3.2. EFFECTIVE WATER DIFFUSIVITY

The effective water diffusivity (D_e) of meat was obtained from the experimental drying curve of meat at four different temperatures (5º, 13º, 19º and 26ºC). The drying experiments were developed in two laboratories, the Lodz Technical University (LTU) and the Meat Technology Center (IRTA). The experimental equipment and sample preparation used were different in both laboratories. At the first laboratory (LTU), the D_e was studied from the drying curve by considering the effect of the type of boundary conditions, the effect of the water content dependence, the effect of the shrinkage and the effect of the range of water content. A numerical procedure was used to determine the values of D_e. At the second laboratory (IRTA), the determination of D_e was extended to salted meat at four different NaCl contents (0, 0.08, 0.21 and 0.31 kg NaCl/kg d.m.). In this laboratory, the effect of fiber direction and muscle was also studied. The analytical solution of 2nd Fick's law was used to determine the values of D_e. Using this solution, the effect of the sample length, the effect of relative humidity and the effect of using different terms into the analytical solution were studied.

The experiments developed were considered as isothermal processes because the meat, in the range of temperatures used (5º to 26ºC) and in the whole period of time, had approximately the same temperature as the surrounding air. Therefore the effect of heat transfer was neglected.

3.2.1. Method 1: experiments developed in a drying tunnel

This experiments were developed at Lodz Technical University laboratory .

3.2.1.1. Experimental equipment

The drying experiments were carried out in a laboratory scale drier. The drying tunnel was 120x120 mm cross sectional area, a diagram of which is shown in Figure 3.2.1. The drier is equipped with an air circulating fan, electric heaters and cooling system using glycol as a cooling agent.

The drying process was monitored continuously by an electronic balance with sample tray suspended under it and a video camera which allowed sample image recording on a video camera recorder (VCR). The IBM compatible personal computer was equipped with a PCL-714 labcard for Analogue to Digital or Digital to Analogue transmission. All measuring and controlling devices were accompanied by their suitable interfaces. All the automatic control and data recording were done through the same code written in PASCAL language.

The sample weight, air temperature and sample image were recorded in the required time intervals.

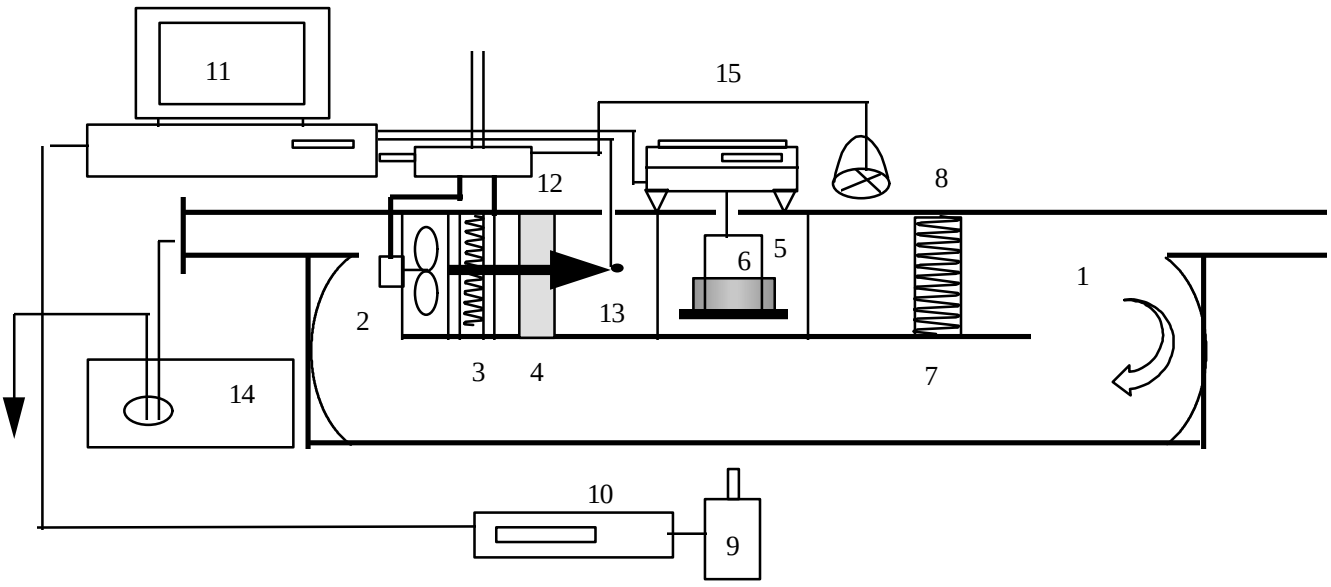

Figure 3.2.1 Schematic of experimental set-up. 1- glass tunnel, 2- fan, 3 - heater, 4 - honeycomb, 5 - sample tray, 6 - sample, 7 - cooling device, 8 - lamp, 9 - TV camera, 10 - CR, 11 - computer, 12 - power controller, 13 - thermocouple, 14 - humidity meter, 15 - balance.

The temperatures were measured by means of thermocouples chromel-aluminium with suitable signal amplification. Control tolerances were ±0.5°C. The weight of the sample was measured by a Mettler PM-400 electronic balance with 0.001 g accuracy, and recorded through an RS232 serial port communication. To eliminate weighing errors caused by air speed fluctuations, the fan was stopped for 30 seconds before each read-out. The air humidity was controlled periodically by a capacitive sensor with an accuracy of ±3 %. The air velocity was controlled through a propellor anemometer with an accuracy of ±0,1 m/s.

3.2.1.2. Sample preparation

The *Gluteus medius* muscles were extracted from three green hams and a sample of 40x40x5 mm was cut from each one. Silicon grease was applied to the edges and bottom of the sample to allow unidimensional water transport. The sample was placed into a special tray to avoid deformation during the drying.

3.2.1.3. Drying procedure

T he temperatures and the air relative humidities used in the experiments are shown in Table 3.2.1. The air velocity was 1.3 m/s in all the experiments.

Table 3.2.1 Drying conditions of meat samples in LTU.

Sample	Measurement interval (min.)	Air Humidy (%)	Average Temp. (ºC)
1	20	20.71	26.9
2	20	18.7	25.6
3	20	26.4	25.7

The external mass transfer coefficient (k_y) necessary in the model was evaluated by evaporating pure water from a vessel of the same size of the meat sample at constant air

temperature (20ºC) and relative humidity conditions (44%). The k_y value was obtained by using the following mass balance:

$$-\frac{1}{A}\frac{dW}{d\tau} = k_Y(Y^* - Y) \qquad 3.2.1$$

where

$$Y^* = 0.662\frac{p_0}{P_a - p_0} \qquad 3.2.2$$

$$Y = 0.662\frac{p_0 \cdot \varphi}{P_a - p_o \cdot \varphi} \qquad 3.2.3$$

and

$$p_0 = \exp\left(23.1964 - \frac{3816.44}{t + 227.02}\right) \qquad 3.2.4$$

A is area (m^2), $dW/d\tau$ is the evaporation rate of water (kg/s), k_y is the external mass transfer (kg/m^2 s), P_s is the saturated water vapor pressure (Pa), p_0 is the atmospheric pressure (Pa), φ is the relative humidity of the air and t is the temperature (ºC).

The Biot number is calculated using the equation obtained for mass transfer (equation 3.2.14). The Biot number was defined for heat transfer (Welty, 1994), and by analogy, the following derivation for mass transfer is applicable.

The mass balance equation is,

$$\rho V\frac{dX}{d\tau} = -k_y A\left(Y - Y^*\right) \qquad 3.2.5$$

Introducing new variables into the mass balance equation

$$\Delta X = X - X^*$$

3.2.6

where

$$dX = d\Delta X$$

3.2.7

the equation becomes

$$\rho R \frac{d\Delta X}{d\tau} = -k_y \Delta X \frac{\left(Y - Y^*\right)}{\left(X - X^*\right)}$$

3.2.8

where *m* is defined as,

$$m = \frac{\left(Y - Y^*\right)}{\left(X - X^*\right)}$$

3.2.9

which is considered constant during the whole drying period.

Integrating the equation

$$\int_{\Phi_0}^{\Phi} \frac{d\Delta X}{\Delta X} = \int_0^{\tau} -\frac{k_y m}{\rho R} d\tau$$

3.2.10

yields

$$\ln \frac{X - X^*}{X_0 - X^*} = -\frac{k_y m}{\rho R} \tau$$

3.2.11

which may be rewritten

$$\frac{\Delta X}{\Delta X_0} = \exp\left(-\frac{k_y m}{\rho R} \tau\right)$$

3.2.12

The terms in the exponent can be expressed in terms of nondimensional numbers,

$$\frac{k_y m}{\rho R} \tau = \left(\frac{k_y R}{\rho D} \frac{\left(Y - Y^*\right)}{\left(X - X^*\right)}\right)\left(\frac{D\tau}{R^2}\right)$$

3.2.13

where the second term is the Biot number for mass transfer defined as,

$$Bi = \frac{k_y R}{\rho D} \frac{\left(Y - Y^*\right)}{\left(X - X^*\right)}$$

3.2.14

and the third is Fourrier number,

$$Fo = \frac{D\tau}{R^2}$$

3.2.15

The sample shrinkage was obtained by computer image analysis from the recorded sample image.

3.2.1.4. Mathematical model

3.2.1.4.1. The Fickian diffusion approach

The constitutive equation for diffusion in solids has the following form of Fick's law

$$j = -D_f(t, X)\,\rho_m \frac{\partial X}{\partial r}$$

3.2.16

The flux j is expressed in kg/m^{2}s, ρ_m is density (kg d.m./m^3), X is material moisture content in kg H_2O/kg d.m., r is distance in the direction of diffusion in m, and finally D_e is the effective diffusivity of moisture in the meat. This equation assumes that moisture migrates in the solid by molecular diffusion mechanism only. In foods the mechanism is more complex, nevertheless the Fick's equation is still used as a suitable approximation. To account for discrepancies of the real process with the above model the diffusivity is allowed to vary widely in function of moisture content and temperature.

The Fick's equation can be used to set-up a balance of differential volume of the solid. This can be done in three basic coordinate systems: cartesian, cylindrical and spherical; which corresponds to the following cases: an infinite plate exposed to drying at both sides, an infinite cylinder and a sphere. The development of the governing equation now depends on the solid shrinks during drying.

Drying with no shrinkage

Assuming that moisture diffusion takes place in one direction only i.e. in the direction normal to surface for plate and in radial direction in a cylinder and a sphere, and that no other way of moisture transport exists. The second Fick's law may be written as follows:

$$\frac{\partial X}{\partial \tau}=\frac{1}{r^n}\frac{\partial}{\partial r}\left[r^n D_e(t,X)\frac{\partial X}{\partial r}\right] \qquad 3.2.17$$

where n=0 it is plate, 1 it is cylinder and 2 it for sphere. r is current distance (radius) measured from the solid center. This parameter reaches a maximum value of R i.e. plate is 2R thick.

Initially we assume that moisture content is equally distributed and the initial solid moisture content is X_0.

To solve equation (3.2.17) one requires a set of boundary conditions. For externally controlled drying the boundary conditions (B.C.) are called B.C. of the first kind and assume the following form:

at surface, r=R

$$X = X^*(\tau, Y) \qquad 3.2.18$$

at symmetry plane, r=0

$$\frac{\partial X}{\partial r} = 0 \qquad 3.2.19$$

For externally and internally controlled drying they are known as B.C. of the second kind and assume the following form:

at surface r=R

$$-D_e\rho_m\left(\frac{\partial X}{\partial r}\right)_i=k_Y\left[Y^*(X,t)_i - Y\right] \qquad 3.2.20$$

at symmetry plane r=0

$$\frac{\partial X}{\partial r} = 0 \qquad 3.2.21$$

In equation (3.2.20) i denotes the solid-gas interface.

Drying with shrinkage

When shrinkage is considered, wet solid density ρ_m is allowed to vary with moisture content in the process. We will assume uniform shrinkage i.e. the solid will be responding rather to the mean moisture content than to the local one. Therefore if the solid is divided into layers each layer will shrink equally if the moisture is evaporated. Another type of shrinking is the non uniform shrinkage i.e. surface layers with lower moisture content will shrink more than the inner layers. Consequently a drying stress will develop and the process will require another type of numerical treatment that is not considered here.

Uniform shrinkage can be one, two or three dimensional, depending on the arrangement of the solid. Freely shrinking solids will shrink in 3D (Appendix A).
If a cube of initial solid density ρ_0 and initial size R_0 in each direction will shrink uniformly to size R in one, two and three dimensions, the following relationship can be derived:
in 3D shrinkage

$$\rho_m = \frac{\rho_0 R_0^3}{R^3} = \rho_0 \left(\frac{R_0}{R} \right)^3 = \rho_0 \delta^{-3} \qquad 3.2.22$$

i.e. the following relationship between the actual and the initial wet solid densities is established:

$$\rho_m = \rho_0 \delta^{-m} \qquad 3.2.23$$

where δ is R/R_0 and m is number of dimensions in which shrinkage occurs.

Using the above relationship allows to derive the following governing equation of diffusion with uniform shrinkage (Pakowski, 1998):

$$\frac{\partial X}{\partial \tau}=\frac{1}{r^n}\frac{\partial}{\partial r}\left[r^n D_e(t,X)\frac{\partial X}{\partial r}\right]-(n+1-m)\frac{X}{\delta}\frac{d\delta}{d\tau} \qquad 3.2.24$$

Boundary conditions are the same except for boundary conditions type II at the solid surface, which due to interface moving at velocity $dR/d\tau$ can be written as:

$$-D_e\rho_m\left(\frac{\partial X}{\partial r}\right)_i=k_Y\left[Y^*(X,t)_i-Y\right]+\left(X^i\rho_m-Y^i\rho_g\right)\frac{dR}{d\tau} \qquad 3.2.25$$

It is obvious that at the interface $Y^i = Y^*$.

Velocity of the moving interface can be calculated from the balance of moisture over the solid as:

$$\frac{dR}{d\tau}=\frac{dR}{d\overline{X}}\frac{d\overline{X}}{d\tau} \qquad 3.2.26$$

where the rate of change of average moisture content can be calculated from the following equation

$$\frac{d\overline{X}}{d\tau}=\delta^{m+1}\frac{n+1}{\rho_0 R_0}w_D \qquad 3.2.27$$

The derivative dR/dX can be calculated analytically or numerically if the function R=f(X) is known. The following function is:

$$R = R_0 \left(s_1 \overline{X} + 1 \right)$$

3.2.28

In the above formula S is a dimension (sometimes hypothetical) of a bone dry solid. s_1 is an empirical coefficient.

The solution of Fick's equation is done numerically (Sincovec and Madsen, 1975). The drying kinetic curve is obtained by plotting space averaged Φ versus drying time. Space averaging over the solid is done using the following formulae

$$\overline{X} = \frac{n+1}{R} \int_0^R X(r,\tau)\ r^n dr$$

3.2.29

Drying rate is obtained from the definition

$$w_D = -\frac{m_S}{A} \frac{d\overline{X}}{d\tau} \approx -\frac{m_S}{A} \frac{\Delta \overline{X}}{\Delta \tau}$$

3.2.30

The Biot number is calculated using equation (3.2.14).

3.2.1.4.2. Equation fitting procedure

The theoretical drying curves calculated from the equation parameters are plotted against the experimental ones. The sum of squared residues between the calculated and the experimental drying curves is calculated, and by changing the equation parameters a minimum of this sum of squared residues is obtained. This process is done by means of the Complex optimization algorithm included in DryPack (Pakowski, 1998). The numerical method to solve the partial differential equation (PDE) used is the method of lines according to Sincovec and Madsen (1975).

The following equations have been solved numerically to be able to obtain the goal parameters:

1 parameter (D_e)

$$\frac{\partial X}{\partial \tau} = -D_e \frac{\partial^2 X}{\partial r^2} \qquad 3.2.31$$

2 parameters (d_1, d_2): D_e depends on moisture content

$$D_e(X) = d_1 X^{d_2} \qquad 3.2.32$$

The sorption isotherm data used was the model type II.

The shrinkage curves (equation 3.2.28) came from the fitted experimental data obtained in LTU.

3.2.2. Method 2: experiments developed in a drier-box

This method was used in IRTA. This determination of water diffusivity has some similarities to the real drying of dry-cured ham. For example, the air flux is low, the relative humidity is similar to the one used in the industrial drying chambers of dry cured ham. The sample size is bigger than the one used in LTU, as it is in ham.

The drying process is considered an isothermal process because the product in the whole range of temperatures used (5º to 26ºC) in a very long period of time (1 to 24 months) has approximately the same temperature as the surrounding air. Therefore the effect of heat transfer is neglected in our study.

3.2.2.1. Experimental equipment

The drying experiments were carried out in an experimental drier-box. The drier-box size was 0.50x0.30x0.20 m and it was isolated by 0.015 m polystyren. The drier was equiped with a capacitive sensor to control the relative humidity (R.H.) of the drying air. Control tolerances were ±4%. A membrane air-pump (0.2-0.5 m^3/h) controlled by the humidity sensor was used to impulse the air. When the relative humidity of the air inside the drier increased above the desired values, the air was pumped through a silica gel filter to decrease its relative humidity. This dry air, once introduced again into the dryer and mixed with the wet air, allowed to reduce the level of relative humidity to the required value. The process was not continuous. A plastic mesh in the upper part of the drier allowed the air to diffuse homogeneously through the meat samples.

The drier-box was placed into a chilling chamber to maintain the required temperature (±0.5ºC) in each experiment.

A diagram of the experimental set-up is shown in Figure 3.2.2.

The weight of the sample was measured periodically by using a Mettler PM3000 electronic balance with 0.1 g accuracy. The process was manual. The drying curve was obtained from the weight of the samples.

The size of the sample was measured periodically by a SOMET calliper of an accuracy of ±0.0001m

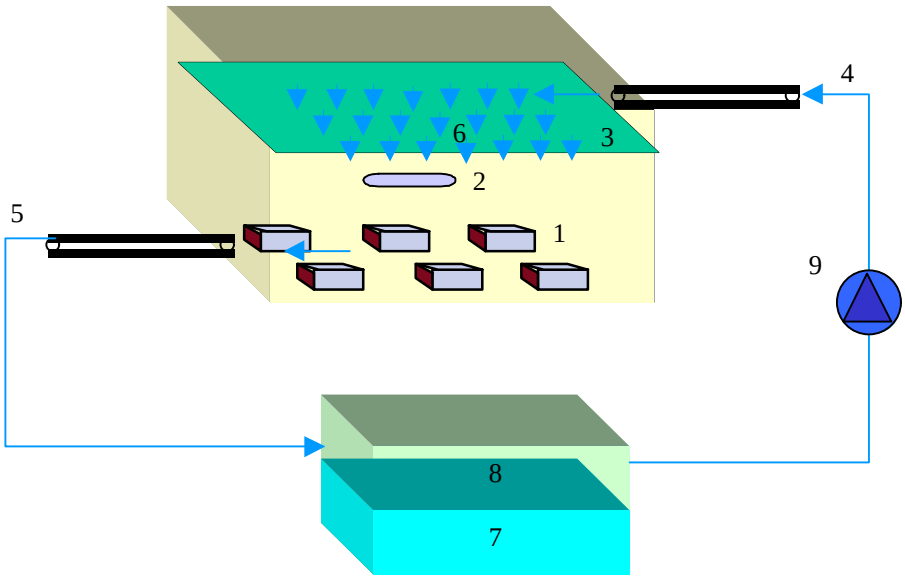

Figure 3.2.2 Experimental set-up used for drying of meat samples. 1. Meat samples. 2. Air humidity sensor. 3. Plastic mesh. 4. Air inlet. 5. Air outlet. 6. Air diffusion through the plastic mesh. 7. Silica gel. 8. Dry air. 9. Membrane air pump.

3.2.2.2. Sample preparation

The fresh pork meat used was bought at the slaughterhouse and selected by temperature (T<4ºC) and pH (pH_{24h}=5.8-6.2). The pH was measured by a lab pH-meter (Crison) at 14ºC. Most of the experiment was done using the *Gluteus medius* muscle because it is an external muscle of low economical cost and it is not needed to destroy all the ham to be able to determine the D_e. *Semimembranosus*, *Semitendinosus* and *Biceps femoris* were also used in one experiment to test the effect of muscle on D_e.

The muscle was extracted from the ham and the meat sample was shaped as a parallelepiped of an average of 0.03x0.04x0.055 m depending on the size of the muscle. The length used in these experiments was about 10 times longer than the ones reported in literature (Palmia *et al*., 1993; Diaferia *et al*., 1998). Every sample was obtained from a different ham.

The water diffusion was computed taking into account the fiber direction and the presence of connective tissue covering the muscle (Figure 3.2.3). The muscle samples were covered with plastic film in the appropriate faces to assure the direction of the water movement in

the tissue (perpendicular or parallel to the fiber direction). The meat samples were dried in two faces.

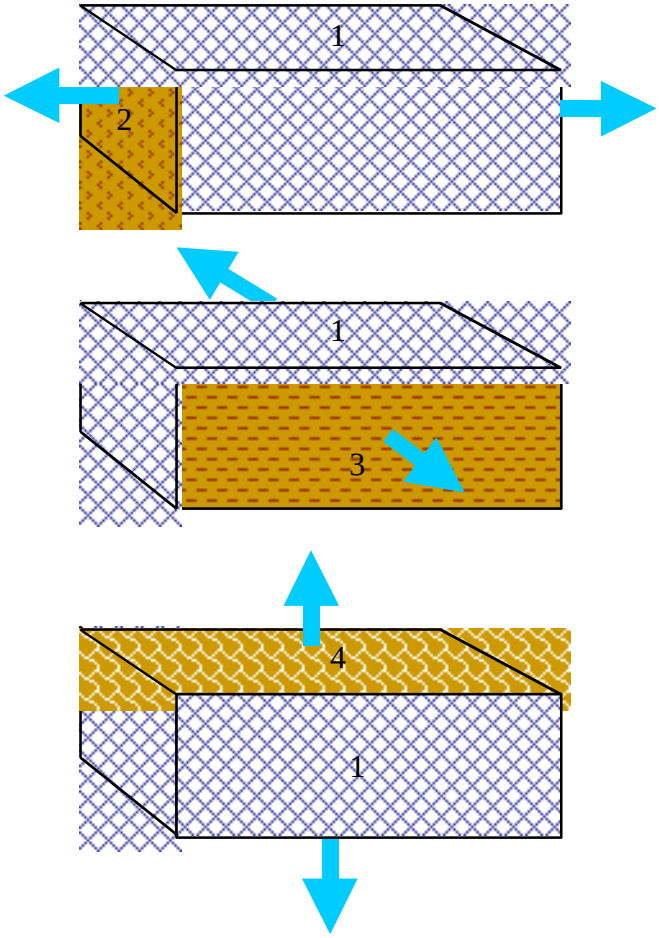

Figure 3.2.3 Shape of meat samples. 1. Plastic film to cover the appropiate faces to allow unidimencional diffusion. 2. Face to water diffusion parallel to meat fibers. 3. Face to water diffusion perpendicular to meat fibers. 4. Face to water diffusion through the connective tissue.

3.2.2.3. Salting process

Two different processes were used for salting the meat samples.

Process A : the meat samples were salted by immersion into saturated brine salt (NaCl) at 4ºC. By controlling the immersed time of the samples into the brine, the salt content of the samples was also controlled. The required salting time was 4.7 hours. Using this method is assumed that the NaCl content is equally distributed into the sample very fast.

Processs B: the meat samples were salted by immersion into NaCl solutions of 0.02, 0.05 and 0.08 of kg NaCl/kg H_2O. The required salting time was 10 days. At the end of salting process, the NaCl content into the sample was considered to be homogeneous.

3.2.2.4. Preparation of the NaCl Brine

Process A: The saturated brine salt solution was made by stirring destiled water at 40ºC and NaCl untill the solution was over 26%(p/p) NaCl. The brine was cooled and keept at 4ºC and stirred periodically.

Process B: Brine salt solution was used with known NaCl content. The brine concentrations were calculated by using the following expression:

$$\left(\frac{NaCl}{H_2O}\right)_{brine} = \left(\frac{NaCl}{H_2O}\right)_{meat} \qquad 3.2.33$$

The required brines were at the concentrations of 0.02, 0.05 and 0.08 kg NaCl/kg H_2O.
Destiled water at 40ºC and NaCl salt was stirred until the total dissolution of NaCl.
The volume of the meat into the brine was taken into consideration to prepare the brine solution.
Thereafter, the brine container was kept at 4ºC. The brine was stirred periodically to assure the dissolution of the NaCl into the water.

3.2.2.5. Drying Procedure

After salting, the appropiate faces of the meat samples were covered by a PVC film and the samples were introduced into the drier-box. The meat samples were weighed periodically at different intervals depending on the temperature of the experiment until the end of the drying process (Table 3.2.2).

Table 3.2.2 Wheighing intervals

Experimental temp. (ºC)	Weighing intervals (days)
5	2
13	1
19	1
26	1/2

3.2.2.6. Procedure diagram

The determination of effective water diffusivity experiments have been developed following Figure 3.2.4.

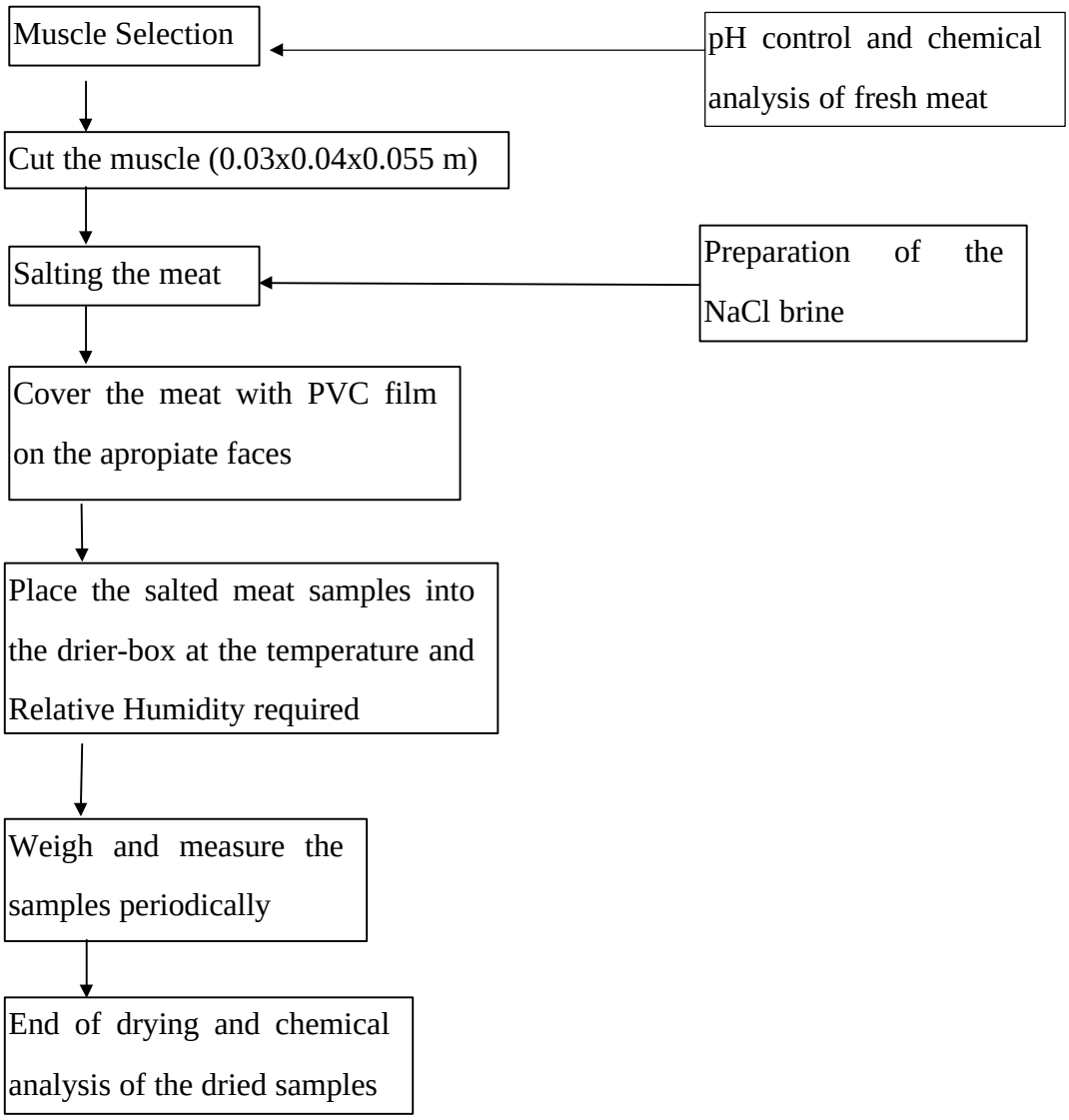

Figure 3.2.4 Procedure diagram of effective water diffusivity experiments.

The experiments that were carried out in IRTA are shown in **Table 3.2.3**.

Table 3.2.3. Experiments design.

Num.	Purpose	Variables	Salting process
1	Effect of sample lenght on D_e.	Temperature: 13 NaCl: 0.08, 0.23, 0.30 kg NaCl/kg d.m. Fibers[1]: L Length: from 0.039 to 0.067 m Relative humidity: 80% Muscle[2]: GM	B
2	Effect of temperature and NaCl content on D_e.	Temperature: 5, 13, 19 and 26ºC NaCl: 0, 0.03, 0.08, 0.20, 0.31 kg NaCl/kg d.m. Fibers[1]: L Relative humidity: 80% Muscle[2]: GM	B
3	Effect of Fiber direction on D_e.	Temperature: 5ºC NaCl: 0.08 kg NaCl/kg d.m. Fibers[1]: L, T, TC Relative humidity: 80% Muscle[2]: GM	A
4	Effect of muscle on D_e.	Temperature: 5ºC NaCl: 0.08 kg NaCl/kg d.m. Fibers[1]: L Relative humidity: 80% Muscle[2]: SM, ST, BF	A
5	Effect of pH on D_e.	Temperature: 13ºC NaCl: 0.08, 0.20, 0.31 kg NaCl/kg d.m. Fibers[1]: L Relative humidity: 80% Muscle[2]: GM	B

[1]L: water diffusion along the meat fibers direction, T: water diffusion across the meat fibers direction, TC: water diffusion across the meat fibers direction and with connective tissue. [2]Meat muscle used: GM: *Gluteus medius*, SM: *Semimembranosus*, ST: *Semitendinosus*, BF: *Biceps femoris*.

The sample length was measured by triplicate with a SOMET caliper at the beginning and at the end of the drying process.
The experimental data was obtained in triplicate.

3.2.2.7. Diffusion model

3.2.2.7.1. Definition of the model

In this mathematical model the diffusion transport mechanism is also assumed. The rate of water movement is described by the effective diffusivity value (D_e), where no matter which mechanism is really involved in water movement.

To apply this mathematical model the following assumptions are made:

- The water movement into the samples occurs in one direction and always according to the same mechanism during the whole period considered. The meat sample behaves as a slab (unidimensional water movement).
- The initial water content is uniform.
- The internal water movement is the main resistance to water transfer. External mass transfer is neglected.
- D_e does not depend on shrinkage and water concentration.

By solving the second Fick's law (equation 1.6.4) and assuming the commonly admitted boundary conditions on surface equilibrium and symmetry, the solution for an infinite slab takes the form of a series development (equation 3.2.34). Solution of 2^{nd} Fick's law for a slab (Crank, 1975):

$$\frac{X - X_e}{X_0 - X_e} = 2\sum_{n=0}^{\infty} \frac{(-1)^n \sin(\lambda_n r)}{(\lambda_n r)^2} e^{-D_e \lambda_n^2 \tau}$$

3.2.34

where

$$\lambda_n r = (2n+1)\frac{\pi}{2}, \quad n = 0,1,2,...$$

3.2.35

X is the average water content of the meat sample (kg H_2O/kg dm). X_e is the water content of the meat in equilibrium with the surrounding air relative humidity (kg H_2O/kg dm). X_0 is the initial water content (kg H_2O/kg dm). D_e is the effective diffusion coefficient (m^2/s). τ is the time in (s) and r is the half-thickness of the slab (m).

3.2.2.7.2. Equation fitting procedure

Expresion 3.2.34 allows to compute the data considering several number of terms of the series of development to obtain the D_e of the meat sample in an easy way (Mulet and Bon, 1993).

Therefore, in order to solve the equation representing the diffusion problem, the spreadsheet Microsoft Excel 5.0™ (Microsoft Corporation, 1992) is used. From the spreadsheet containing the experimental data of average dimensionless water content of the meat sample versus drying time, the diffusivity coefficient (D_e) is determined using SOLVER, a tool included in Excel that uses an optimization method (Newton or Conjugate Gradient) to identify one unknown variable by minimizing the total sum of squared deviations between the experimental and calculated dimensionless average concentrations. The solution must accomplish the constrain $D_e>0$.

3.2.3. Chemical analysis

The fresh meat was analysed to obtain the water content and the protein content. The dried samples were analysed to obtain the NaCl content, fat content and also the water content at the end of the drying process.

The water content was obtained by drying at 103 ºC until constant weight (A.O.A.C., 1980). The sodium chloride (NaCl) content was determinated using the Charpentier-Volhard method (A.O.A.C., 1980) . The protein content was measured using the Kjeldahl method (A.O.A.C., 1980), digesting 2g fresh sample by H_2SO_4. The fat content was measured using the ether extract method (A.O.A.C., 1980).

3.2.4. Statistical analysis

The estimated D_e values were analysed using variance procedure analysis (SAS, 1985).
The statistical models used in the experiments included the fixed effects, interactions and covariables shown in Table 3.2.4.
To test the homogeneity of slopes in experiment 1, the model 1 in Table 3.2.4 has been applied.

Table 3.2.4 Statistical models used.

Experiment	Model
1	$De_{ij} = \mu + S_i + b \cdot l_{ij} + e_{ij}$
2	$De_{ij} = \mu + T_i + S_i + T \cdot S_{ij} + e_{ij}$
3	$De_{ij} = \mu + F_i + e_{ij}$
4	$De_{ij} = \mu + M_i + e_{ij}$
5	$De_{ij} = \mu + pH_i + e_{ij}$

Where,

μ is the model average,

S_i is the effect of level i of NaCl content (i = 0, 0.09, 0.23, 0.30 kg NaCl/ kg d.m.),

l_{ij} is the sample length,

b is a constant (slope of regresion),

T_i is the effect of i level of temperature (i = 5, 13, 19, 26 ºC),

F_i is the effect of i level of fiber (i = L, T, TC),

M_i is the effect of i level of muscle (i = GM, SM, ST, BF),

pH_i is the effect of i level of pH (Normal, DFD)