

**Title of the Invention: BUBBLE RELEASE APPARATUS, DEVICE, SYSTEM
AND METHOD FOR CLEANING SUBMERGED MEMBRANES**

Field of the Invention

5 The invention relates generally to membrane gas cleaning techniques, and in particular, to a bubble release apparatus, device, system and method for effectively and efficiently cleaning submerged membranes.

Background

10 A submerged membrane filtering system is being incorporated into wastewater treatment plant as a tertiary treatment process to improve on the plant's treated water quality. Although the capital and operational cost of such upgrade may seem prohibitive, the filtered water from such plant can be used for water reuse purposes, making such upgrade viable.

15 A submerged membrane filtering system relies on effective membrane cleaning techniques to ensure reliable operation. In general, membrane gas cleaning is used in almost all submerged membrane filtering systems to clean the surface of the membranes to mitigate fouling. Therefore, it is critical for a submerged membrane filtering system to have a gas cleaning system with high cleaning effectiveness and efficiency.

In a gas cleaning system, a stream of bubbles exited from a bubble release apparatus are used for cleaning or scrubbing the surface of membranes. In some existing technology, the cleaning effectiveness and efficiency of the gas cleaning system may be improved by increasing the bubble release frequency of the bubble release apparatus in the gas cleaning system. However, this method is impractical due to high energy consumption since more gas is required to be supplied to the bubble release apparatus to increase the bubble release frequency.

It is therefore desirable to provide a solution to increase the cleaning effectiveness and efficiency of the gas cleaning system without necessarily increasing the energy consumption.

Summary of the Invention

Embodiments of the invention provide a bubble release apparatus for a gas cleaning system which can generate and release bubbles with a size large enough so that the released bubbles have higher shear force to effectively and efficiently clean the submerged membranes without increasing the energy consumption.

According to a first aspect of the embodiments of the invention, a bubble release apparatus for cleaning submerged membranes is provided. The apparatus comprises a first chamber, a second chamber and a third chamber,

wherein each of the three chambers has a bottom opening configured to allow fluid communication between inside of the chamber and outside of the apparatus;

wherein the first chamber is configured to receive a stream of gas from a gas source, the first chamber and the second chamber are configured to be in fluid communication with each other through an upper fluid communication path to accumulate a pocket of gas at an upper end of the first chamber and the second
5 chamber;

the second chamber and the third chamber are configured to be in fluid communication with each other through an intermediate fluid communication path located between the bottom opening of the third chamber and the upper fluid communication path to allow the accumulated pocket of gas to be discharged as
10 a gas bubble into the third chamber; and

the third chamber is configured to allow the gas bubble to expand to a predetermined size before being released from the apparatus to clean submerged membranes.

According to a second aspect of the embodiments of the invention, a bubble
15 release device is provided. The device comprises a plurality of bubble release apparatuses according to embodiments of the invention, wherein the plurality of bubble release apparatuses are disposed in a guideline rail to form an integral device.

According to a third aspect of the embodiments of the invention, a gas
20 cleaning system for cleaning submerged membranes is provided. The system comprises at least one bubble release apparatus or at least one bubble release

device according to embodiments of the invention, which is to be positioned below at least one hollow fiber membrane module to clean submerged membranes.

According to a fourth aspect of the embodiments of the invention, a method of releasing bubbles for cleaning submerged membranes is provided. The method
5 comprises:

positioning a gas cleaning system below at least one submerged hollow fiber membrane module, wherein the gas cleaning system comprises at least one bubble release apparatus or at least one bubble release device according to embodiments of the invention; and

10 supplying a stream of gas from a gas source to a first chamber of each bubble release apparatus in the gas cleaning system continuously or intermittently so that gas bubbles with a predetermined size for cleaning submerged membranes are released from the gas cleaning system to clean at least one submerged hollow membrane module.

15 **Brief Description of the Drawings**

The invention will be described in detail with reference to the accompanying drawings, in which:

[Fig. 1] is an isometric view of a bubble release apparatus according to a first embodiment of the invention;

20 [Fig. 2] is a cross-sectional side elevation view of the bubble release apparatus in [Fig. 1];

[Fig. 3] is a schematic view of the bubble release apparatus in [Fig. 1] at various stage of operations according to one embodiment of the invention;

[Fig. 4] shows three different configurations of the first chamber to receive a stream of gas from a gas source according to embodiments of the invention;

5 [Fig. 5] is a cross-sectional side elevation view of a bubble release apparatus according to a second embodiment of the invention;

[Fig. 6A] is a cross-sectional view of a bubble release apparatus according to a third embodiment of the invention;

10 [Fig. 6B] is a cross-sectional view of a bubble release apparatus according to a fourth embodiment of the invention;

[Fig. 6C] is a cross-sectional view of a bubble release apparatus according to a fifth embodiment of the invention;

[Fig. 7] shows top views of three bubble release devices according to three embodiments of the invention;

15 [Fig. 8] is a side elevation view of a gas cleaning system according to one embodiment of the invention.

Detailed Description of Embodiments of the Invention

In the following description, numerous specific details are set forth in order to provide a thorough understanding of various illustrative embodiments of the

invention. It will be understood, however, to one skilled in the art, that embodiments of the invention may be practiced without some or all of these specific details. It is understood that the terminology used herein is for the purpose of describing particular embodiments only and is not intended to limit the scope of
5 the invention.

Embodiments described in the context of one of the systems or methods are analogously valid for the other systems or methods. Similarly, embodiments described in the context of a method are analogously valid for a system, and vice versa.

10 Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or
15 combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

As used herein, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

20 As used herein, the term “configured to” is interchangeable with “operative to” or “adapted to”.

As used herein, the term “coupled to” refers to connecting to an element with or without a coupling means.

Embodiments of the invention provide a bubble release apparatus for cleaning submerged membrane. The bubble release apparatus comprises: a first
5 chamber, a second chamber and a third chamber.

Each of the three chambers has a bottom opening configured to allow fluid communication between inside of the chamber and outside of the apparatus. The first chamber is configured to receive a stream of gas from a gas source, the first chamber and the second chamber are configured to be in fluid communication
10 with each other through an upper fluid communication path to accumulate a pocket of gas at an upper end of the first chamber and the second chamber.

The second chamber and the third chamber are configured to be in fluid communication with each other through an intermediate fluid communication path located between the bottom opening of the third chamber and the upper fluid
15 communication path to allow the accumulated pocket of gas to be discharged as a gas bubble, e.g. a slug bubble, into the third chamber; and the third chamber is configured to allow the gas bubble to expand to a predetermined size before being released from a top opening of the third chamber to clean submerged membranes.

The size of the gas bubble released from the apparatus may be determined
20 based on the volume of the pocket of gas that is accumulated in the first chamber and the second chamber, the size of the intermediate fluid communication path and the cross-sectional area of the third chamber.

In embodiments of the invention, as each of the chambers has a bottom opening allowing the chamber to be in fluid communication with the outside of the apparatus, no solids will be trapped in the apparatus to affect the operation of the apparatus. Further, with the bubble release apparatus proposed in embodiments
5 of the invention, gas bubbles with a predetermined size are released from the apparatus. Therefore, the cleaning effectiveness and efficiency of the gas cleaning system will be improved significantly by releasing large bubbles with higher shear force.

In some embodiments of the invention, the first chamber may be configured
10 to receive the stream of gas from a gas diffuser through the bottom opening of the first chamber, or a gas port located on a side surface or a top surface of the first chamber.

To further increase the size of the gas bubbles released from the apparatus, thereby further improve the cleaning effectiveness and efficiency of the gas
15 cleaning system, in some embodiments of the invention, the third chamber is further configured to include a first portion extending downwards from the top opening of the third chamber and a second portion extending downwards from the first portion till an upper end of the intermediate fluid communication path, wherein the first portion of the third chamber has a cross-sectional area greater than that
20 of the second portion. In some embodiments, the first portion may have a greater size in the lateral direction than the second portion.

In some embodiments of the invention, it is preferable that the first portion has a cross-sectional area which is greater than 100% and less than 1000% of that of the second portion, more preferably, the first portion may have a cross-sectional area which is greater than 100% and less than 400% of that of the
5 second portion.

In some embodiments of the invention, the upper fluid communication path may have a height which is 5% to 50%, more preferably 5% to 15%, of the height of the first chamber of the bubble release apparatus. It should be noted that the upper communication path must be sufficiently large such that no solids shall be
10 trapped in the upper fluid communication path when the solids entrained in the liquid medium enter and exit the first chamber and the second chamber.

In some embodiments of the invention, the intermediate fluid communication path may have a height which is 5% to 20%, more preferably 5% to 15%, of the height of the first chamber of the bubble release apparatus.

15 In some embodiments of the invention, the first chamber and the second chamber may have a first common wall, and a top end of the common wall is disposed below a top surface of the first chamber to form the upper fluid communication path.

In some embodiments of the invention, the third chamber and the second
20 chamber may have a second common wall, and the intermediate fluid communication path is an intermediate opening located on the second common wall.

In some embodiments of the invention, the second chamber is surrounded by the first chamber, and the third chamber is surrounded by the second chamber. In one embodiment, to fix the chambers in the apparatus, the apparatus may include a first connection part extending from the second common wall to the first
5 common wall, and a second connection part extending from the first common wall and coupling to an outer body of the apparatus. In one example, the first connection part and the second connection part may be formed as an integral connection panel extending from the second common wall, passing through the first common wall and coupling to the outer body of the apparatus. It should be
10 noted that more than one first connection part and more than one second connection part may be used to fix the chambers in some embodiments of the invention.

In some embodiments of the invention, the first chamber, the second chamber and the third chamber may be arranged in a row. For example, the first
15 chamber is arranged to be adjacent to one side of the second chamber, and the first chamber and the second chamber may or may not share a common wall; and the second chamber is arranged to be adjacent to another side of the second chamber, and the second chamber and the third chamber may or may not share a common wall.

20 In some embodiments of the invention, the first chamber may be connected to the second chamber through the upper fluid communication path. In other words, the upper fluid communication path is a separate portion which is disposed between the first chamber and the second chamber.

In some embodiments of the invention, the second chamber may be connected to the third chamber through the intermediate fluid communication path. In other words, the intermediate fluid communication path is a separate portion which is disposed between the second chamber and the third chamber.

5 Embodiments of the invention also provide a bubble release device which comprises a plurality of bubble release apparatuses according to embodiments of the invention, e.g. 2-10 bubble release apparatuses. The plurality of bubble release apparatuses are disposed in a guideline rail to form an integral device.

10 Embodiments of the invention also provide a gas cleaning system for cleaning submerged membranes. The system comprises at least one bubble release apparatus or at least one bubble release device according to embodiments of the invention, which is to be positioned below at least one hollow fiber membrane module to clean submerged membranes.

15 In some embodiments of the invention, the system may comprise a plurality of the bubble release devices which are to be arranged in a row below a plurality of hollow fiber membrane modules. In one example, each bubble release device is to be positioned to be aligned with one of the plurality of hollow fiber membrane modules, when the system is in use.

20 To further increase the cleaning effectiveness and efficiency of the gas cleaning system, in some embodiment of the invention, the plurality of hollow fiber membrane modules may be arranged to be in close proximity with one another so

that bubbles released from each of the bubble release devices are used to clean more than one hollow fiber membrane modules thereabove.

Further, in some embodiments of the invention, it is preferable that each bubble release apparatus or bubble release device is to be positioned in a range
5 of 0 to 100mm below at least one hollow fiber membrane module to allow the bubbles released from the bubble release apparatus or bubble release device to further expand to a bigger size,

Embodiments of the invention also provide a method of releasing bubbles for cleaning submerged membranes. The method comprises:

10 positioning a gas cleaning system below at least one submerged hollow fiber membrane module, wherein the gas cleaning system comprises at least one bubble release apparatus or at least one bubble release device according to embodiments of the invention; and

supplying a stream of gas from a gas source to a first chamber of each
15 bubble release apparatus in the gas cleaning system continuously or intermittently so that gas bubbles with a predetermined size for cleaning submerged membranes are released from the gas cleaning system to clean the at least one submerged hollow membrane module.

The step of positioning the gas cleaning system below at least one
20 submerged hollow fiber membrane module, comprises: arranging a plurality of the bubble release devices in a row below a plurality of hollow fiber membrane

modules. In one example, each bubble release device is positioned to be aligned with one of the plurality of hollow membrane modules in a vertical direction relative to a surface of the bubble release device from which the gas bubbles are to be released.

5 To further increase the cleaning effectiveness and efficiency of the gas cleaning system, in some embodiment of the invention, the method may further comprise: arranging a plurality of hollow fiber membrane to be in close proximity with one another so that gas bubbles with a predetermined size released from each bubble release device are used to clean more than one hollow fiber
10 membrane modules thereabove.

 To allow the gas bubbles released from the gas cleaning system to further expand to a bigger size, in some embodiments of the invention, the step of positioning the gas cleaning system below at least one submerged hollow fiber membrane module may comprise: positioning the at least one bubble release
15 apparatus or the at least one bubble release device in a range of 0 to 100mm below the at least one hollow fiber membrane module.

 [Fig. 1] is an isometric view of a bubble release apparatus 100 according to a first embodiment of the invention. [Fig. 2] is a cross-sectional side elevation view of the apparatus 100 in [Fig. 1]. As shown in [Fig. 1] and [Fig. 2], in this
20 embodiment, the apparatus 100 includes a first chamber 110, a second chamber 120 and a third chamber 130. The second chamber 120 is surrounded by the first

chamber 110 and the third chamber 130 is surrounded by the second chamber 120.

As shown in [Fig. 2], the first chamber 110 has a bottom opening 110a, the second chamber 120 has a bottom opening 120a, and the third chamber 130 has
5 a bottom opening 130a. The bottom opening of each chamber is configured to allow fluid communication between the inside of the chamber and the outside of the apparatus 100. The third chamber 130 includes an upper portion 130c with a top opening 130b, and a lower portion 130d.

In this embodiment, the first chamber 110 is formed between an outer body
10 101 and a first tubular structure 102 disposed in a housing formed by the outer body 101. The second chamber 120 is formed between the first tubular structure 102 and a second inner tubular structure 103. The first tubular structure 102 is a first common wall of the first chamber 110 and the second chamber 120. The second inner tubular structure 103 is a second common wall of the second
15 chamber 120 and the third chamber 130.

The first inner tubular structure 102 has a top opening/end 102a which is disposed below a top surface 101a of the first chamber 110 to form an upper fluid communication path 104 which allows fluid communication between the first chamber 110 and the second chamber 120. In this embodiment, the upper fluid
20 communication path 104 may have a height which is 5% to 50%, preferably 5% to 15% of the height of the first chamber 110 or the outer body 101.

The second inner tubular structure 103 includes an upper part 103a and a lower part 103b, an intermediate fluid communication path 105 is formed between the upper part 103a and the lower part 103b. The intermediate fluid communication path 105 is provided to allow fluid communication between the second chamber 120 and the third chamber 130. The height of the intermediate fluid communication path 105 in this embodiment may be 5% to 20%, preferably 5% to 15%, of the height of the first chamber 110 or the outer body 101.

When the apparatus 100 is in use, the first chamber 110 is configured to receive a stream of gas from a gas source, e.g. a gas diffuser, through the bottom opening 110a. The first chamber 110 and the second chamber 120 are configured to be in fluid communication with each other through the upper fluid communication path 104 so that a pocket of gas is to be accumulated at the upper end of the first chamber 110 and the second chamber 120.

The second chamber 120 and the third chamber 130 are configured to be in fluid communication with each other through the intermediate fluid communication path 105 located between the bottom opening of the third chamber 130 and the upper fluid communication path 104 to allow the accumulated pocket of gas to be discharged as a gas bubble, e.g. a slug bubble, into the third chamber 130.

The third chamber 130 is configured to allow the gas bubble to expand to a predetermined size before being released from the top opening 130b of the third chamber 130 to clean submerged membranes. The size of the top opening 130b

may be determined based on the predetermined size of the gas bubble to be released from the apparatus 100.

In this embodiment, the top opening 130b of the third chamber 130 is coupled to an opening on the top surface 101a of the outer body 101. It should be noted that in other embodiments, the top opening of the third chamber may be disposed above the top surface 101a of the outer body 101.

The size of the gas bubbles released from the apparatus 100 may be determined based on the volume of the pocket of gas that is accumulated in the first chamber 110 and the second chamber 120, the size of the intermediate fluid communication path 105 and the cross-sectional area of the third chamber 130.

As shown in [Fig. 1], in this embodiment, two connection panels 104 are provided to fix the first inner tubular structure 102 and the second inner tubular structure 103 in the outer body 101 of the apparatus 100. Each connection panel 104 is arranged to extend from the second inner tubular structure 103, pass through the first inner tubular structure 102 and be coupled to the outer body 101 of the apparatus 100. It should be noted that in other embodiments, the number and shape of the connection panels 104 may be different. In some embodiments of the invention, the apparatus 100 may comprise at least one first connection part extending from the lower portion 103b of the second inner tubular structure 103 to the first inner tubular structure 102, and at least one second connection part extending from the first inner tubular structure 102 and being coupled to the outer body 101 of the apparatus 100. Although in the apparatus 100, the first connection

part and the associated second connection part are formed an integral connection panel 104, It should be noted that in other embodiments of the invention, more than one separate or combined connection part may be provided to fix the first inner tubular structure 102 and the second inner tubular structure 103. Also,
5 different fixing means/ways may be used to fix the first inner tubular structure 102 and the second inner tubular structure 103 in the outer body 101 in other embodiments of the invention.

In this embodiment, the outer body 101 has a cuboid structure, the first inner tubular structure 102 and the second inner tubular structure 103 have a
10 cylindrical structure. However, it should be noted that this is only for illustration purpose, not to limit the scope of the invention. In other embodiments, the shape of the outer body, the first and/or the second inner tubular structure may have a different shape, For example, the outer body 101 may have a cylindrical structure, while the first and the second inner tubular structure may have a cuboid structure.

15 [Fig. 3] is a schematic view of the apparatus 100 at various stage of operations according to one embodiment of the invention. In [Fig. 3](A), a stream of gas is received by the first chamber 110 from a gas diffuser through the bottom opening 110a of the first chamber 110. A pocket of gas is to be accumulated at the top/upper end of the first chamber 110 and the second chamber 120. The
20 spatial volume of the pocket of gas increases with more and more gas is accumulated. When the accumulated pocket of gas reaches the lower end of the intermediate communication path 105, the accumulated pocket of gas will be discharged as a gas bubble into the third chamber 130 as shown in [Fig. 3](B).

The gas bubble discharged into the third chamber 130 will go upwards and expand to a predetermined size before being released from the top opening 130b of the third chamber 130. The released gas bubble is to be used for cleaning submerged membranes. [Fig. 3](C) shows the release of the expanded gas bubble from the top opening 130b and at the same time, the spatial volume of the pocket of gas in the first chamber 110 and second chamber 120 will decrease as liquid fills the first chamber 110, second chamber 120 and third chamber 130 through the bottom openings 110a, 120a and 130a of the chambers, and the sequence of operations will return back to [Fig. 3](A). The same cycle will be repeated.

It should be noted that in embodiments of the invention, the stream of gas may be supplied to the apparatus 100 continuously or intermittently. Accordingly, in some embodiments, the gas bubbles may be released from the apparatus 100 intermittently and the frequency of releasing the gas bubbles from the apparatus 100 may be between 0.5 to 30 seconds, preferably between 1 to 10 seconds, further preferably between 1 to 5 seconds.

As the size of the gas bubbles released from the apparatus 100 may be greatly influenced by the size of the pocket of gas accumulated in the first chamber 110 and the second chamber 120, the internals of the first chamber 110 and second chamber 120 should not have any solids trapped in the spatial volume of the chambers, particularly when the apparatus 100 is used in an environment where the apparatus 100 is submerged in a liquid medium that contains particulate solids, biological solid materials, and other solid materials. The upper fluid communication path 104 between the first chamber 110 and the second chamber

120 must be sufficiently large such that no solids shall be trapped in the upper fluid communication path when the solids entrained in the liquid medium enter and exit the first chamber 110 and the second chamber 120. In some embodiments of the invention, the upper communication path may have a height which is 5% to 50%, preferably 5% to 15%, of the height of the first chamber.

Further, the intermediate fluid communication path 105 should be sufficiently sized such that the pocket of gas that is accumulated in the first chamber 110 and the second chamber 120 shall be discharged into the third chamber 130 through the intermediate fluid communication path 105 as a gas bubble with a big size instead of a steady stream of smaller bubbles. Also, the intermediate communication path 105 should not be sized excessively large such that the liquid medium in the third chamber 130 can enter via the bottom part of the intermediate fluid communication path 105 into the second chamber 120, thereby interfering with the discharge of the gas bubbles and resulting in smaller bubbles being discharged into the third chamber 130. In some embodiments of the invention, the height of the intermediate fluid communication path may be 5% to 20%, preferably 5% to 15%, of the height of the first chamber 110 of the apparatus 100.

In addition, the third chamber 130 should also not have any solids trapped in its spatial volume, thereby allowing smooth discharge of a pocket of gas through the intermediate communication path 105 and also allowing the gas bubbles discharged through the intermediate communication path 105 to smoothly go upwards in the third chamber 130 and exit from the top opening 130b.

[Fig. 4] shows three different configurations of the first chamber 110 to receive a stream of gas from a gas source according to embodiments of the invention. In [Fig. 4](A), the stream of gas is received from a gas source 22 through the bottom opening 110a of the first chamber 110. The gas source may be a gas
5 port or a gas diffuser arranged below the bottom opening of the first chamber 110. In [Fig. 4](B), the stream of gas is received through a gas port 23 located on a side wall of the first chamber 110. In [Fig. 4](C), the stream of gas is received through a gas port 23 located on a top surface of the first chamber 110.

[Fig. 5] is a cross-sectional side elevation view of an apparatus 200
10 according to a second embodiment of the invention. In this embodiment, the structure of the apparatus 200 is similar to the apparatus 100 except that the upper portion 130c of the third chamber 130 includes a first portion 131 extending downwards from the top opening 130b of the third chamber 130 and a second portion 132 extending downwards from the first portion 131 till an upper end of the
15 intermediate fluid communication path 105, wherein the first portion 131 has a cross-sectional area greater than that of the second portion 132. In this embodiment, the first portion 131 has a greater size in the lateral direction than the second portion 132, as shown in [Fig. 5]. It should be noted that in this embodiment, the cross-sectional area of the first portion 131 may be greater than
20 100% and less than 1000% of that of the second portion 132, more preferably, greater than 100% and less than 400% of that of the second portion 132.

In this embodiment, as the first portion 132 in the upper portion 130c of the third chamber 130 has a greater cross-sectional area, the size of gas bubbles to

be released from the apparatus 200 will be further increased, thereby the cleaning effectiveness and the efficiency of the bubble release apparatus 200 for cleaning submerged membranes will be further improved.

As shown in [Fig. 5], in the embodiment, a common bottom opening 106 in
5 fluid communication with external of the apparatus 200 may be further formed for the second chamber 120 and the third chamber 130 by an extension part extending from the bottom end of the second chamber 120. It should be noted that the common bottom opening 106 may also be provided in the embodiment shown in [Fig. 1] and [Fig. 2].

10 In the first and the second embodiments shown in [Fig. 1] to [Fig. 5], the second chamber 120 is surrounded by the first chamber 110, and the third chamber 130 is surrounded by the second chamber 120. Alternatively, in some embodiments of the invention, the three chambers of the bubble release apparatus may be arranged in a row.

15 [Fig. 6A] is a cross-sectional view of an apparatus 300 according to a third embodiment of the invention. In this embodiment, the apparatus 300 includes a first chamber 310, a second chamber 320 and a third chamber 330. The first chamber 310 has a bottom opening 310a, the second chamber 320 has a bottom opening 320a and the third chamber 330 has a bottom chamber 330a. The bottom
20 opening of each chamber is to allow fluid communication between the inside of the chamber and the outside of the apparatus 300.

In this embodiment, the first chamber 310 and the second chamber 320 has a common wall 302. The top end of the common wall 302 is disposed below the top surface of the first chamber 310 to form an upper fluid communication path 304. The height of the upper fluid communication path 304 may be 5% to 50%,
5 more preferably 5% to 15%, of the height of the first chamber 310. In this embodiment, the first chamber 310 and the second chamber 320 may be formed by an outer body 301 and the common wall disposed in a housing formed by the outer body 301. The outer body 301 may have a cuboid structure and the common wall 302 may be a rectangular common panel.

10 The second chamber 320 and the third chamber 330 have a common wall 303. An intermediate fluid communication path 305 is provided on the common wall 303 between the upper fluid communication path 304 and the bottom opening 330a of the third chamber 330 to allow the accumulated pocket of gas to be discharged as a gas bubble, e.g. a slug bubble, into the third chamber 330.

15 The third chamber 330 is configured to allow the gas bubble to expand to a predetermined size before being released from a top opening 330b of the third chamber 330 to clean submerged membranes.

It should be noted that as the operation of the apparatus 300 when it is in use, is similar to that of the apparatus 100. It will not be described in detail here
20 for this and the following embodiments shown in [Fig. 6B] and [Fig. 6C]. The ranges of the size/height of the upper fluid communication path and the size/height of the intermediate fluid communication path in this and the following embodiments

shown in [Fig. 6B] and [Fig. 6C] are also same as those in the first and second embodiments, i.e. the upper fluid communication path may have a height which is 5% to 50%, preferably 5% to 15% of the height of the first chamber, and the height of the intermediate fluid communication path may be 5% to 20%, preferably 5% to 15%, of the height of the first chamber of the apparatus.

[Fig. 6B] is a cross-sectional view of a bubble release apparatus 400 according to a fourth embodiment of the invention. In this embodiment, the apparatus 400 includes a first chamber 410, a second chamber 420 and the third chamber 430. The first chamber 410 has a bottom opening 410a, the second chamber 420 has a bottom opening 420a and the third chamber 430 has a bottom opening 430a. The bottom opening of each chamber is to allow fluid communication between the inside of the chamber and the outside of the apparatus 400.

Different from the apparatus 300 shown in [Fig. 6A], in this embodiment, the first chamber 410 is connected to the second chamber 420 through an upper fluid communication path 404. The second chamber 420 and the third chamber 430 have a common wall 403. An intermediate fluid communication path 405 is provided on the common wall 403 between the upper fluid communication path 404 and the bottom opening of the third chamber 430a. As shown in [Fig. 6B], in this embodiment, a common opening 406 in fluid communication with external of the apparatus 400 may be further formed for the second chamber 420 and the third chamber 430 by a first extension part 406a extending from the bottom end of

the second chamber 420 and a second extension part 406b extending from the bottom end of the third chamber 430.

The third chamber 430 is configured to allow the gas bubble to expand to a predetermined size before being released from a top opening 430b of the third chamber 430 to clean submerged membranes.

[Fig. 6C] is a cross-sectional view of an apparatus 500 according to a fifth embodiment of the invention. In this embodiment, the apparatus 500 includes a first chamber 510, a second chamber 520 and the third chamber 530. The first chamber 510 has a bottom opening 510a, the second chamber 520 has a bottom opening 520a and the third chamber 530 has a bottom chamber 530a. The bottom opening of each chamber is to allow fluid communication between the inside of the chamber and the outside of the apparatus 500.

In this embodiment, the first chamber 510 is connected to the second chamber 520 through an upper fluid communication path 504. The height of the upper fluid communication path 504 may be 5% to 50%, preferably 5% to 15% of the height of the first chamber 510. The second chamber 520 is connected to the third chamber 530 through an intermediate fluid communication path 505 located between the upper fluid communication path 504 and the bottom opening of the third chamber 530a. The height of the intermediate fluid communication path 505 may be 5% to 20%, preferably 5 to 15%, of the height of the first chamber 510.

The third chamber 530 includes a first portion 531 extending downwards from the top opening 530b of the third chamber 530 and a second portion 532

extending downwards from the first portion 531 till an upper end of the intermediate fluid communication path 505, wherein the first portion 531 of the third chamber 530 has a cross-sectional area greater than that of the second portion 532. In this embodiment, the cross-sectional area of the first portion 531
5 may be greater than 100% and less than 1000%, more preferably, greater than 100% and less than 400%, of that of the second portion 532. As the first portion 531 has a greater cross-sectional area, the size of the bubbles to be released from the top opening 530b will be increased, thereby the cleaning effectiveness and efficiency of the apparatus 500 will be further improved.

10 Embodiments of the invention also provide a bubble release device for cleaning submerged membranes. The bubble release device includes a plurality of bubble release apparatuses according to the embodiments of the invention. In some embodiments of the invention, the bubble release device may include 2 to 10 bubble release apparatuses, preferably 2-6 bubble release apparatuses. In
15 some embodiments of the invention, the plurality of bubble release apparatus may be disposed/held/fixed in a guideline rail to form an integral device. Each bubble release apparatus in the device may have some structure or have different structure.

[Fig. 7] shows the top views of bubble release devices 70a, 70b and 70c
20 according to three embodiments of the invention. In these embodiments, each of the bubble release devices 70a, 70b and 70c include four bubble release apparatuses 700. It should be noted that each bubble release apparatus 700 in these embodiments may be any possible bubble release apparatus according to

the embodiments of the invention, e.g. the bubble release device 70a/70b/70c may include four bubble release apparatuses 100 according to the first embodiment as shown in [Fig. 1]; or the bubble release device 70a/70b/70c may include two bubble release apparatuses 100 and two apparatuses 200 according to the second embodiment. [Fig. 7](A) shows four bubble release apparatus 700 of the bubble release device 70a which are arranged in a zig-zag manner, with respect to the top opening of the third chamber of each bubble release apparatus 700 to form the bubble release device 70a. In [Fig. 7](B), the four bubble release apparatus 700 are arranged such that the top opening of the third chamber of each bubble release apparatus 700 is offset from a centreline 71 and located on the same side of the centreline 71. In [Fig. 7](C), the four bubble release apparatuses 700 are arranged such that the top opening of the third chamber of each bubble release apparatus 700 is positioned on the centreline 71. Also further, when the apparatuses 700 are lined and joined together to form the bubble release device 70a/70b/70c, a slot 72 or other forms of guideline rails may be used to secure, hold and fix the device 70a/70b/70c in an upright position. The horizontal cross-section of the top opening of the third chamber of each bubble release apparatus 700 is arranged to be perpendicular to the vertical plane of a liquid tank when the device 70a/70b/70c is in operation and submerged in the liquid tank.

Embodiments of the invention also provide a gas cleaning system for cleaning submerged membranes. The system comprises at least one bubble release apparatus or at least one bubble release device according to embodiments of the invention, which is to be positioned below at least one hollow

fiber membrane module when the gas cleaning system is in use. In some embodiments of the invention, each bubble release apparatus or bubble release device is positioned in a range of 0 to 100mm below the at least one hollow fiber membrane module to further improve the cleaning effectiveness and efficiency of the gas cleaning system.

[Fig. 8] is a side elevation view of a gas cleaning system 10 according to one embodiment of the invention. In this embodiment, the gas cleaning system 10 includes three bubble release devices 70 which are positioned below three hollow fiber membrane modules 80. Each of the bubble release devices 70 may be any bubble release device according to the embodiments of the invention, e.g. the bubble release device 70a, 70b or 70c as shown in [Fig. 7]. Each release bubble device 70 is disposed to be aligned with one of the modules 80 in the vertical direction. The vertical distance between the bubble release devices 70 and the hollow membrane modules 80 is in a range of 0 to 100mm to allow the bubbles released from the devices 70 to further expand and have sufficient horizontal reach and higher shear force to clean the surface of the hollow fiber membranes. In [Fig. 8], the three release bubble devices 70 are arranged in a row to form the gas cleaning system 10. To further improve the cleaning effectiveness and efficiency of the gas cleaning system 10 by allowing bubbles released from each bubble release device 70 to be used for cleaning more than one hollow fiber membrane modules 80 positioned above the devices 70, the plurality of hollow fiber membrane modules 80 may be arranged to be in close proximity with one another, e.g. the distance between two adjacent modules 80 may be 5mm to

100mm, preferably 10mm to 50mm. Since each bubble release devices 70 is disposed to be aligned with one of the modules 80 in the vertical direction, the bubble release devices 70 are also arranged to be close proximity with one another. With this arrangement, each bubble release device 70 is capable of
5 cleaning membrane surface of a module 80 positioned thereabove, as well as the membrane surface of an adjacent module 80. This ensures a greater coverage of membrane cleaning by each bubble release device 70.

As will be appreciated from the above, embodiments of the invention provide a bubble release apparatus, a bubble release device, a gas cleaning
10 system and a method for releasing bubbles for cleaning submerged membranes. In the bubble release apparatus, as each of the chambers has a bottom opening that is in fluid communication with the outside of the chamber, and this allows any solids conveyed by the fluid to each chamber to sink and freely exit the chambers. Therefore, no solids will be trapped in the apparatus to affect the operation of the
15 apparatus. Further, with the bubble release apparatus proposed in embodiments of the invention, gas bubbles with a predetermined size can be released from the apparatus. Therefore, the cleaning effectiveness and efficiency of the gas cleaning system may be improved significantly by releasing large bubbles with higher shear force. In addition, to further increase the size of the gas bubbles released from the
20 apparatus, the third chamber may be further configured to have a top portion with a greater cross-sectional area.

It is to be understood that the embodiments and features described above should be considered exemplary and not restrictive. Many other embodiments will

be apparent to those skilled in the art from consideration of the specification and practice of the invention. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. Furthermore, certain terminology

5 has been used for the purposes of descriptive clarity, and not to limit the disclosed embodiments of the invention.

Claims

[Claim 1] A bubble release apparatus for cleaning submerged membranes, the apparatus comprising a first chamber, a second chamber and a third chamber,

wherein each of the three chambers has a bottom opening configured to
5 allow fluid communication between inside of the chamber and outside of the apparatus;

wherein the first chamber is configured to receive a stream of gas from a gas source, the first chamber and the second chamber are configured to be in fluid communication with each other through an upper fluid communication path to
10 accumulate a pocket of gas at an upper end of the first chamber and the second chamber;

the second chamber and the third chamber are configured to be in fluid communication with each other through an intermediate fluid communication path located between the bottom opening of the third chamber and the upper fluid
15 communication path to allow the accumulated pocket of gas to be discharged as a gas bubble into the third chamber; and

the third chamber is configured to allow the gas bubble to expand to a predetermined size before being released from the apparatus to clean submerged membranes, wherein the intermediate fluid communication path has a height
20 which is 5% to 20% of that of the first chamber.

[Claim 2] The apparatus according to claim 1, wherein the first chamber is further configured to receive the stream of gas from a gas diffuser through the bottom opening of the first chamber, or a gas port located on a side surface or a top surface of the first chamber.

5 [Claim 3] The apparatus according to claim 1 or claim 2, wherein the third chamber includes a first portion extending downwards from the top opening of the third chamber and a second portion extending downwards from the first portion till an upper end of the intermediate fluid communication path, wherein the first portion of the third chamber has a cross-sectional area greater than that of the second
10 portion.

[Claim 4] The apparatus according to claim 3, wherein the first portion has a cross-sectional area which is greater than 100% and less than 1000% of that of the second portion.

[Claim 5] The apparatus according to any preceding claim, wherein the upper fluid
15 communication path has a height which is 5% to 50% of that of the first chamber.

[Claim 6] The apparatus according to any preceding claim, wherein the first chamber and the second chamber have a first common wall, and a top end of the common wall is disposed below a top surface of the first chamber to form the upper fluid communication path.

20 [Claim 7] The apparatus according to claim 6, wherein the third chamber and the second chamber have a second common wall, and the intermediate fluid

communication path is an intermediate opening located on the second common wall.

[Claim 8] The apparatus according to claim 7, wherein the second chamber is surrounded by the first chamber, and the third chamber is surrounded by the
5 second chamber.

[Claim 9] The apparatus according to claim 8, further comprising a first connection part extending from the second common wall to the first common wall, and a second connection part extending from the first common wall and coupling to an outer body of the apparatus.

10 [Claim 10] The apparatus according to claim 9, wherein the first connection part and the second connection part are an integral connection panel extending from the second common wall, passing through the first common wall and coupling to the outer body of the apparatus.

[Claim 11] The apparatus according to claim 7, wherein the first chamber, the
15 second chamber and the third chamber are arranged in a row.

[Claim 12] The apparatus according to any one of claim 1 to claim 5, wherein the first chamber is connected to the second chamber through the upper intermediate communication path.

[Claim 13] The apparatus according to claim 12, wherein the second chamber is
20 connected to the third chamber through the intermediate fluid communication path.

[Claim 14] A bubble release device comprising a plurality of bubble release apparatuses according to any one of claim 1 to claim 13, wherein the plurality of bubble release apparatuses are disposed in a guideline rail to form an integral device.

5 [Claim 15] A gas cleaning system for cleaning submerged membranes, the system comprising at least one bubble release apparatus according to any one of claim 1 to claim 13, or at least one bubble release device according to claim 14, which is to be positioned below at least one hollow fiber membrane module.

[Claim 16] The system according to claim 15, wherein the system comprises a
10 plurality of the bubble release devices which are to be arranged in a row below a plurality of hollow fiber membrane modules.

[Claim 17] The system according to claim 16, wherein the plurality of hollow fiber membrane modules are to be arranged to be in close proximity with one another so that bubbles released from each of the bubble release devices are used to
15 clean more than one hollow fiber membrane modules thereabove.

[Claim 18] The system according to any one of claim 15 to claim 17, wherein each bubble release apparatus or each bubble release device is to be positioned in a range of 0 to 100mm below the at least one hollow fiber membrane module.

[Claim 19] A method of releasing bubbles for cleaning submerged membranes,
20 the method comprising:

positioning a gas cleaning system below at least one submerged hollow fiber membrane module, wherein the gas cleaning system comprises at least one bubble release apparatus according to any one of claim 1 to claim 13, or at least one bubble release device according to claim 14; and

- 5 supplying a stream of gas from a gas source to a first chamber of each bubble release apparatus in the gas cleaning system continuously or intermittently so that gas bubbles with a predetermined size for cleaning submerged membranes are released from the gas cleaning system to clean the at least one submerged hollow membrane module.

10