



Foams and antifoams

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ABSTRACT

Foams and antifoams are two entities with completely different natures. For example, the foams are structures of bubbles in contact, while the antifoams are emulsions containing hydrophobic particles. The interaction between them makes the foam decay faster and in the same time exhausts the antifoam. The mechanism of such an effect is complex of many phenomena taking place in the foam. Thus the antifoams are known as powerful foam suppressors. For these reasons, they are very important from fundamental and practical viewpoints.

This paper summarizes the knowledge on antifoams since their very creation till nowadays. In this regard, the review discloses the scientific interpretations on antifoams in chronological order in accord with the literature. Thus, for example it begins with description of the first antifoams (oils) from the 1940s and the pioneering studies of S. Ross and his group. The first physical methods for studying antifoams were presented along with the concepts of spreading and entering coefficients of oils (W. Harkins, 1941, J. Robinson and W. Woods, 1948). The further development of the antifoams (oils + hydrophobic particles) was described by means of the works of R. Kulkarni et al., A. Dippenaar and P. Garrett in the late 1970s and the early 1980s. The theoretical models on the antifoam performance of R. Pelton and P. Garrett, developed in 1980s and 1990s, were presented and analyzed as well in regard with their limits of applicability. Substantial advance on the experimental techniques for studying antifoams has been achieved by introducing different variants of the film trapping technique (FTT) developed by D. Wasan et al., I. Ivanov et al. and T. Tamura et al. in the middle and the late 1990s. An assessment of these techniques was carried out in regard with their capacity for detailed studying the antifoam action within the thin liquid films. Finally, the latest knowledge on the antifoams was achieved due to N. Denkov and his group, who harnessed both the most successful type of FTT and the interferometric thin film setup of Scheludko to conduct innovative experiments on the antifoam's action in the foam films under different conditions. They derived new more detailed understanding on the antifoam's action. For this reason, we must acknowledge the series of works under the supervision of N. Denkov performed between 1996 and 2004 as the lately ones in the field.

The present work contains in addition a subchapter devoted to describing alternative methods for design and control of the foam stability. As far as the foaminess and the rate of foam decay depends on the states of the surfactant adsorption layers situated on the bubble surfaces, both foaminess and foam durability can be designed by means of proper choices of surfactants, concentrations and methods of foam generation. Therefore, this paper scrutinized the very mechanism of foam generation whose product is initial foam. Afterwards it was pointed out that the elastic modulus of the foam bubbles is responsible for the further "life" of the already generated foam. A compilation between foaminess and average rate of foam decay named foam production was shown as more successful way to describe the foaming capacity of the frothers. In addition, the properties of tenacious famous under various conditions were exhibited as well. This subchapter does not give any formula for precise design of foams with entailed durability but rather outlines new ways to achieve such recipe.

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1. Introduction

Foams and froths are highly non-equilibrium systems, which can be created by sudden large increase of the contact area between air and water. Upon its very generation, the froth starts draining. At this stage, it can collapse or be converted in foam with rapidly decreasing liquid volume fraction. The rate of bubble coalescence is a complex property depending on the rheology of the froth [1–4], the interaction forces between the gas bubbles [5,6] and the Gibbs elasticity [7,8]. In most of the cases these processes are controlled by a certain surfactant, which is present in the system [9]. Hence, two kinds of foam exist – transient and tenacious ones. It is well-known (e.g. Ref. [10,11]) that the elastic moduli of the foam bubbles control the foam durability. In addition, the formation of black foam films makes the foam ultra-stable [12]. The latter can last for many months and even years. One can control both the foaminess and the foam durability by means of proper choice of surfactants, concentrations and method of foam generation. Unfortunately, such precise selection is often not possible. Moreover, tenacious foams appear to be problematic in a number of industrial processes. For this reason, the anti-foam products were created and developed.

The contemporary antifoam is O/W emulsion containing hydrophobic particles. It can either prevent the foam generation or increase the rate of foam decay [13,14]. Therefore, there are fast and slow antifoams. The solubility of the oils in water is also important parameter. We have to acknowledge here the works of N. Denkov and his group [13] for achieving the latest scientific knowledge on the mechanism of action of the antifoam globules. Yet, there is a long prehistory of research on antifoams since the 1940s. The present review aims at presenting the history of the “antifoam” science in the chronological order of its development in the literature. The reader can follow the evolution of the scientific understanding on the antifoam action for a period of about 65 years (1940s–2004). Meanwhile this review acknowledges chronologically the researchers, who in our opinion mostly contributed to the development of this field as for example S. Ross, W. Harkins, J. Robinson, W. Woods, S. Okazaki, S. Sasaki, H. Tsuge et al., R. Kulkarni et al., A. Dippenaar, G. Frye, J. Berg, R. Aveyard, P. Garrett, R. Pelton, D. Wasan et al., I. Ivanov et al., T. Tamura et al., and finally N. Denkov et al. We do not state that the whole research work on antifoams is covered, although we did our best. In this sense, this paper could be helpful for both beginning and advanced researchers in this field.

It is well-known that the foamability and the foam stability depend on the surfactant adsorption layer located on the walls of the bubbles. To achieve better understanding about foams and how to design them, the basic steps in the evolution of the foam system from the very agitation to the complete decay should be followed and analyzed.

There are various ways to generate foam [15]. In all of them gas bubbles are introduced somehow into a solution with low surface tension. Each method for foam generation has its own specific way for introducing gas into the foaming solution – e.g. bubbling through porous frit, circulation in turbulent regime, shaking, pouring the foaming solution, gas cavitation in the foaming solution, chemical

reaction causing releasing of gas bubbles, etc. These methods for foam generation have two basic mechanisms for introducing of gas bubbles: (i) entrapping of air bubbles from the ambient atmosphere due to liquid turbulence; and (ii) artificial introducing of gas bubbles by physical or chemical manners. The second way is more productive, and its efficiency depends on the number of the bubbles introduced per unit time into the foaming solution. The second chapter of this work is devoted to alternative ways to control and design foams with entailed durability. It covers a substantial part of our research work on foams in the recent years. It was clearly shown that the critical Weber number is responsible for the rate of the bubble coalescence in the froths upon the very generation of foams. The rate of foam decay correlates well with the elastic moduli of the foam bubbles. It was shown as well a new selection criterion about the capacity of the surfactants as frothers. This criterion named foam production is actually a ratio between the “Bikerman's unit of foaminess” and the average rate of foam decay. Various effects related with the production of tenacious foams were shown. For example, the air's humidity influences the height of the stationary foams produced by means of the Bikerman's method. It was shown as well that the rate of foam growth coincides with the gas delivery rate within certain limits of the latter. Above them the foam raises faster than the gas delivery. The latter effect becomes greater upon reducing the surface tension until a certain critical speed of the gas delivery, at which the foam growth does not depend on the surface tension anymore.

2. Antifoams – creation and development

2.1. Industrial need for powerful foam suppressors – basic reason for creation of the antifoams

The prevention of foaming dates back to the beginning of 20th century when mechanical devices were utilized [16–20] as for example air jets, special still heads, paddle wheels, perforated spiral canals, centrifuges, change of pressure, heating elements, ultraviolet rays, X-rays, supersonic waves, etc. These ways to suppress foaming were expensive due to the energy, which was required for their applications. To reduce the costs, chemical methods were preferred to mechanical devices [20]. Among the chemical methods the addition of small quantities of caprylic alcohol, amyl alcohol, octyl alcohol, linseed oil, castor oil, rapeseed oil, trimethylcyclohexanol, phenyl ether, isoamil isovalerate, milk, kerosene, polyamides, etc. [20–23] were recommended for various aqueous foam systems. Since the late 1940s they were commercialized and found many applications in the pharmaceutical industry [24], medicine [25], food industry [26], chemical industry [20], for the work of steam engines [23], etc. The lab research on the foam inhibitors begun at this time as well [20,27–30].

The history of the antifoams can be split to two periods – (i) period of “oil” antifoam products (early 1940s–late 1970s); and (ii) period of “oil + hydrophobic particles” antifoam products (late 1970s–present). The research methods of their investigations underwent development as well upon time.

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