Colloids and Surfaces A: Physicochem. Eng. Aspects 467 (2015) 97–106

Contents lists available at ScienceDirect

Colloids and Surfaces A: Physicochemical and Engineering Aspects

journal homepage: www.elsevier.com/locate/colsurfa

Response of wet foam to fibre mixing

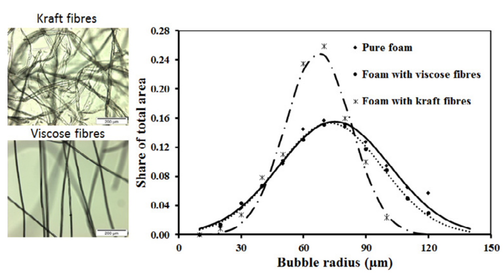
Ahmad M. Al-Qararah, Tuomo Hjelt, Antti Koponen, Ali Harlin, Jukka A. Ketoja*

VTT Technical Research Centre of Finland, P.O. Box 1000, FI-02044 VTT, Finland

HIGHLIGHTS

- The response of wet foam to natural and regenerated fibres is quite different.
- A new bubble breaking mechanism for natural fibres is proposed.
- Bubble size varies much more than the air content for stable macroscopic flow.
- For an unstable flow, air content can drop suddenly with increasing shear rate.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 October 2014
Received in revised form
13 November 2014
Accepted 14 November 2014
Available online 21 November 2014

Keywords:
Wet foam
Mixing
Fibre
Bubble size
Air content

ABSTRACT

Air content and bubble size are the key parameters in describing aqueous wet foam. These two parameters respond differently to added fibres in axially agitated mixing. Both air content and bubble size depend on the process characteristics such as mixing geometry, rotation speed and surface tension. However, for moderate rotation speeds, air content is rather insensitive to the added cellulose-based fibres, whereas the mean bubble size varies strongly with the fibre type. Even though the bubble size is usually reduced by the added fibres, short fibres can also increase the bubble size. The mean bubble size clearly becomes smaller for wood fibres than for viscose fibres even if these two types of fibres have similar geometric dimensions. Moreover, the bubble size distribution becomes narrower with wood fibres. This suggests a bubble breaking mechanism induced both by the rough surfaces of wood fibres and by the associated fine particle fraction that are both absent with smooth viscose fibres. At high rotation speeds, the air content becomes extremely sensitive to the fibres due to macro-instabilities causing an irregular flow of the wet foam.

1. Introduction

In recent years, there has been an increasing interest in foam-fibre systems by both industry and researchers due to the so-called foam forming application where fibre networks (similar to paper structures) are formed using foam as the carrier phase instead of water [1–8]. Foam forming provides many advantages compared to water forming. In particular, the suitability of the foam forming technology to a broad range of fibre types, from cellulose nanofibres to long synthetic fibres, opens up a new avenue in material development. One of the most intriguing possibilities is the possibility of tailoring the formed structure with the foam properties [9,10]. Thus, it is very important to understand the key parameters underlying foam properties and the interaction of foam with fibres and particles.

Most of the research on aqueous foams has concentrated on the so called “dry” foams with air content above 80% [11]. The properties of “wet” foams are much more poorly understood. In a recent study on axially agitated mixing of the wet foam [12], rotation speed was seen to affect both air content and bubble size for a given mixing geometry. With an additional parameter such as liquid surface tension, air content and bubble size can be varied

* Corresponding author. Tel.: +358 405476146; fax: +358 207227604.
E-mail address: jukka.ketoja@vtt.fi (J.A. Ketoja).

http://dx.doi.org/10.1016/j.colsurfa.2014.11.034
0927-7757/

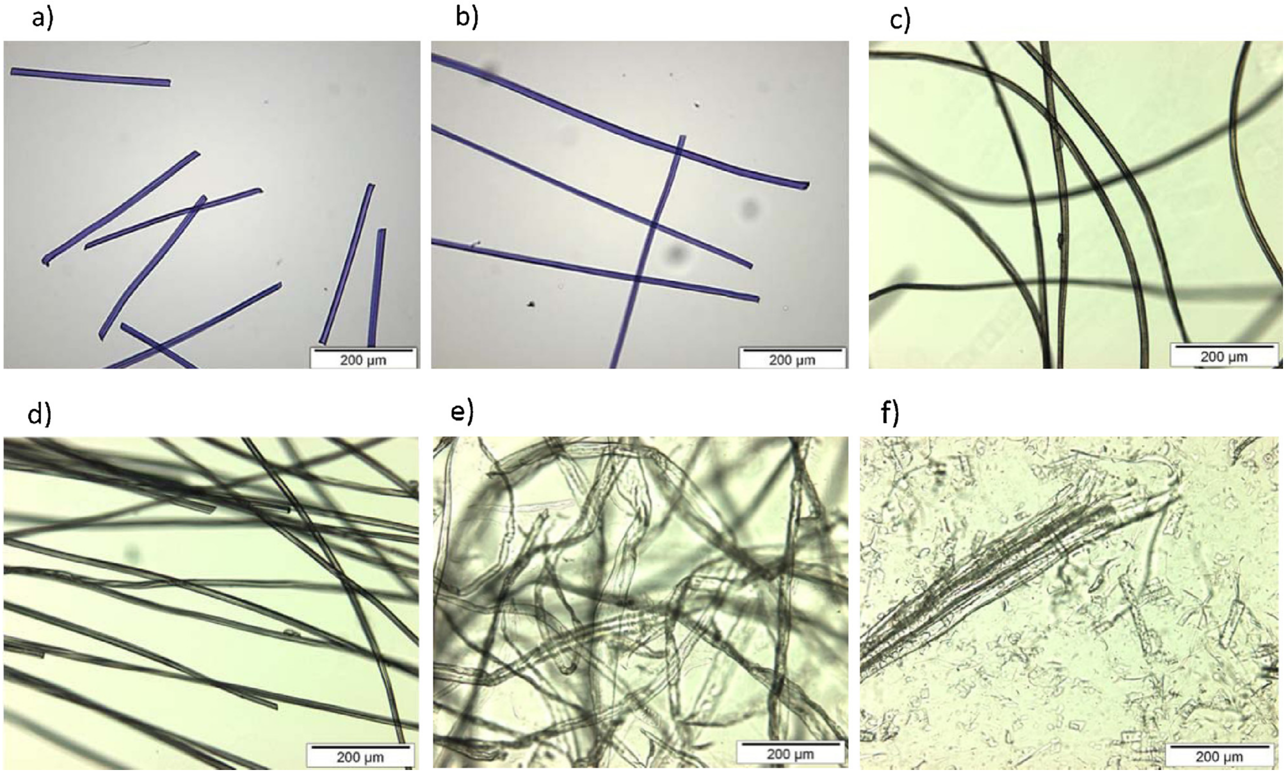


Fig. 1. Light microscope images of different types of fibres used in the experiments: (a) rayon (0.35 mm), (b) rayon (1.0 mm), (c) viscose L, (d) viscose K, (e) kraft R, (f) CTMP. The natural fibres have rough surfaces and they are associated with fine particles also visible in figures e and f.

independently. A simple formula describes the mean bubble size quite well over a broad range of rotations speeds, surface tensions and air contents [12].

The previous studies on fibre-laden foams indicate that the bubble size is often reduced when fibres are added to foam in dynamic mixing conditions [10,12,13]. It has been proposed that a possible cause is the strengthening of local shear forces due to fibre inertia enhancing the breaking tendency of the larger bubbles. However, for very high rotation speeds very similar bubble sizes have been observed with and without fibres. In this region, the shear forces due to the fluid phase could become strong enough to completely dominate the bubble breakup process [12].

In this paper, we study the response of wet foam to added fibres for a spectrum of different fibre types with varying dimensions and fibre surface properties. The fibres studied include both natural wood fibres and regenerated cellulose fibres. In other words, the focus is on physical properties, and the basic (cellulose) surface chemistry is similar for all fibres studied. In addition to fibre length and diameter, we also vary microscopic surface properties, as the regenerated fibres have much smoother surfaces than the natural fibres. Moreover, natural fibres have broad size distributions and typically include a considerable number of fine particles. We consider not only the mean bubble size but also the effect of fibres on the bubble size distribution. The study results in a new proposal on the underlying bubble breaking mechanisms.

2. Experimental

2.1. Fibre materials

The fibres studied include regenerated cellulose fibres and natural wood fibres, see Fig. 1. The density of the viscose and (viscose) rayon fibres is about 1500 kg/m^3 [14], i.e. close to the density of crystal cellulose, which is the main component of the wood fibre wall. However, a wood fibre includes a lumen that causes the density of the whole fibre to be clearly lower, around 1000 kg/m^3 [15]. The advantage of the regenerated viscose and rayon fibres studied is that the fibre length can be controlled and varied independently of the diameter. However, the smooth surface of the man-made fibres differentiates from that of pulp fibres, which can have an impact on the results. In the present study, very long fibres such as cotton were excluded, as they could be associated with macroscopic flock formation, and we wanted to avoid this additional complexity.

The regenerated fibres were obtained from two producers. Such fibres are usually characterized in terms of their linear mass density [14]. The corresponding unit, decitex (abbreviated dtex), gives the mass in grams per 10,000 metres. The Lenzing viscose staple fibres (viscose L, 1.7 dtex) and rayon (1.9 dtex) fibres were delivered in a dry form. The Kelheim staple viscose fibres (viscose K, 1.7 dtex) were delivered at 50% moisture content. The lengths of the regenerated fibres varied from 0.35 mm to 10 mm. For a given fibre type, all regenerated fibres had practically equal length and diameter. This was confirmed by optical microscopy for the length and confocal laser scanning microscopy for the width. For the rayon fibres, slight changes in cross-sectional shape were noticed in moving from 1.0 mm length (flat cross-section) to 0.35 mm length (oval cross-section).

The natural wood fibres, obtained from Finnish paper mills, were either unrefined bleached kraft (denoted below as kraft U), refined bleached kraft (kraft R), or chemi-thermo-mechanical pulp (CTMP) fibres. The average lengths of the kraft (scots pine) and CTMP (spruce) fibres were 2.3 mm and 1.6 mm, respectively. However, the fibre length and the fibre diameter distributions are rather broad for these types of wood fibres [15]. Moreover, the wood fibre pulps contain a significant proportion of sub-micron fine particles (called “fines”). These particles are mostly fibrillar or flake-like fragments of the fibre wall. Typically, 30% by weight of CTMP pulp and less than 10% of kraft pulp consist of such small particles.