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Emulsion Separation, Classification and Stability Assessment

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ABSTRACT

An emulsion is a dispersed system consisting of at least two immiscible liquids, one of which is an internal or dispersed phase (dispersed as globules) within the external or continuous phase (other liquid phase), generally stabilized by an emulsifying agent. Emulsions have been widely used in many areas including petroleum, agriculture, food, pharmaceuticals and cosmetics, however, consumers highly appreciate emulsions for dermal application. Emulsions can be classified on the basis of their type or droplet size. The physical stability can be evaluated by two accelerated aging methods discussed i.e. storage of emulsions at different temperatures and measurement of creaming process by centrifugation. A stable emulsion is one in which there is a uniform distribution of the dispersed globules throughout the continuous phase. Major types of physical instabilities are discussed in this review including flocculation, creaming, coalescence and breaking and this review will concentrate on methods of improving emulsion stability in practice.

Keywords: Emulsion, Creaming, Coalescence, Breaking.

INTRODUCTION

Introduction to Emulsions

An emulsion is a biphasic system consisting of at least two immiscible liquids, one of which is an internal or dispersed phase (dispersed as globules) within the external or continuous phase (other liquid phase), generally stabilized by an emulsifying agent [1,2]. Emulsions have been widely used in many areas including petroleum [3], agriculture [4,5] food [6-12], pharmaceuticals [13-21] and cosmetics. [14-16,22-24] Mostly, emulsions are used in cosmetics products as topical agents for dermal application since they are highly appreciated among consumers.

Preparation of Emulsions and Techniques of Emulsification

The preparation techniques of emulsion formulations can be divided into laboratory-scale productions and large-scale productions. Each method requires the introduction of energy into the system by trituration, homogenization, agitation, or heat. For stable emulsions, appropriate preparation and formulation techniques are required. Following physical and chemical properties before the preparation of an emulsion are considered [25].

i. Structure formula.
ii. Melting point.
iii. Solubility in different media.
iv. Stability.
v. Dose.

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vi. Specific chemical incompatibilities.
vii. Selection of an appropriate emulsifying agent and its concentration.

The emulsification techniques of pharmaceutical products have been reviewed by Block [26] Freitas et al.[27] Schramm [28] and mainly four emulsification methods have been discussed:

i. The emulsion system is subjected to shear or fracture at the time of addition of the internal phase.

ii. The addition of external phase into the internal phase, this is known as phase inversion technique. In an oil-in-water emulsion system the aqueous phase is added into the oil phase, at first a water-in-oil emulsion is formed which on further addition of water results in the inversion of the phase and hence forms an oil-in-water emulsion.

iii. Separate heating of both phases and then mixing them together. This method is frequently used for the preparation of creams.

iv. In small portions, alternate addition of the two phases to the emulsifying agent, which is suitable for food emulsion preparation.

Classification of Emulsions

Emulsions can be classified on the basis of their type or droplet size. Based on their type, they are divided into two groups i.e. simple emulsions and multiple emulsions.

Simple Emulsions

The simple emulsions may further be divided into either oil-in-water (o/w) or water-in-oil (w/o), depending upon the nature of the continuous phase. In topical w/o preparations, a greasy texture is experienced as it exhibits a higher apparent viscosity then o/w emulsions. On the contrary, o/w emulsions exert a less greasy or sticky texture on application to the skin. They are usually quickly absorbed and are easily washed off from the skin surface due to low oil content [28].

Multiple Emulsions

Multiple emulsions constitute a more sophisticated system. The simplest ones are oil-in-water-in-oil (o/w/o) or water-in-oil-in-water (w/o/w) double emulsions. In the latter, for example, the emulsion is composed of aqueous droplets, which are dispersed inside oily drops, these oily drops are further dispersed in an external aqueous phase [29]. Complex multiple emulsions may contain several phases such as o/w/o/w, w/o/o, o/w/o/o, etc. depending on their use [25,28].

Emulsions can also be classified according to their droplet size into three categories: macroemulsions, microemulsions, and nanoemulsions.

Macroemulsions

Extensive and careful studies have been carried out on macroemulsions and several excellent books have been written on various aspects of formulation and stability of these systems. Macroemulsions are the emulsion systems with droplet sizes ranging from 0.1 to 100 µ. These sizes allow light scattering and thus gives white color to the emulsions [28].

Microemulsions

The term microemulsion was first introduced by Schulman et al [30]. Their droplet size varies from 100 Å to 100 nm [31]. Microemulsions generally contain both a surfactant and co-surfactant that induce spontaneous formation of the system. Microemulsions are often transparent to the eye with low viscosity and are thermodynamically stable [32]. This stability is due to their very low interfacial tension (enthalpy), typically [10^{-1} to 10^{-2}] mN/m 33, and small droplet size (entropy) [31,34].

Nanoemulsions

Nanoemulsions refer to the emulsions with the droplet sizes in the nanometric scale, i.e. with a mean diameter of 20–200 nm. The relatively small size of these droplets with respect to the optical wavelengths of the visible spectrum implies that many nanoemulsions appear optically transparent, even at large droplet volume fraction and for large refractive index contrast

[35,36]. However, nanoemulsions may become slightly turbid if the droplet diameter approaches 80 nm [37,38]. Above this size, still in the submicron range, they appear white due to significant multiple scattering. In comparison to microemulsions, nanoemulsions are not thermodynamically stable [34].

Emulsion Stability Assessment

Stability of an emulsion is a combination of physical (no phase separation), chemical (no chemical reaction) and microbiological stability (no microbial growth or spoilage). The physical stability can be evaluated by two accelerated aging methods, which mimic conditions that emulsions could undergo during transport and storage. The first method evaluates the samples stored at different temperatures (e.g. from 0 to 40°C) and for varying time periods (e.g. from 24 h to 15 days). It may also include repeated hot–cold cycles. The second method is based on the centrifugation of emulsions and measurements of the sedimentation or creaming processes that can lead to coalescence [39]. Accelerated aging studies by centrifugation allow the determination of the emulsion stability index (ESI), or most commonly referred as creaming index (CI), by the following formula: [40,41].

$$CI\ (\%) = \frac{H_C}{H_E} \times 100$$

Where H_C is the height of cream or aqueous layer in the container and H_E is the initial or total height of emulsion in the container. Creaming is a natural phenomenon in biphasic systems and is an indication of destabilization. The higher the CI, lesser will be the stability of emulsion [40,41]. This method may sometimes pose problems in visual observation such as in distinguishing or identifying the boundary between the two phases.

Alternatively, the emulsion stability can be evaluated by using an instrumental technique known as TurbiscanTM (Formulaction, L’Union, France). It is composed of a near infrared light source ($\lambda = 850$ nm) and two synchronous detectors that scan the entire length of an emulsion filled tube. Diffuse reflectance and transmittance versus sample height and time are obtained, allowing detection of flocculation and coalescence processes even at an early stage that is not visible to the eye, i.e. up to 50 times quicker than naked eye [34].

Types of Instability

A stable emulsion is one in which there is a uniform distribution of the dispersed globules throughout the continuous phase. Major types of physical instabilities (Fig. 1) include flocculation, creaming, coalescence and breaking [42-44] which are discussed as follows:

Flocculation

Loose clusters formed due to the aggregation of dispersed phase globules are called floccules and the phenomenon is termed as flocculation (Fig. 1). It causes an increase in the rate of creaming and is said to be a precursor of coalescence. However, in flocculation the interfacial film and individual droplets remains linked together [25,28].

Prevention of flocculation

On shaking, the emulsion is easily redispersed. High charge density of the dispersed droplets will cause the presence of high energy barrier and reduce the incidence of flocculation. Effects of any ions in the formulation must be considered early in the formulation process, particularly in emulsions for parenteral nutrition containing high levels of electrolytes [45,46].

Creaming

Separation of an emulsion into two layers, one of which is richer in the disperse phase than the other is called creaming (Fig. 1). Creaming causes inelegancy to the emulsion and if it is not shaken adequately, the patient might obtain an incorrect dosage [25].

Prevention of creaming

Reducing the droplet or globule size through efficient emulsification may result in the stabilization of the emulsion by avoiding creaming. An increase in the viscosity of the system may also help in the stabilization of the emulsion. Methylcellulose is known to reduce the mobility of the dispersed phase globules in an o/w emulsion. Similarly, addition of soft paraffin in w/o emulsion will produce the same effect on water droplets. Storage temperature also influences the creaming of the product as at low temperature the viscosity of continuous phase increases which decreases the kinetic energy of the system. Another approach used for decreasing the creaming phenomenon in emulsions is by making the densities of the two phases identical or by increasing the dispersed phase concentration that would result in a movement of dispersed phase globules and thus decreasing the rate of creaming [25,45].

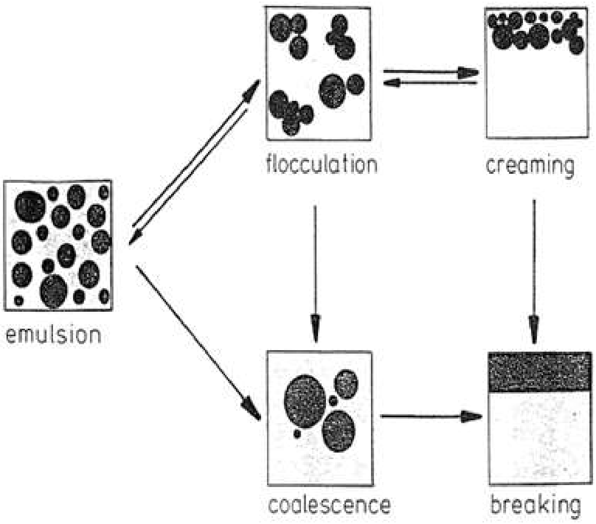

Figure 1: Types of Instability in Emulsions

Coalescence
Coalescence (Fig. 1) takes place when the mechanical and/or electrical barrier is not efficient to prevent the large droplets to aggregate and finally leads to complete phase separation (breaking)of the emulsion formulation [44].

Prevention of coalescence
Coalescence might be delayed by the formation of thick interfacial films, made up of macromolecules or particulate solids. Long cohesive hydrocarbon chains projecting into the oil phase will prevent coalescence in a w/o emulsion [45].

Phase Separation (Breaking)
Phase separation or breaking may or may not be observed visually. Generally creaming, coalescence and flocculation occur before the phase separation and thus makes its visibility and quantitative analysis difficult to evaluate (Fig. 1). Centrifugation of the samples or determination of creaming index helps in the quantitative determination of this process [25]. Details on the creaming and phase separation mechanisms including some advance techniques of monitoring have been discussed by Robins [47].

Prevention of breaking
Breaking of an emulsion can be avoided by controlling the factors responsible for other forms of instability such as flocculation, creaming and coalescence.

Instability in emulsions can also be controlled by a number of other factors such as proper selection of formulations ingredients, their appropriate quantity, optimum hydrophilic-lipophilic balance (HLB), appropriate storage conditions, etc. All these factors have been reviewed by Rieger [48]. Another approach employed for the stabilization of emulsions includes the use of biopolymers [34]. They can act as emulsifier because of their ability to adsorb at the oil-water interface and increase emulsion stability [1,49]. Most polysaccharide polymers behave as emulsion stabilizers by forming an extended network in the continuous phase which thus becomes highly viscous [50] and can even form a gel [51,52]. Such polymers can form complexes through covalent bonding or attractive electrostatic interactions [34,53,54].

CONCLUSION

The texture or feel of a product intended for external use must also be considered and this fact is often used to convey a feeling of richness to many cosmetic formulations. Ideally emulsions should exhibit the rheological properties of plasticity/pseudoplasticity and thixotropy. A high apparent viscosity at the very low rates with the shear movement of dispersed globules is necessary for a stable emulsion. Addition of polymers in the emulsion under appropriate conditions such as concentration, protein-to-polysaccharide ratio, pH, ionic strength, and temperature etc, may be a valuable strategy for improving its stability. A wide range of emulsion consistencies can be tolerated for an externally applied product.

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