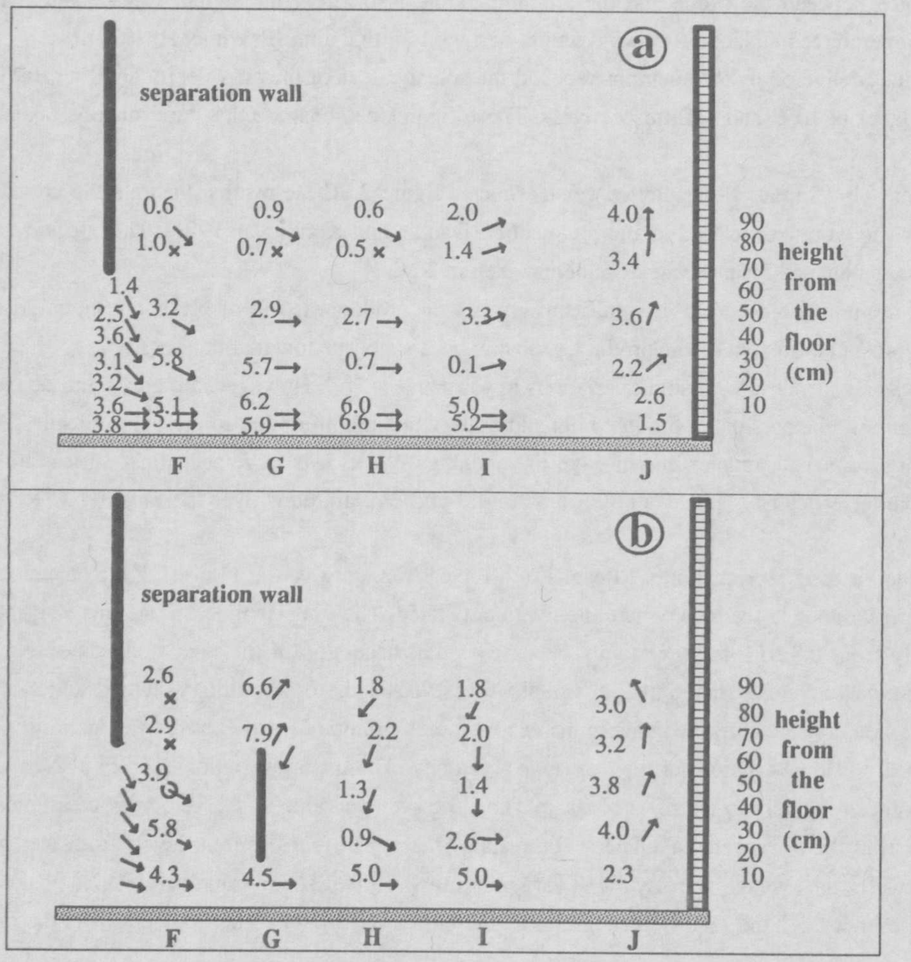


FIGURE 6 : Histograms derived from velocity measurements in part I.

It would be interesting to be able to evaluate how much the temperatures kinetics would be affected by changing the chilling conditions like air temperature, transfer time, increase in fans power... etc. In a first approximation, charts that have been already established to predict the temperatures kinetics under constant chilling conditions could be used ( James and Bailey, 1990 ; Letang et al, 1989 ), but this needs to know the " average " air velocity. The bar chart in figure 6.a indicate the distribution of the air velocities in part I. Because the heat transfer coefficient between products and air is approximately proportional to the square root of air velocity, the distribution of these values were also calculated (figure 6.b). Both distributions are far from being Gaussian. Therefore, to eliminate the



**FIGUE 7 : Air direction and average air velocity at different locations in part II**
**a - normal**
**b - modified**

effect of the high velocities, it is proposed to calculate the median which is the best indicator of the average conditions relatively to the heat exchange as shown in figures 6.

Specific softwares are available to simulate air circulation in ventilated rooms ( Van Grewen and Van Oort, 1990 ). They provide the air velocity and direction at many locations (Van Gerwen, 1990) and enable to optimise chiller geometry and dimensions. It seems however essential to validate these calculations by comparing them to measurements in practical cases. The results presented in figures 7 are intended to that purpose, but right now practical conclusions can be inferred by observing the arrows which allow a rough identification of the stream lines. Figure 7.a clearly showed that a great part of the flow was diverted along the floor and the wall, leading to the lack of ventilation previously mentioned. Figure 7.b indicates how much the air circulation was improved by placing a slab of 0.5 m height in the air stream. The position and height of the slab were adjusted empirically by measuring the air velocity at some points.

**CONCLUSION :** The experimental procedure developed in this study enable to describe rapidly the air circulation and to identify the weakest points in chillers. However mathematical modelling of this air circulation is needed to optimise the chilling conditions.

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