Original Research Article

Stabilization of a pickering emulsion by nanoparticles of Eudragit RSPO and polyepsilon caprolactone: Contact angle measurement and surface tension studies.

Abstract

The use of colloidal particles to prepare and stabilize emulsions, known as "Pickering emulsions" has aroused growing interest in recent years. Pickering and Ramsden demonstrated at the beginning of the last century the feasibility of surfactant-free emulsions, in the presence These emulsions are called "Pickering Emulsions". This concept of emulsions stabilized by solid particles is experiencing renewed interest nowadays given the many advantages it offers: good stability, environmental protection, user safety, particle varieties.

A first part is devoted to the synthesis of Eudragit RSPO and polyepsilon caprolactone nanoparticles and their characterization. The characterisation of the nanoparticles is performed by dynamic light scattering and zetametry. The understanding of the interfacial behaviour of these nanoparticles and their associated stabilisation mechanisms for emulsions was carried out. The second part of the study investigated the formulation and stabilisation of the emulsion using the washed suspension containing the nanoparticles as the only stabiliser. The objective of this part is to stabilise and characterise the formulated emulsions. Droplet size determination and microscopy were performed using a Zeiss optical microscope. The direction of the formulated emulsions was determined by conductimetry. In conclusion, Pickering emulsions stabilised solely by Eudragit RSPO and Polyepsilon Caprolactone nanoparticles appear to be highly effective innovative drug carriers, opening new doors as potential drug delivery systems.

Keywords: Pickering Emulsion, Polymer, Contact angle, Eudragit RSPO, Polyepsilon Caprolactone

Introduction

The term emulsion has a very wide application and is usually difficult to identify with a particular product. Emulsions are metastable mixtures of two immiscible liquids and an amphiphilic agent. One of the liquids is dispersed in the other in the form of small spherical drops whose size varies according to the conditions from 0.1 to a few tens of micrometres. There are different types of emulsions: Water-in-oil emulsions where the dispersing phase, also called the external phase or continuous phase, is constituted by the oil, and the internal phase or discontinuous phase or dispersed phase is represented by the water; Oil-in-water emulsions with the aqueous dispersing phase and the dispersed oily phase; Mixed emulsions or multiple emulsions (W/O or O/W/O). The system thus created does not correspond to a thermodynamically stable state, the most stable state would be the macroscopic separation of the two fluids. Kinetic stability is ensured by the presence of amphiphilic molecules, called emulsifiers, adsorbed at the interface between the two phases (Cabane and Henon, 2007).

These emulsifiers are most often surfactants. These are molecules with an affinity for both water and oil. In fact, they are made up of a polar hydrophilic head and an apolar hydrophobic tail. However, because they are harmful to the environment and the body, their use is not without risk.

The use of colloidal particles to prepare and stabilise emulsions, known as 'Pickering emulsions', has attracted increasing interest in recent years (Iwashita, 2020; Pickering, 1907). These emulsions are called "Pickering emulsions". These emulsions are known in the petroleum industry, food industry, and in the design of inks, paints, road surfaces. Recently, the possibilities of applications of particle-stabilised emulsions have been considered in the pharmaceutical industry. This type of formulation can be a potential encapsulation system for active ingredients, allowing the controlled and targeted release of the active from the internal phase (Bago Rodriguez and Binks, 2019; Gonzalez Ortiz et al., 2020; Sy et al., 2020; Yang et al., 2017; Zakir Hossain et al., 2021). However, this type of emulsion is not yet commercially available. There are many studies on the formulation and physicochemical properties of emulsions stabilised by solid particles, but to date studies in a biological environment have not been described in the literature.

The control of the adsorption of colloidal particles at the liquid/ liquid interface leads to the development of new functionalized. However, the study of the adsorption of colloidal particles is very important to better understand their own properties, materials such as colloidosomes (Binks, 2017, 2007; Böker et al., 2007) as it can be, for instance, strong and irreversible at the oil/water interface. The irreversible adsorption of the particles allows one to obtain very stable emulsions (Binks, 2002; Binks and Horozov, 2005). This leads to the formation of a dense film, thus creating a barrier around the droplets, giving them high resistance to coalescence. The particle adsorption or desorption energy DE is mainly related to their ability to be partially wetted by the two phases of the emulsion (Binks, 2007; Cayre et al., 2012; Dickinson, 2010; Hunter et al., 2008). The particle wetting is characterized by the contact angle between the aqueous phase, the oil phase and the solid particles, measured on the aqueous phase side, making the contact angle and the particle diameter two crucial parameters to determine the interfacial adsorption forces. The well-documented literature in this research area concerns, in most cases, the development of Pickering emulsions and foams, and their potential use(Crossley et al., 2010; Dinsmore et al., 2002; Duan et al., 2005; Velev et al., 1996; Wang et al., 2012; Yow and Routh, 2009).

The direct effect of the nanoparticles on the interfacial tension, which, is still in discussion, the ‘‘macroscopic’’; the result of their impact on the formulation lies in their capabilities of Pickering emulsion stabilization. The stabilization is generally higher when they form a dense ‘‘monolayer’’ around the droplets, while partial coverage does not stabilize the emulsion effectively because the ‘‘bald’’ plates favor the drainage of the film and flocculation/coalescence. For this reason, it is acknowledged that better coverage is generally obtained with smaller particles (Levine et al., 1989).

This work is devoted to the preparation and study of Pickering emulsions stabilised by a polymer such as poly epsilon caprolactone and eudragit RSPO. The work is divided into three parts: first, the synthesis and characterisation of nanoparticles for emulsion stabilisation. Then we carried out a formulation study including the determination of the contact angle and the interfacial tension to better understand the stabilisation mechanisms, and finally the preparation and characterisation of the emulsions obtained.

SECTION EXPERIMENTALE

Material and methods

1-1 Material

The equipment used for the synthesis and characterisation of the nanoparticles is a Malvern Zetasizer and a rotary evaporator. To measure the contact angle we have developed an experimental device. This device consists of: Optical bench, a light source, a thermostatic tank filled with oil and needle with rising drop, a syringe filled with the aqueous phase, a calibrated telecentric lens, a CCD camera, and a video monitor and computer. A Wilhelmy blade tensiometer (Dogno Abribat tensiometer) was used in the tensiometry study.

1-2 Regents

The polymers used for the synthesis of the nanoparticles are poly epsilon caprolactone (Sigma Aldrich) and Eudragit RSPO (Rohm germany), and the surfactant used is sodium dodecyl sulphate (SDS) (LABOSI). As aqueous phase we used MilliQ water (Millipore). The organic solvent used for the synthesis was acetone (sigma Aldrich). Various other chemicals were used.

1-3 Methods

1-3-1 Synthesis and characterizations of nanoparticles

Synthesis of poly epsilon-caprolactone and eudragit RSPO nanoparticles: The nanoprecipitation technique, sometimes described as "solvent displacement", allows the production of nanospheres or nanocapsules. It consists of dissolving the polymer in the organic solution. The solvent chosen is generally a semi-polar solvent such as acetone or ethanol, which must be miscible with water in all proportions. This solution is injected, with moderate stirring, into an aqueous phase, possibly including sodium dodecyl sulphate, in which the polymer is not soluble. The nanoparticles are then formed instantaneously under the effect of the diffusion of the acetone towards the aqueous phase. The polymer, insoluble in the water-solvent mixture, precipitates in the form of nanospheres. The organic solvent is then removed by evaporation under reduced pressure.

Dynamic light scattering. Size distributions and poly- dispersity indices (PDI) were measured by dynamic light scattering (DLS) with a NanoZS Malvern apparatus (Malvern, Orsay, France). The helium/neon laser, 4 mW, was operated at 633 nm, with the scatter angle fixed at 1731 and the temperature maintained at 25 1C. DLS data were analyzed using a cumulant-based method, and experiments were performed in triplicate.

<u>*ζ Potential Measurements*</u> ζ were mesured, with a NanoZS Malvern apparatus (Malvern, Orsay, France). ζ potentials measurements were performed 1 h after formulation. The NanoZS used in this study determined the electrophoretic mobility of the particles, and then calculated the values of ζ potential using the Henry's equation under the Smoluchowski approximation. All experiments were performed in triplicate.

1-3-2 Contact angle measurement

The contact angle measurement reports the ability of a liquid to spread on a surface by wettability. The method consists of measuring the angle of the tangent of the profile of a drop deposited on the substrate, with the surface of the substrate. It allows the surface energy of the liquid or solid to be measured. The measurement of the contact angle gives access to the free energy of a surface. It also allows the discrimination of the polar or apolar nature of the interactions at the liquid-solid, liquid-liquid, liquid-gas interface. The hydrophilic or hydrophobic nature of a surface can thus be deduced.

To measure the contact angle we have developed an experimental device. This device consists of : 1-Optical bench, 2-Light source, 3-Thermostatic tank filled with oil and needle with rising drop, 4-Syringe filled with the aqueous phase, 5-Calibrated telecentric lens, 6-CCD camera, 7-Video monitor and computer.

For drop formation, we have a system consisting of a micrometric syringe with a volume of 1 ml, a silicone tube and a stainless steel flat-tip needle with an external diameter of 0.8 mm and an internal diameter of 0.5 mm.

The drop images are acquired by a CCD camera. They are then transmitted to a computer equipped with a graphics card and Studio acquisition software. The images are then processed with Image J image processing software.

To obtain good image contrast, diffuse lighting is used. The intensity of the lamp is set to its minimum. The optimal objective-drop distance x is about 13 cm; the best compromise between magnification and image quality is then obtained. The camera-drop distance x' is 30 cm and the optical fiber-diffuser distance x' is 22 cm. The diffuser-drop distance affects the contrast of the image obtained. The height of the millimetric syringe has no influence on the results but must be fixed during handling in order to avoid any instability.

The equipment used must be as clean as possible. The acquisition of the image of a drop is done using the Studio software and the processing of this image in order to obtain the contact angle using the ImageJ software

Before starting the measurements, it must be ensured that the lamp, the camera and the control screen are switched on. In order to obtain a sharp image of the drop, it is advisable to place the camera lens approximately 13 cm from the drop.

Determination of the contact angle; Using Image J software

We use the Image J software to open the images, to measure a length or an angle. Opening an image: File/Open and choose your image in the appropriate directory.

Measurement of a length: To measure a length on an image, you need a standard. So, on the same image as what you want to measure, you must have a millimeter ruler or an object whose size you know. In the rising drop experiment, a good standard is the syringe. To measure the diameter of the drop, use the same method and note the length in pixels. Then, draw a vertical line of the same length in pixels which will allow you to measure the diameter ds in the right place. You can permanently draw this line by right clicking / draw or clear.

Measuring an angle: To measure an angle, you must use the “Angle tool”. To measure the angle between two lines, first click on the two lines then at the intersection, hold the mouse click and position it on the other line. The angle (“angle”) is then displayed in the main Image J window.

1-3-3 Tensiometer

Interfacial tension is the free energy per unit area between two liquids (Cabane and Henon, 2007). It is called surface tension when one of the two liquids is gaseous. This interfacial tension is measured using a tensiometer. Therefore, the main technique used in our study is the Wilhelmy blade method.

In the case of the blade method, the liquid is brought into contact with a platinum blade (Pt), itself connected to a precision balance. The force (F) necessary to tear the blade is measured in order to determine the interfacial tension (according to the equation).

$$\gamma = \frac{F}{L\cos\theta}$$

γ: surface tension, F: surface tension force, L: length of the platinum plate, θ: contact angle A Wilhelmy plate tensiometer (Dogno Abribat tensiometer) was used during this work. For interfacial tension measurements, oil was gently added to the surface of the aqueous phase so as to completely immerse the slide. The zero was performed prior to the measurement by immersing the Wilhelmy blade in oil.

1-3- 4 Formulation and characterizations of emulsion

Macroscopic Examination: The emulsions are left to stand in the dark and at room temperature in 15 ml conical tubes fitted with lids. This visual inspection highlights certain phenomena of instability such as sedimentation, flocculation and coalescence.

pH Determination: The determination of the pH of the solutions is based on the measurement of the potential between two electrodes immersed in a solution rich in H + ions After calibrating the pH meter with solutions of known pH, the electrode is dipped into a 15 ml conical tube containing the preparation to be studied. Like conductivity, care should be taken to immerse the electrodes to the level of the emulsified phase for tubes with sedimentation. The reading is made a few minutes after the insertion of the electrode.

Conductivity Measurement: It is based on the measurement of the electrical resistance of a solution located between 2 plates covered with platinum black. Depending on the concentration of ions present, the solution will have a greater or lesser conductivity. The conductimetry cell is introduced into a 15 ml tube fitted with a screw-on lid containing the preparation to be studied. In the presence of a conductive preparation, the conductivity meter displays a value corresponding to the conductivity and expressed in Siemens per meter (S. m-1). In the case of tubes with sedimentation, immerse the conductive cell to the level of the emulsified fraction.

Droplet Size of Pickering Emulsion: a droplet of emulsion is placed on a slide and then covered with a coverslip. The slide is placed on the stage of the microscope and the observation is carried out with the 40X objective. The device is equipped with software that allows direct photography of the observed image. The image of the droplets obtained thereafter is correlated by the software which makes it possible to determine the size of the droplets by delimiting the diameter of each droplet.

1- Results

2-1 Synthesis and characterization of nanoparticles

Synthesis of poly epsilon-caprolactone and eudragit RSPO nanoparticles

Dynamic light scattering. Size distributions and poly- dispersity indices (PDI)

We have developed nanoparticles by nanoprecipitation at different concentrations of polymers 0.5%, 1%, 2%, 3%, and 4% for eudragid RSPO and Poly epsilon caprolactone. Figure 1 shows the size distribution of the nanoparticles. The size of the nanoparticles obtained varies from 90 to 300 nanometers with polydispersity indices from 0.1 to 0.3.

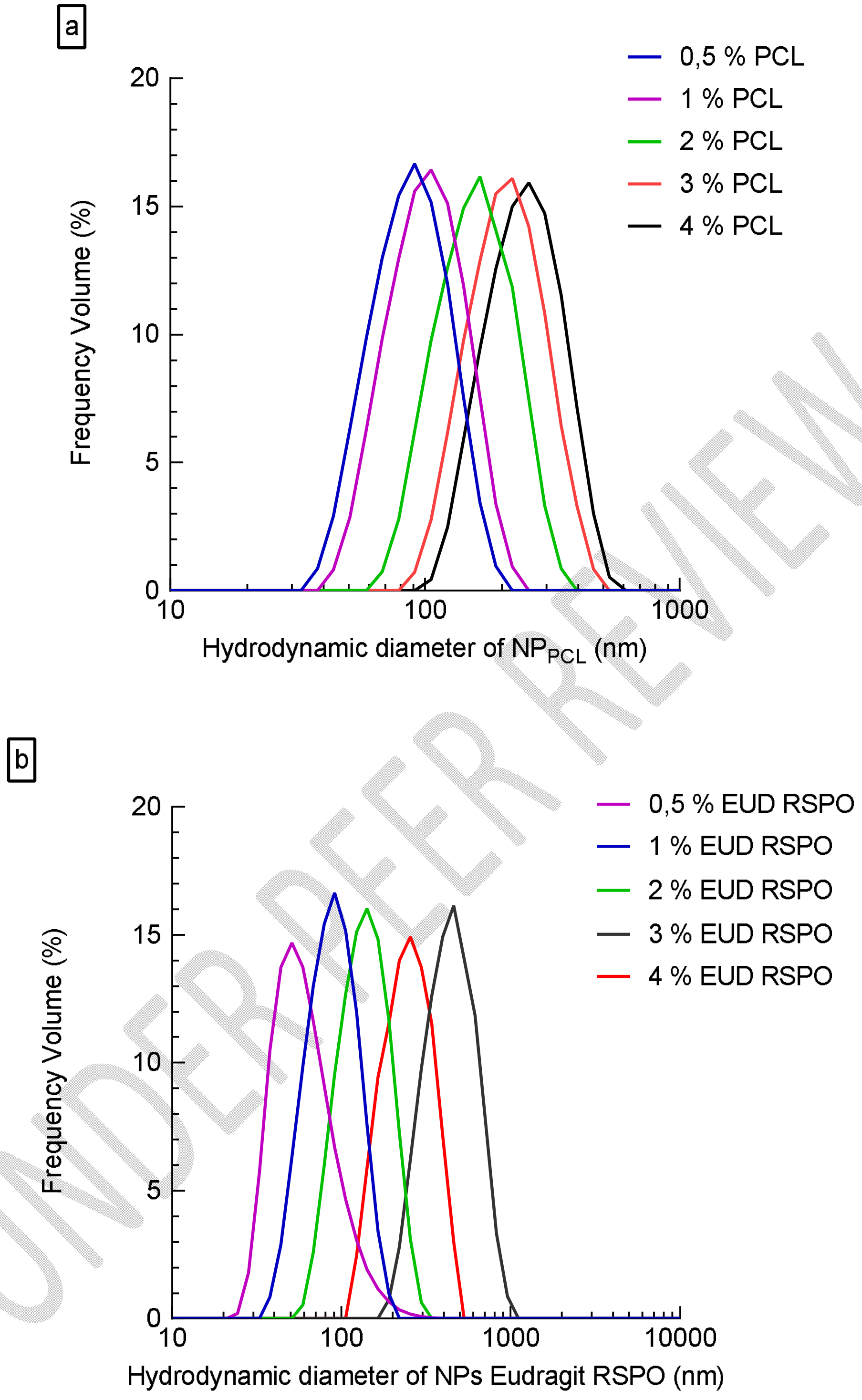
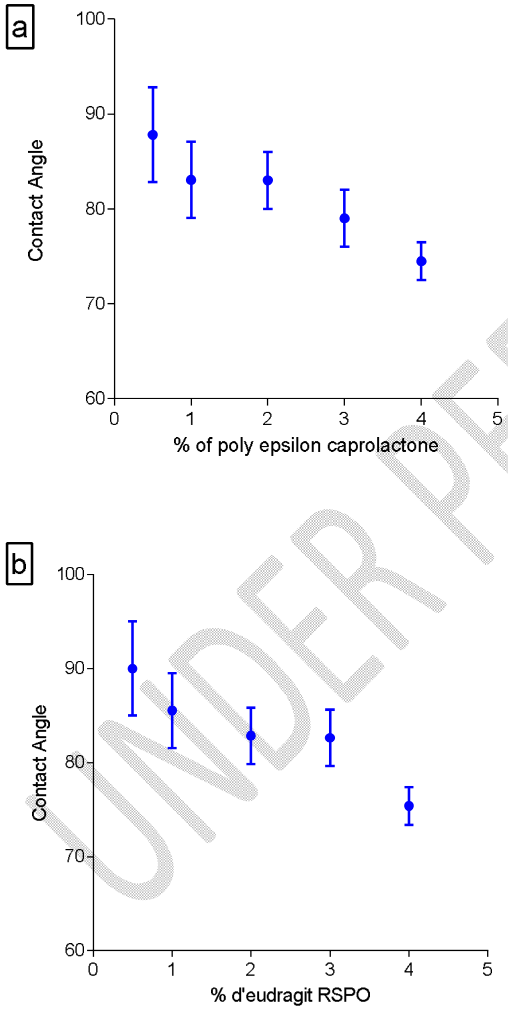


Figure1: hydrodynamic diameter of nanoparticles (a) polyepsilon caprolacton (b) Eudragit RSPO

Potential Measurements ζ : Le Potentiel Zeta déterminé pour le poly epsilon caprolactone nous donne des valeurs comprises entre -25 et -30 Mv et pour ceux de l’eudragit RSPO on a des valeurs comprises entre +20 et +40Mv.

2-2 Contact angle mesurement

The following figures show the transformations of the image obtained with the assembly and the determination of the liquid-liquid contact angle by the Image J software. The results obtained are presented in Figures 2a and 2b.



Tubes	*T1*	*T2*	*T3*	*T4*	*T5*
% PCL	0,5	1	2	3	4
Contact Angle	87,8	83,05	83,01	79,01	74,48

Tubes	*T'1*	*T'2*	*T'3*	*T'4*	*T'5*
% Eud RSPO	0,5	1	2	3	4
Contact Angle	90	85,55	82,87	82,63	75,38

Figure 2 : Contact angle (°) (a) Polyepsilon Caprolactone, (b) Eudragit RSPO.

2-3 Tensiometer studies

The surface tension measurements carried out show a lowering of the tension which is conferred on the activity of the polymers at the water/oil interface. The reference voltage without the nanoparticles being higher than that with the nanoparticles, Figure 3 shows the results of the tensiometric studies:

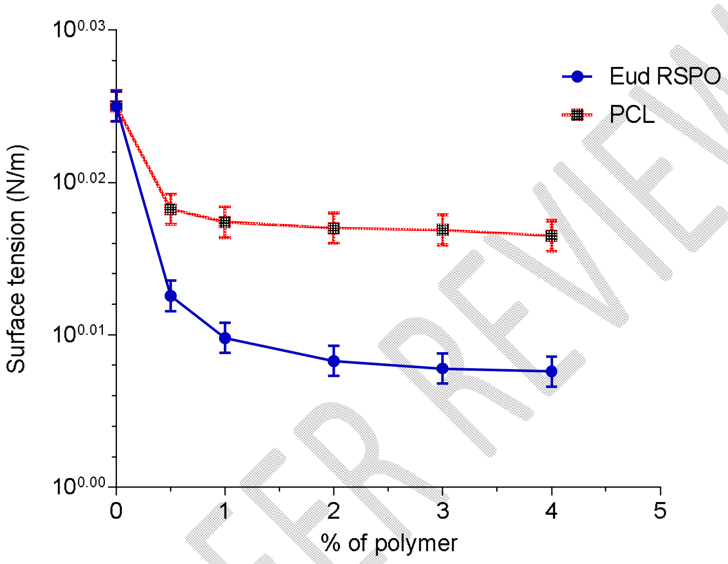


Figure 3: Surface tension as a function of polymer percentage

2-4 Formulation and characterisation of Pickering emulsion

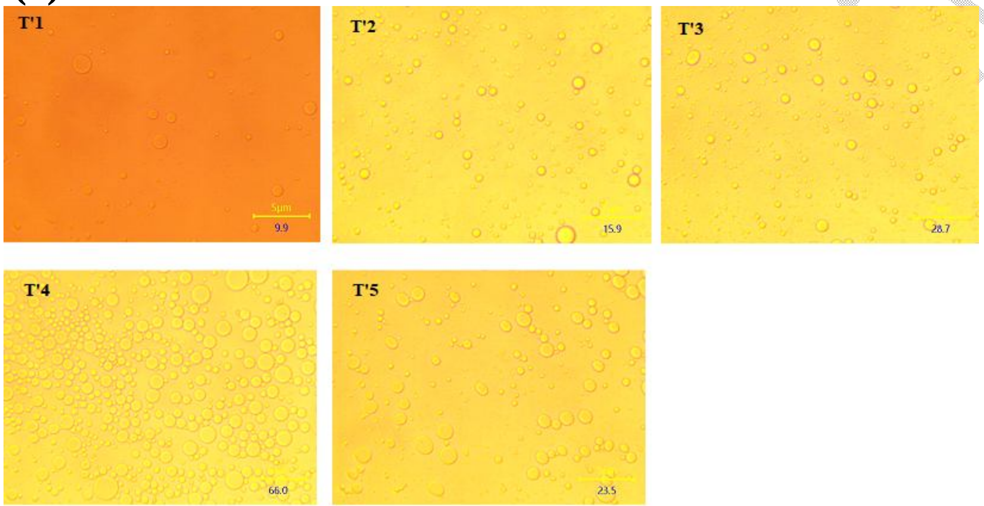
<u>Macroscopic Examination:</u>

In this part, the study consisted in preparing series of emulsions with the suspensions of nanoparticles prepared (Eudragit RSPO and Poly Epsilon Caprolactone), in order to study their stability. With the exception of the T1 tube, which has become destabilized since the first day after preparation, and the T'1 tube, which has a redispersible cream by simple shaking, the emulsions obtained have a white color and are stable. All the preparations (with the exception of tube 1 which is not stable and tube 1' which presents a redispersible creaming by simple shaking), appear macroscopically stable. That is to say that they do not show any destabilization phenomenon visible to the naked eye at the end of the 28 days of storage.

Examen microscopique

The microscopic examination carried out with a ZEISS microscope shows us that these synthesized particles are active at the water/oil interface and are capable of stabilizing emulsions. The size and density of the droplets depends on the quantity of polymer used for the synthesis of the nanoparticles. Figure 3(a) and (b) show us the microscopic appearance of emulsion droplets.

(a)



(b)

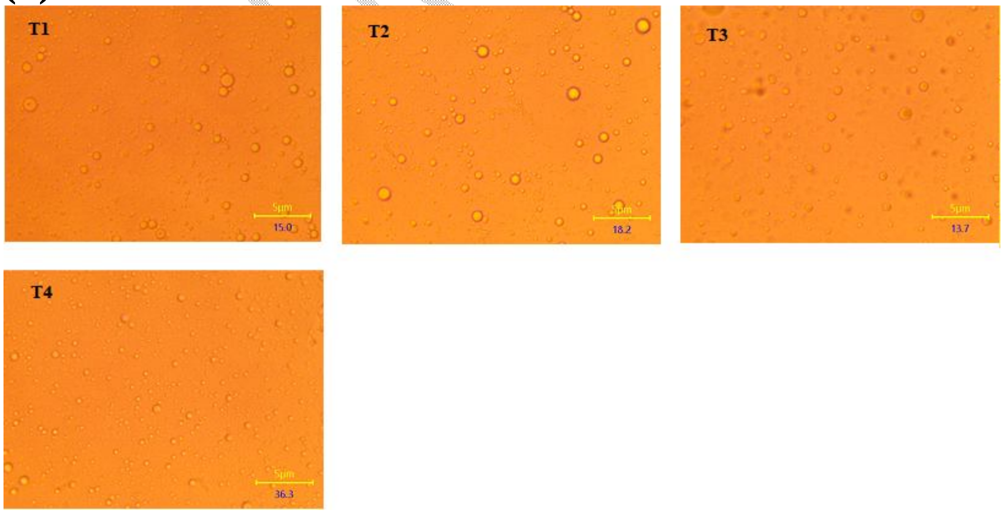
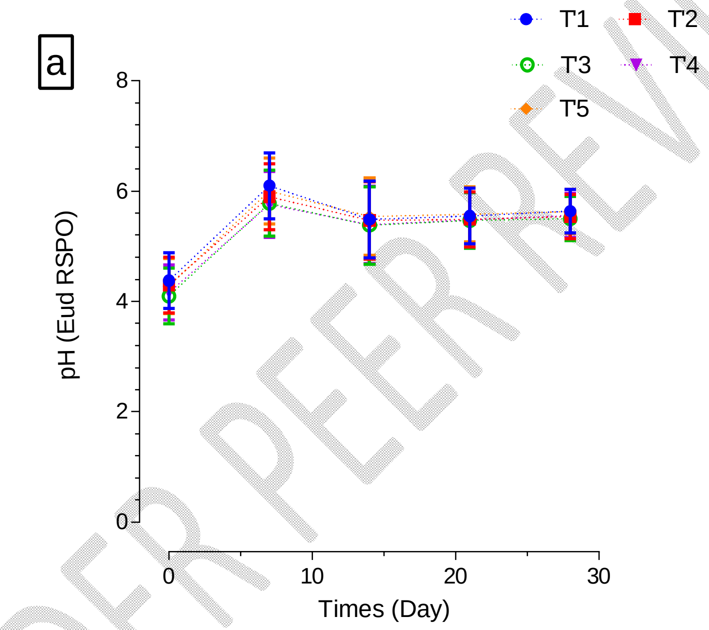


Figure 4 : optical microscopy (a) emulsion stabilized by nanoparticles of Eudragit RSPO, (b) emulsion stabilized by nanoparticles of polyepsilon caprolactone

pH Determination:

Les mesures de pH ont été réalisées à J1, J7, J14, J21. Les résultats sont représentés dans les figures 5a et 5b ci-dessous.

The pH measurements were carried out on D1, D7, D14, D21. The results are shown in Figures 5a and 5b below.



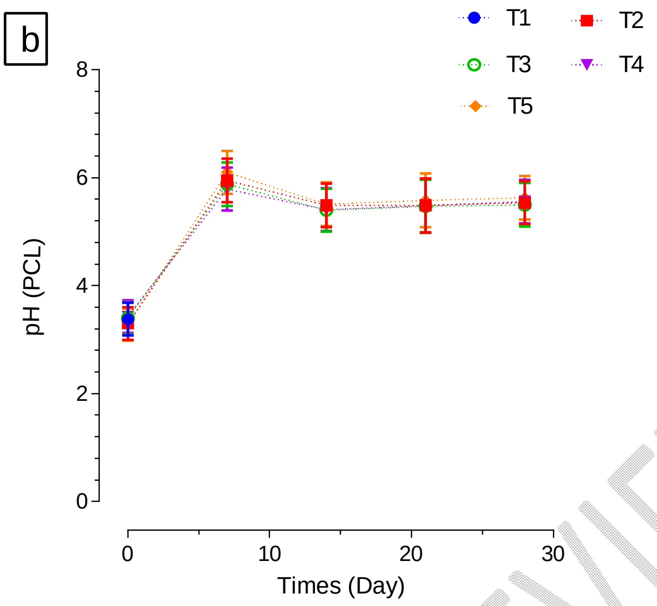


Figure 5: pH of emulsions, (a) with Eudragit RSPO, (b) with polyepsilon caprolactone

Conductivity Measurement:

The conductivity measurements were taken on D1, D7, D14, D21. The results give conductivity values of less than 0.02 mS/cm for all the preparations. The emulsions being conductive, then we can confirm the direct direction of the emulsions obtained.

Droplet Size of Pickering Emulsion:

The measurement of the size of the droplets carried out on D15 after preparation shows the results indicated in figure 6 As the T1 tube was not stable, we did not consider it necessary to study the size of its droplets.

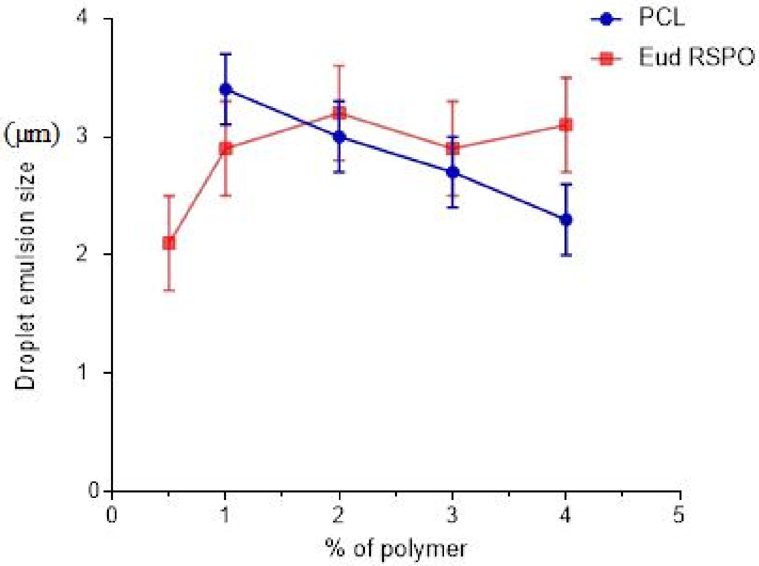


Figure 6: droplet size as a function of polymer percentage

2- *Discussion*

The main results obtained show that polymeric nanoparticles are potential candidates for emulsion stabilization. Indeed, the replacement of solid particles by biodegradable organic particles is an interesting prospect. This would make it possible to consider other routes of application, for example local injection (oral, subcutaneous, intramuscular). The absorption of nanoparticles by intestinal cells is well known (Borm et al., 2006), so it is necessary to choose a type of particle without any possible toxicity.

In our context, which was emulsion stabilization by polymer nanoparticles, we demonstrated the possibility of using poly epsilone caprolactone and eudragit RSPO nanoparticles of size between 90 and 300 nm and having stable emulsions. We prepared the emulsions by varying the percentage of polymers to obtain suspensions of particles obtained by nanoprecipitation.

The study of the mechanisms of stabilization of emulsions by nanoparticles has become essential. There are many studies on the mechanism of stabilization of Pickering emulsions by ideally spherical particles and stabilization theories have been developed. In this study we studied the contact angle at the oil-water interface and the influence of nanoparticles on the contact angle but also the surface tension between water and oil and to see the influence of nanoparticles. The drop in surface tension as a function of the percentage of nanoparticles indicates an increase in the stability of the formulated emulsions.

The main results obtained with regard to the physical properties showed that macroscopically, all the formulations were stable during the first hours. Immediately afterwards, the T1 tube destabilized. For the T'1 tube, a redispersible cream was observed by simple agitation.

However, it should be kept in mind that these physical characteristics perceived with the naked eye do not prejudge the stability of the emulsions obtained. Indeed, macroscopic observation does not allow to see droplets smaller than 50 µm.

The determination of the direction of the emulsion was established thanks to measurement of the conductivity. The conductivity of the emulsions (all <0.02mS/cm) therefore confirms their O/W nature. Indeed, the value of the conductivity of an emulsion depends on its external phase (Redhead et al., 2001). The results thus obtained throughout the observation period show that the emulsions did not undergo any phase inversion phenomenon.

With regard to the pH measurements, the results obtained indicated an acid character for all the tubes. This acidity is unfavorable to the stability and preservation of the emulsions. In fact, the basic nature gives the emulsions better stability. Yang and his collaborators showed that the adjustment due to high values (9-12) allows a good stabilization of the emulsion by favoring a better adsorption of the particles at the interfaces (Rouzes et al., 2000). In addition, the pH value of the emulsions influences its conservation and determines the incompatibilities that there could be with the other components possibly present (Barbault-Foucher et al., 2002).

For all the preparations we used a fixed quantity of oil, the variable parameter being the percentage of polymer used for the synthesis of the nanoparticles. We find that the size of the droplets depends on the percentage of polymer used for the synthesis of the nanoparticles. As for the size of the droplets, it plays an important role in the stability of emulsions and it is one of the parameters that can modify the sedimentation rate described by Stokes' law (Binks and Lumsdon, 2000; Hórvölgyi et al., 1996; Kabalnov and Wennerström, 1996; Langevin et al., 2004), thus a 100 micrometer globule rises 10 cm in water in only 3 minutes, while it takes 5 hours and 20 days for globules respectively of 10 micrometers and 1 micrometer.

We observed that for all the tubes the average diameters are between 20 and 35 micrometers

For the tubes with the poly epsilon caprolactone nanoparticles, a reduction in the average size of the droplets is observed as a function of the percentage of polymer used for the synthesis of the nanoparticles. Indeed, the most probable hypothesis would be, the increase in the quantity of particles which would reduce the size of the droplets thus leading to an increase in the interfacial zone (Langevin et al., 2004).

The relationship between the diameter and the quantity of particles is illustrated by the following formula

$$D=(6\O v\ V)/A$$

D is the diameter of the droplets

A/V is the interfacial area per unit volume

Øv is the fraction of the dispersed phase

However, for emulsions stabilized by eudragit RSPO, this logic is not verified, we have average sizes ranging from 2.1 to 3.2 nm (T1 (2.1 µm) T2 (2.9 µm) T3 (3.2 µm) T4(2.9µm) T5(3.1µm)).

The results made it possible to obtain Pickering emulsions stabilized by nanoparticles of poly epsilon caprilactone and eudragit RSPO.

3- *Conclusion*

Unlike surfactant molecules which adsorb and desorb continuously, the particles adsorb at the interfaces under the effect of agitation and irreversibly (the desorption energy of a particle is of the order of 1500KBT where KB is the Boltzmann constant). We set ourselves the objective of producing Pickering emulsions stabilized by polymeric nanoparticles of poly epsilone caprolactone and eudragit RSPO.

Of all the preparations, only T1 shows a phenomenon of instability and creaming for T'1. Conductive made-up emulsions are therefore of the O/W type. We had to note an acidity for all the emulsions which is unfavorable for the stability of the latter. Compared to the two batches, we observed that the size of the droplets is controlled by the quantity of nanoparticles. Indeed, a high percentage of poly epsilon caprolactone decreases the size of the emulsion droplets. Also the increase in the percentage of eudragit RSPO leads to a reduction in the size of the droplets from 2%.

We also found that the amount of polymer used influences the value of the contact angle. Indeed, the increase in the percentage of polymer decreases the contact angle of the emulsions. Better stability is noted with low surface tension values. The lower the surface tension, the more stable the emulsion. This is why emulsions with eudragit RSPO are more stable than those with poly epsilon caprolactone. We can retain that the respect of various physicochemical parameters makes it possible to guarantee a better stability of the emulsions.

During this work all the emulsions prepared except for T1 are stable and those with eudragit RSPO had better stability than emulsions with poly epsilon caprolactone. For further work the stability can be improved by using a very high speed stirrer. The prospect of a double encapsulation allowing a release in two stages, from nanoparticles and droplets, opens up the prospects for significant therapeutic modulation. It would also be interesting to study the incorporation of hydrophilic molecules in this type of formulation in order to determine their mode of encapsulation in these particles and their release mechanisms.

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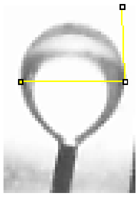
Annexes



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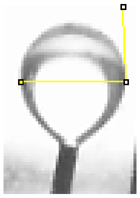

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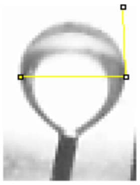

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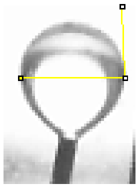

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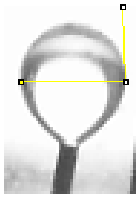

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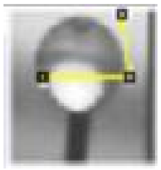

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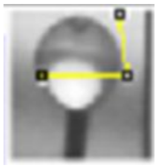

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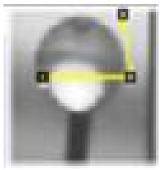

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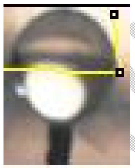

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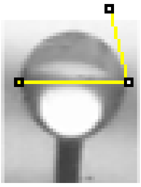

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