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Fine bubble technology — Environmental applications —

Part 1: Inspection method using online particle counter in dissolved air flotation (DAF) plant

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Contents

Page

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 4240 series can be found on the ISO website.

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Introduction

The dissolved air flotation process is widely used for water treatment plant. This process used micro bubbles to remove particles by floating them on the surface. There are various factors to check the operation of the DAF plant. Many of these factors can be measured in field scale DAF plant. However, some factors are very difficult to measure in the field.

One of these factors is bubble volume concentration (BVC). BVC is usually used as index of the number of bubbles. Generally, BVC is evaluated by the water displacement method. This method measures the volume of bubbles as the volume of water displaced. The water displacement method is a direct way to give accurate BVC of bubble water. However, this method needs large equipment depending on the capacity of the bubble generator. So, it is almost impossible to measure BVC directly from the DAF plant. Lab and pilot test with the same nozzle of DAF plant and predictions based on the test results are most widely used.

Bubble bed depth is also difficult to measure in DAF plant. It is easy to observe the creation of a bubble bed interface in the middle part of the reactor by the naked eye in a lab and pilot scale DAF reactor manufactured with a transparent wall. Although it is not possible to present the interface by a single straight line, a bubble interface zone exists in which above the interface there are clouds of bubbles and below the interface almost no bubbles are observed. The centre of the bubble interface zone is defined as the bubble bed interface. Bubble bed depth is defined by the height from the water surface to the bubble bed interface as presented in Figure A.1. However, in a full-scale DAF plant, it is not easy to locate the bubble bed interface. The difficulty is that observation by the naked eye is not possible due to structural constraints.

Therefore, this document specifies indirect measurement methods of BVC and bubble bed depth. This approach can be useful for on-site inspection of DAF plant.

Fine bubble technology — Environmental applications —

Part 1: Inspection method using online particle counter in dissolved air flotation (DAF) plant

1 Scope

This document specifies the bubble volume concentration and bubble bed depth measurement methods by online particle counter for checking DAF process performance in plant.

The test method of bubble volume concentration is made by measuring bubble size distribution in contact zone of DAF tank and calculating using formula. And bubble bed depth is evaluated by measuring the number of bubbles and particles according to the depth at five points in separation zone of DAF tank.

This document provides the advantages and limitations of using online particle counter in plant.

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 20480-4, *Fine bubble technology — General principles for usage and measurement of fine bubbles — Part 4: Terminology related to microbubble beds*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20480-4 and the following apply.

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

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

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

3.1
bubble volume concentration
BVC
index of the volume of bubbles contained in the unit volume of water

Note 1 to entry: It is calculated by the ratio of the total bubble volume to the volume of generated bubble water during any given time, expressed in %.

[SOURCE: ISO 20480-4:2021, 3.16, modified — "index" has been removed from the term.]

3.2
particle counting method
indirect method to count the number of bubbles and its size distribution in a measurement

Note 1 to entry: Particle counting method (PCM) can trace the variation tendency of the BVC index.

Note 2 to entry: Effective range of particle counter to measure bubble size is from 1 µm to 100 µm.

Note 3 to entry: The sampling flowrate is normally adjusted, and the numbers of bubble are counted in the applied volume of sample.

3.3
bubble and particle size distribution
range (minimum to maximum) of bubble and particle size in a measurement

4 Principle

A particle counter is an instrument which is widely used for the determination of bubble size distribution (see Annex A)[1]-[4]. Based on this characteristic, it can be used to evaluate BVC in DAF plant. Even though the result of this method is not accurate, it can be used to show the tendency of BVC according to time by real-time monitoring in DAF plant.

5 BVC measurement technique

5.1 Test equipment

This document aimed to evaluate BVC in DAF plant. Therefore, test equipment should be easy to move. Figure 1 shows the example of equipment for BVC evaluation. The list of equipment is shown below.

a) Online particle counter:

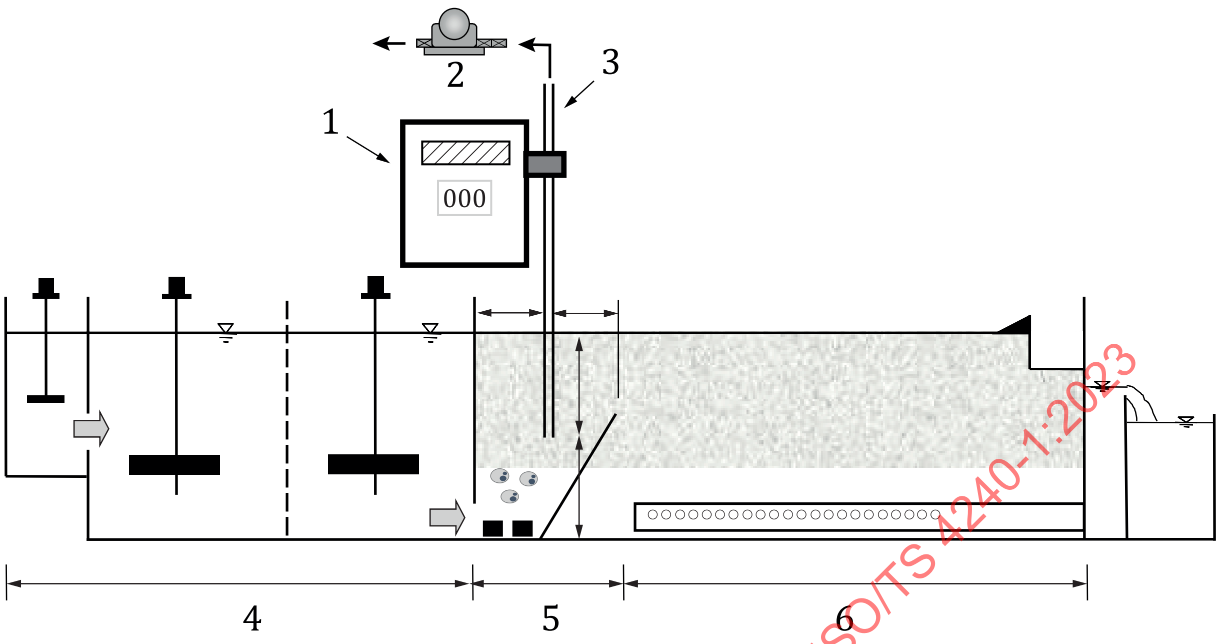
— detecting range: approximately 10 µm to 100 µm;

— support online-mode;

— portable.

b) Metering pump which can be operated at flowrate approximately 100 l/min to 200 l/min.

c) Tube of sufficient length (the effect of sampling tube length is shown in Annex G).



Key

1 online particle counter
2 pump
3 tube
4 flocculation basin
5 contact zone
6 separation zone

Figure 1 — Schematic diagram of equipment for BVC evaluation

5.2 Procedure

a) To minimize errors caused by particles entering the DAF tank, the inflow valve is locked in the DAF tank to prevent entry of untreated water. In this state, the bubble generator is operated to remove residual particles in the DAF tank and to make a stable state.

b) The test equipment should be installed near the contact zone for evaluating BVC. The sample is taken in the middle of the point at the contact zone of the inlet and the outlet. Sampling depth is at half the depth of the contact zone. Tube for sampling is installed 1 m away from the sidewall to prevent from interruption of sidewall. Metering pump flowrate shall be approximately 100 l/min to 200 l/min to minimize the influence on the DAF bubble bed.

c) The bubble size distribution is measured using online particle counter. The measurement time shall be 5 ± 1 min to obtain stable data.

d) Based on the measurement results, the bubble size distribution graph shall be drawn. The horizontal axis represents the bubble size range, and the vertical axis represents the number of bubbles. The example is shown in Figure A.1.

e) Calculate BVC using Formula (1).

$$\mathrm{BVC} = \frac{\sum n_{i^*} \times i^*}{Q} \times 100 \qquad (1)$$

where

BVC	is the bubble volume concentration in %;
i^*	is the volume of median size bubble of a certain range in ml;
n_{i^*}	is the number of bubbles of a certain range whose median size bubble volume is i^*;
Q	is the volume of sampled water from the contact zone in ml.

6 Bubble bed depth measurement technique

In the case of laboratory and pilot test, bubble bed depth can be measured with the naked eye by making DAF tank of transparent wall. However, it is impossible in DAF plant. This document provides the measurement method of bubble bed depth based on particle counting method. The accuracy of particle counting method was verified in Annex C through the experiments in pilot plant.

6.1 Test equipment

This document aimed to measure bubble bed depth in plant. Therefore, test equipment should be easy to move. Figure 2 shows the typical example of equipment for bubble bed depth measurement. The list of equipment is shown below.

a) Online particle counter:

— detecting range: approximately 10 µm to 100 µm;

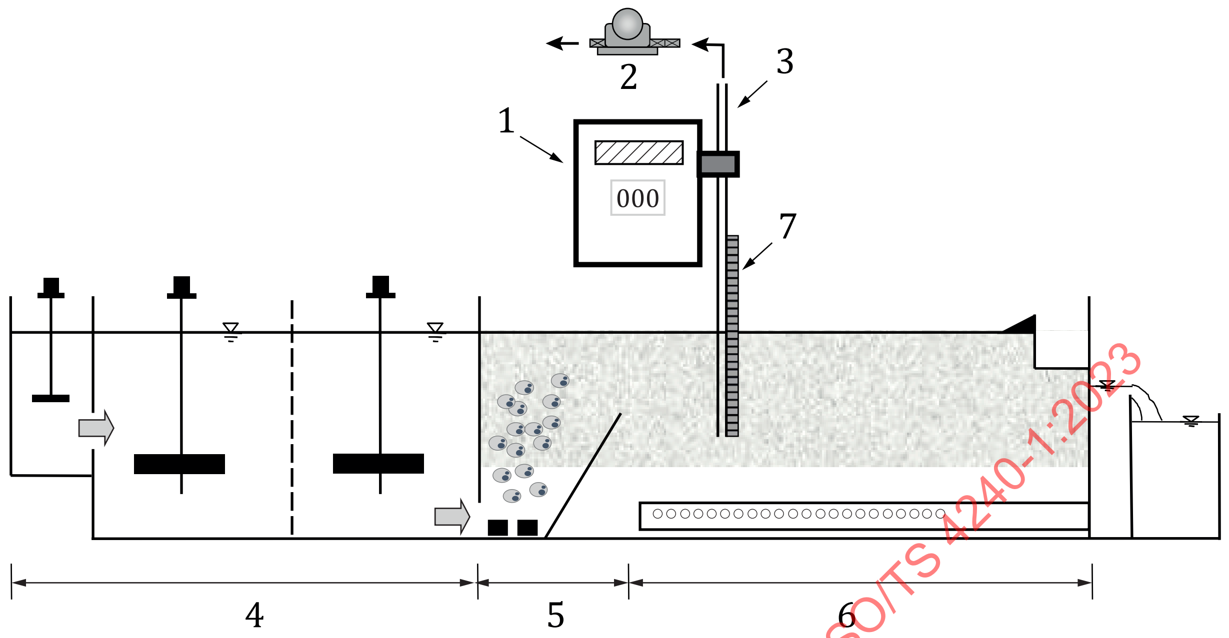
— support online-mode;

— portable.

b) Metering pump which can be operated at flowrate 100 l/min stably.

c) Tube of sufficient length from the bottom of DAF tank to online particle counter.

d) Scaled pole with sufficient length for marking the position of the hose.



Key

1 online particle counter
2 pump
3 tube
4 flocculation basin
5 contact zone
6 separation zone
7 scaled pole

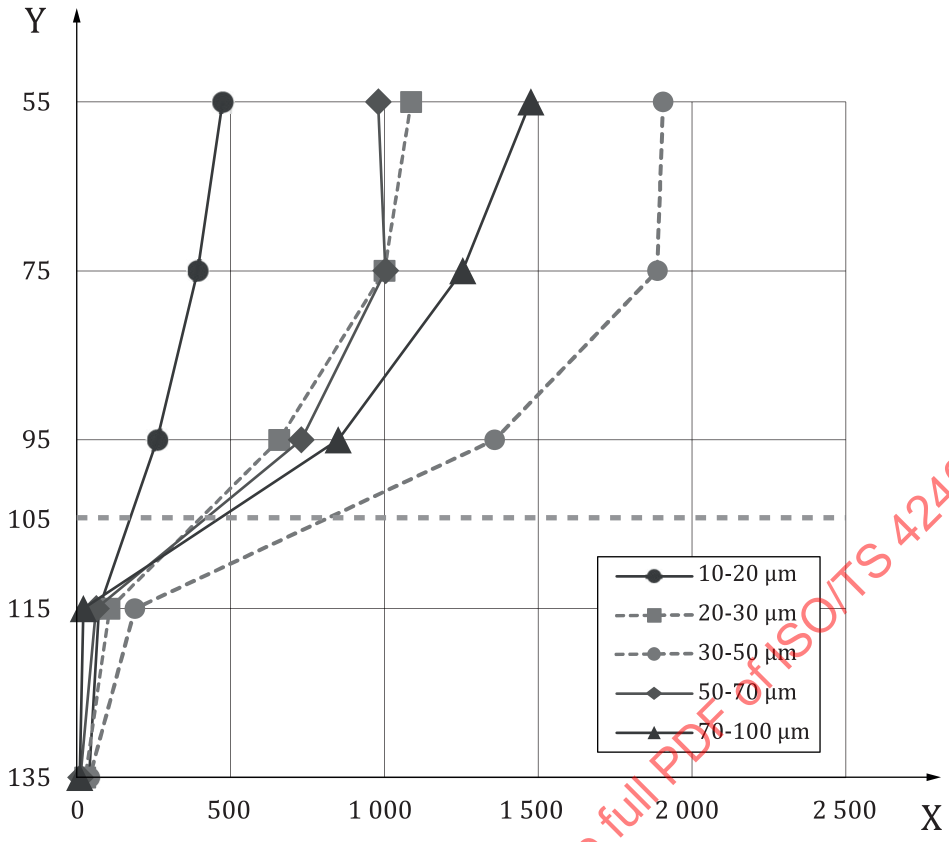
Figure 2 — Schematic diagram of equipment for bubble bed depth measurement

6.2 Procedure

a) In order to determine the horizontal profile, five points are selected as investigating point. They are inflow and outflow points of separate zone and three more points with equal interval between them.

b) At each point, bubble and particle size distribution is investigated using online particle counter and metering pump according to depth while DAF process is operated. To make bubble bed depth constant, pressure of bubble generator and recycle ratio should remain constant during the measurement (see Annex E). Particles from inflow do not affect the measurement of the bubble layer (see Annex F). Detection range shall be set to approximately 10 µm to 100 µm. The samples are taken from 1 m away from the sidewall using a tube tied on a scaled pole at different depths. In this time, measuring depths shall have same interval. Metering pump flowrate shall be 100 l/min to minimize the influence on the DAF bubble bed.

c) Based on the results of investigation at each point, bubble bed depth of the point is determined. After getting bubble and particle distribution according to depth, the number of bubbles and particles can be known. Based on the measurement results, the middle value of the interval in which the number is suddenly changed is determined as the bubble bed depth at that point. Figure 3 shows one example of how to locate the bubble bed interface. For the operating conditions given above and listed in Figure 3, the particle and bubble counts decreased rapidly in the depth range of 95 to 135 cm. From this result, the bubble bed depth is determined as 105 ± 0,5 cm. Details of the experiment are shown in Annex D.



Key

X number concentration (counts/100 ml)

Y depth from the surface (cm)

NOTE Operating conditions: pressure, 415 ± 0,5 kPa; recycle ratio, 6,6 %; separation zone loading rate, 12 mh^{-1}; water temperature, 7,5 ± 0,1 °C.

Figure 3 — Bubble and particle count at different depths at sampling position C

After evaluating bubble bed depth at five points, determine the bubble bed depth of investigated DAF plant as the minimum of them.

7 Advantages and limitations

7.1 Advantages

The particle counter method can be used for the determination of bubble and particle count and its size distribution in a variety of liquid streams. There are some applied case of measuring bubble size, concentration and depth of bubble bed at an actual water and wastewater treatment facilities.

Particle counting method is an accurate tool for measuring BVC and bubble bed depth in DAF process for both small and large scale. In the laboratory, the particle counting method is a well-performed method in both pilot plant and full-scale DAF plant by showing very accurate and meaningful data.

The measurement device is simple and easy to operate, and the measurement time is shorter than other methods. In addition, the measurement cell of particle counter is very large (1 mm × 1 mm), making it easy to clean and resists clogging.

7.2 Limitations

The particle counting method would be applicable only for the tendency analysis and comparison of BVC or bubble bed depth because the results vary according to the sampling rate and size range. For ultrafine bubbles (less than 700 nm), this method is not suitable. In some cases, the coalescence of bubble can occur, affecting measurement results. A suction tube should have a proper length to minimize the possibility of coalescence occurring.

Annex A
(informative)

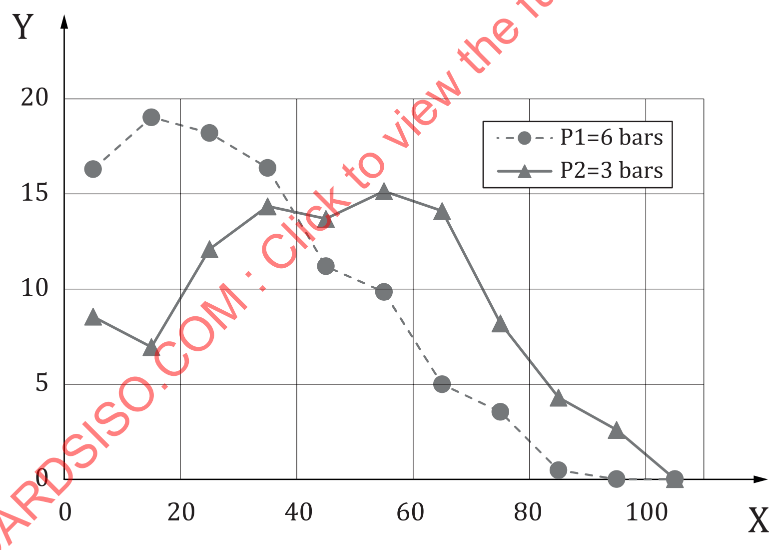
Measurement of bubble size and size distribution by PCM

At higher saturated pressure, bubble size decreased; at a critical pressure of approximately 3,5 bars, the average bubble size was constant.[1],[2] The average bubble size reached 30 µm at 6 bars and 45 µm at 3 bars when the bubble rate was fixed at 30 % (see Table A.1) and Reference [7].

Table A.1 — Average bubble size and size range depending on pressures

Pressure (atm)	Size range (µm)	Average size (µm)	Sources
6	10 to 110	30	See Reference [7]
	15 to 85	28	See References [1] and [8]
3	10 to 110	45	See Reference [7]
	15 to 85	41	See Reference [1]

Our average bubble size was slightly larger than those reported by Han.[1] In this study, approximately 1 500 bubbles were measured within 10 min in online particle counter. The results are provided in Figure A.1 where the bubble size was distributed differently.



Key

X bubble size (µm)

Y fraction of bubble (%)

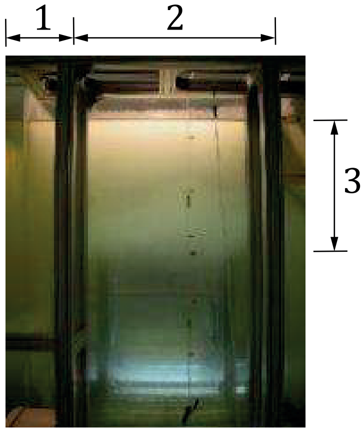
Figure A.1 — Bubble size distribution at different pressures[7]

Figure A.1 shows that more than 80 % of the sizes ranged from 5 µm to 45 µm for the bubbles generated from a pressurized saturator of 6 bars and from 5 µm to 65 µm for those of 3 bars. This can be explained by the possible coalescence or overlapping of bubbles during their transport to the tube and sensor of the particle counter. In addition, the bubbles inside the tube and sensor of the particle counter cannot collapse to form smaller bubbles, and the opportunity for bubble coalescence rise with the increase in transport duration from the reactor to the sensor of particle counter.

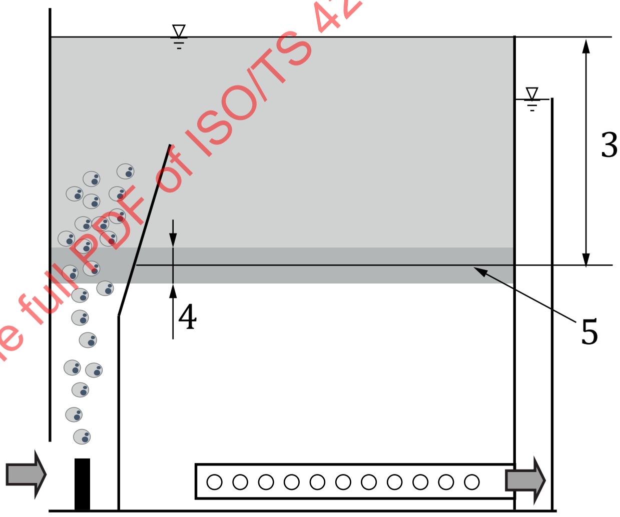
Annex B
(informative)

Height from the water surface to the bubble bed depth

It is easy to observe the creation of a bubble bed interface in the middle part of the reactor by the naked eye in a pilot scale DAF reactor manufactured with a transparent wall. Although it is not possible to present the interface by a single straight line, a bubble interface zone exists in which above the interface there are clouds of bubbles and below the interface almost no bubbles are observed. The centre of the bubble interface zone is defined as the bubble bed interface. Bubble bed depth is defined by the height from the water surface to the bubble bed interface as presented in Figure B.1.



a) Pilot plant manufactured from transparent acrylic



b) Cross-section of pilot plant

Key

1 contact zone
2 separation zone
3 bubble bed depth
4 bubble bed interface zone
5 bubble bed interface

Figure B.1 — Pilot plant used to determine the bubble bed depth

Annex C
(informative)

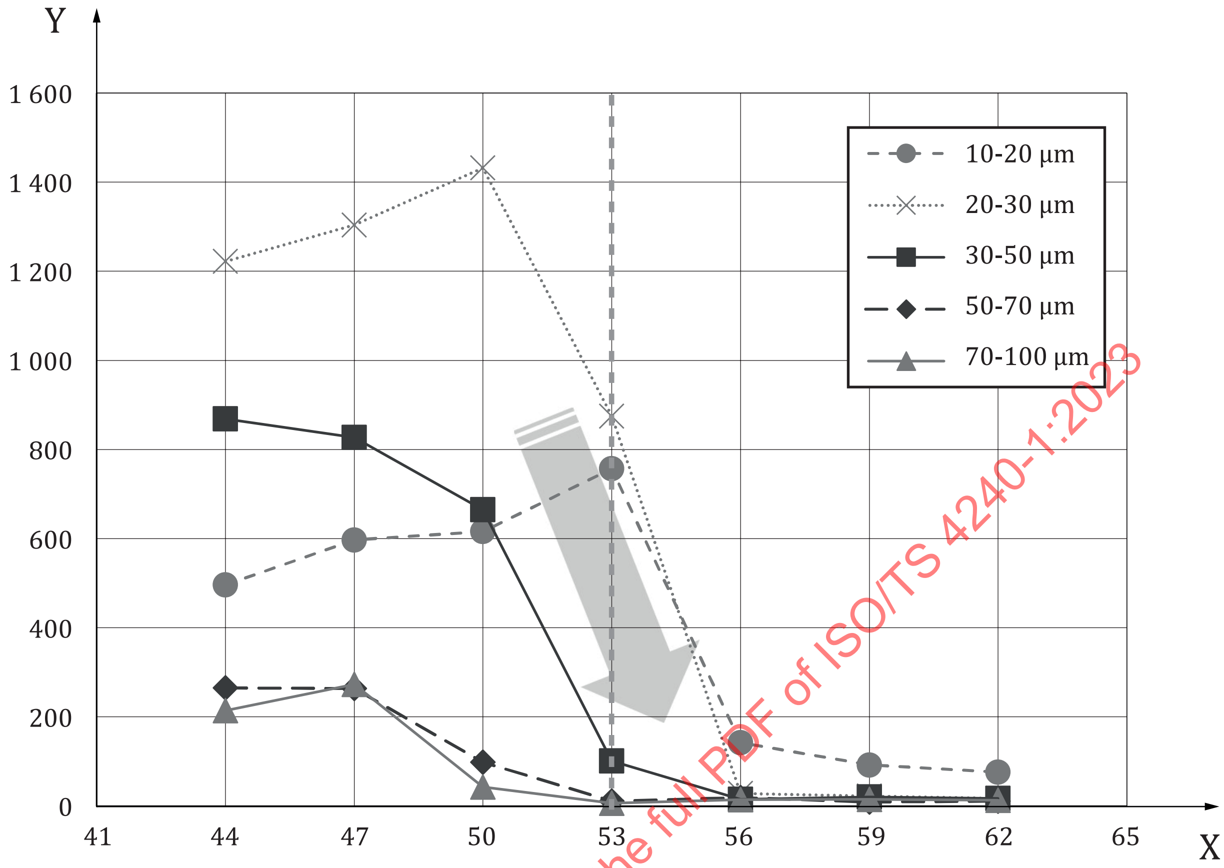
Comparison of the results of bubble bed depth obtained by using the naked eye and by using a particle counting method

A set of experiments was carried out at a pilot plant manufactured from transparent acrylic as illustrated in Figure B.1. The size of the pilot plant is 1 m (width) × 1,2 m (length) × 1,6 m (height). At the pilot plant made with an acrylic wall, the existence and location of the bubble bed interface are determined easily by the naked eye (see Annex B), and therefore the results made by the particle counting method can be verified.

Bubbles are introduced from the bottom of the contact zone. Then, bubbles and flocculated particles undergo collisions in the contact zone, and removal of bubbles and flocs attached to bubbles occurs in the separation zone. The effluent is drawn from the bottom of the separation zone. The operating conditions such as pressure and recycle ratio are easily adjustable. The samples are taken by a tube using a pump from any positions of interest. The on-line particle counter is located at the suction side of the pump to avoid possible breakup by the impeller.

As can be seen from Figure B.1 a), the bubble bed is formed from the surface down to some depth, but a clear interface is hard to define, therefore a mid-depth with a certain range can be defined. In this case, the depth is defined as 53 ± 3 cm by the naked eye. Despite some ambiguity, it is a reasonable way of defining the bubble bed depth because the relative depth is more important than the exact depth.

Figure C.1 shows the distribution of particle counts (combination of particle and bubble counts) from five channels between 10 mm to 100 mm size near the interface at 3 cm intervals under the conditions shown in the figure. The graph shows that the particle counts for size 10 mm to 100 mm rapidly decrease from 50 cm to 56 cm depth. From these results, the bubble bed interface is taken as 53 cm which is the value at the mid-point of the bubble bed interface zone by naked eye.



Key

X depth (cm)

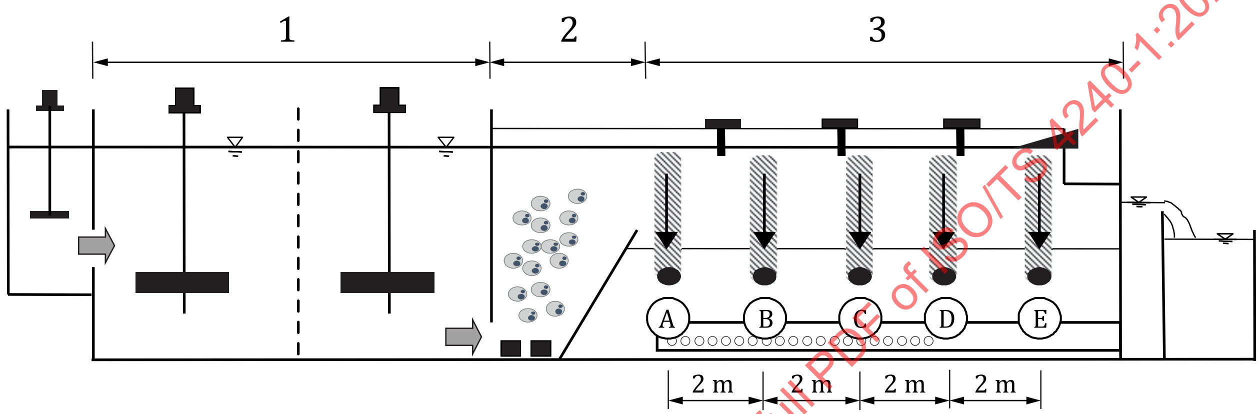
Y number concentration (counts/ml)

Figure C.1 — Particles and bubble counts with depth in a pilot plant

Annex D
(informative)

Measuring bubble bed depth of DAF process in full scale

The schematic diagram of DAF tank and sampling points are shown in Figure D.1. The size of each separation zone is 9,1 m (width) × 9,6 m (length) × 2,6 m (height). Samples are collected at several heights in five positions (A, B, C, D, E), which are spaced at 2 m intervals.



Key

1 flocculation basin

2 contact zone

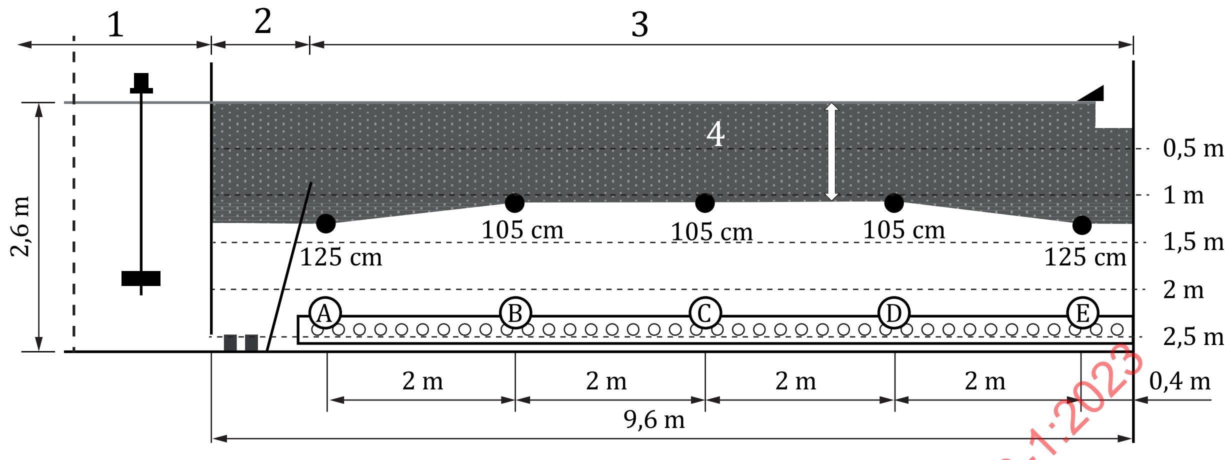
3 separation zone

Figure D.1 — Schematic diagram and sampling points at full scale DAF

The bubble bed depth was measured at an operating DAF plant. The standard operating conditions were pressure, 415 ± 0,5 kPa; recycle ratio, 6,6 %; and separation zone loading rate, 12 mh^{-1}. The samples were taken at five sampling positions at 2 m intervals to determine the horizontal profile of the bubble bed. At each sampling position, the water samples were taken at several depths.

Figure 3 shows one example of how to locate the bubble bed interface at sampling position C. Because the interface was not visible and there were so many samples to take for the full-scale experiment, vertical samples at 20 cm depth intervals were taken. The particle and bubble counts decreased rapidly in the depth range of 95 cm to 135 cm. From this result, the bubble bed depth is determined as 105 ± 0,5 cm.

Using the same method, the horizontal distribution of bubble bed depth was measured and drawn as in Figure D.2. Under the operating conditions for this study, the bubble bed depth at the front and at the end (125 ± 0,5 cm) is deeper than in the middle (105 ± 0,5 cm). In this case, the bubble bed depth of this DAF plant is determined as 105 ± 0,5 cm.



Key

1 flocculation basin

2 contact zone

3 separation zone

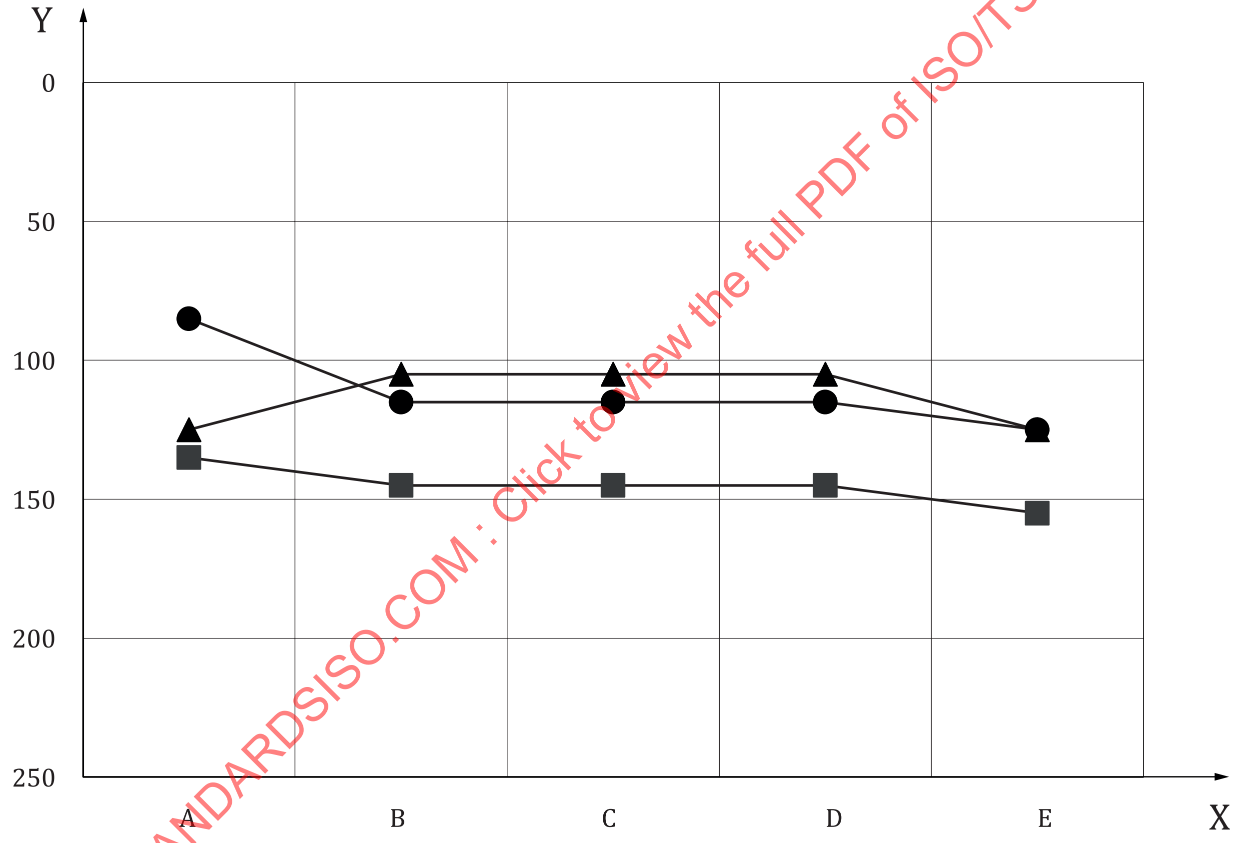
4 bubble bed depth (≈ 105 cm)

Figure D.2 — Horizontal profile of bubble bed depth

Annex E
(informative)

Change of bubble bed depth at different operating conditions

Figure E.1 shows the comparison of bubble bed depth under different operating conditions. During the experiment, the plant was operated with a separation zone loading rate of 12 mh^{-1} and water temperature was 7,5 ± 1,0 °C. Bubble bed depth is significantly affected by the pressure and recycle ratio. By increasing the pressure from 415 to 517 kPa, the bubble bed becomes deeper by 10 cm (Case 2). Also, by increasing the recycle ratio from 6,6 % to 10 %, the bubble bed becomes deeper by 30 cm (Case 3). The depths of the bubble bed at the middle of the separation zone (Points B, C and D) are uniform. The trend near the inlet is not clear. The bubble bed at the end of the reactor is increasing in depth, probably due to the wall effect.



Key

X sampling positions

Y depth from the surface (cm)

Case 1: 4, 1 atm, 6,6 %

Case 2: 5, 1 atm, 6,6 %

Case 3: 4, 1 atm, 10 %

NOTE Operating conditions: separation zone loading rate, 12 mh^{-1}; water temperature, 7,58 °C.

Figure E.1 — BVC change of bubble bed depth at different operating conditions

