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Fine bubble technology — General principles for usage and measurement of fine bubbles —

Part 2: Categorization of the attributes of fine bubbles

Technologie des fines bulles — Principes généraux pour l'utilisation et la mesure des fines bulles —

Partie 2: Classification des attributs des fines bulles

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Foreword

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This document was prepared by Technical Committee ISO/TC 281 *Fine bubble technology*.

A list of all parts in the ISO 20480 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In recent years, readily available measurement techniques of bubbles have made it possible to characterize microbubbles and ultrafine bubbles. Such techniques have shown that ultrafine bubbles can almost remain as they are for a number of months.

Fine bubble technologies are very new, and their applications are useful in a number of fields today. Developing appropriate terminology for such a diverse area of technology is therefore critical to business trade or product acceptance, in view of the wide range of users of fine bubbles.

For better communication among the users of fine bubbles, this document introduces the quality criteria of a medium such as water, as well as two indices, one for size and the other for number concentration. This document also provides an explanation for classifying fine bubbles by dimensional characteristics and by rise velocity.

It should be noted that the motion of bubbles in a medium can be determined by buoyancy forces or randomly and thermally activated processes leading to Brownian motion. For this reason, larger bubbles can display buoyant behaviour (rise upwards) and smaller bubbles remain in the liquid medium displaying random motion. This document focuses on the definitions of such entities.

Fine bubble technology — General principles for usage and measurement of fine bubbles —

Part 2:
Categorization of the attributes of fine bubbles

1 Scope

This document establishes the general principles and descriptors to allow users to describe the quality of the liquid media and the size and concentration of fine bubbles. It is also intended to allow users to classify fine bubbles by rise velocity.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20480-1, *Fine bubble technology — General principles for usage and measurement of fine bubbles — Part 1: Terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20480-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
rise velocity
velocity of a fine bubble upwards in liquid

3.2
terminal rise velocity
balancing velocity between the buoyancy of fine bubbles and the viscous drag

Note 1 to entry: It is the velocity in the opposite direction to the terminal settling velocity. If a rise velocity were to be defined as the terminal settling velocity, the rise velocity would be negative. Therefore, in the classification of fine bubbles, terminal rise velocity is preferred over terminal settling velocity to avoid confusion.

4 General principles for usage and measurement of fine bubbles

4.1 Standards system of fine bubble technology

The purpose of this document is to provide people who develop standards for fine bubble technology with an overall framework and guidelines, and to facilitate communication among users of fine bubbles. To assist in the preparation of consistent standards, a three-layered standard system has been established.

This consists of the following.

a) The **first layer (basic standards)** covers common terminology, basic concepts, and principles for measurement and usage that can be applied to fine bubble technology. This document is part of the basic standards, and is intended to be used as a basis for the next two layers.

b) The **second layer (measurement standards)** covers various measurement methodologies for characterization, such as bubble diameter and number concentration index, as well as common methods for sampling and sample preparation.

c) The **third layer (individual application standards)** covers individual applications in areas including:

   1) food, plant cultivation, agriculture, drinking water, and cosmetics industries;

   2) the medical and pharmaceutical fields;

   3) manufacturing of new functional materials, solar cells, semiconductors, and liquid crystals;

   4) processes such as cleaning, toilet flushing, soil washing, water treatment, etc.

4.2 Quality of liquid medium

The performance of the liquid medium with fine bubbles is strongly dependent on its pH value and the inorganic and organic substances contained therein. Therefore, the important properties of the liquid medium should be measured and clarified. This includes properties such as electrical conductivity, total organic carbon concentration, concentration of silica, sodium, oxygen component of oxidizable substance, evaporation residue heated at 100 °C in the case of fresh water and pH, optical absorbance at 25 °C for wavelength 254 nm and path length 1 cm and evaporation residue after heating at 110 °C in the case of fresh water. Typical examples of standards for the quality of fresh water are ISO 3696, ASTM D1193 and CODEX STAN 108[3].

5 Expression of attributes for fine bubbles

5.1 Application of size index and number concentration index

5.1.1 General

The terms “size index” and “number concentration index” are intended to benefit those who are exclusively engaged in the application of fine bubble technology.

A bubble is a closed interface between gas and liquid. An ideal size measurement would distinguish a bubble from solid particles or liquid droplets (such as oil), which may also be present in the medium. The measurement would be able to size each material separately.

Most currently available measurement methods that use optical scattering or acoustic characteristics cannot differentiate one type of phase from another, and will characterize them as an ensemble (even if the particle types are different). Although the reported values for size and concentration may not be entirely due to bubbles, in most cases they are accurate enough for users in their work. The terms “size index” and “number concentration index” should be used in preference to size and number concentration to better reflect the uncertainties involved.

5.1.2 Size index rules

The following rules apply to the use of the term “size index”.

a) The size index shall be accompanied with a description of the relevant measurement method and applicable field for relevant fine bubbles.

   1) The “measurement method” in practice includes an industrially available and agreed method.

   2) The “applicable field” in practice includes a description of the application specific functional components other than fine bubbles.

   3) Example: “size index measured by the particle tracking analysis (PTA) method on untreated raw water for aquafarming technology”.

   NOTE For more information on particle tracking analysis (PTA), see ISO 19430.

b) Size indices from different techniques are not comparable.

c) The size index is preferably to be accompanied with an acknowledgement of the uncertainty inherent in the definition of fine bubbles size.

5.1.3 Number concentration principles

A practical measurement of number concentration assumes a measurement principle. For example, optical measurement cannot identify a fine bubble from a solid particle in a given fine bubble water sample. But users can estimate the number concentration contribution of solid particles once they know the history of the sample’s generation.

A very clean generator will not add any solid particles to the original water sample. Thus, the number concentration index of fine bubbles in the generated water can be estimated by subtracting the concentration of solid particles in the original water sample from the total number concentration. The uncertainty can be assigned by estimating, for example, how clean the generator is.

Alternatively, if it is possible to run the sample through the generator without generation of bubbles occurring, it could be used as a background measure that would take into account any contamination from pipes/tank walls.

5.1.4 Number concentration index rules

The following rules apply to the use of the number concentration index:

a) the number concentration index shall be accompanied with a description of the measurement method and applicable field for relevant fine bubbles;

b) different types of number concentration indices are not comparable;

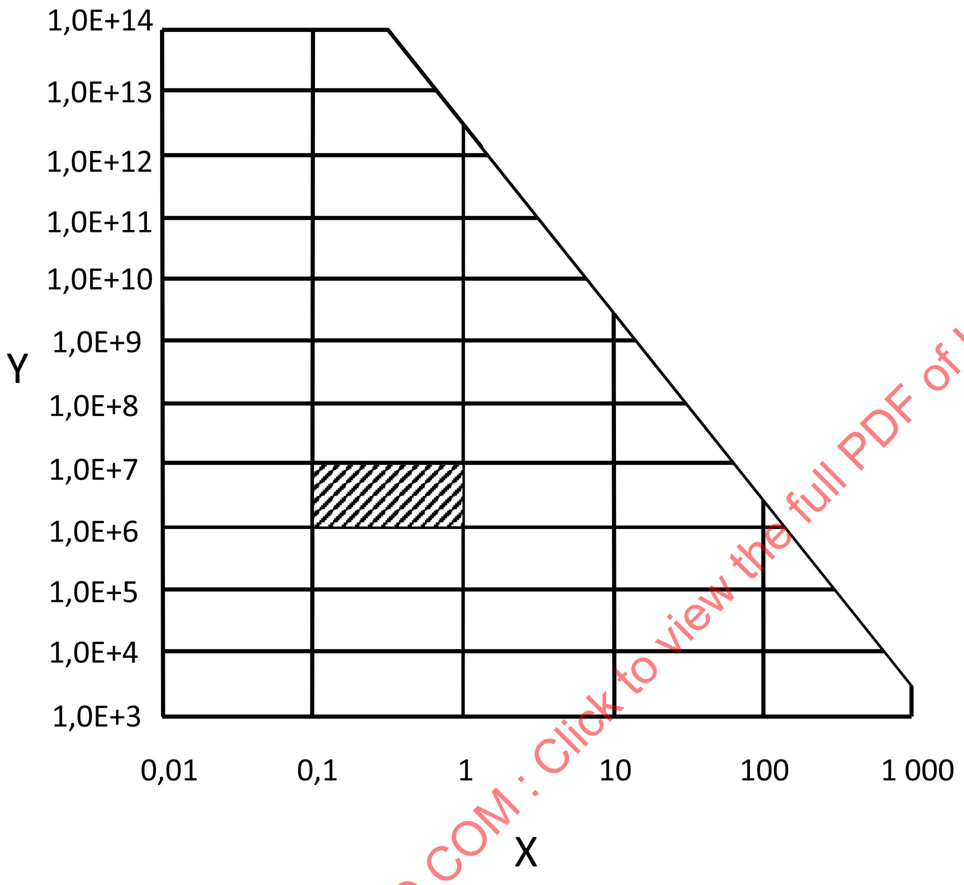
c) the number concentration index is preferably to be accompanied with an acknowledgement of the uncertainty inherent in the definition of fine bubbles size.

5.2 Expression of class of fine bubbles in dimensional characteristics

Since the definition of fine bubbles ranges over 5 decades in size and 11 decades in number concentration, many physical, chemical and mechanical characteristics can differ according to the dimensional range of fine bubbles.

While detailed and precise specifications of the size and number concentration ranges will be useful for the fine bubble community, the wide scope over several decades will be useful for all those engaged in fine bubble applications.

Fine bubbles dispersed in water may be defined within regions as shown in Figure 1, based on size and number concentration. This type of categorization can be used to define which areas of the matrix are most appropriate for certain applications.



Key

X size (µm)

Y number concentration (per ml)

EXAMPLE Ultrafine bubbles with a size ranging from 0,1 µm to 1 µm and number concentration ranging from 10^6/ml to 10^7/ml are expressed by the class indicated by the hatched box.

Figure 1 — Fine bubble water dispersion categorization

6 Classification of the attributes of fine bubbles by rise velocity

6.1 Attributes of fine bubbles by rise velocity

The number concentration of fine bubbles contained in a liquid decreases with time. One reason for this decrease is that a portion of the bubbles rise to the surface due to the buoyant force and disappear in the air.

Rise velocity depends on bubble size.

- Fine bubbles with a very low rise velocity can remain in liquids for a long time. This extended lifetime of fine bubbles may then enable a variety of industrial applications.
- Fine bubbles with a high rise velocity can also be applicable to a variety of industrial applications. These include:
  - using bubble rise to separate materials,
  - using the gas-liquid surface area of fine bubbles for the mass transport of materials,
  - generating bubble towers through gas-liquid reactions, etc.

6.2 Classification of fine bubbles by rise velocity

6.2.1 General

The terminal rise velocity of a fine bubble is defined as a balancing velocity between the buoyancy of fine bubbles and the viscous drag. The terminal rise velocity is affected by the diameter of fine bubbles, the viscosity (fluid friction), the boundary condition and the number concentration of bubbles in liquid. Figure 2 shows the terminal rise velocity of an isolated fine bubble in water.

Brownian movement velocity is defined as the amount (distance) of average displacement per second in Brownian movement, which can be calculated from Formula (1):

$$v_{\mathrm{Br}} = \sqrt{\frac{2RT}{3\pi \mu d N_{\mathrm{A}} t}} \qquad (1)$$

where

v_{Br} is the Brownian movement velocity, in $m \cdot s^{-1}$;

R is the gas constant, in $J \cdot K^{-1} \cdot mol^{-1}$;

T is the temperature, in K;

μ is the viscosity, in Pa·s;

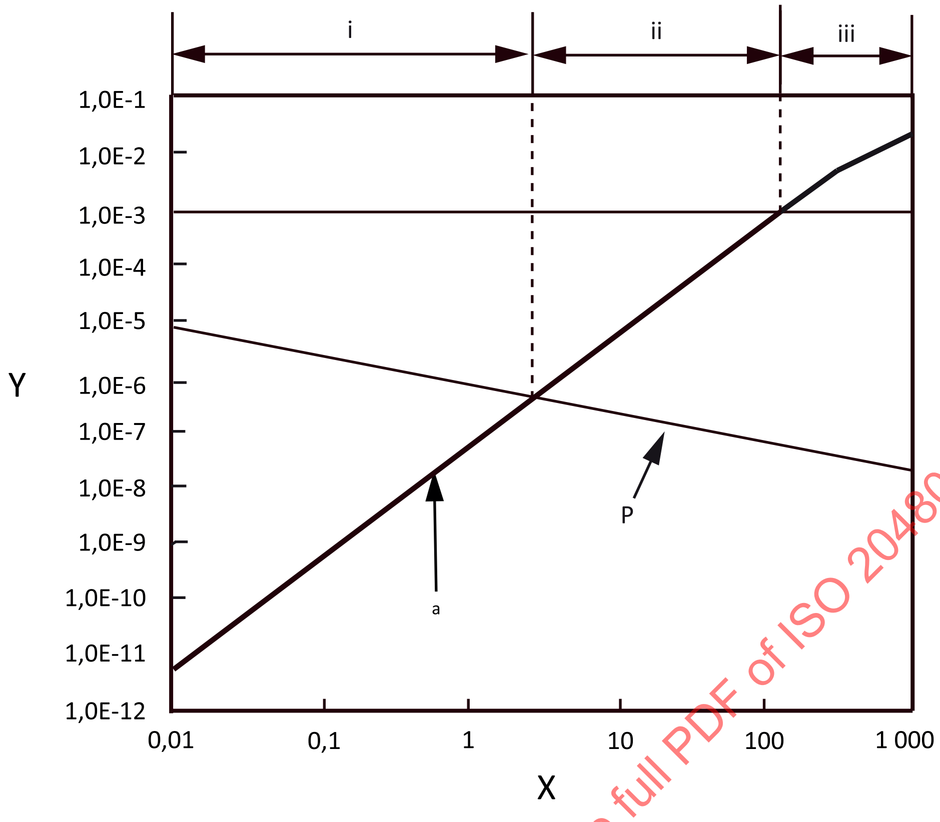
d is the bubble diameter, in m;

N_{A} is the Avogadro constant in mol^{-1};

t is the time, in s.

The random velocity associated with Brownian motion decreases with increasing bubble size.

The actual rise velocity can be influenced by flow in the liquid or the effect of multiple bubbles, but in Figure 2 these effects are ignored.



Key

X bubble diameter (µm)

Y terminal rise velocity ($m \cdot s^{-1}$)

i region in which terminal rise velocity < Brownian movement velocity;

ii region in which Brownian movement velocity < terminal rise velocity < 1,0E-3;

iii region in which 1,0E-3 < terminal rise velocity;

P random velocity of fine bubbles in Brownian motion in a medium with a viscosity of 0,001 (Pa·s)

[a] Water (20 °C).

NOTE Reproduced from Reference [5] with the permission of the author.

Figure 2 — Classification of fine bubbles by rise velocity in a fine bubble water dispersion under the ideal condition of bulk flow absence and of isolated fine bubbles

6.2.2 Classification and definition of regions

a) Region i

Region i is where the terminal rise velocity of fine bubbles is lower than the velocity of Brownian movement, the loss of bubbles via buoyancy can be ignored, and the bubble number stability of fine bubbles in a liquid may be very long.

NOTE Annex A shows observation examples of bubble number stability of ultrafine bubbles.

b) Region ii

Region ii is an intermediate region where the terminal rise velocity of fine bubbles is greater than Brownian velocity but still low. In this region, bubbles are expected to rise slowly to the surface, reducing stability.

c) Region iii

Region iii is where the terminal rise velocity of fine bubbles dominates. Here the rise velocity is sufficient for applications that depend on significant bubble rise velocities.

NOTE 1 For example, it seems to be effective to use fine bubbles for the purpose of floatation separation, where the rise velocity of a group of fine bubbles is 4,0 m/h (about 1,1 mm/s) or higher.

NOTE 2 In the case of water, a threshold bubble terminal rise velocity for effective rise would be about 1 mm/s.

Annex A
(informative)

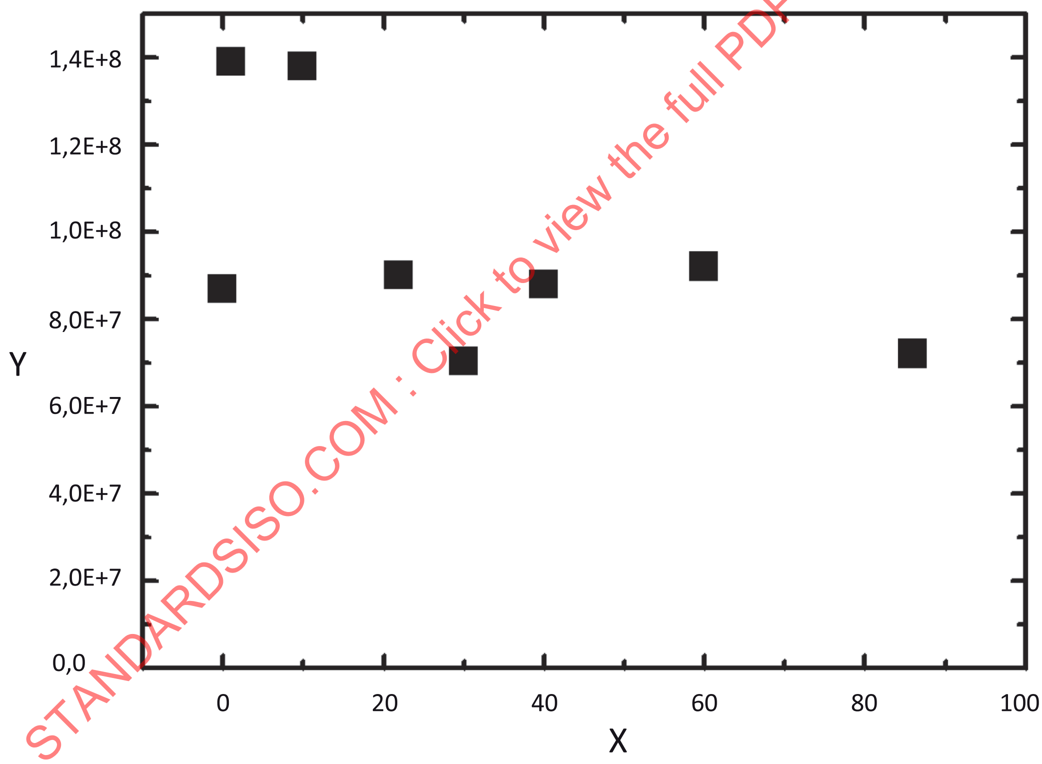
Observation examples of ultrafine bubble number stability in liquids

A.1 General

This annex shows examples of bubble number stability of ultrafine bubbles in water, over time. The examples are based on work carried out by two research institutes[4][5].

A.2 Example 1

As shown in Figure A.1, for ultrafine bubbles where the initial number concentration index was about (0,8 to 1,4) E+8 bubbles/ml, the number concentration index remained steady for about 3 months.



Key

X time (day)

Y total number of ultrafine bubbles in water per ml

NOTE Reproduced from Reference [4] with the permission of the authors.

Figure A.1 — Example 1: Observation of bubble number stability of ultrafine bubbles in water over time

