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(54) **METAL PIPE CLEANING METHOD AND CLEANING DEVICE**

(57) An object of the present disclosure is to provide a washing method and a washing apparatus that maintains high washing performance for a long time. A washing method for washing a metal tube (2) includes a storing step of storing a washing liquid (3) in a washing tank (10), a soaking step of soaking the metal tube (2) in the washing liquid (3) in the washing tank (10) while generating fine bubbles from a gas dissolved in the washing liquid (3) in the washing tank (10) and radiating ultrasonic

waves into the washing liquid (3) in the washing tank (10), a supplying step of newly supplying the washing liquid (3) to the washing tank (10), and a discharging step of, when a liquid surface of the washing liquid (3) in the washing tank (10) exceeds a predetermined reference liquid surface level (S), discharging the washing liquid (3) from the washing tank (10) by an amount corresponding to the excess over the predetermined reference liquid surface level (S).

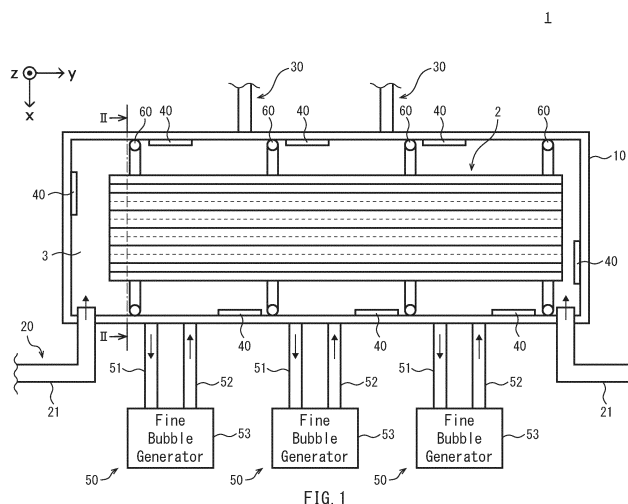


FIG. 1

Description

TECHNICAL FIELD

5 **[0001]** The present disclosure relates to a method and an apparatus for washing a metal tube.

BACKGROUND ART

10 **[0002]** In a metal tube manufacturing process, conventionally, acid pickling is carried out to remove scale from the surface of a metal tube. After being subjected to the acid pickling, the metal tube is washed in a washing liquid so that residual scale on the surface can be removed. (For example, the metal tube is rinsed with water.) For example, ultrasonic washing, which is washing that is carried out with ultrasonic waves radiated in the washing liquid, can be applied to the metal tube after subjected to the acid pickling.

15 **[0003]** Patent Literature 1 discloses an ultrasonic washing apparatus that carries out ultrasonic washing of an object under the presence of microbubbles. The ultrasonic washing apparatus includes an ultrasonic generator and a deaerator. The ultrasonic generator is disposed in a washing tank where a washing liquid is stored. The deaerator is disposed in a circulation route connected to the washing tank. The washing liquid in the washing tank is taken into the deaerator through the circulation route. The deaerator separates dissolved air from the washing liquid and generates bubbles, preferably microbubbles. These bubbles (microbubbles) are returned to the washing tank through the circulation route
20 together with the washing liquid. Accordingly, the concentration of air dissolved in the washing liquid in the washing tank decreases gradually. When the concentration of air dissolved in the washing liquid becomes equal to or lower than a predetermined value, the object to be washed is soaked in the washing liquid in the washing tank, and the ultrasonic generator radiates ultrasonic waves to the washing liquid.

25 CITATION LIST

PATENT LITERATURES

30 **[0004]** Patent Literature 1: Japanese Patent Application Publication No. 2007-29944

SUMMARY OF INVENTION

TECHNICAL PROBLEM

35 **[0005]** Patent Literature 1 states that maintaining the concentration of air dissolved in the washing liquid at a level equal to or lower than a predetermined value makes it possible to carry out efficient and good ultrasonic washing without causing a decrease in the sound pressure of the ultrasonic waves. However, when the ultrasonic washing apparatus of Patent Literature 1 is used for washing of a metal tube after being subjected to acid pickling, there is concern that the washing performance may be lower. Specifically, during ultrasonic washing of a metal tube, the amount of scale in the
40 washing liquid is increasing as time passes. This scale causes attenuation of the ultrasonic waves radiated in the washing liquid and results in degradation of the washing performance.

[0006] An object of the present disclosure is to provide a metal tube washing method and a metal tube washing apparatus that maintain high washing performance for a long time.

45 SOLUTION TO PROBLEM

[0007] A metal tube washing method according to the present disclosure includes: a storing step of storing a washing liquid in a washing tank; a soaking step of soaking a metal tube in the washing liquid in the washing tank while generating fine bubbles from a gas dissolved in the washing liquid and radiating ultrasonic waves into the washing liquid in the
50 washing tank; a supplying step of newly supplying the washing liquid to the washing tank; and a discharging step of, when the liquid surface of the washing liquid in the washing tank exceeds a predetermined reference liquid surface level, discharging the washing liquid from the washing tank by an amount corresponding to the excess over the reference liquid surface level.

55 ADVANTAGEOUS EFFECTS OF INVENTION

[0008] The present disclosure makes it possible to maintain high performance in washing a metal tube for a long time.

BRIEF DESCRIPTION OF DRAWINGS

[0009]

[FIG. 1] FIG. 1 is a plan view of a washing apparatus according to an embodiment.

[FIG. 2] FIG. 2 is a sectional view of the washing apparatus shown in FIG. 1 along a line II-II.

[FIG. 3] FIG. 3 is an illustration diagram of an exemplary discharge mechanism that is employable in the washing apparatus according to the embodiment.

[FIG. 4] FIG. 4 is an illustration diagram of another exemplary discharge mechanism employable in the washing apparatus according to the embodiment.

[FIG. 5] FIG. 5 is a graph showing the relationship between the concentration of oxygen dissolved in the washing liquid, the sound pressure of ultrasonic waves, and the performance in washing metal tubes.

[FIG. 6] FIG. 6 is a graph showing the relationship between the overflow time of the washing liquid, the concentration of oxygen dissolved in the washing liquid and the amount of washing liquid supplied to the washing tank.

[FIG. 7] FIG. 7 is a graph showing the density of scale in the washing liquid, the attenuation rate of the sound pressure of ultrasonic waves, and the performance in washing metal tubes.

[FIG. 8] FIG. 8 is a graph showing the surface area of washed metal tubes, the density of scale in the washing liquid, and the amount of washing liquid supplied to the washing tank.

DESCRIPTION OF EMBODIMENTS

[0010] A metal tube washing method according to an embodiment includes: a storing step of storing a washing liquid in a washing tank; a soaking step of soaking a metal tube in the washing liquid in the washing tank while generating fine bubbles from a gas dissolved in the washing liquid and radiating ultrasonic waves into the washing liquid in the washing tank; a supplying step of newly supplying the washing liquid to the washing tank; and a discharging step of, when the liquid surface of the washing liquid in the washing tank exceeds a predetermined reference liquid surface level, discharging the washing liquid from the washing tank by an amount corresponding to the excess over the reference liquid surface level (first structure).

[0011] In the washing method of the first structure, fine bubbles are generated in the washing liquid in which a metal tube is soaked, and ultrasonic waves radiated in the washing liquid are scattered therein. Accordingly, the washing performance is improved. The fine bubbles are generated from gasses dissolved in the washing liquid, and thereby, during the ultrasonic washing, the concentration of oxygen dissolved in the washing liquid becomes lower. This allows good ultrasonic washing performance.

[0012] In the washing method of the first structure, for example, when the washing liquid is supplied to the washing tank or when a metal tube is soaked in the washing liquid in the washing tank, the washing liquid surface in the washing tank rises and may exceed a predetermined reference liquid surface level. In this case, the washing liquid is discharged from the washing tank by an amount corresponding to the excess over the reference liquid surface level. Thereby, scale that was removed from the metal tube and is dispersed and floating in the washing liquid is discharged from the washing tank together with the washing liquid. The washing tank is replenished with the washing liquid. Accordingly, the density of scale in the washing liquid in the washing tank can be decreased. Therefore, it is possible to suppress attenuation of ultrasonic waves radiated in the washing liquid, which makes it possible to maintain high washing performance for a long time.

[0013] In the soaking step, the concentration of oxygen dissolved in the washing liquid in the washing tank is preferably 5.2 mg/L or lower (second structure).

[0014] With the second structure, good washing performance is more certainly obtained.

[0015] The supplying step can be carried out in parallel with the soaking step. In the supplying step, the amount of washing liquid supplied to the washing tank per minute is preferably within the range of 0.17% to 1.25% of the amount of washing liquid stored in the washing tank (third structure).

[0016] With the third structure, it becomes more certain to suppress an increase in the amount of scale in the washing liquid, while the concentration of oxygen dissolved in the washing liquid can be maintained within a preferable range.

[0017] The amount of washing liquid supply is more desirably within the range of 0.17% to 0.83% of the amount of washing liquid stored in the washing tank (fourth structure), and still more desirably within the range of 0.33% to 0.83% of the amount of washing liquid stored in the washing tank (fifth structure).

[0018] With the fourth or fifth structure, it becomes still more certain to suppress an increase in the amount of scale in the washing liquid, while the concentration of oxygen dissolved in the washing liquid can be maintained within a more desirable range.

[0019] The metal tube may be a steel tube having a specific chemical composition. The chemical composition preferably contains, in mass%, C: 0.01 to 0.13%, Si: 0.75% or less, Mn: 2% or less, P: 0.045% or less, S: 0.030% or less, Ni: 7 to

14%, and Cr: 16 to 20%, the balance being Fe and impurities (sixth structure).

[0020] The chemical composition may contain at least one of, in mass %, Nb: 0.2 to 1.1%, Ti: 0.1 to 0.6%, Mo: 0.1 to 3%, and Cu: 2.5 to 3.5% as substitute for part of Fe in the balance (seventh structure).

[0021] The chemical composition may contain, in mass %, B: 0.001 to 0.1% and N: 0.02 to 0.12% as substitute for part of Fe in the balance (eighth structure).

[0022] A metal tube washing apparatus according to an embodiment includes a washing tank, a supply mechanism, a discharge mechanism, a fine bubble generation mechanism, and an ultrasonic radiation mechanism. A washing liquid is stored in the washing tank, and a metal tube is placed therein. The supply mechanism supplies the washing liquid to the washing tank. When the liquid surface of the washing liquid in the washing tank exceeds a predetermined reference liquid surface level, the discharge mechanism discharges the washing liquid from the washing tank by an amount corresponding to the excess over the reference liquid surface level. The fine bubble generation mechanism generates fine bubbles from a gas dissolved in the washing liquid in the washing tank. The ultrasonic radiation mechanism radiates ultrasonic waves into the washing liquid in the washing tank (ninth structure).

[0023] The washing apparatus of the ninth structure includes a fine bubble generation mechanism. The fine bubble generation mechanism generates fine bubbles in the washing tank by using a gas dissolved in the washing liquid in the washing tank. This ensures good washing performance in ultrasonically washing a metal tube.

[0024] In the washing apparatus of the ninth structure, when the liquid surface of the washing liquid in the washing tank exceeds a predetermined reference liquid surface level, the discharge mechanism discharges the washing liquid from the washing tank by an amount corresponding to the excess over the reference liquid surface level. Thereby, scale that was removed from the metal tube and is dispersed and floating in the washing liquid is discharged from the washing tank together with the washing liquid. Meanwhile, the supply mechanism replenishes the washing tank with the washing liquid. Thus, by the supply and discharge of the washing liquid, the density of scale in the washing liquid in the washing tank can be decreased. Therefore, it is possible to suppress attenuation of ultrasonic waves radiated in the washing liquid, which makes it possible to maintain high washing performance for a long time.

[0025] Embodiments of the present disclosure will hereinafter be described with reference to the drawings. In the drawings, the same or equivalent members are provided with the same reference signs, and repetitions of the same description will be avoided.

[Washing Apparatus]

[0026] FIG. 1 is a schematic plan view of a washing apparatus 1 according to an embodiment. FIG. 2 is a sectional view of the washing apparatus 1 shown in FIG. 1 along a line II-II.

[0027] Referring to FIG. 1, the washing apparatus 1 ultrasonically washes metal tubes 2, which are objects to be washed. The washing apparatus 1, for example, is capable of rinsing the metal tubes 2, which was subjected to acid pickling, in water.

[0028] The washing apparatus 1 includes a washing tank 10, a supply mechanism 20, a plurality of discharge mechanisms 30, a plurality of ultrasonic radiation mechanisms 40, and a plurality of fine bubble generation mechanisms 50. The washing apparatus 1 further includes a plurality of cushions 60.

(Washing Tank)

[0029] The washing tank 10 is configured to accommodate the metal tubes 2. In the washing tank 10, usually, a plurality of metal tubes 2 are accommodated at the same time to be subjected to ultrasonic washing.

[0030] A washing liquid 3 for washing of the metal tubes 2 is stored in the washing tank 10. The kind of the washing liquid 3 is not particularly limited, and it is possible to arbitrarily select and adopt one of well-known washing liquids. The washing liquid 3 is, for example, water (tap water or industrial water).

[0031] In the present embodiment, the washing tank 10 is rectangular in a plan view. The washing tank 10 has an open upper side. The bottom surface of the washing tank 10 is, for example, an inclined surface inclined from one end to the other end along the length direction. Accordingly, the depth of the washing tank 10 (the height of the inner wall) at one end with respect to the length direction is different from the depth (the height of the inner wall) thereof at the other end with respect to the length direction. The washing tank 10 is a large washing tank that has, for example, a length of about 10 to 25 meters, a width of about 1 to 2 meters, and a maximum depth of about 0.4 to 1 meter.

[0032] The material of the washing tank 10 is not particularly limited. For example, metallic materials such as stainless steel, etc., plastic resin such as fiber-reinforced plastic (FRP), polypropylene (PP), etc., acid-proof brick, and the like are usable as the material of the washing tank 10.

(Supply Mechanism)

[0033] The supply mechanism 20 supplies the washing liquid 3 to the washing tank 10. The supply mechanism 20 includes at least one supply pipe 21. In the present embodiment, the supply mechanism 20 includes a plurality of supply pipes 21. The washing liquid 3 is supplied to the washing tank 10 through the supply pipes 21. The plurality of supply pipes 21 are arranged at intervals. Therefore, the washing liquid 3 is decentrally supplied to the washing tank 10. When there are three or more supply pipes 21, it is preferred that the intervals between the supply pipes 21 are substantially equal for uniform supply of the fresh washing liquid 3.

[0034] In the present embodiment, the plurality of supply pipes 21 are arranged along one of two lengthwise extending side walls of the washing tank 10. The number and arrangement of the supply pipes 21 are not particularly limited. Along each of the lengthwise extending side walls of the washing tank 10, one or more supply pipes 21 may be arranged. In addition to or instead of the supply pipes 21 arranged along one or both of the lengthwise extending side walls of the washing tank 10, one or more supply pipes 21 may be arranged along at least one of two widthwise extending side walls of the washing tank 10.

(Discharge Mechanism)

[0035] Each of the discharge mechanisms 30 discharges the washing liquid 3 from the washing tank 10 when the amount of washing liquid 3 in the washing tank 10 exceeds a predetermined amount. The plurality of discharge mechanisms 30 are arranged at intervals. Accordingly, the washing liquid 3 is decentrally discharged from the washing tank 10. When there are three or more discharge mechanisms 30, it is preferred that the intervals between the discharge mechanisms 30 are substantially equal. However, only one discharge mechanism 30 may be provided.

[0036] In the present embodiment, the plurality of discharge mechanisms 30 are arranged along the lengthwise extending side wall of the washing tank 10 on the opposite side of the side wall where the supply pipes 21 are arranged. However, the number and arrangement of the discharge mechanisms 30 are not particularly limited. The discharge mechanisms 30 may be arranged along the lengthwise extending side wall of the washing tank 10 where the supply pipes 21 are arranged. In addition to or instead of the discharge mechanisms 30 arranged along one or both of the lengthwise extending side walls of the washing tank 10, one or more discharge mechanisms 30 may be arranged along at least one of two widthwise extending side walls of the washing tank 10.

[0037] FIG. 3 shows an exemplary discharge mechanism 30A that is employable in the washing apparatus 1. The discharge mechanism 30A includes a discharge outlet 31 and a discharge pipe 32.

[0038] The discharge outlet 31 is a hole made in a side wall of the washing tank 10. The discharge pipe 32 is located outside the washing tank 10 and connected to the discharge outlet 31. The washing liquid 3 is discharged from the washing tank 10 through the discharge outlet 31 and the discharge pipe 32.

[0039] In the washing apparatus 1, a reference liquid surface level S is predetermined for the washing liquid 3 in the washing tank 10. For washing of the metal tubes 2, the washing liquid 3 is supplied to the washing tank 10 until the surface of the washing liquid 3 reaches the reference liquid surface level S. With respect to the depth direction of the washing tank 10, the position of the lower edge of the discharge outlet 31 is substantially same as the position of the reference liquid surface level S.

[0040] As indicated by alternate long and two short dashes line in FIG. 3, when the liquid surface of the washing liquid 3 in the washing tank 10 becomes higher than the reference liquid surface level S, the washing liquid 3 overflows through the discharge outlet 31 by an amount corresponding to the excess over the reference liquid surface level S. For example, in a state where the surface of the washing liquid 3 in the washing tank 10 is on the same level with the reference liquid surface level S, when the supply mechanism 20 newly supplies the washing liquid 3 to the washing tank 10, the washing liquid 3 overflows through the discharge outlet 31 by an amount substantially same as the amount of supply.

[0041] Thus, the discharge mechanism 30A discharges the washing liquid 3 from the washing tank 10 when the amount of washing liquid 3 in the washing tank 10 exceeds the amount defined by the reference liquid surface level S (the predetermined amount).

[0042] FIG. 4 shows another exemplary discharge mechanism 30B that is employable in the washing apparatus 1. The discharge mechanism 30B includes a discharge outlet 33, a discharge pipe 34, a discharge pump 35, and a liquid surface detector (not shown). As the liquid surface detector, a commercially available liquid level sensor or the like may be used.

[0043] The discharge outlet 33 is a hole made in a side wall of the washing tank 10. The discharge outlet 33 is located on the side wall of the washing tank 10, at a lower level than the reference liquid surface level S. The discharge pipe 34 is located outside the washing tank 10 and connected to the discharge outlet 33. The washing liquid 3 is discharged from the washing tank 10 through the discharge outlet 33 and the discharge pipe 34.

[0044] The discharge pump 35 is located in the middle of the discharge pipe 34. When the surface of the washing liquid 3 in the washing tank 10 exceeds the reference liquid surface level S, the discharge pump 35 is controlled to suck

the washing liquid 3 from the washing tank 10 by an amount corresponding to the excess over the reference liquid surface level S. For example, the discharge pump 35 is controlled as follows based on signals sent from the liquid surface detector located in the washing tank 10. When the surface of the washing liquid 3 exceeds the reference liquid surface level S, the discharge pump 35 is driven, and when the surface of the washing liquid 3 becomes lower than the reference liquid surface level S, the drive of the discharge pump 35 is stopped.

[0045] Thus, as with the discharge mechanism 30A (FIG. 3), the discharge mechanism 30B discharges the washing liquid 3 from the washing tank 10 when the amount of washing liquid 3 in the washing tank 10 exceeds a predetermined amount.

(Ultrasonic Radiation Mechanism)

[0046] With reference to FIG. 1 again, the ultrasonic radiation mechanisms 40 radiate ultrasonic waves into the washing liquid 3 in the washing tank 10. As the ultrasonic radiation mechanisms 40, well-known ultrasonic vibrators commonly used in ultrasonic washing may be used.

[0047] The frequency of ultrasonic waves radiated from the ultrasonic radiation mechanisms 40 is preferably 20 kHz to 200 kHz. When the frequency of ultrasonic waves is 20 kHz or more, there is no fear that ultrasonic wave propagation in the washing liquid 3 is blocked by large bubbles emitted from the surfaces of the metal tubes 2, and washing performance degradation can be prevented. When the frequency of ultrasonic waves is 200 kHz or less, a decrease in the uniformity of washing due to the strong straightness of the travel of ultrasonic waves can be prevented. The frequency of ultrasonic waves is more desirably 20 kHz to 150 kHz, and still more desirably 25 kHz to 100 kHz.

[0048] The ultrasonic radiation mechanisms 40 preferably have a frequency sweeping function. With the frequency sweeping function, the ultrasonic radiation mechanisms 40 are capable of radiating ultrasonic waves into the washing liquid 3 while sweeping the frequency within the range of ± 0.1 kHz to ± 10 kHz from a predetermined frequency.

[0049] In the present embodiment, at least one ultrasonic radiation mechanism 40 is set on the inside surface of each side wall of the washing tank 10. However, the number and arrangement of the ultrasonic radiation mechanisms 40 are not particularly limited. One or more ultrasonic radiation mechanisms 40 may be set on the bottom surface of the washing tank 10. When a plurality of ultrasonic radiation mechanisms 40 are set in the washing tank 10, it is preferred that the ultrasonic radiation mechanisms 40 are arranged in such a manner as to achieve uniform ultrasonic wave propagation in the entire washing tank 10. In this case, the ultrasonic radiation mechanisms 40 have the same load in oscillation, and interference between the ultrasonic waves radiated from the ultrasonic radiation mechanisms 40 can be prevented.

(Fine Bubble Generation Mechanism)

[0050] The fine bubble generation mechanisms 50 generate fine bubbles from gasses dissolved in the washing liquid 3 in the washing tank 10. The fine bubble generation mechanisms 50 are located outside the washing tank 10. The plurality of fine bubble generation mechanisms 50 are arranged along a lengthwise extending side wall of the washing tank 10. However, the number and arrangement of the fine bubble generation mechanisms 50 are not particularly limited.

[0051] Each of the fine bubble generation mechanisms 50 includes pipes 51 and 52, and a fine bubble generator 53. The pipes 51 and 52 connect the washing tank 10 and the fine bubble generator 53. The washing liquid is introduced from the washing tank 10 to the fine bubble generator 53 through the pipe 51. The fine bubble generator 53 generates fine bubbles by using gasses in the washing liquid 3. The fine bubbles are returned to the washing tank 10 together with the washing liquid 3 through the pipe 52.

[0052] The fine bubble generator 53 can be arbitrarily selected from known fine bubble generators. The known fine bubble generators are, for example, fine bubble generators that generate fine bubbles by shear of bubbles, passage of bubbles through fine holes, reduction in liquid pressure (change in pressure), dissolution of gasses under pressure, ultrasonic waves, electrolyzation, chemical reaction, etc. The fine bubble generator 53 is preferably such a thing as the bubble diameter and the density of fine bubbles can be easily controlled. For example, the fine bubble generator 53 may be a known fine bubble generator that generates fine bubbles by causing a pressure change of a liquid in the middle of circulation of the liquid.

[0053] Fine bubbles mean minuscule bubbles with an average bubble diameter of 100 μm or less. In some cases, fine bubbles with an average bubble diameter on the order of micrometers are referred to as microbubbles, and fine bubbles with an average bubble diameter on the order of nanometers are referred to as nanobubbles. The average bubble diameter is a diameter at which the number of samples is the largest in a number distribution of fine bubble diameter.

[0054] Fine bubbles increase the efficiency of ultrasonic propagation to the object to be washed in ultrasonic washing. Fine bubbles serve as nuclei for ultrasonic cavitation and improve the washing performance. Being in the washing liquid 3 under ordinary liquid conditions, fine bubbles have a negatively charged surface potential in most cases. Meanwhile, substances that are stuck on the surfaces of the metal tubes 2 and are to be washed out therefrom (for example, scale, smut, oil, etc.) are positively charged in most cases. Accordingly, when fine bubbles come close to the metal tubes 2,

the fine bubbles are attracted to the metal tubes 2 because of the opposite polarity of electric charge. When ultrasonic waves are radiated into the washing liquid 3 with fine bubbles therein, cavitation occurs on the surfaces of the metal tubes 2, and the metal tubes 2 can be washed efficiently.

[0055] The average bubble diameter of the fine bubbles in the washing liquid 3 is preferably equal to or greater than 0.01 μm in order to avoid the necessity of enlarging the fine bubble generation mechanisms 50 and to facilitate control of the bubble diameter. Also, the average bubble diameter of fine bubbles is preferably equal to or less than 100 μm in order to prevent the fine bubbles from increasing in drift-up rate and from blocking the propagation of ultrasonic waves to the metal tubes 2. More desirably, the fine bubbles are microbubbles with an average bubble diameter of 1 μm to 50 μm .

[0056] It is preferred that at least some of the fine bubbles in the washing liquid 3 have bubble diameters equal to or less than a frequency-resonance diameter. The frequency-resonance diameter means a bubble diameter that resonates to the frequency of ultrasonic waves in the washing liquid 3. The fine bubble generation mechanisms 50 preferably generate fine bubbles in the washing liquid 3 such that the number of fine bubbles with bubble diameters equal to or less than the frequency-resonance diameter is 70% or more of the total number of fine bubbles. The reason will be described below.

[0057] The eigenfrequencies of various bubbles including fine bubbles are also known as Minnaert resonance frequencies and are given by the following formula (1).

[formula 1]

$$f_0 = \frac{1}{2\pi R_0} \sqrt{\frac{3\gamma p_\infty}{\rho}} \quad (1)$$

[0058] In formula (1), the marks indicate the following.

f_0 : eigenfrequency (Minnaert resonance frequency) of a bubble

R_0 : average radius of the bubble

p_∞ : average pressure of ambient liquid

γ : heat capacity ratio (γ of air = 1.4)

ρ : density of liquid

[0059] Under the conditions that there is air inside a target bubble, that the liquid around the bubble is water and that the pressure is atmospheric pressure, the product $f_0 R_0$ of the eigenfrequency f_0 of the bubble and the average radius R_0 of the bubble is calculated as about 3 kHz-mm by using formula (1). Accordingly, when the frequency of radiated ultrasonic waves is 20 kHz, the radius of a bubble which resonates with the ultrasonic waves (resonance radius R_0) is about 150 μm . The frequency-resonance diameter $2R_0$ means a diameter of a bubble which resonates with ultrasonic waves, and therefore, when the frequency of radiated ultrasonic waves is 20 kHz, the frequency-resonance diameter $2R_0$ is about 300 μm . When the frequency of radiated ultrasonic waves is 100 kHz, the resonance radius is about 30 μm , and the frequency-resonance diameter $2R_0$ is about 60 μm .

[0060] Bubbles with radii greater than the resonance radius R_0 constitute a limiting factor. During resonance, a bubble, including a fine bubble, expands and contracts repeatedly for a short time, and finally, the bubble is broken by pressure. In this regard, if the size of the bubble is greater than the frequency-resonance diameter $2R_0$ when the first sound wave comes to the bubble, the ultrasonic wave is diffused by the surface of the bubble. On the other hand, if the size of the bubble is equal to or less than the frequency-resonance diameter $2R_0$ when the first sound wave comes to the bubble, the ultrasonic wave passes through the bubble without being diffused by the surface of the bubble.

[0061] Therefore, it is preferred that the ratio of the number of fine bubbles with diameters equal to or less than the frequency-resonance diameter $2R_0$ to the total number of fine bubbles in the washing liquid 3 is 70% or more. Considering that some fine bubbles expand immediately after the outbreak thereof, it is more desirable that the above-described ratio is within the range of 80% to 98%. This arrangement makes it possible to improve the propagation efficiency of ultrasonic waves in the washing liquid 3. Also, when the first sound wave is caused to reach the walls and/or the bottom of the washing tank 10, the ultrasonic wave is propagated entirely in the washing tank 10 by diffusion and reflection, repeatedly, and it becomes possible to achieve homogeneous ultrasonic washing ability. A bubble with a diameter equal to or smaller than the frequency-resonance diameter $2R_0$ expands and contracts repeatedly and is broken by pressure after it is exposed to ultrasonic waves for a certain period of time, and in this way, the bubble contributes to cavitation washing.

[0062] In order to improve the propagation efficiency of ultrasonic waves and ensure a sufficient number of nuclei for ultrasonic cavitation, the concentration (density) of fine bubbles in the washing liquid 3 is preferably equal to or more than 10^3 bubbles per mL. Also, in order to avoid the necessity of increasing the size of each of the fine bubble generation

mechanisms 50 and the necessity of increasing the number of fine bubble generation mechanisms 50, the concentration (density) of fine bubbles in the washing liquid 3 is preferably equal to or less than 10^6 bubbles per mL.

[0063] The average bubble diameter and the concentration of fine bubbles can be measured by known devices, such as a particle counter for counting particles in liquid, a bubble diameter distribution measurement device, etc.

(Cushion)

[0064] The cushions 60 are located in the washing tank 10. The plurality of cushions 60 are arranged in the length direction of the washing tank 10.

[0065] As shown in FIG. 2, each of the cushions 60 has substantially a U-shape. The metal tubes 2 are placed on the cushions 60 in the washing tank 10. In the washing tank 10, the respective inside surfaces of the cushions 60 are positioned closer to the center of the washing tank 10 than the ultrasonic radiation mechanisms 40. Therefore, there is no fear that the metal tubes 2 may come into contact with the ultrasonic radiation mechanisms 40, and the ultrasonic radiation mechanisms 40 can be protected from the metal tubes 2.

[Washing Method]

[0066] A method for washing the metal tubes 2 by using the washing apparatus 1 will hereinafter be described.

[0067] The metal tubes 2 have been subjected to hot working, heat treatment, etc. and have scale on the respective surfaces. In order to remove the scale, the metal tubes 2 are subjected to acid pickling. The washing method according to the present embodiment is a method for washing the metal tubes 2 after the metal tubes 2 are soaked in an acid solution for a specified time at an acid pickling step (conventional acid pickling step).

[0068] The metal tubes 2 to be washed are, for example, stainless steel tubes, Ni-based alloy tubes, etc. When the metal tubes 2 are stainless steel tubes, the metal tubes 2 are steel tubes containing 10.5% or more Cr in mass%. For example, each of the steel tubes has a chemical composition containing, in mass%, C: 0.01 to 0.13%, Si: 0.75% or less, Mn: 2% or less, P: 0.045% or less, S: 0.030% or less, Ni: 7 to 14%, and Cr: 16 to 20%, the balance being Fe and impurities. The chemical composition may contain, in mass%, at least one of Nb: 0.2 to 1.1%, Ti: 0.1 to 0.6%, Mo: 0.1 to 3%, and Cu: 2.5 to 3.5% as substitute for part of Fe in the balance. Also, the chemical composition may contain, in mass%, B: 0.001 to 0.1% and N: 0.02 to 0.12% as substitute for part of Fe in the balance.

[0069] The metal tubes 2 with the above chemical composition have an austenitic structure and accordingly are excellent in heat resistance, corrosion resistance and steam oxidation resistance. These metal tubes 2 have excellent strength and for example, have yield strength of 550 MPa or higher. Such metal tubes 2 are subjected to a heat treatment at a high temperature over 1000 °C during a manufacturing process thereof, and therefore, a large amount of scale is deposited on the surfaces. Accordingly, it is necessary to carry out acid pickling after the heat treatment and to wash out (rinse) the scale remaining on the surfaces after the acid pickling.

[0070] When the metal tubes 2 are Ni-based alloy tubes, the metal tubes 2, for example, have a chemical composition containing, in mass%, C: 0.05% or less, Si: 0.5% or less, Mn: 1% or less, P: 0.030% or less, S: 0.030% or less, Cr: 19.5 to 24.0%, Mo: 2.5 to 4.0%, Ti: 1.2% or less, and Fe: 22% or more, with the balance being mainly Ni (typically, the balance being Ni and impurities). The chemical composition may contain, in mass%, at least one of Cu: 0.5% or less, Nb: 4.5% or less, and Al: 2.0% or less as substitute for part of Ni in the balance. Such metal tubes 2 are subjected to a heat treatment at a high temperature during a manufacturing process thereof, and therefore, a large amount of scale is deposited on the surfaces. Accordingly, it is necessary to carry out acid pickling after the heat treatment and to wash out (rinse) the scale remaining on the surfaces after the acid pickling.

[0071] According to the present embodiment, a method for washing metal tubes 2 includes: a step of storing the washing liquid 3 in the washing tank 10; a step of soaking the metal tubes 2 in the washing liquid 3 in the washing tank 10; a step of supplying the washing liquid 3 to the washing tank 10; and a step of discharging the washing liquid 3 from the washing tank 10.

(Storing Step)

[0072] Referring to FIG. 1 again, first, the washing liquid 3 is stored in the washing tank 10 for washing of the metal tubes 2. The washing liquid 3 is supplied to the washing tank 10 by the supply mechanism 20. However, at the storing step of supplying the washing liquid 3 to the empty washing tank 10, the washing liquid 3 may be supplied by any other means than the supply mechanism 20. The washing liquid 3 to be supplied to the washing tank 10 preferably has an oxygen concentration of about 7 mg/L to 11 mg/L, and more desirably has an oxygen concentration of about 8 mg/L to 10 mg/L. The washing liquid 3 is typically water (tap water or industrial water). When the washing liquid 3 is water (tap water or industrial water) at a temperature of 10 to 35 °C, the concentration of oxygen dissolved in the washing liquid 3 is within the range of 7 mg/L to 11 mg/L. When the washing liquid 3 is water (tap water or industrial water) at a temperature

of 15 to 25 °C, the concentration of oxygen dissolved in the washing liquid 3 is within the range of 8 mg/L to 10 mg/L. The oxygen concentration serves as an index of the amount of gasses dissolved in the washing liquid 3.

[0073] When the liquid surface of the washing liquid 3 in the washing tank 10 exceeds the reference liquid surface level S (see FIG. 3 or FIG. 4), the discharge mechanisms 30 start discharging the washing liquid 3. The supply mechanism 20 continues supplying the washing liquid 3 to the washing tank 10 even after the liquid surface of the washing liquid 3 in the washing tank 10 reaches the reference liquid surface level S. Therefore, discharge of the washing liquid 3 from the washing tank 10 is carried out in parallel with supply of the washing liquid 3 to the washing tank 10. In this regard, the amount of discharge of the washing liquid 3 is substantially equal to the amount of supply of the washing liquid 3. The washing liquid 3 (water) discharged by the discharge mechanisms 30 is subjected to a specified wastewater treatment and discarded.

(Soaking Step, Supplying Step and Discharging Step)

[0074] Next, the metal tubes 2 are soaked in the washing liquid 3 stored in the washing tank 10 for a predetermined time. The metal tubes 2 can be placed in the washing tank 10 by a crane or the like to be soaked in the washing liquid 3. Typically, a plurality of metal tubes 2 are soaked in the washing liquid 3 at the same time; however, the metal tubes 2 may be soaked in the washing liquid 3 one at a time.

[0075] In the soaking step, soaking the metal tubes 2 in the washing liquid 3 in the washing tank 10, holding the metal tubes 2 in the washing liquid 3, and pulling up the metal tubes 2 from the washing tank 10 are defined as one cycle, and the cycle is repeated a predetermined number of times. The holding time of the metal tubes 2 in the cycle and the number of cycles to be carried out can be determined such that the total time of soaking the metal tubes 2 in the washing liquid 3 will be a specified time or longer. The total soaking time of the metal tubes 2 may be arbitrarily determined according to the amount of scale deposited on the metal tubes 2, and the like. The total soaking time of the metal tubes 2 is preferably, for example, 30 seconds or longer, and more desirably, 1 minute or longer.

[0076] When the metal tubes 2 are pulled up from the washing tank 10, the metal tubes 2 are preferably inclined from the horizontal surface. Thereby, the washing liquid is drained from the inside of the metal tubes 2. When the above-described cycle is repeated a plurality of times, it is preferred that the direction of inclination of the metal tubes 2 is changed for each cycle.

[0077] During the soaking step, the washing liquid 3 is newly supplied to the washing tank 10 continuously by the supply mechanism 20. In the meantime, the washing liquid 3 is continuously discharged from the washing tank 10 by an amount corresponding to the excess over the reference liquid surface level S. Thus, in the present embodiment, the soaking step, the supplying step, and the discharging step are executed in parallel with one another. The amount of washing liquid 3 supplied to the washing tank 10 by the supply mechanism 20 per minute is desirably within the range of 0.17% to 1.25%, more desirably within the range of 0.17% to 0.83%, and still more desirably within the range of 0.33% to 0.83% of the amount of washing liquid 3 stored in the washing tank 10 (the amount of washing liquid 3 stored in the washing tank 10 up to the reference liquid surface level S with no metal tubes 2 soaked therein).

[0078] During the soaking step, ultrasonic waves are radiated from the ultrasonic radiation mechanisms 40 into the washing liquid 3 in the washing tank 10, and fine bubbles are supplied by the fine bubble generation mechanisms 50.

[0079] In the washing method according to the present embodiment, the fine bubble generation mechanisms 50 uses gasses dissolved in the washing liquid 3 in the washing tank 10 to generate bubbles, and accordingly, the concentration of oxygen dissolved in the washing liquid 3 becomes lower. The fine bubble generation mechanisms 50 decrease the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 to 5.2 mg/L or lower. The fine bubble generation mechanisms 50 decrease the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 desirably to 4.5 mg/L or lower, and more desirably to 4.2 mg/L or lower.

[0080] Specifically, the supply mechanism 20 supplies the washing liquid 3 with an oxygen concentration of about 7 mg/L to 11 mg/L, and preferably about 8 mg/L to 10 mg/L, to the washing tank 10. When the washing liquid 3 passes through the fine bubble generators 53 of the fine bubble generation mechanisms 50, gasses dissolved in the washing liquid 3 are caused to come out as fine bubbles, and the concentration of oxygen dissolved in the washing liquid 3 becomes lower. As the washing liquid 3 is circulated between the washing tank 10 and the fine bubble generation mechanisms 50, the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 becomes 5.2 mg/L or lower, desirably 4.5 mg/L or lower, and more desirably 4.2 mg/L or lower.

[0081] After the metal tubes 2 are soaked in the washing liquid 3 for the predetermined total soaking time or longer, the metal tubes 2 are retrieved from the washing tank 10 by a crane or the like. At the moment, it is preferred to pull up the metal tubes 2 while inclining the metal tubes 2. This prevents the washing liquid 3 from remaining in the metal tubes 2.

[0082] With the retrieval of the metal tubes 2, the washing of the metal tubes 2 is completed. Meanwhile, in the washing tank 10, ultrasonic waves and fine bubbles are provided to the washing liquid 3, and supply and discharge of the washing liquid 3 are continued. Therefore, it is possible to successively carry out the soaking step of other metal tubes 2.

[0083] There is fear that an acid solution, water, or the like containing no fine bubbles may be brought into the washing

tank 10 by the metal tubes 2, which will heighten the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10. When the concentration of oxygen dissolved in the washing liquid 3 becomes higher, it is preferred to stop ultrasonic washing of metal tubes 2 until the concentration of oxygen dissolved in the washing liquid 3 is sufficiently decreased by the operation of the fine bubble generation mechanisms 50. The soaking of the metal tubes 2 should be

restarted when the concentration of oxygen dissolved in the washing liquid becomes 5.2 mg/L or lower, 4.5 mg/L or lower, or 4.2 mg/L or lower.

[0084] In the present embodiment, after the washing liquid 3 is stored in the washing tank 10 at the storing step, the metal tubes 2 are placed in the washing tank 10 at the soaking step. However, at the storing step, the metal tubes 2 may be placed in the washing tank 10 in an empty state, and thereafter, the washing liquid 3 may be stored in the washing tank 10.

[Numerical Range]

[0085] Referring to FIGS. 5 to 8, the numerical range of the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 and the numerical range of the amount of washing liquid 3 supplied to the washing tank 10 will hereinafter be described. In the description and consideration with reference to FIGS. 5 to 8, the metal tubes 2 to be washed are austenitic stainless steel tubes (containing Ni: 9 mass%, Cr: 18.5 mass%, Cu: 3 mass%, Nb: 0.5 mass%), the washing liquid 3 supplied to the washing tank 10 is water (industrial water) at a temperature of about 20 °C, and the amount of washing liquid 3 stored in the washing tank 10 (to the reference liquid surface level S) is about 12000 L.

(Dissolved Oxygen Concentration)

[0086] FIG. 5 is a graph showing the relation between the concentration of oxygen dissolved in the washing liquid 3, the sound pressure of ultrasonic waves radiated in the washing liquid 3, and the performance in washing the metal tubes 2. Before drawing the graph 5, the performance in washing the metal tubes 2 was evaluated while the concentration of oxygen dissolved in the washing liquid 3 and the sound pressure of ultrasonic waves radiated in the washing liquid 3 were varied.

[0087] The dissolved oxygen concentration [mg/L] was measured by a commercially available dissolved oxygen meter (LAQUA OM-71 made by Horiba, Ltd.). In this disclosure, measured values obtained by use of such a measurement device were considered as dissolved oxygen concentrations. The sound pressure [mV] was measured by a commercially available ultrasonic sound pressure meter (sound pressure level monitor 19001D made by KAIJO Corporation) in a measurement mode to calculate an average value for 5 seconds with a probe (vibration transmission bar with a piezo-electric element) inserted 100 mm deep in the washing liquid 3 from the liquid surface. In the present disclosure, measured values obtained in this way were considered as sound pressures. The frequency of the ultrasonic waves was 38 kHz.

[0088] In the graph of FIG. 5, circles, triangles and crosses show the evaluation results of the washing performance. A circle indicates that scale was completely removed from the surfaces of the metal tubes 2 and that the ultrasonic washing performance was excellent. A triangle indicates that scale was left on some part of the surfaces of the metal tubes 2 but that the ultrasonic washing performance was considered good. A cross indicates that the ultrasonic washing performance was bad.

[0089] According to FIG. 5, when the concentration of oxygen dissolved in the washing liquid 3 was equal to or lower than 5.2 mg/L, there were many cases in which the evaluation results were marked with a circle or triangle, and the washing performance was good in most of the sound pressure regions. Therefore, according to the present embodiment, the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 is set to 5.2 mg/L or lower.

[0090] According to FIG. 5, when the concentration of oxygen dissolved in the washing liquid 3 was equal to or lower than 4.5 mg/L or equal to or lower than 4.2 mg/L, the sound pressure region in which good washing performance was achieved was wider. Therefore, the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 is desirably equal to or lower than 4.5 mg/L, and more desirably equal to or lower than 4.2 mg/L.

[0091] According to FIG. 5, when the concentration of oxygen dissolved in the washing liquid 3 was equal to or lower than 5.2 mg/L, the evaluation results in a ultrasonic sound pressure region of 120 mV or higher were marked with a circle or triangle. According to FIG. 5, when the concentration of oxygen dissolved in the washing liquid 3 was equal to or lower than 4.5 mg/L or equal to or lower than 4.2 mg/L, all the evaluation results in the ultrasonic sound pressure region of 120 mV or higher were marked with a circle. Therefore, the ultrasonic radiation mechanisms 40 preferably output ultrasonic waves such that the ultrasonic sound pressure in the washing liquid 3 will be 120 mV or higher.

[0092] The concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 is usually equal to or higher than 2.0 mg/L. However, it is not necessary to adjust or control the lower limit of the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10.

(Relationship between Amount of Washing Liquid Supply and Dissolved Oxygen Concentration)

[0093] FIG. 6 is a graph showing the relationship between the overflow time of the washing liquid 3, the concentration of oxygen dissolved in the washing liquid 3, and the amount of supply of the washing liquid 3 to the washing tank 10. Before drawing the graph of FIG. 6, the concentration of oxygen dissolved in the washing liquid 3 was measured while the amount of supply was varied to 40L/min, 100L/min, and 150L/min. The washing liquid 3 supplied by the supply mechanism 20 was water (industrial water) at a temperature of about 20 °C, and it is considered that the water had an oxygen concentration of about 8 mg/L to 10 mg/L. The overflow time means a duration of overflow (discharge through the discharge mechanisms 30) of the washing liquid 3 from the washing tank 10. In other words, the overflow time is a period of time for which the supply mechanism 20 continues supplying the washing liquid 3 to the washing tank 10.

[0094] According to FIG. 6, in any of the cases in which the amount of supply of the washing liquid 3 to the washing tank 10 was 40 L/min, 100 L/min, or 150 L/min, the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 was maintained at 4.5 mg/L or lower. When the amount of supply of the washing liquid 3 was 40 L/min or 100 L/min, the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 was maintained at 4.2 mg/L or lower. If the amount of supply of the washing liquid 3 to the washing tank 10 is less than 40 L/min, the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 will be probably maintained at a still lower level.

[0095] According to FIG. 6, when the washing liquid 3, which has an oxygen concentration of about 8 mg/L to 10 mg/L, is supplied to the washing tank 10 with a storage capacity of about 12000 L, the amount of washing liquid supply is desirably set to 150 L/min or lower, and more desirably set to 100 L/min or lower. When the amount of supply is converted into a ratio to the storage capacity of the washing tank 10 (about 12000 L), the amount of supply per minute of the washing liquid 3 to the washing tank 10 is desirably 1.25% or lower of the storage capacity of the washing tank 10, and more desirably 0.83% or lower of the storage capacity. With this arrangement, it is possible to maintain the concentration of oxygen dissolved in the washing liquid 3 in the washing tank 10 at the above-described level or lower.

(Relationship between Amount of Washing Liquid Supply and Scale Density)

[0096] FIG. 7 is a graph showing the relationship between the density of scale in the washing liquid 3, the sound pressure attenuation rate of ultrasonic waves (with a frequency of 38 kHz and a sound pressure of 120 mV) radiated into the washing liquid 3, and the performance in washing the metal tubes 2.

[0097] According to FIG. 7, the lower the density of scale in the washing liquid 3 was, the smaller the sound pressure attenuation rate was. The higher the density of scale was, the greater the sound pressure attenuation rate was. When the density of scale was 2.5 g/L or lower, the scale deposited on the metal tubes 2 was completely removed, and the ultrasonic washing performance was excellent. When the density of scale exceeded 2.5 g/L, scale partly remained on the metal tubes 2 (presence of remaining scale). When the density of scale exceeded 5.0 g/L, the ultrasonic washing performance was bad. Therefore, the density of scale in the washing liquid 3 is preferably 2.5 g/L or lower.

[0098] FIG. 8 is a graph showing the relationship between the washed surface area of the metal tubes 2, the density of scale in the washing liquid 3, and the amount of supply of the washing liquid 3 to the washing tank 10. FIG. 8 shows the relationship under the condition that the washing liquid 3 was not supplied, under the condition that the amount of supply of the washing liquid 3 was 20 L/min, and under the condition that the amount of supply of the washing liquid 3 was 40 L/min. Ultrasonic waves with a frequency of 38 kHz and a sound pressure of 120 mV were radiated into the washing liquid 3 in the washing tank 10.

[0099] As shown in FIG. 8, in the case in which the washing liquid 3 was not supplied to the washing tank 10, the density of scale in the washing liquid 3 became almost 2.0 g/L when the washed surface area became about 4000 m². From an extension of the approximate straight line shown in FIG. 8, it is predictable that the density of scale will become 2.5 g/L when the washed surface area become about 5000 m². As described above, when the density of scale exceeds 2.5 g/L, remaining scale starts to be seen. Therefore, in the case in which the washing liquid 3 is not supplied to the washing tank 10, it is considered necessary to change the washing liquid 3 in the washing tank 10 when the washed surface area becomes about 5000 m².

[0100] In the cases in which the washing liquid 3 was supplied to the washing tank 10, an amount of washing liquid 3 that is almost the same amount of washing liquid 3 supplied to the washing tank 10 overflow from the washing tank 10, and thereby, the washing liquid 3 in the washing tank 10 was changed gradually. As shown in FIG. 8, in the cases in which the washing liquid 3 was supplied to the washing tank 10, the density of scale in the washing liquid 3 was 1.0 g/L or lower even when the washed surface area became 6000 m². Thus, in these cases, the intervals between changes of the washing liquid 3 in the washing tank 10 is longer, as compared with the case in which the washing liquid 3 was not supplied to the washing tank 10. In the case in which the amount of washing liquid 3 supplied to the washing tank 10 is 40 L/min, the increase rate of the density of scale is smaller, and the intervals between changes of the washing liquid 3 in the washing tank 10 become longer, as compared with the case in which the amount of washing liquid 3

supplied to the washing tank 10 is 20 L/min.

[0101] As is clear from FIG. 7 and 8, in supplying the washing liquid 3 to the washing tank 10 with a storage capacity of about 12000 L, the amount of supply is desirably set to 20 L/min or more, and more desirably set to 40 L/min or more. When these amounts of supply are converted into ratios to the storage capacity of the washing tank 10 (about 12000 L), the amount of supply per minute of the washing liquid 3 to the washing tank 10 is desirably 0.17% or higher of the storage capacity of the washing tank 10, and more desirably 0.33% or higher of the storage capacity. With this arrangement, the density of scale in the washing liquid 3 can be kept 2.5 g/L or less for a long time. Accordingly, the intervals between changes of the washing liquid 3 in the washing tank 10 become longer, and the number of changes of the washing liquid 3 can be reduced.

[Effects of Embodiment]

[0102] According to the present embodiment, fine bubbles are generated in the washing liquid 3 in which the metal tubes 2 are soaked, and thereby, ultrasonic waves in the washing liquid 3 are dispersed and propagated three-dimensionally. Then, the performance in washing the metal tubes 2 is improved. In the present embodiment, the fine bubbles are generated from gasses dissolved in the washing liquid 3, and the concentration of oxygen dissolved in the washing liquid 3 can be decreased to 5.2 mg/L or lower. Therefore, as described with reference to FIG. 5, excellent ultrasonic washing performance can be achieved.

[0103] According to the present embodiment, during the soaking step of soaking the metal tubes 2, supply of the washing liquid 3 to the washing tank 10 and discharge of the washing liquid 3 from the washing tank 10 are continuously carried out. Therefore, while scale peeled from the metal tubes 2 is discharged from the washing tank 10 together with the washing liquid 3, the washing liquid 3 is newly supplied to the washing tank 10. As described with reference to FIGS. 7 and 8, this disturbs an increase in the density of scale in the washing liquid 3 and a decay of ultrasonic waves. Thus, high washing performance can be achieved in ultrasonic washing of the metal tubes 2.

[0104] In the present embodiment, the concentration of oxygen dissolved in the washing liquid 3 is desirably 4.5 mg/L or lower, and more desirably 4.2 mg/L or lower. This arrangement makes it possible to improve the ultrasonic washing performance in a wide sound pressure region.

[0105] According to the present embodiment, the amount of supply per minute of the washing liquid 3 to the washing tank 10 is set to fall within the range of 0.17% to 1.25%, more desirably within the range of 0.17% to 0.83%, and still more desirably within the range of 0.33% to 0.83% of the amount of the washing liquid 3 stored in the washing tank 10. This arrangement makes it possible to maintain the concentration of oxygen dissolved in the washing liquid 3 within a preferable range and to disturb an increase in the density of scale in the washing liquid 3. Then, the ultrasonic washing performance can be further improved.

[0106] According to the present embodiment, the bottom surface of the washing tank 10 is an inclined surface inclined from one end to the other end in the length direction. This makes it easier for the washing liquid 3 to come inside the metal tubes 2, and the inside surfaces of the metal tubes 2 can be certainly washed.

[0107] According to the present embodiment, the ultrasonic radiation mechanisms 40 preferably have a frequency sweeping function. This makes it possible to improve the performance in washing the metal tubes 2.

[0108] Specifically, when ultrasonic waves are applied to microbubbles including fine bubbles, Bjerknes forces act on microbubbles, and the microbubbles are attracted to nodes or antinodes of ultrasonic waves depending on the diameters of the microbubbles. Microbubbles with bubble diameters equal to or smaller than the frequency-resonance diameter $2R_0$ are attracted to antinodes of ultrasonic waves and contribute to cavitation washing. When the frequency of ultrasonic waves is changed by the frequency sweeping function of the ultrasonic radiation mechanisms 40, the frequency-resonance diameter $2R_0$ changes along with the change in the frequency of ultrasonic waves, and the number of microbubbles that contribute to cavitation washing increases. Then, it becomes possible to use more microbubbles as nuclei for ultrasonic cavitation. As a result, the efficiency in washing the metal tubes 2 is improved.

[0109] When the wavelength of ultrasonic waves is a quarter of the thickness of the object to be exposed to the ultrasonic waves, the ultrasonic waves pass through the object. Therefore, by applying ultrasonic waves while sweeping the frequency in a certain appropriate range, the ultrasonic radiation mechanisms 40 can radiate more ultrasonic waves that can pass through the walls of the metal tubes 2. Thereby, the efficiency in washing the metal tubes 2 is improved.

[0110] Ultrasonic waves not only are vertically incident to the object to be exposed thereto but also propagate while being multiply reflected. Therefore, it is not easy to form a stable sound field. However, since the ultrasonic radiation mechanisms 40 have a frequency sweeping function, the ultrasonic radiation mechanisms 40 radiate ultrasonic waves in the washing liquid 3 while sweeping the frequency within a range of ± 0.1 kHz to ± 10 kHz from a specified frequency. Thereby, the condition that the wavelength of ultrasonic waves is a quarter of the wall thicknesses of the metal tubes 2 can be satisfied in various portions of the metal tubes 2. Accordingly, in various portions of the metal tubes 2, ultrasonic waves can penetrate the metal tubes 2 from outside to inside.

[0111] Although an embodiment of the present disclosure has been described, the present disclosure is not limited to

the embodiment above, and it is possible to modify the embodiment in various ways without departing the gist of the present disclosure.

[0112] In the present embodiment, the soaking step of soaking the metal tubes 2, the supplying step of supplying the washing liquid 3 to the washing tank 10, and the discharging step of discharging the washing liquid 3 from the washing tank 10 are executed in parallel. However, these steps do not need to be executed in parallel. The supply or discharge of the washing liquid 3 to or from the washing tank 10 is not necessarily carried out continuously. For example, when the metal tubes 2 are soaked in the washing liquid 3 with the supply of the washing liquid 3 to the washing tank 10 stopped, the liquid surface of the washing liquid 3 in the washing tank 10 rises by the volume of the metal tubes 2 and may exceed over the reference surface level S. In this case, an amount of washing liquid 3 corresponding to the excess over the reference liquid surface level S is discharged from the washing tank 10. In this regard, scale is dispersed and floats evenly in the washing liquid 3 in the washing tank 10 because the washing liquid 3 is stirred along with taking of the metal tubes 2 into and from the washing tank 10 and is circulated between the washing tank 10 and the fine bubble generators 53 via the pipes 51 and 52. Accordingly, the washing liquid 3 in which scale is dispersed and floats is discharged from the washing tank 10. By newly supplying the washing liquid 3 to the washing tank 10 after taking out the metal tubes 2, the density of scale in the washing liquid 3 in the washing tank 10 is decreased. Thus, even without executing the soaking step, the supplying step, and the discharging step in parallel, it is possible to suppress an increase in the density of scale in the washing liquid 3.

EXAMPLES

[0113] The present disclosure will be described in more detail by providing some examples. However, the present disclosure is not limited to the examples below.

[0114] Ultrasonic washing of a large number of metal tubes 2 was performed for four days by use of the washing apparatus 1 shown in FIGS. 1 to 3, and the results of the ultrasonic washing were evaluated. The metal tubes 2 were prepared as follows. The metal tubes 2 were subjected to cold drawing and thereafter heat treatment, and further, the metal tubes 2 were subjected to acid pickling. Each of the metal tubes 2 had an outer diameter of 38 mm to 95 mm. Each of the metal tubes 2 was an austenitic stainless steel tube and has a chemical composition as follows.

[Chemical Composition]

[0115] The chemical composition contains, in mass%,

C: 0.07 to 0.13%;
Si: 0.30% or less;
Mn: 1.0% or less;
P: 0.040% or less;
S: 0.010% or less;
Ni: 7.5 to 10.5%;
Cr: 17.0 to 19.0%;
Nb: 0.30 to 0.60%; and
Cu: 2.5 to 3.5%;

the balance being Fe and impurities.

[0116] In the washing process according to the present example, ultrasonic waves were radiated from the ultrasonic radiation mechanisms 40 into the washing liquid 3 in the washing tank 10, and fine bubbles are supplied from the fine bubble generation mechanisms 50. The washing conditions of the present example were as follows.

[Washing Conditions]

[0117]

- washing liquid: industrial water at room temperature
- storage capacity of washing tank: 12000 L
- frequency of ultrasonic waves: 38 kHz
- supply of washing liquid to washing tank: about 40 L/min

[0118] During the washing of the metal tubes 2, the average sound pressure of ultrasonic waves in the washing liquid 3 in the washing tank 10 and the average concentration of oxygen dissolved in the washing liquid 3 were measured

every day. The average sound pressure was measured by a commercially available ultrasonic sound pressure meter (sound pressure level monitor 19001D made by KAIJO Corporation) in a measurement mode to calculate an average value for 5 seconds with a probe (vibration transmission bar with a piezoelectric element) inserted 100 mm deep in the washing liquid 3 from the liquid surface. The average concentration of dissolved oxygen was measured by a commercially available dissolved oxygen meter (LAQUA OM-71 made by Horiba, Ltd.). The weight of the washed metal tubes 2 (load), measurement results, and washing performance evaluation results are shown in TABLE 1.

TABLE 1

	Load (ton)	Cumulative total load (ton)	Average sound pressure (mV)	Average concentration of dissolved oxygen (mg/L)	Density of scale (g/L)	Washing performance
Day 1	43.5	43.5	157	3.93	0.186	Good
Day 2	58.1	101.6	149	3.87	0.166	Good
Day 3	68.2	169.8	155	3.83	0.175	Good
Day 4	41.6	211.4	155	3.55	0.108	Good

[0119] As shown in TABLE 1, on Day 4, the cumulative total load was more than 200 tons. However, the average concentration of oxygen dissolved in the washing liquid 3 was 3.55 mg/L and was maintained at a level not higher than 5.2 mg/L. Also, the density of scale in the washing liquid 3 was 0.108 g/L and did not exceed 2.5 g/L, which is the level at which degradation of washing performance starts. Therefore, the washing performance was kept good for four days. These results show that the washing method and the washing apparatus according to the present disclosure provides high ultrasonic washing performance.

REFERENCE SIGNS LIST

[0120]

- 1: washing apparatus
- 2: metal tube
- 3: washing liquid
- 10: washing tank
- 20: supply mechanism
- 30: discharge mechanism
- 40: ultrasonic radiation mechanism
- 50: fine bubble generation mechanism

Claims

1. A washing method for washing a metal tube, the washing method comprising:

- a storing step of storing a washing liquid in a washing tank;
- a soaking step of soaking the metal tube in the washing liquid in the washing tank while generating fine bubbles from a gas dissolved in the washing liquid in the washing tank and radiating ultrasonic waves into the washing liquid in the washing tank;
- a supplying step of newly supplying the washing liquid to the washing tank; and
- a discharging step of, when a liquid surface of the washing liquid in the washing tank exceeds a predetermined reference liquid surface level, discharging the washing liquid from the washing tank by an amount corresponding to the excess over the predetermined reference liquid surface level.

2. The washing method according to claim 1, wherein in the soaking step, a concentration of oxygen dissolved in the washing liquid in the washing tank is 5.2 mg/L or lower.

3. The washing method according to claim 1 or 2, wherein:

the supplying step is executed in parallel with the soaking step; and
in the supplying step, an amount of supply per minute of the washing liquid to the washing tank is within a range of 0.17% to 1.25% of an amount of the washing liquid stored in the washing tank.

4. The washing method according to claim 3, wherein the amount of supply per minute of the washing liquid to the washing tank is within a range of 0.17% to 0.83% of the amount of the washing liquid stored in the washing tank.

5. The washing method according to claim 4, wherein the amount of supply per minute of the washing liquid to the washing tank is within a range of 0.33% to 0.83% of the amount of the washing liquid stored in the washing tank.

6. The washing method according to any one of claims 1 to 5, wherein the metal tube is a steel tube which has a chemical composition containing, in mass%,

C: 0.01 to 0.13%;

Si: 0.75% or less;

Mn: 2% or less;

P: 0.045% or less;

S: 0.030% or less;

Ni: 7 to 14%; and

Cr: 16 to 20%,

the balance being Fe and impurities.

7. The washing method according to claim 6, wherein the chemical composition contains, in mass%, at least one of Nb: 0.2 to 1.1%, Ti: 0.1 to 0.6%, Mo: 0.1 to 3%, and Cu: 2.5 to 3.5% as substitute for part of Fe in the balance.

8. The washing method according to claim 6 or 7, wherein the chemical composition contains, in mass%, B: 0.001 to 0.1% and N: 0.02 to 0.12% as substitute for part of Fe in the balance.

9. A washing apparatus for washing a metal tube, the washing apparatus comprising:

a washing tank in which a washing liquid is to be stored and the metal tube is to be placed;

a supply mechanism configured to supply the washing liquid to the washing tank;

a discharge mechanism configured to, when a liquid surface of the washing liquid in the washing tank exceeds a predetermined reference liquid surface level, discharge the washing liquid from the washing tank by an amount corresponding to the excess over the predetermined reference liquid surface level;

a fine bubble generation mechanism configured to generate fine bubbles from a gas dissolved in the washing liquid in the washing tank; and

an ultrasonic radiation mechanism configured to radiate ultrasonic waves into the washing liquid in the washing tank.

1

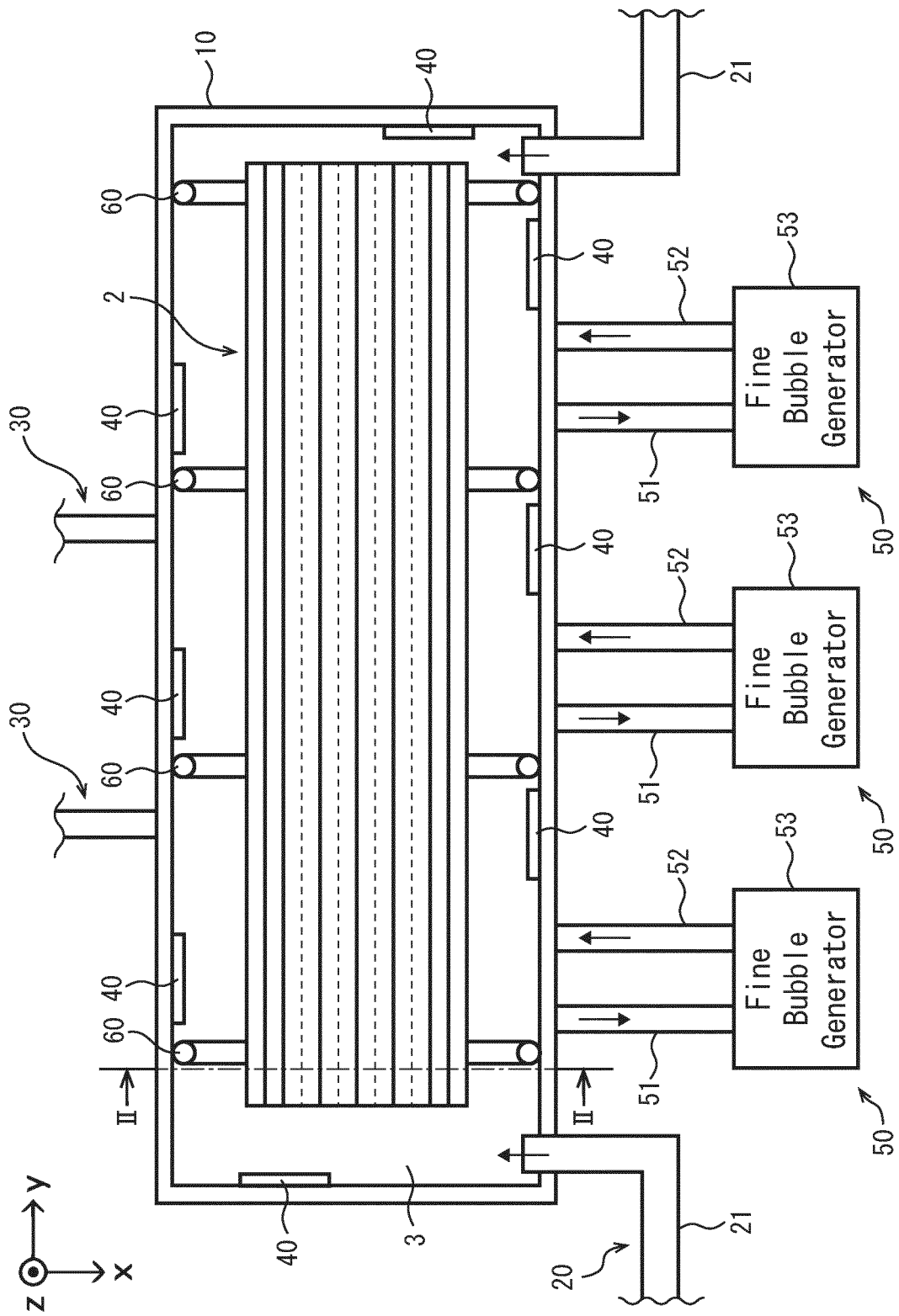


FIG. 1

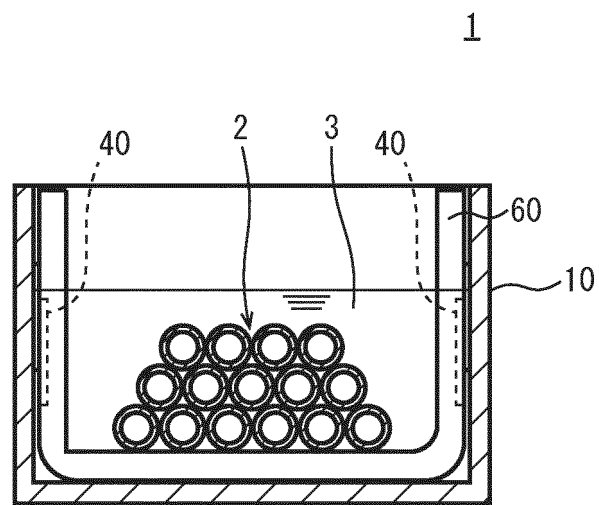


FIG. 2

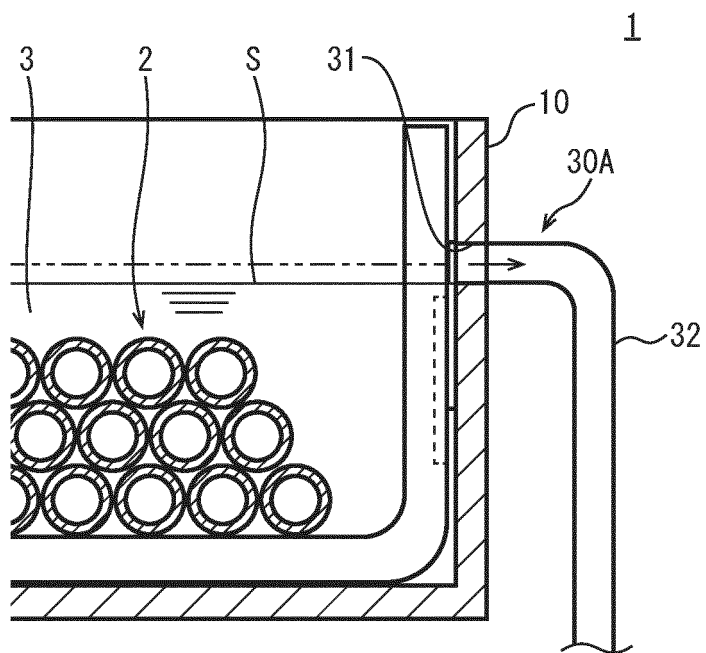


FIG. 3

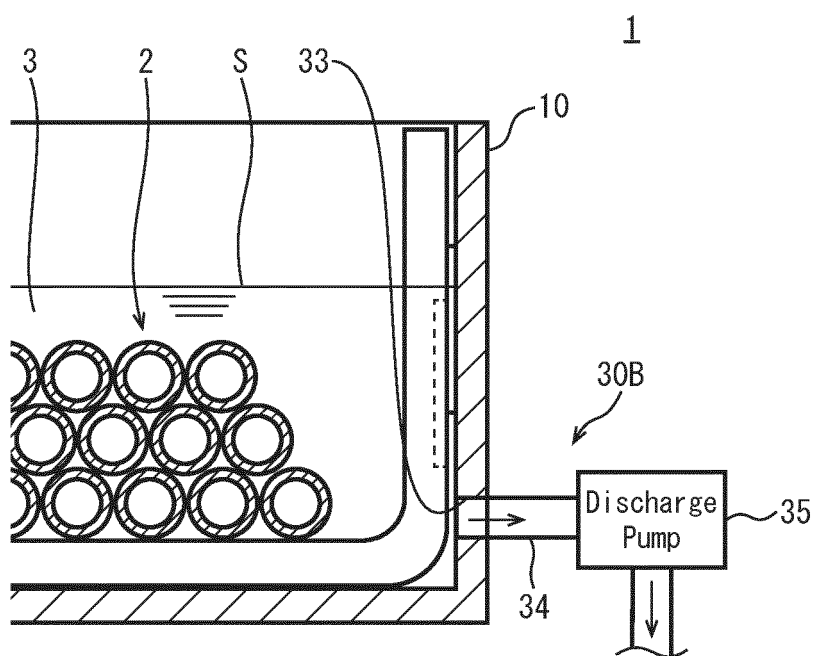


FIG. 4

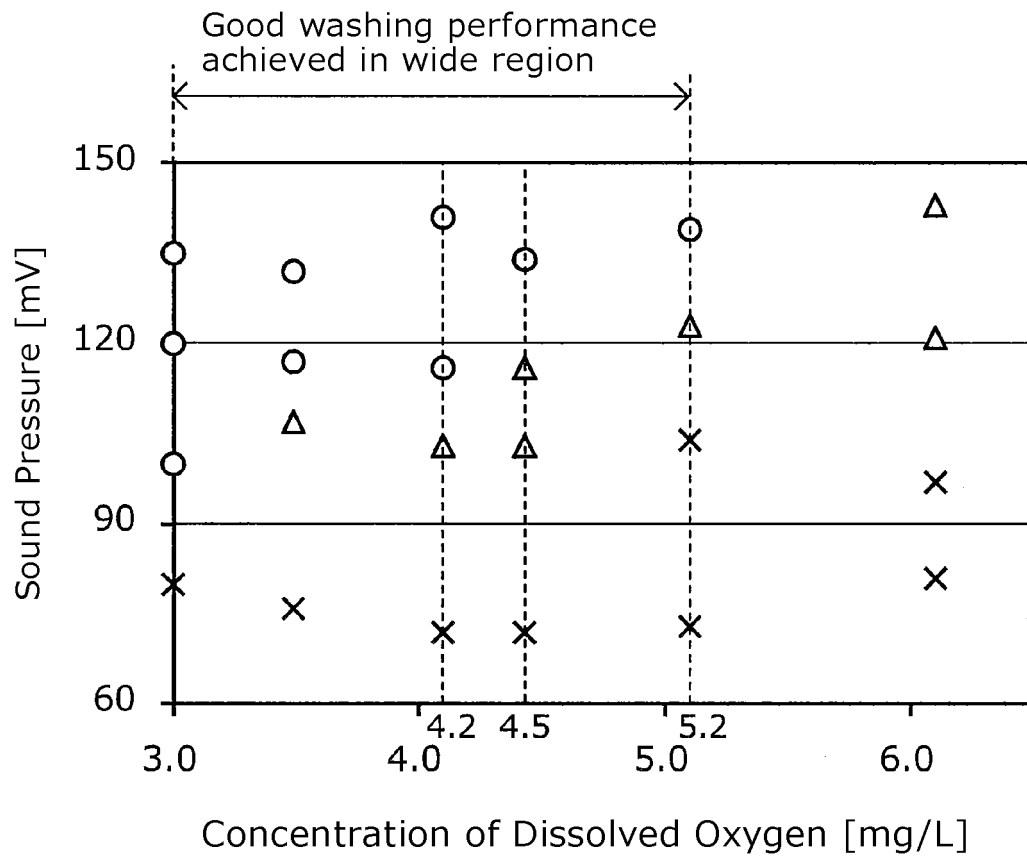


FIG. 5

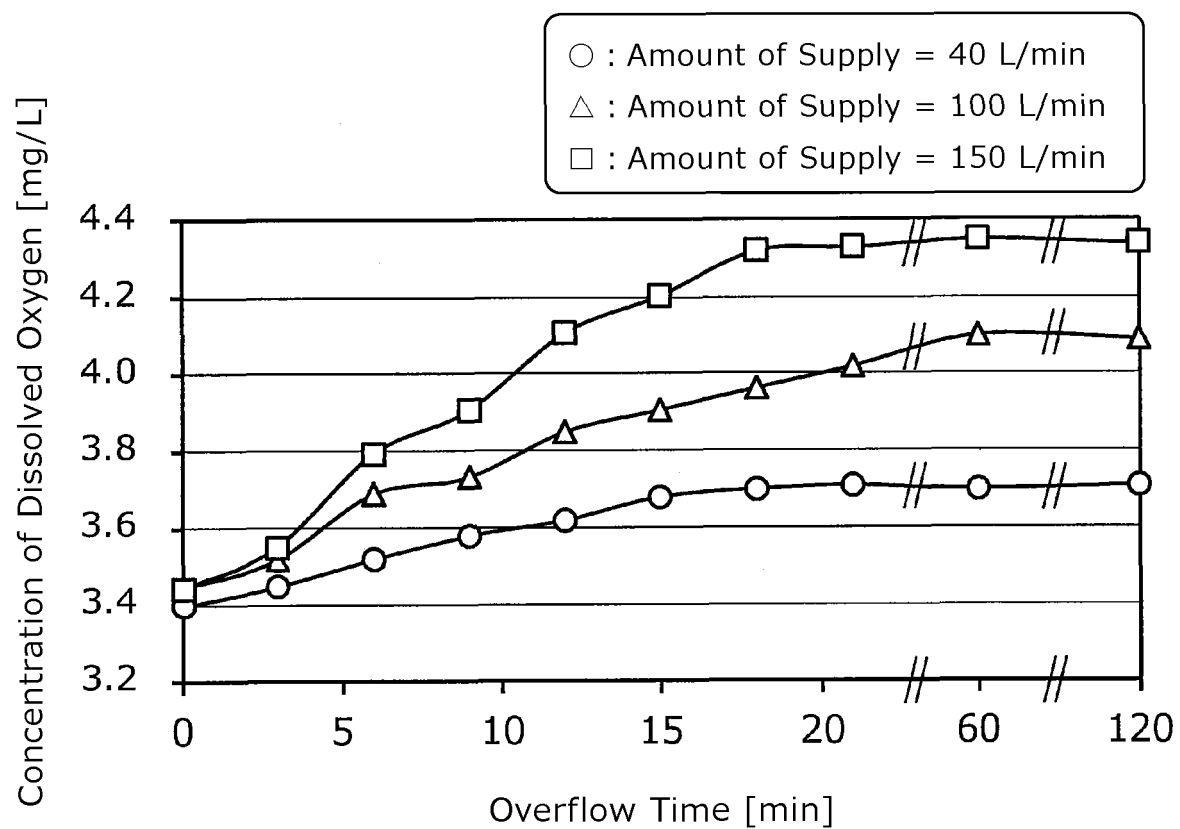


FIG. 6

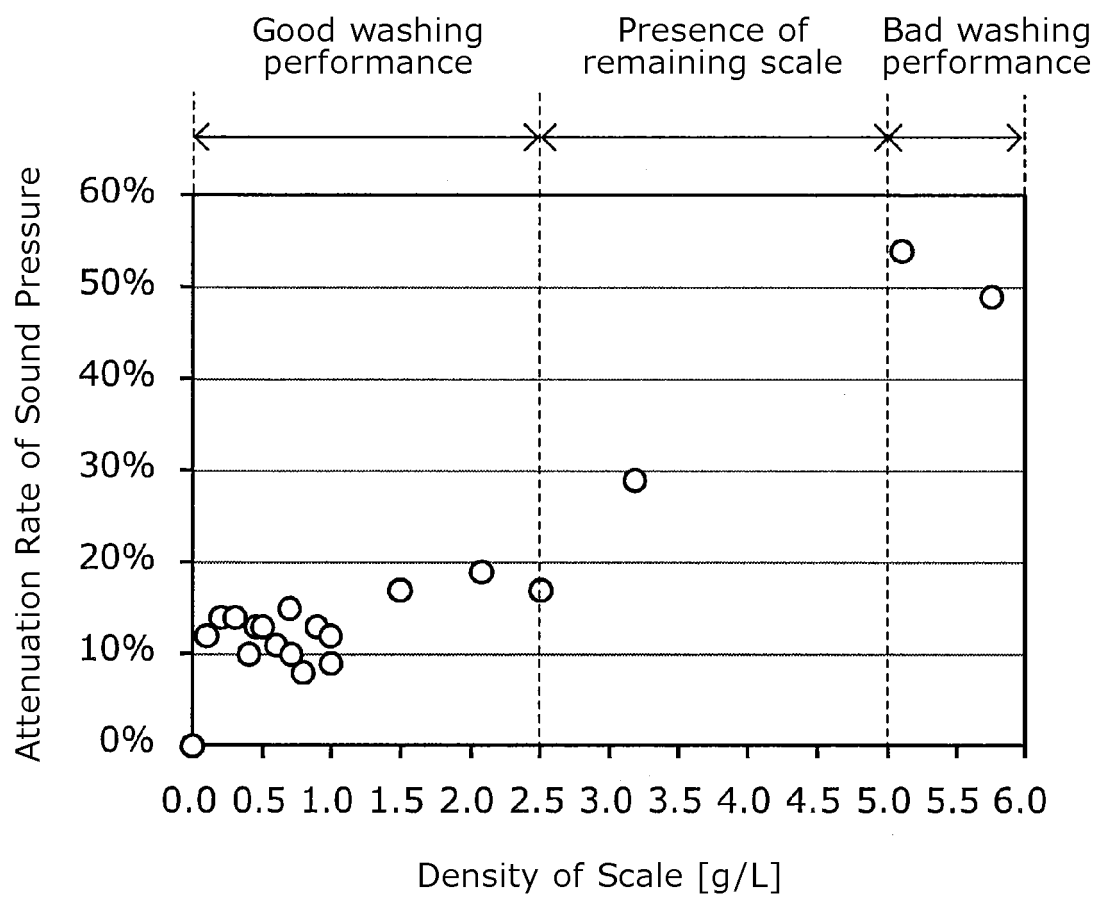


FIG. 7

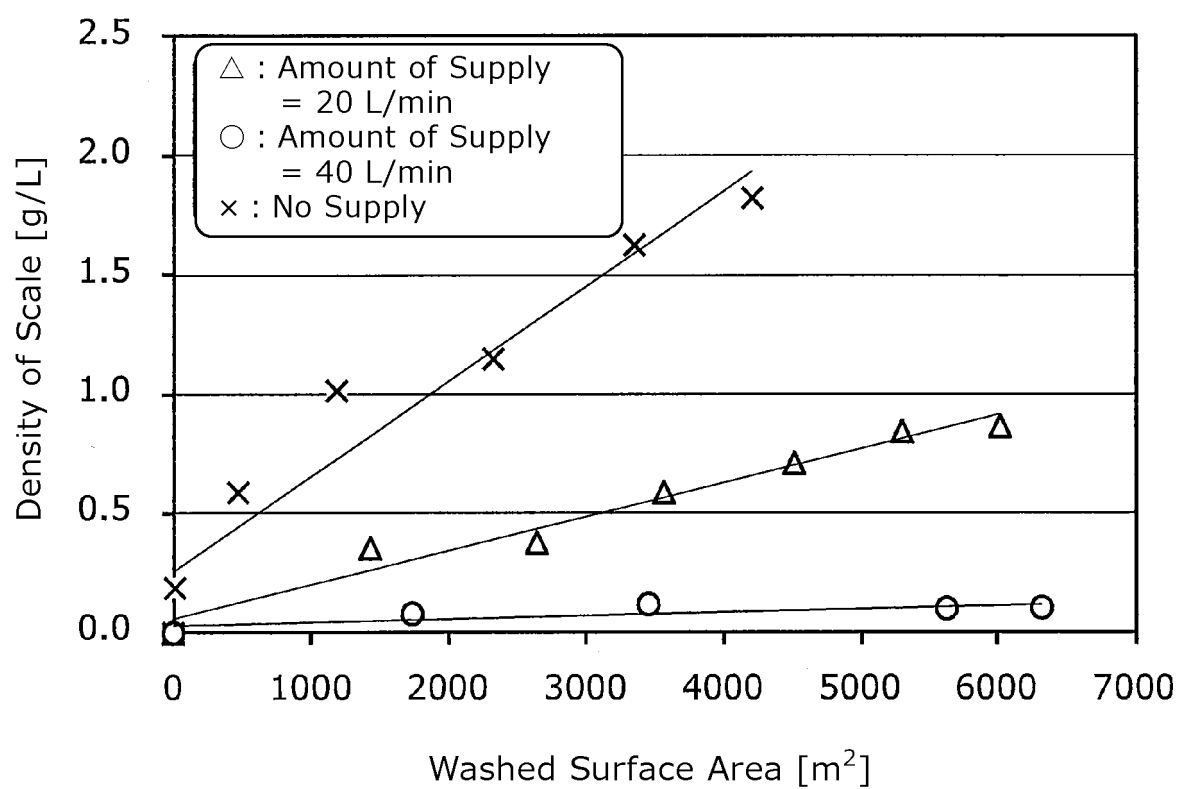


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2019/037730

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. B08B3/12 (2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. B08B3/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2019

Registered utility model specifications of Japan 1996-2019

Published registered utility model applications of Japan 1994-2019

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2018/169050 A1 (NIPPON STEEL CORPORATION) 20 September 2018, paragraphs [0015]-[0018], [0025], [0057]-[0059] (Family: none)	1-9
Y	JP 8-39025 A (OLYMPUS OPTICAL CO., LTD.) 13 February 1996, paragraphs [0014]-[0017] (Family: none)	1-9
A	JP 2016-36785 A (TOYOTA INDUSTRIES CORPORATION) 27 March 2016, paragraphs [0014]-[0051] (Family: none)	1-9



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search
21 November 2019 (21.11.2019)Date of mailing of the international search report
03 December 2019 (03.12.2019)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2007029944 A [0004]