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Smart and green interfaces: From single bubbles/drops to industrial environmental and biomedical applications

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ABSTRACT

Interfaces can be called Smart and Green (S&G) when tailored such that the required technologies can be implemented with high efficiency, adaptability and selectivity. At the same time they also have to be eco-friendly, i.e. products must be biodegradable, reusable or simply more durable. Bubble and drop interfaces are in many of these smart technologies the fundamental entities and help develop smart products of the everyday life. Significant improvements of these processes and products can be achieved by implementing and manipulating specific properties of these interfaces in a simple and smart way, in order to accomplish specific tasks. The severe environmental issues require in addition attributing eco-friendly features to these interfaces, by incorporating innovative, or, sometimes, recycle materials and conceiving new production processes which minimize the use of natural resources and energy. Such concept can be extended to include important societal challenges related to support a sustainable development and a healthy population.

The achievement of such ambitious targets requires the technology research to be supported by a robust development of theoretical and experimental tools, needed to understand in more details the behavior of complex interfaces. A wide but not exhaustive review of recent work concerned with green and smart interfaces is presented, addressing different scientific and technological fields. The presented approaches reveal a huge potential in relation to various technological fields, such as nanotechnologies, biotechnologies, medical diagnostics, and new or improved materials.

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1. Introduction

Bubble and drop (B&D) interfaces are fundamental to numerous industrial, environmental and biomedical applications. The scientific and industrial literature is flooded with information which deals either with phenomena at the scale of single B&D entities or with large scale applications. In this respect, progress has been made in the development of (a) novel instrumentation (e.g. X-ray tomography), (b) direct numerical simulations (e.g. volume-of-fluid or level-set methods) and (c) theoretical and computational tools (e.g. prediction of local fractions and size distributions) for the description of actual complex systems. The above advancements refer primarily to B&D interfaces, which are either clean or covered by conventional surfactants, and this constitutes the current state of knowledge in this field. Nanoscience and nanotechnology in composing new materials for applications, energy producing/saving technologies, environmental protection/restoration and health care have been identified as priority research areas around the globe. All these areas have direct relevance to B&D interfaces as the latter represent efficient means for controlled mass and heat transport across immiscible phases. Unfortunately the above efforts most often lack hierarchical research through multiple length scales and across diverse disciplines.

The increasing demand to tailor interfaces for new applications and for improving the performance of old ones necessitates a new generation of B&D interfaces. This calls for Smart and Green interfaces. Smart and Green (S&G) interfaces are tailored interfaces that can accomplish a technological task with high efficiency, adaptability and selectivity, while being also eco-friendly (biodegradable, reusable or simply more durable). The means to tailor S&G interfaces and accurately control their performance span from synthesis of novel materials to manufacturing processes and advanced diagnostics. A non-exhaustive selection of immediate industrial applications with high social relevance is: detergents that wet fibers uniformly, food foams and emulsions with long lasting stability, cosmetics and paints that are evenly spread, boilers/condensers with heat exchange surface renewal, distillation and flotation columns with homogeneous phase distributions, crude oil transportation, drug encapsulation and controlled drug delivery, "self-cleaning" solid surfaces which eliminate the need for regular washing/polishing.

Interfaces in the generalized notion constitute an interdisciplinary and multiscale subject spanning from fundamental to applied sciences and from molecular to macroscopic size scales. Parallel to the theoretical development of fundamental issues of Colloid and Interface Science by well-known physicists and chemists at the first half of the 20th century, the practical use of systems containing interfaces like emulsions, foams and sols was constantly expanding based on empirical rules without rigid scientific foundation. Regarding sols the convergence of technological practice to fundamental scientific principles came along with a specific event: the development of DLVO theory that explains sols stability based on first principles. The corresponding development for the case of emulsions and foams did not proceed by a huge step like the DLVO theory but it followed a gradual advancement in small steps, like the hydrophilic–lipophilic balance (HLB) in the case of emulsions. Literature on these classical subjects that attempt to relate applications with scientific foundation in order to extend the fundamental knowledge and to improve the applications is extensive today. In parallel, new technological issues appear (such as smart or biomimetic interfaces) that call for fundamental backing and technologies to control them. One of the reasons for the rich literature during the last decade on analyzing applications based on first principles is the vast increase in computational power and the development of sophisticated numerical methods. These tools render possible quantitative analysis that was not accessible before. Further to the above interface-centered issues there are many applications from the medical (diagnosis, controlled drug release), energy (boiling, evaporation), and industrial (flotation, extraction) domains that use interfaces as a device to achieve certain goals.

Developing Smart & Green interfaces requires major scientific and technological advances that need considerable interaction among groups experienced in manufacturing, advanced characterization and modeling of interfaces in order to identify and implement best strategies and means to produce S&G interfaces. Literature survey reveals several topics in the field where substantial effort is undertaken. A tentative selection refers to (a) new eco-friendly materials or processes that increase the efficiency, selectivity and adaptability of interfaces, (b) innovative industrial methods for producing and dispersing B&D of well-controlled size, population and stability, (c) pioneering instrumentation and diagnostic systems, and (d) performance enhancement of multiphase industrial processes.

The research on S&G interfaces is very broad and covers many fields of fundamental and applied science. The present work has therefore to be rather selective and we have to restrict ourselves on only few