MASS TRANSFER UNDER RETAIL DISPLAY CONDITIONS

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SUMMARY

Data on mass transfer coefficients, from a fully wetted surface, that could be used in the predictive modelling of weight loss during retail display of unwrapped products were obtained using a specially designed controlled environment cabinet. The values measured appeared to be independent of air temperature and ranged from 1.94 x 10^{-8} at 0.25 m/s to 14.34 x 10^{-8} at 1.52 m/s.

INTRODUCTION

Considerable quantities of unpackaged chilled meat and sliced meat products are sold from retail display cabinets and requirements for a minimum retail display life of 6 hours may be limited by appearance rather than microbiological considerations. In experiments using slices of beef topside a relationship was found between weight loss per unit surface area and the change in colour (James 1986). Weight losses of 0.02 g/cm^2 and above produced noticeable darkening of the surface tissue that would result in the material being downgraded if displayed alongside freshly cut slices.

Data were obtained on weight loss from meat samples of known surface area in retail display cabinets under store and laboratory conditions (Swain and James 1986) and in a controlled environment chamber operating at 18 combinations of air temperature, relative humidity and velocity (James and Swain 1986). To extend the experimental data and investigate the effect of fluctuating conditions on weight loss, Fulton et al. (1987) developed a finite difference mathematical model.

In the model the rate of weight loss (M) from the surface is described by the equation:

$$M = m.A.(Ps.a_W - Pm)$$

where 'm' is the mass transfer coefficient, 'A' the area, 'Ps' the saturated vapour pressure at the surface, 'a_W' the water activity and 'Pm' the vapour pressure above the meat surface.

'A' is known and values for Ps and Pm can be calculated from temperature and relative humidity data but little published data were located on water activity or the relationship between 'm' and air velocity in the velocity range encountered in display conditions. The following experiment was therefore carried out at INRA Theix to measure mass transfer coefficients from a fully wetted surface at air velocities from 0.25 to 1.5 m/s. Investigations are continuing to determine how water activity changes with display time and conditions.

EXPERIMENTAL

Mass transfer coefficient determinations were made using composite cylinders of phenolic foam (Oasis) comprising three sub-cylinders separated by water reservoirs. This foam was chosen because of the water retaining characteristics of its interconnecting open cell structure.

The investigations were carried out in a closed circuit controlled environmental chamber, shown schematically in Fig.1, in which the air velocity, temperature and relative humidity could be independently controlled to within ±0.05 m/s, ±0.5°C and ±1.0 rh. Three samples of up to 6 kg could be continuously and independently weighed to ±1.0 g using specially strain gauge load cells situated above the chamber and connected to a data logging system. This logging system also provided continuous information on the air temperature, air velocity and relative humidity within the chamber.

Before the main investigations could be undertaken, it was necessary to prove that the total exposed surface area was fully wetted and remained fully wetted throughout an experimental run. If this condition was not maintained, then the assumption that the water activity (a_W) was equal to 1 would not be correct. In the experimental chamber a fully wetted surface should equilibrate at the wet bulb temperature of the air in the chamber and from that time the rate of weight loss from the sample should be constant. An initial experiment at 10°C, 1.0 m/s and 70% rh, in which the surface temperature and weight were continuously monitored, showed that within the limits of experimental accuracy the criteria were achieved.

In the main investigations 35 runs were carried out over the range of conditions shown in Table 1. Before each experiment 3 sample units were soaked in water at either 6 or 10°C until fully saturated. Excess water was then drained off and calibrated (±0.1°C) copper-constantan thermocouple sensors inserted into the upper and middle cylindrical blocks of one of the samples. The sensors

Table 1. Average rate of weight loss and calculated mass transfer coefficients at stated conditions.

Temperature	10°C M (kg/s) x10^{-7}	10°C m (kg/m^{2}s Pa) x10^{-8}		6°C M (kg/s) x10^{-7}	6°C m (kg/m^{2}s Pa) x10^{-8}
Conditions					
65% Rh					
0.25 m/s	3.3095	1.99	0.30 m/s	4.3000	2.84
	3.5437	2.14		2.9680	2.45
	3.1800	1.69	0.35 m/s	4.6875	3.60
70% Rh					
0.35 m/s	4.8071	3.52	0.41 m/s	5.1660	4.90
	4.7369	3.47	0.42 m/s	5.0860	5.04
0.53 m/s	8.2140	7.29		4.8562	4.81
0.60 m/s	6.8148	6.30	0.46 m/s	6.1860	5.98
	6.8898	6.37	0.60 m/s	5.9965	6.91
0.72 m/s	9.2988	9.12		5.9965	6.91
0.8 m/s	8.9573	8.40	0.71 m/s	7.9230	8.93
	9.2735	8.70	0.87 m/s	6.7778	8.86
1.0 m/s	1.0268	10.97		6.7778	8.86
	1.0195	10.89	1.0 m/s	7.4714	10.44
1.02 m/s	1.2070	11.27		7.6151	10.64
1.27 m/s	1.3740	12.06	1.02 m/s	9.3960	10.73
1.5 m/s	1.3273	14.34	1.24 m/s	12.090	12.52
	1.2520	13.53	1.49 m/s	13.490	13.19
1.52 m/s	1.4820	14.34		-	-

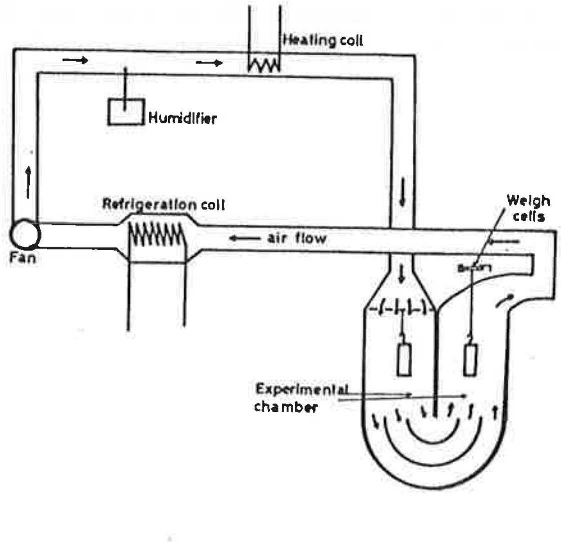

Fig. 1. Schematic diagram of experimental set up.

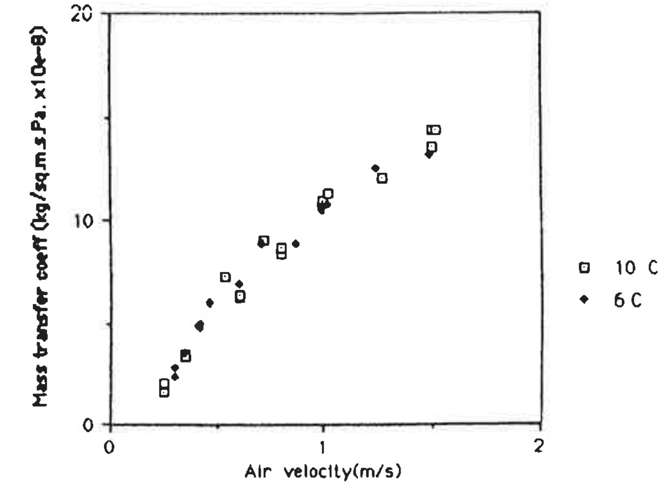

Fig. 2. Relationship between mass transfer coefficient and air velocity.

were positioned to measure the temperature 2 mm below the surface and at the geometric centre of the 2 cylinders. All 3 samples were then held in the controlled environmental chamber until the temperature, monitored using a computer controlled data logging system (Measurement Systems Magus), had equilibrated to within ±0.1°C.

After equilibration the 2 sample units not containing thermocouples were reweighed and all 3 samples suspended in the chamber. The weight (to ±1 g) of the 2 samples and the temperatures (to ±01°C) within the 3rd were then recorded at 5 min intervals for an average of 16 h.

The average rate of weight loss M (kg/s) was calculated and the average mass transfer coefficient m (kg/m^2sPa) was determined from the relationship:

$$M = A\,m\,(Ps.a_W - Pm) \qquad (1)$$

rearranged as:

$$m = \frac{M}{A\,(Ps.a_W - Pa)}$$

RESULTS

The measured average rates of weight loss and the calculated mass transfer coefficients at the 10 combinations of air temperature, velocity and relative humidity are shown in Table 1 and the mass transfer coefficient plotted against air velocity in Fig2.

DISCUSSION AND CONCLUSIONS

These investigations have produced design data on the relationship between the surface mass transfer coefficient and the air velocity over the fully wetted surface of a food substitute. The results confirm that air temperature has a very small effect on the value of the coefficient but a small change in air velocity can substantially effect its magnitude. This is especially critical at the low air velocities that are commonly present in retail display cabinets. A small change in air velocity from 0.25 to 0.4 m/s would increase the rate of weight loss by 75%. Differences in air velocity of 0.1 to 0.18 and 0.3 to 0.66 m/s have already been measured by Swain and James (1986) within the display area of individual cabinets under optimum ambient conditions. In retail stores the range is likely to be much larger.

The data suggest that mass transfer coefficients should be determined at lower air velocities than can be achieved in the chamber to simulate conditions in display cabinets where velocities of the order of 0.05 to 0.25 m/s have been measured. It is especially important to determine the approximate velocity at which the transfer from forced to free convection occurs and the mass transfer coefficient becomes substantially independent of air velocity.

Measurements of rates of weight loss under constant conditions enable surface water activity of lean muscle to be calculated. Initial results indicate that surface aw would remain >0.99 during 6 hours in a retail display where weight loss from the meat surface was <0.03 g/cm^2. These data have been used by James et al (1988) to predict the effect of temperature and relative humidity fluctuations on weight loss during retail display.

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