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Evaluation of O₂ transfer in the food/packaging system for a better shelf life evaluation of modified atmosphere food packaging



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Context

Modified atmosphere packaging (MAP) relies on **modification of the atmosphere** inside the package in order to **extend food shelf life** by reducing physico-chemical (namely oxidation), microbial and physiological (for respiring foods) degradation rate while limiting the use of preservatives.

MAP simulating tool based on the use of mass transfer models concomitantly with predictive microbiology would be the most appropriate method to allow a correct **design and sizing** of modified atmosphere packaging systems. One of the main bottlenecks in the evaluation and study of impact of O₂ transfer on microorganism growth is the quantification of dissolved oxygen in the solid food.

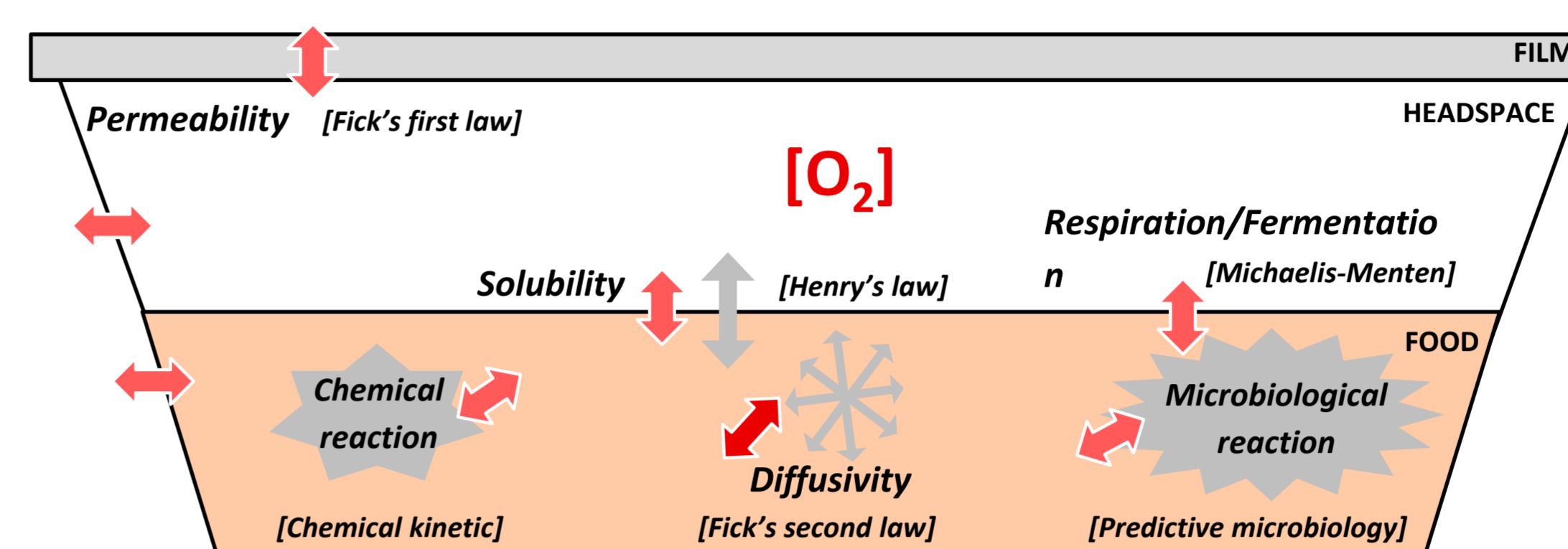


Fig 1. Schematic diagram for oxygen mass transfer and reactions in MAP

Oxygen transfer in food is characterised by a thermodynamic parameter, **solubility**, and a kinetic parameter, **diffusivity**. No data on oxygen diffusivity in non-respiring solid food matrix exists in the scientific literature. The proposed method permits to acquire the value of **oxygen diffusivity in solid matrices**.

Materials and Methods

Experimental set-up for monitoring oxygen transfer

- Establish a concentration gradient between the atmosphere and the product (Oxygen adsorption kinetics) (Fig 2.)
- Have an appropriate method for monitoring the oxygen transfer (Fig 3.)
- Mathematical modelling and identification of the diffusivity (Fig 4.)

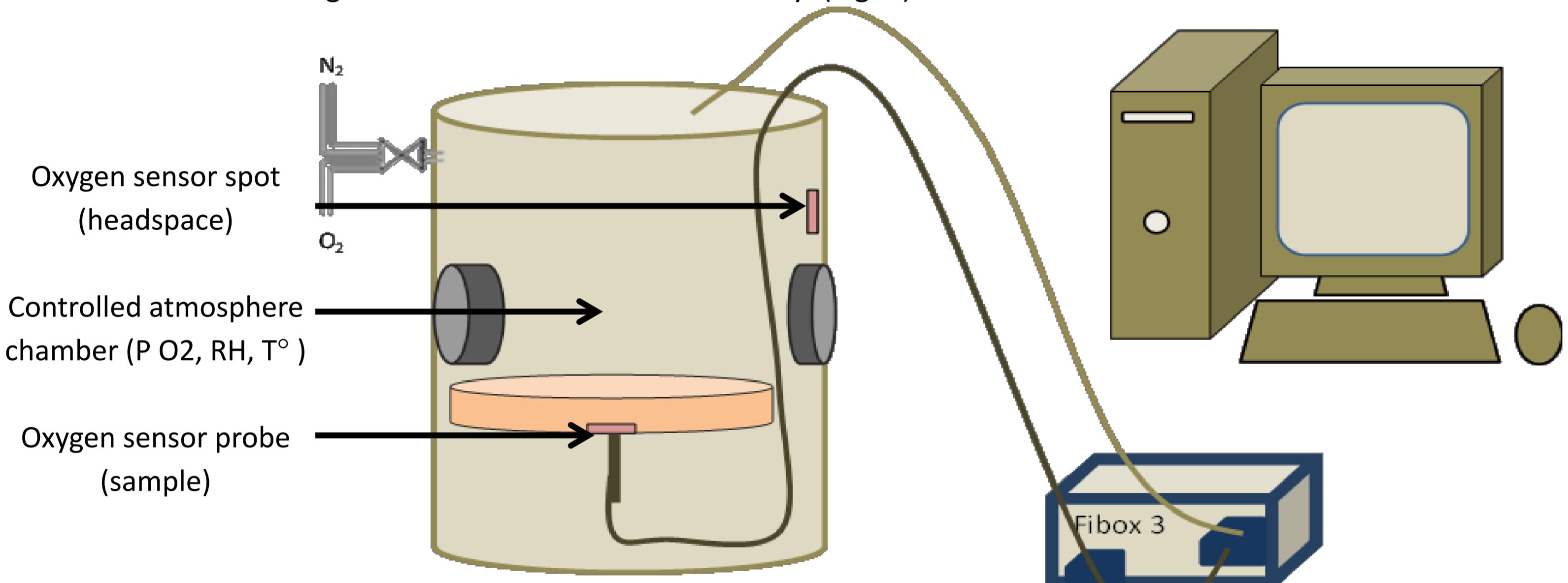


Fig 2. Experimental set up to measure the oxygen diffusivity in solid sample

Non-invasive and non-destructive optical oxygen sensor:

A **non-invasive** and **non-destructive** method was used to measure the **oxygen partial pressure** inside a transparent container by monitoring the fluorescence without consumption of oxygen (PSt6 & Fibox 3Presens, Neuburg, Germany).

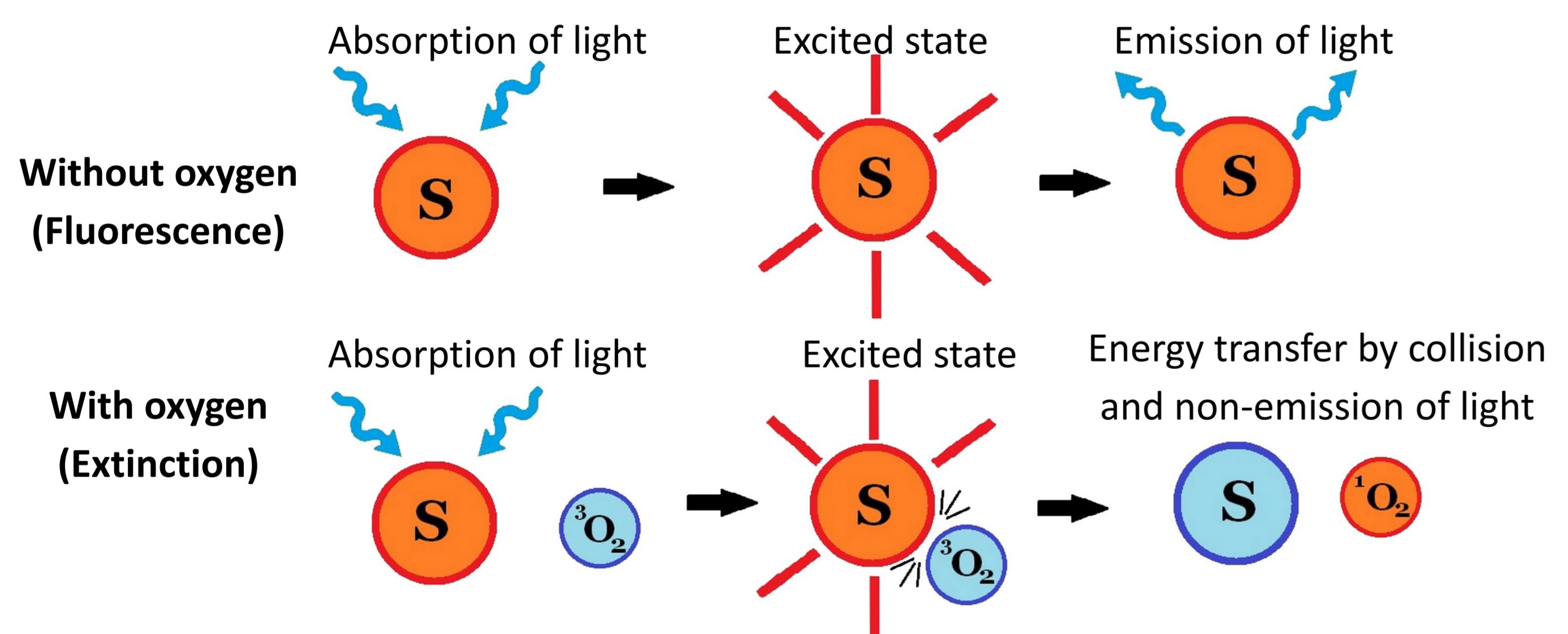


Fig 3. Principle of measurement of the oxygen partial pressure by extinction of luminescence

Our reference to validate the methodology is the invasive method syringe with luminescence quenching ⁽¹⁾ (Fig 3.). Both the method (syringe and spot (Fig 2.)) have used in this work.

Mathematical model

Fick's second law is used to model the oxygen transfer and express the variation of the concentration with space (x) and time (t). The system of equations given in Fig 4 is numerically solved and programmed on MATLAB [®] software. Then the **diffusivity (D)** is identified by minimizing the sum of squared error between experimental and predict data.

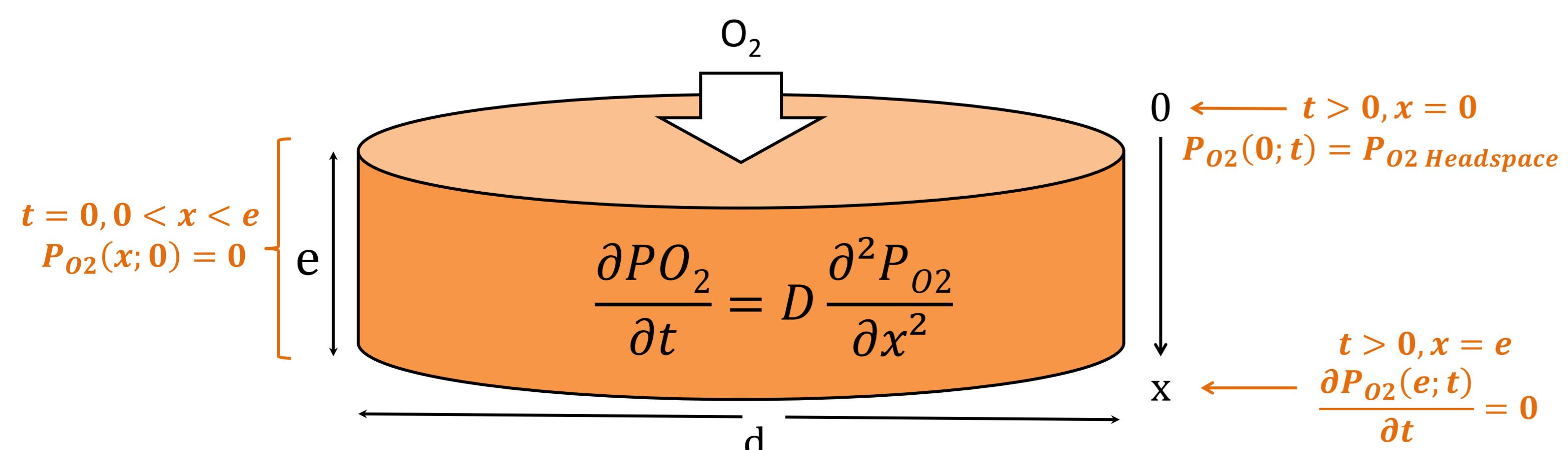


Fig 4. Thin slab type system for the analysis of gas transport in food matrix

Results

Validation of method :

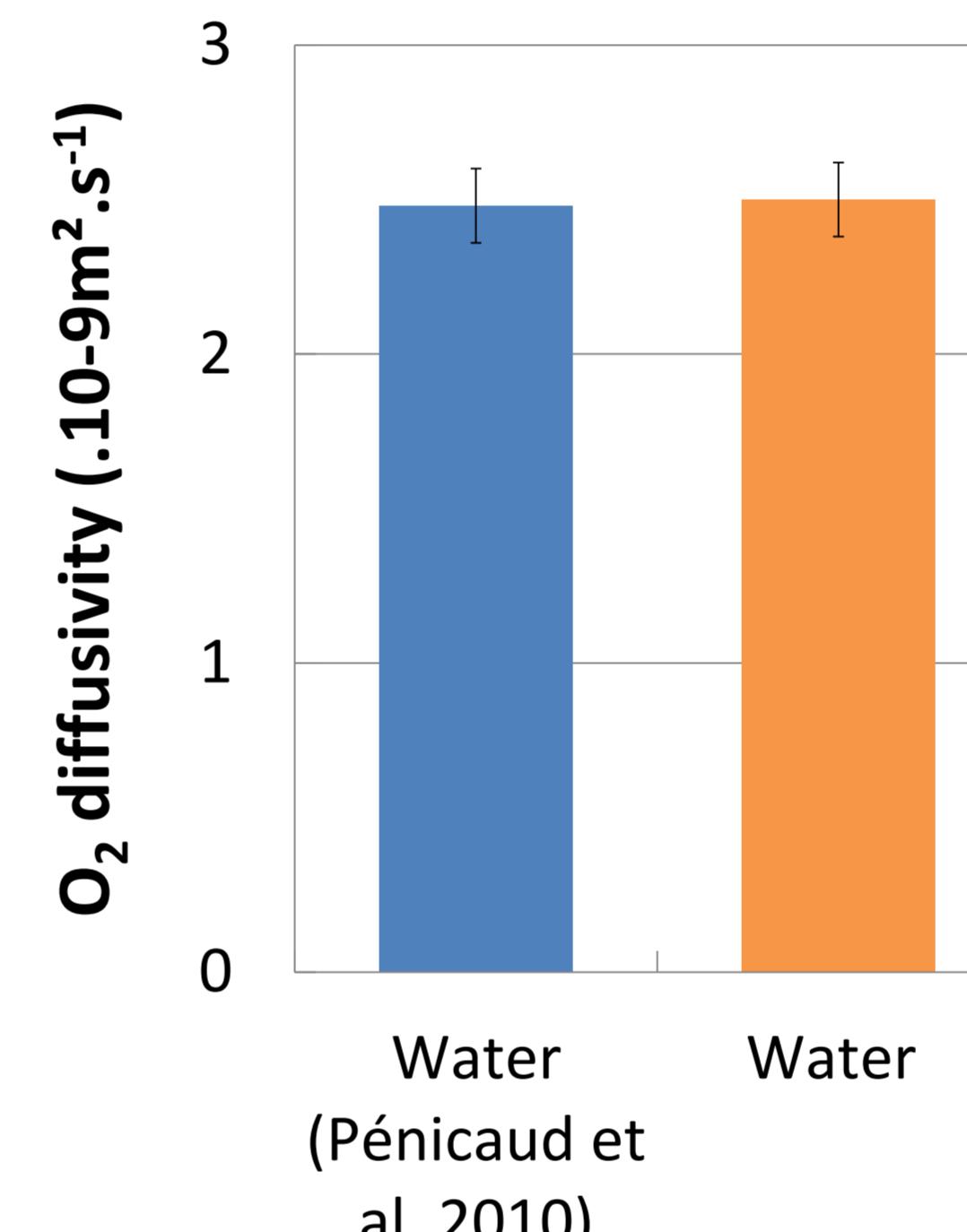


Fig 5. Oxygen diffusivity in water in the literature versus experimental (20°C)

Activation energy of O₂ diffusivity in model matrix : Miglyol 812

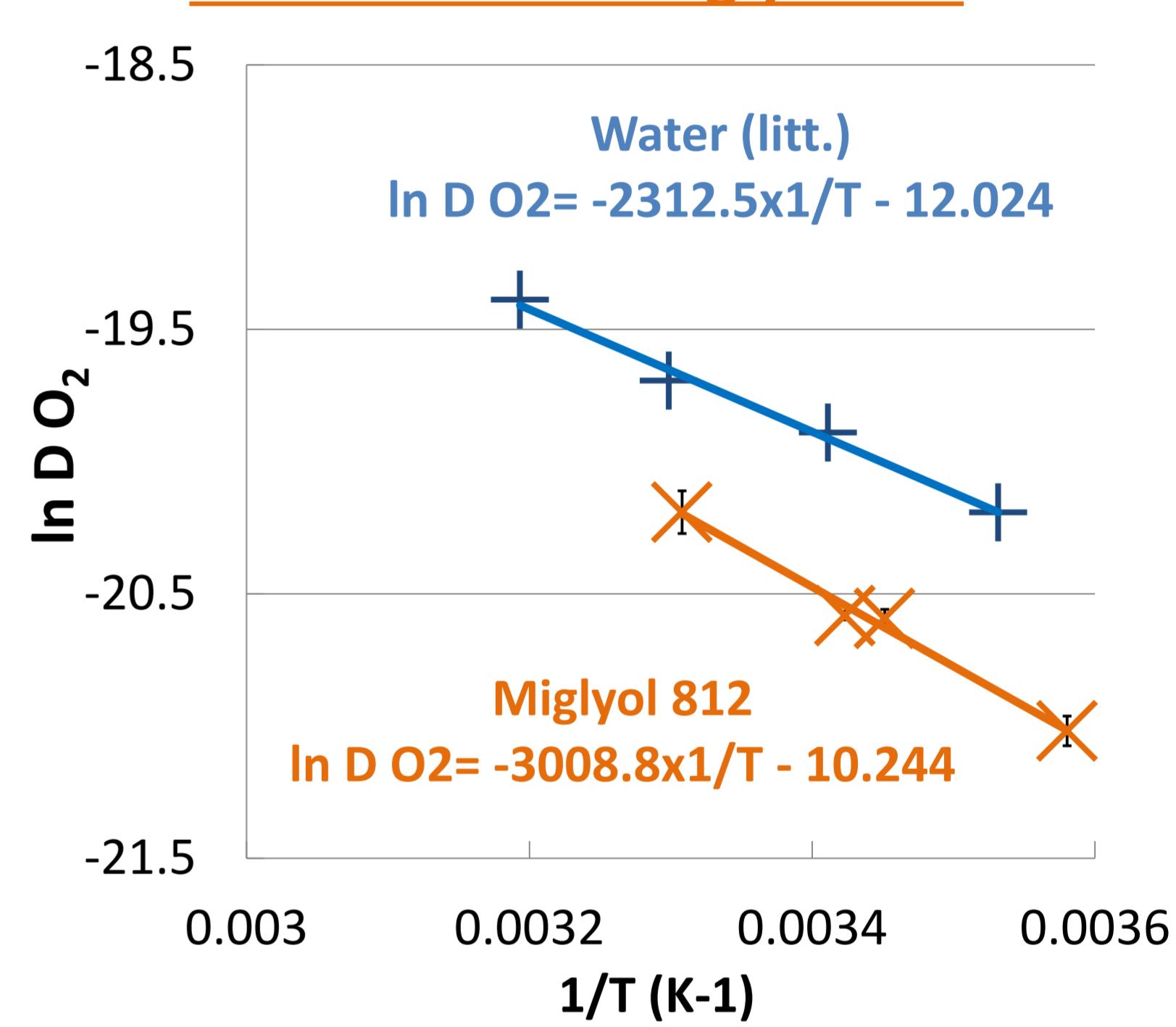


Fig 6. Arrhenius plot showing the temperature dependence on oxygen diffusivity in Miglyol 812 between 6°C and 29°C

Oxygen diffusivity in viscous and solid food matrices:

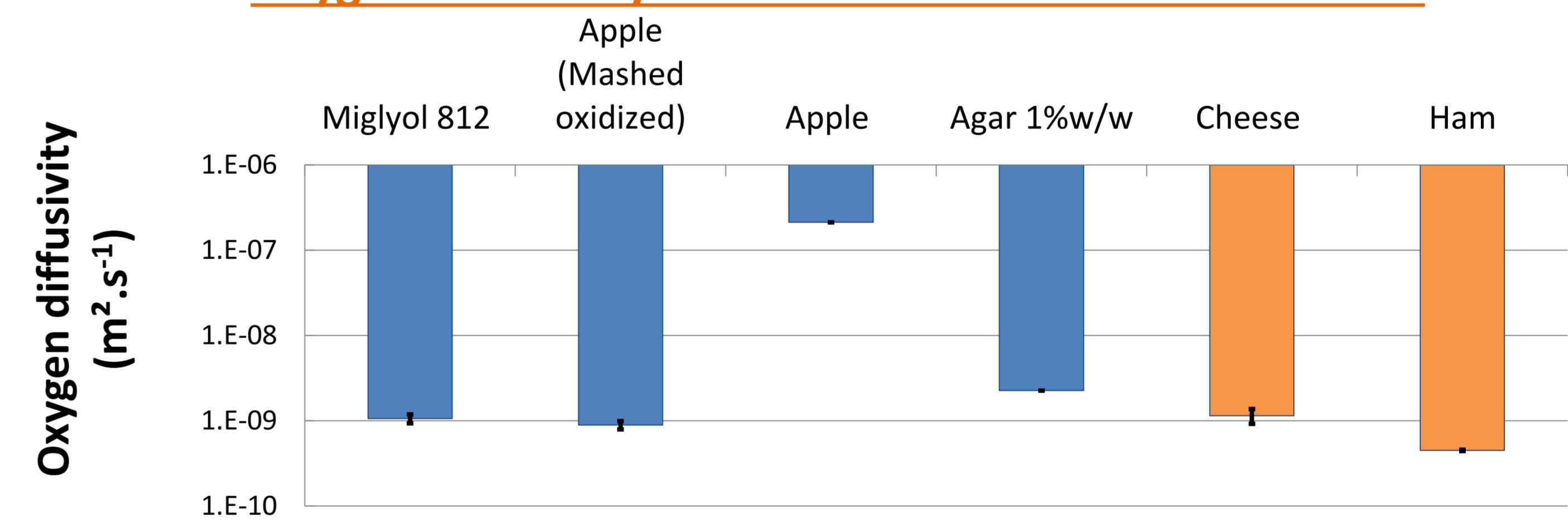


Fig 7. Data diffusivity of oxygen in the literature versus experimental (20°C)

Discussion

- The values obtained for water are in **agreement** with those found in the literature, and that **permits a validation of our method** (Fig 5.)
- The oxygen diffusion was found to be **strongly dependent on temperature**: oxygen diffusivity increase with temperature, in accordance with the **Arrhenius equation**. The activation energies of oxygen diffusivity is 25 kJ.mol⁻¹ in miglyol 812, from 6 to 29°C, and we estimated at 19.2 kJ.mol⁻¹ the activation energy of oxygen diffusivity in water, from literature value, from 10 to 40°C ⁽²⁾.
- Oxygen diffusivity data in food matrix in the literature are **widely dispersed**, especially for fruit (e.g. D_{O2} in apple are between 2.12x10⁻⁷ m².s⁻¹ ⁽³⁾ to 9.9x10⁻¹⁰ m².s⁻¹ ⁽¹⁾). For inert materials, the values of oxygen diffusivity are between 1.57x10⁻¹⁰ m².s⁻¹ (agar) ⁽⁴⁾ to 2.6x10⁻⁹ m².s⁻¹ (water) ⁽¹⁾. Our values of oxygen diffusivity for cheese matrix and ham are in accordance with the data available in the literature (Fig 7.)

This work presents a **non-invasive and non-destructive methodology**, to measure oxygen sorption kinetic in solid food. The use of luminescence sensor allows the implementation of a simple experiment set-up. A strong dependence between Temperature and Oxygen Diffusion was found. The first results in solid food matrices are in accordance with literature data.