# Application of thermodifussion in the development of new separation procedures

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## Abstract

This work is focused on the analysis of thermal forces as an advance solution to develop new separation techniques. For this purpose, the effect of thermodifussion as separator technique has been numerically validated for both liquid mixtures and colloidal particle suspensions. Once the technique has been validated, a numerical and experimental study for the optimization of the molecular diffusion separation process of a protective cryo (10% DMSO in PBS) used to cryopreserve cells by means of thermodifussion has been analysed.

**Keywords:** *Thermodifussion, Thermophoresis Separation, Microdevice.*

## 1. Introduction

Transport phenomenon related to thermodifussion are highlighting in the science community due to the high number of ambits where they play an important role such as separation techniques [1], combustion processes [2], geological fields characterization [3], etc. Related to the separation techniques, thermodifussion is getting of high importance in the biomedical field [4]. Most of actual separation techniques are long, with various tedious steps, hindering the investigations to find clinical applications. In front of this problems, thermodifussion has been presented as alternative, easy and affordable separation mechanism.

In macromolecules and colloids, thermodifussion is of high interest due to its potential in biological fluids characterization and study [5]. Moreover, it has been presented as a biological transport mechanism, on living beings material transport. It has also been demonstrated that thermal gradients are an important factor in the navigation of sperm cells to the ovule inside the feminine genital tract [6].

The representing magnitude of this phenomena is the Soret coefficient, $S_T = D_T / D$ being $D_T$ the thermal diffusion coefficient and $D$ the diffusion coefficient. When a particle suspension is placed in a thermal gradient, a stationary state of concentrations $\nabla c = cS_T \nabla T$ is given, where $c$ the concentration is. It has been seen that a $\nabla T$ =1ºC is able to obtain a c/c=20 % in a 20 µm cannel [7]. In this way, it has been seen that thermodifussion can be an attractive separation technique in biotechnological processes.

## 2. Project development

Various numerical simulations using the software ANSYS Fluent 16.0 have been done. First, the actual state of the technique in the biomedical world has been analysed, then the validation of the technique is done. Finally, the optimization of a microfluidic separation has been studied.

### 2.1 Biological background

Thermodifussion as a technology for separation is growing fast in the biotechnological market. One of the enterprises in the new technologies development is Postnova Analytics GmbH, which has developed new products of flow division below temperature gradients. The microdevice TF2000 has a large separation range and it is able to separate different polymers with a high resolution. Moreover, it permits to separate gels or nanoparticles.

On the other hand, Nano Temper Technologies Gmbh, has developed a micro scale technology based on thermophoresis that allows to measure a wide number of interactions between biomolecules close to natural conditions. The microscopic temperature gradient is generated by an infrared laser and the movement of particles is monitored by fluorescence.

Therefore, the numeric calculation tool ANSYS Fluent 16.0 has been used to add value to the developments related to separation processes of biotechnological interest in a micron scale.

### 2.2 Numerical validation

Two different numerical validations of the technique have been done. First, the separation of liquid mixture water-isopropanol has been simulated. Then a Polystyrene particle suspension in a 100mM of NaCl dissolution has been simulated.

#### 2.2.1 Binary mixture water-isopropanol 50%

For the first validation, a well-studied mixture has been selected, water-isopropanol in a concentration of 50 % [8]. Starting from the values of the thermophysical properties defined in bibliography, the Soret coefficient stated in the article have been compared to the obtained numerically.

A three dimensional rectangular channel (0.02 x 5 x 30 mm) has been defined, where a binary mixture of water-isopropanol 50% has been introduced.

Regarding the numerical model, Species Transport model has been used. The properties of each component of the mixture have been defined, as well as the properties of the mixture. The most characteristic coefficient has been the thermal diffusion coefficient. A unit change has been done to introduce the parameter in the software by the equation 1.

$$D_{T\ fluent} = D_{T\ experimental} \cdot C_0 \cdot (1 - C_0) \cdot T_0 \cdot \rho_0 \quad (1)$$

A temperature difference of 8 K has been stablished among the top and the bottom wall and the lateral walls have been defined as adiabatic. Once all parameters have been set the case has been solved. The mass fraction of each component has been measured in different points of the device as it can be seen in Figure 1.

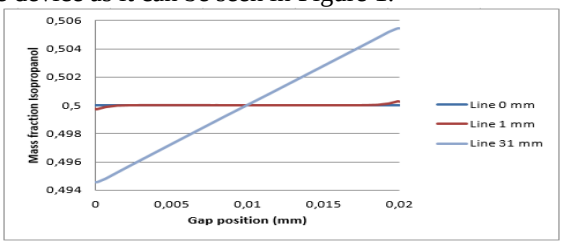


**Figure 1:** Mass fraction of Isopropanol in different positions of the device.

In order to analyse the efficiency of Fluent 16.0 the Soret coefficient stated in the article has been compared to the obtained numerically. The experimental value is 5.89e-3 $K^{-1}$ while the numerically obtained is 5.87e-3 $K^{-1}$, giving to a percentage error of 0.24 %.

### 2.2.2 PS particle suspension

Once the technique has been validated for binary mixtures, a particle suspension separation has been simulated. The trajectory of polystyrene particles in a microdevice has been analysed and results have been compared to the ones shown in the article [10].
A particle population of polystyrene of 477 nm suspended in a dissolution of 100mM NaCl has been introduced in a 50 mm length 3D rectangular channel shown in Figure 2.

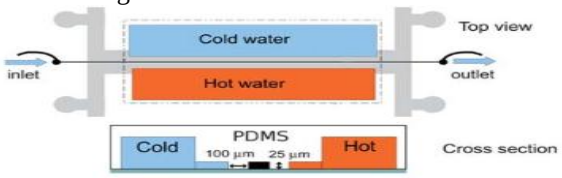


**Figure 2:** Microdevice configuration scheme.

The case has been resolved using the Euler-Lagrange approach and the particles have been injected in the fluid using the Discrete Phase Model (DPM) in a two-way interaction. The two phases exchange heat, mass and momentum, but the interaction between particles have been ignored since the particle volume fraction is relatively low, around 1%. The properties of each component have been defined and the thermophoretic coefficient have been introduced using the equation 2 [11].

$$D_{T\ fluent} = 6\pi \cdot \mu \cdot T \cdot D_{T\ \exp} \cdot \frac{P_{DIAM\,(p)}}{2} \quad (2)$$

Moreover, as submicron particles in a shear field experience a lift force perpendicular to the direction of the flow, the Saffman Lift force has been activated. After setting all the affecting forces, the boundary conditions have been defined. A 2.42 K difference has been set among the lateral walls and the suspension have been introduced at a velocity of 90 µm/s.
The results show a particle displacement toward the cold wall. Due to this displacement, a concentration gradient among the channel has been generated. The value of the mass fraction of particles in the outlet of the device shown in the article has been compared to the obtained numerically. The percentage error obtained in the cold wall has been 0.379 %, whether in the hot wall has been of 0.412 %.

## 2.2 Optimization of microfluidic separation

Nowadays, one of the applications of microfluidic devices is cleaning cryopreserved cells, getting rid of the protective cryo by molecular diffusion [12-13]. One of the protective cryo is Dimethyl Sulfoxide (DMSO) that is used to cryogenate cells, tissues or organs but a high period exposure can damage the cells due to their toxicity [14]. The standard cleaning technique is the spin cleaning, but around the 30% of the cells are damaged [15]. However, microdevices used for extracting cells DMSO can have limited applicability because the separation by molecular diffusion can be slow.
A numerical and experimental study of the optimization in the separation of the mixture PBS/DMSO used in biological samples on a mass fraction of 10% by means of thermodifussion have been done.
First the determination of thermophysical and transport properties of the mixtures have been done. The thermodifussion coefficient has been measured by the thermogravitational column technique and the molecular diffusion coefficient by means of Sliding Symmetric Tubes. By the relationship of this two parameters the Soret coefficient has been measured. Among these properties the density, the viscosity and the thermal and mass expansion coefficients have also been measured.
Then, a numerical study has been done in order to analyse the separation of DMSO, based on the device used by Mata et. Al shown in Figure 3[13].

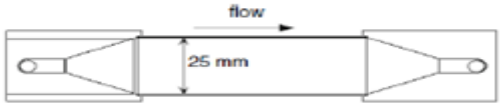


**Figure 3:** Top view of the device diagram

The device consists on a central cavity in which separation occurs. The flows are introduced through two opposite inputs, and a divider plate redirects the flows and prevents their mixing. Finally, flow extraction is done by two outputs identical to the inlet. From the upper inlet, PBS is introduced, whether a mixture of 10% DMSO in PBS is introduced from the lower one. A temperature difference of 7 K has been stablished among the top and the bottom walls. Once the simulations have been done, the simulated device has been constructed and an experimentally studied. The separation validation has been performed using the system shown in Figure 4.

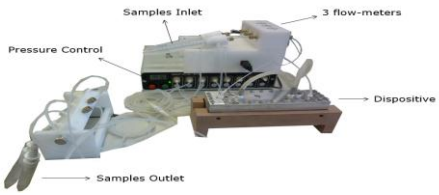


**Figure 4:** Installation used for experimental study.

## 3. Results

Regarding the numerical results, the mass fraction of DMSO is shown in Figure 5. As it can be seen, DMSO is introduced from the lower inlet and it is displaced toward the top wall.

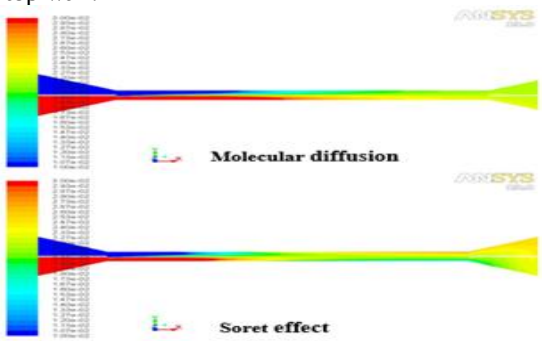


**Figure 5:** Numerical result of 10% DMSO/PBS separation.

The DMSO concentration extracted from the top outlet is bigger in the case of the Soret effect than in the case of the molecular diffusion, so it can be said that the separation is improved by the thermodifussion effect. Different cases have been analysed and compared to the experimental results as it can be seen in Figure 6. The concentration of the bottom plate is represented $c_c/c_0$, where $c_0$ is the initial mass concentration of DMSO (10%) and $c_c$ the mass concentration of DMSO in the output against $(1/P_e)$x$(L/d)$, the relation between the Peclet number $(P_e)$ and the length $(L)$ and height $(d)$ of the diffusion zone.

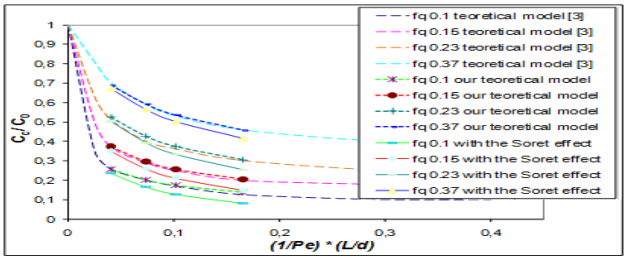


**Figure 6:** DMSO extraction fraction $c_c/c_0$ as a function of $(1/P_e)$x(L/d)

As it can be seen the results obtained for the diffusion model agree with the results obtained of the work [13]. Moreover, it can be seen that the Soret effect improves the separation.

Finally, experimental trials have been done. The extraction efficiency has been above 55 % and it has been seen that there is a 10 % improvement on the separation process compared to devices that use only molecular diffusion.

## 4. Conclusions

In this work it has been demonstrated numerically and experimentally that thermodiffusion effect is a valid technique for separation and optimization processes and can improve the functioning of microdevices.

## Acknowledgements

The author would like to thank the support of BG2015(KK-2015/0000089), Research Groups (IT009-16) and MICROXOM (PI_2014_1_70) of Basque Government and TERDISOMEZ (FIS2014-58950-C2-1-P) of MINECO.

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