International Journal of Agriculture Innovations and Research
Volume 7, Issue 1, ISSN (Online) 2319-1473
Manuscript Processing Details (dd/mm/yyyy):
Received: 30/07/2018 | Accepted on: 07/08/2018 | Published: 13/08/2018

Emulsions: Micro and Nano-emulsions and their Applications in Industries - A Mini-Review

Wedad Q. AL-Bukhaiti[a], Anwar Noman[a,b] and Hongxin Wang[a*]
[a] State Key Laboratory of Food Science and Technology, School of Food Science and Technology, Jiangnan University, Wuxi 214122, China.
[b] Department of Agricultural Engineering, Faculty of Agriculture, Sana'a University, Sana'a, Yemen.
*Corresponding author email id: hxwang@jiangnan.edu.cn

***Abstract* – Emulsions are showing rising application in food processing industries because of their unique physicochemical and functional properties. There are wider ranges of food products where emulsions are used to encapsulate, deliver, and protect food components such as oil-soluble flavors, vitamins, colorants, preservatives, and other bioactive ingredients. It has ability to promote the product physicochemical properties like texture, taste, and other sensory attributes. For example coloring and flavoring strength and process ability. This review describes the emulsions, Types of emulsions, Stability, Membrane emulsification and applications of emulsions in food industry.**

***Keywords* – Emulsions; Stability; Microemulsions; Nanoemulsions; Application.**

I. Introduction

Emulsions are a heterogeneous system consisting of two immiscible liquid phases which are mixed using mechanical shear and surfactant. The amphiphilic surface-active molecules are called as 'surfactants' which are responsible to decrease naturally existing attractive forces in the form of surface tension [1, 2]. The food industries currently relies on the principles of emulsion science and technology to make a wide variety of different food products, including milk, cream, ice cream, margarine, butter, mayonnaise, coffee creamer, soft drinks, nutritional beverages, sauces and dressings [3]. Emulsions are found in all aspects of life and an understanding of how to control and optimize their properties is essential for the production of high quality product. Quality can be defined as fitness for purpose. As a result, the manufacturing process for an emulsion in one industry can vary greatly from another industry. These variations can include the components being used, the method of emulsification, the conditions of processing and many more [4].

Food emulsions are thermodynamically unstable, compositionally and structurally complex systems consisting of two immiscible liquids with one of the liquids being dispersed in the other as small spherical droplets (0.1–100 µm) [5]. Some food emulsions are end- products by them-selves (milk, cream, salad dressings, mayonnaise) whereas others can be used as ingredients, participating in the structures of more complex products (yoghurts, ice creams, whipped products). Oil-in-water (O/W) emulsions appearing in many industrial processes as the basis of various food products are systems consisting of oil droplets dispersed and stabilized in an aqueous phase. The behavior of O/W emulsions in food preparations is defined by the composition of the three parts: the fat or oil of the emulsion droplets, the interfacial material separating the two immiscible liquids and the continuous aqueous phase [5]. Oil-in-water (o/w) and water-in-oil (w/o) emulsions are important colloid structures in food products, as many foods exist as emulsions or have been in an emulsified state at some time during their existence [6]. The o/w emulsions such as milk, mayonnaise, and salad dressing constitute a particularly large — and widely consumed — group of such complex, heterophasic food systems, but also w/o emulsions, including margarine and butter, are consumed in large amounts [7]. There are several types of emulsions: they are, water-in-oil (W/O) emulsion, oil-in-water (O/W) emulsion and multiple emulsion [8]. The multiple emulsions such as water-in-oil-in-water (w/o/w) and oil-in-water-in-oil (o/w/o) [2]. Micro and nanoparticles are defined as particulate dispersions or solid particles with a size in the range of 10–1000 nm and 1– 1000 mm, respectively [4]. In view of the importance of emulsions in the food, pharmaceutical, and other industries, this review aims to highlight emulsions in general and micro and nano emulsions for more knowledge about these products.

II. Stability of Emulsions

The long-term stability of emulsions is one of the most important factors determining their shelf life in commercial food and beverage applications [9]. Emulsions face two different types of stability problems during storage: physical instability due to creaming, flocculation, and instability due to lipid oxidation. Lipid oxidation is an interfacial phenomenon, and because emulsions have a large interfacial area, they are particularly susceptible to oxidation. Lipid oxidation is induced by transition metals, light, temperature, and oxygen and is also affected by pH, droplet size, and numerous other factors related to the composition of the emulsion. Importantly, the oxidative stability of food emulsions is greatly dependent on the chemical composition of the lipid phase [7]. Droplet size and droplet size distribution are important characteristics for the evaluation of the stability of emulsions [5]. Several factors and processes affect the stability of emulsions. The aqueous phase in the emulsion may contain ions, which may destabilize the emulsions or macromolecules such as polysaccharides, which may exert stabilizing effects [10]. Emulsions stabilized with high concentration (>2% wt/wt) of *ulva fasciata* polysaccharide (UFP) had an average droplet size (D 3, 2) less than 1.0 mm, and the average droplet size significantly decreased until the polysaccharide concentration reached 3%. Light microscopy images and emulsion zeta-potentials demonstrated 3% (wt/wt) UFP to be the optimum emulsifying agent concentration. UFP revealed better emulsifying properties and improved physical stabilities of b-carotene emulsions when compared to other commercial polysaccharides, including gum Arabic and beet pectin [11]. Emulsions built-up with food grade emulsifiers such as di- and triglycerides, caprylocaproyl poly-oxylglycerides (Labrasol), polyethylene glycol (25) cetostearylether (Cremophor) and polyoxyethylene (20) sorbitan monooleate (Tween-80) are susceptible to destabilization by environment factors, such as pH, temperature and ionic strength. Coalescence, aggregation, creaming and catastrophic inversion are the main mechanisms involved in emulsion instability. For instance, creaming is caused by differences in mass density between the dispersed and the continuous phase. On the other hand, coalescence occurs when two or more emulsion droplets become joined together forming larger droplets, due to the thinning and disruption of the liquid film between the droplets [12].

The stability of emulsions affected also by pressure and protein concentration. The application of ultra-high-pressure homogenization (UHPH) treatment at 200 and 300 MPa resulted in emulsions that were highly stable to creaming and oxidation, especially when the protein content increased from 1 to 3 and 5 g/100 g. Further, increasing the protein content to 3 and 5 g/100 g in UHPH emulsions tended to change the rheological behavior from Newtonian to shear thinning. Conventional homogenization (CH) emulsions containing 1 g/100 g of protein exhibited Newtonian flow behavior with lower tendencies to creaming compared to those formulated with 3 or 5 g/100 g. This study has proved that UHPH processing at pressures (200-300 MPa) and in the presence of sufficient amount of sodium caseinate (5 g/100 g), produces emulsions with oil droplets in nano-/submicron scale with a narrow size distribution and high physical and oxidative stabilities, compared to colloid mill (CM) and CH treatments [13].

Emulsion-based foods need to be stable against harsh condition (i.e., pH, ionic strength and temperature) during their processing, storage and transportation. It is well known that an emulsifier is one of the most important materials required to determine the stability of an emulsion-based food against the destabilization process. The selection of appropriate emulsifier is critical for producing emulsion-based products with high stability [14]. The emulsions containing 25-30% w/w rice bran oil demonstrated low emulsion stability (high percent creaming index). This is probably pectin was not sufficient to prepare stable emulsions. Using 1.5% w/w of pectin could produce the stable o/w emulsions with low percent creaming index, at the oil concentration of 15 and 20% w/w, when kept at ambient temperature (25 $^{\circ}$C) for 14 days. Interestingly, the emulsions containing higher concentration of pectin (i.e., 2% w/w) has higher percent creaming index, at the oil concentration of 15 and 20% w/w. This kind of behavior can be attributed to the formation of weak flocs by depletion flocculation [15].

Membrane emulsification (ME) represents an alternative way to produce emulsions and particles by permeating the disperse phase, e.g. a vegetable oil, through a porous membrane to form a drop-by-drop emulsion. These droplets detach from the membrane surface due to the shear stress of the moving continuous aqueous phase. To maintain the stability of the emulsion and avoid the coalescence of the droplets, one or more surface active agents are generally used [4, 16]. ME techniques can be divided into direct ME, when the disperse phase is injected through the membrane into the continuous phase, and premix ME, when a coarse emulsion is pressed through the membrane to reduce the droplet size [17]. Membranes used in the membrane emulsification process are specifically designed for this purpose, such as the shirasu porous glass membranes, due to their narrow pore size range. Besides, ceramic membranes have also been used for ME in cross-flow systems [18].

III. Microemulsions

The microemulsion is a four-component system prepared by emulsifying oil in aqueous system with the help of surfactant and co-surfactant. The co-surfactants are generally intermediate chain length alcohols such as pentanol or butanol [19]. Microemulsions are isotropic mixtures of oil, water, and surfactant, thermodynamically stable transparent or translucent systems of oil, water, and surfactant, frequently in combination with a co-surfactant with a droplet size usually in the range of 20-200 nm. They can be classified as oil-in-water (o/w), water-in-oil (w/o) or bicontinuous systems depending on their structure and are characterized by ultra-low interfacial tension between oil and water phases [2, 20]. The droplet sizes of the dispersed phase in microemulsions are generally in the magnitude of ~10 nm. Regardless of being more commercially applicable because it is lower energy requirements. Microemulsions are also attracting the interest of researchers due to their potential as drug delivery compounds in other food, pharmaceutical applications, and in the petrochemical industry [21]. There are three kinds of microemulsions: o/w (normal microemulsion), bicontinuous microemulsion, and w/o (reverse microemulsion). Few theories have tried to explain the formation of microemulsions; however, three approaches have been used to explain formation and stability. These are: i) interfacial or mixed fi lm theories; ii) solubilization theories; iii) thermodynamic treatments [22]. Since the discovery of microemulsions, they have attained increasing significance both in basic research and in industry. Due to their unique properties, namely, ultralow interfacial tension, large interfacial area, thermodynamic stability and the ability to solubilize otherwise immiscible liquids, uses and applications of microemulsions have been numerous [23].

IV. Nanoemulsions

Nanoemulsions are kinetically stable liquid-in-liquid dispersions with droplet sizes about 100 nm. Their small size leads to useful properties such as high surface area per unit volume, transparent appearance, strong stability, and tunable rheology. There are two broad categories of techniques for the preparation of nanoemulsions: high-energy methods and low energy methods. The input energy density in high energy methods is on the order of 10^8–10^{10} W kg, and power density in low energy methods is about 10^3-10^5 w/kg (**Fig. 1**). [24]

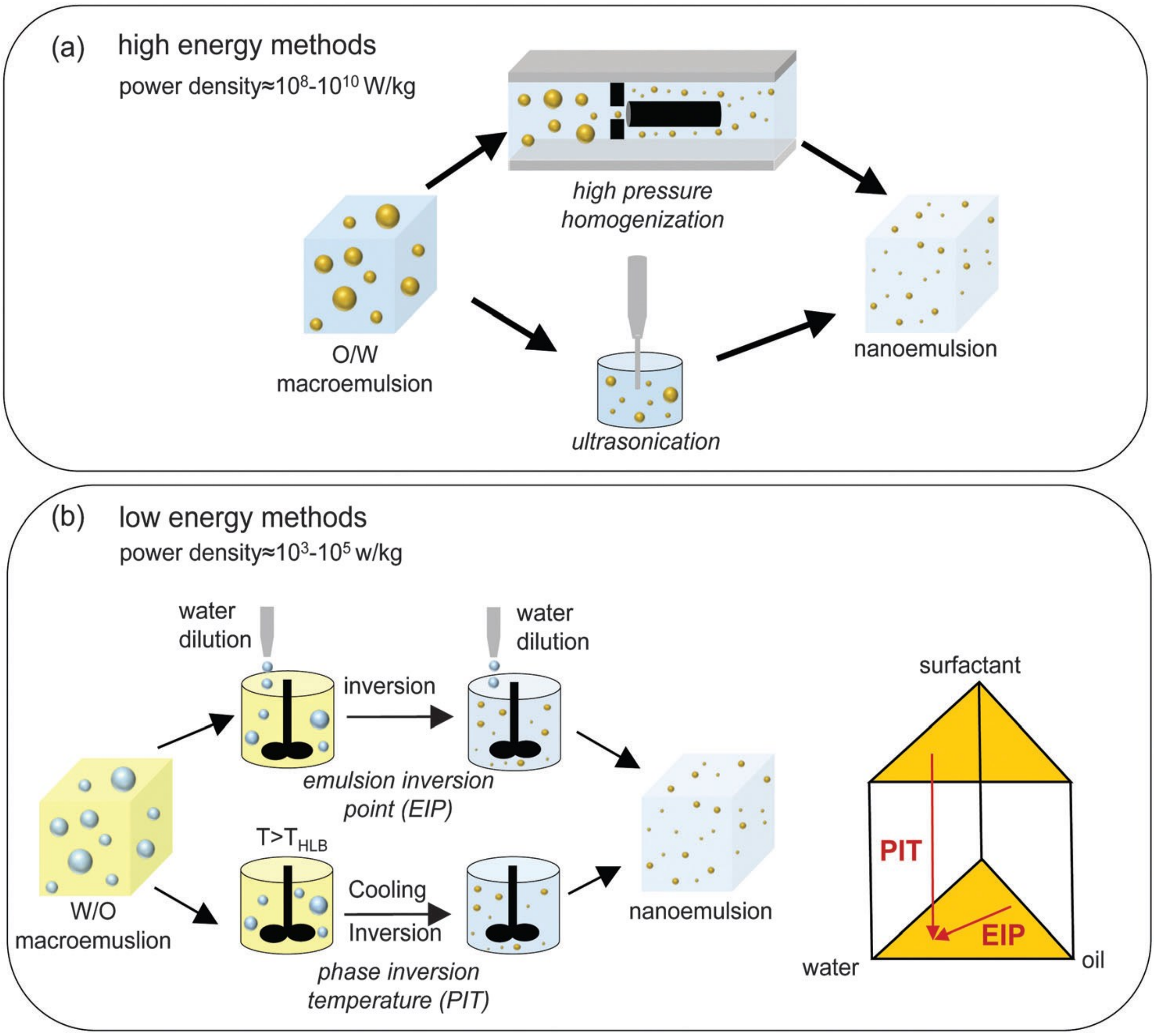

Fig. 1. High energy and low energy methods for preparing O/W nanoemulsions: (a) High energy, (b) Low energy methods.

Nanoemulsions are very similar to microemulsions that are dispersions of Nano scale particles but obtained by mechanical force unlike to microemulsions, which forms spontaneously [20, 25]. Nanoemulsions are utilized within the food, pharmaceutical, and personal care industries because of their unique physicochemical properties and functional attributes: high optical clarity; prolonged stability; and, enhanced bioavailability. For many applications, it is desirable to utilize natural ingredients to formulate Nanoemulsions so as to create “label-friendly” products [9]. Nanoemulsions are used in the food, cosmetics, personal care and pharmaceutical industries to provide desirable optical, textural, stability, and delivery characteristics. In many industrial applications, it is desirable to formulate Nanoemulsions using natural ingredients so as to develop label-friendly products. Rhamnolipids are biosurfactants isolated from certain microorganisms using fermentation processes. They are glycolipids that have a polar head consisting of rhamnose units and a non-polar tail consisting of a hydrocarbon chain [26]. Ergocalciferol loaded nanoemulsions were successfully formulated via the high-pressure homogenization using three different emulsifiers (ML, SC or MO-7S). In addition, some of the major factors affecting the stability of resulting nanoemulsions were systematically evaluated. The stability of nanoemulsions to different environmental stresses were highly dependent on the emulsifier type, whereas no particular emulsifier tested was found to provide absolute stability to the nanoemulsions when exposed to pH, ionic strength, freeze-thawcycles and high temperature treatment.

Independent of emulsifier type, the nanoemulsions exhibited good physical and chemical stability during storage at 25 °C up to 30 days. In contrast, the long-term stability of nanoemulsions was highly dependent on the type of emulsifier tested at elevated temperature. The results some studies could provide useful information on the selection of appropriate emulsifier for producing stable nanoemulsions encapsulating functional bioactive compounds for commercial usage [14].

International Journal of Agriculture Innovations and Research
Volume 7, Issue 1, ISSN (Online) 2319-1473

V. Applications of Micro and Nano-Emulsion

Emulsions play an important role in many industrial applications and products such as cosmetics, pharmaceuticals, and foods [4], pharmaceutics and clinical field [27], chemistry applications [28], cosmetics industry [29] and petroleum industry [30]. Figure 2 shows applications of emulsifiers in different industries. As a matter of fact, emulsions are thermodynamically unstable systems and hence emulsifiers are needed to produce emulsions that are kinetically stable under specific environmental conditions (pH, temperature and storage time) [31]. Macroemulsions and microemulsions are generally well documented as carriers for hydrophilic and lipophilic drugs. In recent decades, attention has been made on controlling the size distribution and understanding the stabilization phenomenon, this had resulted in great attention for these liquid dispersion systems [32]. The major advantages of such systems are that they increase the solubility and bioavailability of therapeutic drugs as well as the ability to favor the topical transport of hydrophilic drugs. The multiple emulsions are used as an alternate to liposomes as a distribution system [32, 33]. Emulsions play an important role in many industrial applications and products such as cosmetics, pharmaceuticals, and foods [4], pharmaceutics and clinical field [27], chemistry applications [28], cosmetics industry [29] and petroleum industry [30]. Figure 2 shows applications of emulsifiers in different industries. As a matter of fact, emulsions are thermodynamically unstable systems and hence emulsifiers are needed to produce emulsions that are kinetically stable under specific environmental conditions (pH, temperature and storage time) [31]. Macroemulsions and microemulsions are generally well documented as carriers for hydrophilic and lipophilic drugs. In recent decades, attention has been made on controlling the size distribution and understanding the stabilization phenomenon, this had resulted in great attention for these liquid dispersion systems [32]. The major advantages of such systems are that they increase the solubility and bioavailability of therapeutic drugs as well as the ability to favor the topical transport of hydrophilic drugs. The multiple emulsions are used as an alternate to liposomes as a distribution system [32, 33]. Over the past several years, microemulsions have been applied to a variety of technological problems, including consumer and commercial cleaning product formulations, distribution systems, polymerization media, and chemical reaction media. Advantages of microemulsion formulations over their solvent-based counterparts include high water content resulting in low cost, reduced volatile organic content, improved ability to formulate water and solvent borne ingredients and ability to clean both water and oil-soluble substrates [34]. Nanoemulsions are widely used in the cosmetic because the active ingredients are easily absorbed to obtain effective action due to the small size of the droplet and decrease the water loss from the skin. The nanoemulsions are used also as moisturizer and creams. The attractive delivery vehicle in the cosmetics as nanoemulsion droplet size is very small, creaming and flocculation is not observed leading to a more elegant and stable products [35].

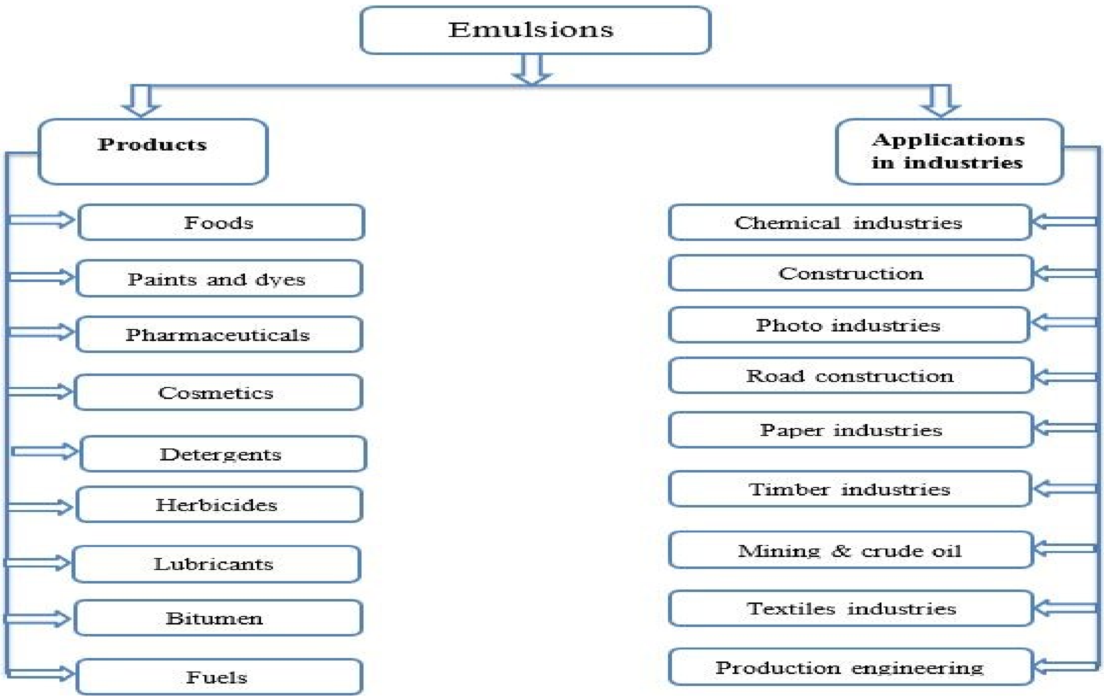

Fig. 2. Applications of emulsions in products and different industries.

VI. Conclusions

Emulsions of various types are widely used in many products encountered in everyday life. Importance of emulsion in the food industry and other industries justifies a great deal of basic research to understand emulsions formation, their properties, types, and applications. More research is needed to develop practical methods for emulsions formation. Understanding the theoretical considerations in emulsion formulation and having the ability and proper instrumentation to fully characterize and monitor the stability of an emulsion system is highly beneficial to provide a superior product in a more efficient method.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgments

This study was financially supported by processing key technology of green tea food (2017YFD0400803), China.

References

[1] A.U. AS, Emulsion and it's Applications in Food Processing–A Review, International Journal of Engineering Research and Applications 4(4) (2014) 241-248.

[2] S.N. Kale, S.L. Deore, Emulsion micro emulsion and nano emulsion: A review, Systematic Reviews in Pharmacy 8(1) (2017) 39.

[3] D.J. McClements, Emulsion design to improve the delivery of functional lipophilic components, Annual review of food science and technology 1 (2010) 241-269.

[4] A. Imbrogno, E. Piacentini, E. Drioli, L. Giorno, Micro and nano polycaprolactone particles preparation by pulsed back-and-forward cross-flow batch membrane emulsification for parenteral administration, International journal of pharmaceutics 477(1-2) (2014) 344-350.

[5] E. Mitsou, G. Tavantzis, G. Sotiroudis, D. Ladikos, A. Xenakis, V. Papadimitriou, Food grade water-in-oil microemulsions as replacement of oil phase to help process and stabilization of whipped cream, Colloids and Surfaces A: Physicochemical and Engineering Aspects 510 (2016) 69-76.

[6] D.J. McClements, Lipid-based emulsions and emulsifiers, Food lipids, CRC Press2002, pp. 82-121.

[7] C. Jacobsen, Oxidative stability and shelf life of food emulsions, Oxidative Stability and Shelf Life of Foods Containing Oils and Fats, Elsevier 2016, pp. 287-312.

[8] S. Wong, J. Lim, S. Dol, Crude oil emulsion: a review on formation, classification and stability of water-in-oil emulsions, Journal of Petroleum Science and Engineering 135 (2015) 498-504.

[9] L. Bai, S. Huan, J. Gu, D.J. McClements, Fabrication of oil-in-water nanoemulsions by dual-channel micro fluidization using natural emulsifiers: Saponins, phospholipids, proteins, and polysaccharides, Food Hydrocolloids 61 (2016) 703-711.

[10] D.G. Dalgleish, Food emulsions—their structures and structure-forming properties, Food hydrocolloids 20(4) (2006) 415-422.

[11] P. Shao, Y. Zhu, W. Jin, Physical and chemical stabilities of β-carotene emulsions stabilized by Ulva fasciata polysaccharide, Food Hydrocolloids 64 (2017) 28-35.

[12] C. Roldan-Cruz, E. Vernon-Carter, J. Alvarez-Ramirez, Assessing the stability of Tween 80-based O/W emulsions with cyclic voltammetry and electrical impedance spectroscopy, Colloids and Surfaces A: Physicochemical and Engineering Aspects 511 (2016) 145-152.

[13] E. Hebishy, M. Buffa, B. Juan, A. Blasco-Moreno, A.-J. Trujillo, Ultra high-pressure homogenized emulsions stabilized by sodium caseinate: Effects of protein concentration and pressure on emulsions structure and stability, LWT-Food Science and Technology 76 (2017) 57-66.

[14] G. Shu, N. Khalid, Y. Zhao, M.A. Neves, I. Kobayashi, M. Nakajima, Formulation and stability assessment of ergocalciferol loaded oil-in-water nanoemulsions: Insights of emulsifiers effect on stabilization mechanism, Food research international 90 (2016) 320-327.

[15] D. Guzey, D.J. McClements, Impact of electrostatic interactions on formation and stability of emulsions containing oil droplets coated by β-lactoglobulin−pectin complexes, Journal of agricultural and food chemistry 55(2) (2007) 475-485.

[16] E. Piacentini, A. Imbrogno, E. Drioli, L. Giorno, Membranes with tailored wettability properties for the generation of uniform emulsion droplets with high efficiency, Journal of Membrane Science 459 (2014) 96-103.

[17] V. Zanatta, K. Rezzadori, F.M. Penha, G. Zin, E. Lemos-Senna, J.C.C. Petrus, M. Di Luccio, Stability of oil-in-water emulsions produced by membrane emulsification with micro porous ceramic membranes, Journal of Food Engineering 195 (2017) 73-84.

[18] M. Matos, M. Suárez, G. Gutiérrez, J. Coca, C. Pazos, Emulsification with microfiltration ceramic membranes: A different approach to droplet formation mechanism, Journal of membrane science 444 (2013) 345-358.

[19] A.D. Gadhave, J.T. Waghmare, A short review on micro emulsion and its application in extraction of vegetable oil, Int J Res Eng Tech 3(9) (2014) 147-158.

[20] S. Talegaonkar, A. Azeem, F.J. Ahmad, R.K. Khar, S.A. Pathan, Z.I. Khan, Microemulsions: a novel approach to enhanced drug delivery, Recent Patents on Drug Delivery & Formulation 2(3) (2008) 238-257.

[21] K.L. Lee, Applications and use of micro emulsions, arXiv preprint arXiv: 1108.2794 (2011).

[22] H.Y. Karasulu, Microemulsions as novel drug carriers: the formation, stability, applications and toxicity, Expert opinion on drug delivery 5(1) (2008) 119-135.

[23] B.K. Paul, S.P. Moulik, Uses and applications of micro emulsions, Current science (2001) 990-1001.

[24] A. Gupta, H.B. Eral, T.A. Hatton, P.S. Doyle, Nanoemulsions: formation, properties and applications, Soft matter 12(11) (2016) 2826-2841.

[25] J.-l. Tang, J. Sun, Z.-G. He, Self-emulsifying drug delivery systems: strategy for improving oral delivery of poorly soluble drugs, Current drug therapy 2(1) (2007) 85-93.

[26] L. Bai, D.J. McClements, Formation and stabilization of nano emulsions using bio surfactants: Rhamnolipids, Journal of colloid and interface science 479 (2016) 71-79.

[27] H. Okochi, M. Nakano, Preparation and evaluation of w/o/w type emulsions containing vancomycin, Advanced drug delivery reviews 45(1) (2000) 5-26.

[28] C. Oh, S.-C. Chung, S.-i. Shin, Y.C. Kim, S.-S. Im, S.-G. Oh, Distribution of macropores in silica particles prepared by using multiple emulsions, Journal of colloid and Interface Science 254(1) (2002) 79-86.

[29] J.S. Lee, J.W. Kim, S.H. Han, I.S. Chang, H.H. Kang, O.S. Lee, S.G. Oh, K.D. Suh, the stabilization of L- ascorbic acid in aqueous solution and water- in- oil- in- water double emulsion by controlling pH and electrolyte concentration, International Journal of Cosmetic Science 26(4) (2004) 217-217.

[30] L.L. Schramm, Fundamentals and applications in the petroleum Industry, Adv. Chem 231 (1992) 3-24.

[31] B. Zeeb, L. Fischer, J. Weiss, Cross-linking of interfacial layers affects the salt and temperature stability of multilayered emulsions consisting of fish gelatin and sugar beet pectin, Journal of agricultural and food chemistry 59(19) (2011) 10546-10555.

[32] B.A. Khan, N. Akhtar, H.M.S. Khan, K. Waseem, T. Mahmood, A. Rasul, M. Iqbal, H. Khan, Basics of pharmaceutical emulsions: A review, African Journal of Pharmacy and Pharmacology 5(25) (2011) 2715-2725.

[33] G. Marti-Mestres, F. Nielloud, Emulsions in health care applications—an overview, Journal of dispersion science and technology 23(1-3) (2002) 419-439.

[34] J. Klier, C.J. Tucker, T.H. Kalantar, D. Green, Properties and applications of micro emulsions, Advanced Materials 12(23) (2000) 1751-1757.

[35] N. Thakur, G. Garg, P. Sharma, N. Kumar, Nanoemulsions: A review on various pharmaceutical application, Global Journal of Pharmacology 6(3) (2012) 222-225.