Influence of the Stirrer Initial Position on Emulsion Morphology. Making Use of the Local Water-to-Oil Ratio Concept for Formulation Engineering Purpose

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The initial location of the stirrer in the emulsification vessel can induce the resulting emulsion type. The interpretation in terms of mixing phenomena leads to the use of the local water-to-oil ratio (WOR) concept in the formulation-composition map. The know-how associated with this phenomenology allows us to interpret in a straightforward way the kind of complex procedures commonly employed in emulsion manufacturing, particularly those associated with inversion and multiple emulsion attainment.

Introduction

In a house-made mayonnaise preparation, oil is progressively incorporated as droplets into the egg yolk, which is actually an aqueous solution containing oil-in-water (O/W) emulsion stabilizing agents. More and more oil is added while maintaining a gentle stirring, often provided by a spoon or a hand beater. The final product is an O/W emulsion that could contain an extremely high proportion of oil internal phase, says 90% or more. On the other hand, if this same amount of oil were initially mixed as a whole with the egg yolk, even under extremely energetic stirring, there would be no way to attain a mayonnaise, but a water-in-oil (W/O) egg yolk dispersion in oil instead. The preparation of mayonnaise is a well-known example of the hysteresis exhibited by emulsions, whose morphology depends on the way they are manufactured. This kind of behavior, which is related to the concept of "memory", is not uncommon in nature and can be modeled by catastrophe theory in some elegant way.[1−5]

Emulsion morphology occurrence and its change from one type to the other, i.e., emulsion inversion, has regained interest lately and several research groups have dedicated their efforts to related topics. A summary of the general understanding and associated know-how may be found in a recent review.[6]

Coming back to the case of mayonnaise manufacturing, it is worth remarking that some kitchen appliances offer a possibility to go around the 90% oil proportion handicap, and to attain a O/W emulsion type by mixing a large amount of oil with the egg yolk (almost) at once, according to a principle proposed quite a long time ago.[7] These devices are made of a turbine blender located at the end of a stem, which is placed at the bottom of a beaker-like vessel. Just above the moving impeller, there is some kind of cap, whose diameter is close to the vessel diameter, and which is outfitted with some foot that keeps the turbine at some distance, 1 in. or so, from the bottom of the container. The role of the cap is not only to protect the user from the rotating blade and to avoid spattering, but also to impede any direct fluid convection in the axial direction. With such a restrain, the stirrer starts blending what happens to be confined below the cap, i.e., the egg yolk and a very small amount of oil, no matter the quantity of oil present in the rest of the container. After a few seconds of stirring, the stem is risen slightly, so that some oil is sucked in the emulsification zone, then it is lowered for more blending, then risen a little again and so on until the entire amount of oil becomes incorporated into the emulsion.

Actually, this process exactly produces the same transient situation that the drop by drop addition of oil in a bowl, i.e., a gradual change in water-to-oil ratio in the fluid region concerned by the stirring process. However the whole system composition is unchanged. This is why it is quite pertinent to introduce the concept of instant or local water-to-oil ratio (WOR)[8] to carry out the analysis of emulsion morphology occurrence and related inversion phenomena.

This concept of local composition is also quite convenient to describe the emulsification in a large vessel in which the stirring device is too small to mix the whole system at once. Since an emulsion can retain the memory of its morphology, what happens during the very first instants of the emulsification could determine the issue. However, there is essentially no way to probe, and even less to scrutinize, the onset on emulsification in most practical cases, particularly in turbulent laboratory blenders, because everything is settled in a glance. To avoid this indetermination, the present study uses a stirring device which is purposely selected to be a very inefficient blender, so that it is possible to analyze the progress of the mixing process over some measurable time scale, e.g., at least a few seconds or minutes. The impeller device is a rotating disk, which can be placed in a horizontal position at, above, or below the original interface, and whose mixing action is linked with the overall fluid motion pattern created in the vessel, since it does not drive any direct axial motion. The purpose of this paper is to report and interpret the influence of the initial position of such a stirrer on the outcome of the emulsification procedure.

Basic Concepts

The influence of the stirrer position in the emulsification procedure, and its coupled effect with the formula-

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