The present invention has been made in light of the aforementioned problem, and an object of the present invention is to provide an ultrasonic cleaning method and an ultrasonic cleaning apparatus by which a high particle removal rate is obtained in a stable manner.

Means for Solving the Problems

The inventors of the present invention have earnestly studied a relationship between the vibration strength of the liquid and the particle removal rate, and as a result, have obtained the following findings. Specifically, the inventors have found that the particle removal rate of the liquid can be increased by cleaning an object to be cleaned while irradiating the liquid with ultrasonic waves so that a ratio determined by dividing a vibration strength of the liquid at a fourth-order frequency of the ultrasonic waves by a vibration strength of the liquid at a fundamental frequency of the ultrasonic waves is larger than 0.8/1000. Accordingly, the inventors of the present invention have arrived at the present invention.

An ultrasonic cleaning method according to an aspect of the present invention is an ultrasonic cleaning method for cleaning an object to be cleaned in a liquid in which a gas is dissolved, by irradiating the liquid with ultrasonic waves, and the method includes the following steps. The liquid in which the gas is dissolved is prepared. The object to be cleaned is cleaned while the liquid is irradiated / applied with the ultrasonic waves so that a ratio determined by dividing a vibration strength of the liquid at a fourth-order frequency that is fourth multiple of a frequency of the ultrasonic waves being applied to said liquid by a vibration strength of the liquid at the ~~a fundamental~~ frequency of the ultrasonic waves is larger than 0.8/1000. Accordingly, a high particle removal rate can be obtained in a stable manner.

sonoluminescence occurs. Accordingly, a high particle removal rate is obtained in a more stable manner.

Preferably, in the ultrasonic cleaning method, the gas is nitrogen and a dissolved gas concentration in the liquid is 5 ppm or more.

An ultrasonic cleaning apparatus according to another aspect of the present invention is an ultrasonic cleaning apparatus for cleaning an object to be cleaned in a liquid in which a gas is dissolved, by irradiating the liquid with ultrasonic waves, and the apparatus includes irradiation means, a container, an adjusting mechanism and a device. The irradiation means is capable of irradiating the liquid with the ultrasonic waves. The container is capable of containing the liquid. The device is capable of measuring a vibration strength of the liquid at a fourth-order frequency that is fourth multiple of a frequency of the ultrasonic waves being applied to the liquid. The adjusting mechanism is capable of adjusting said liquid so that a ratio determined by dividing the vibration strength of said liquid at said fourth-order frequency of said ultrasonic waves by a vibration strength of said liquid at the frequency of said ultrasonic waves is larger than 0.8/1000.

The ultrasonic cleaning apparatus according to the present invention has the device capable of measuring a vibration strength of the liquid at a fourth-order frequency of the ultrasonic waves. Accordingly, the state of the liquid can be confirmed.

Preferably, the ultrasonic cleaning apparatus has an adjusting mechanism capable of realizing a state where bubbles containing the gas continue to be generated in the liquid, based on the vibration strength of the liquid at the fourth-order frequency. Accordingly, the liquid having a high particle removal rate in a stable manner can efficiently be adjusted.

Effects of the Invention

According to the present invention, there can be provided an ultrasonic cleaning method and an ultrasonic cleaning apparatus

Claims

1. An ultrasonic cleaning method for cleaning an object ~~(W)~~ to be cleaned in a liquid in which a gas is dissolved, by irradiating said liquid with ultrasonic waves, the method comprising the steps of:
- preparing said liquid in which said gas is dissolved; and
- cleaning said object ~~(W)~~ to be cleaned while applying said ultrasonic waves to said liquid so that a ratio determined by dividing a vibration strength of said liquid at a fourth-order frequency that is fourth multiple of a frequency of said ultrasonic waves being applied to said liquid by a vibration strength of said liquid at ~~a fundamental~~the frequency of said ultrasonic waves is larger than 0.8/1000.

2. The ultrasonic cleaning method according to claim 1, wherein in said step of cleaning the object ~~(W)~~ to be cleaned, said ultrasonic waves are applied to said liquid so that the vibration strength of said liquid at a fifth-order frequency that is fifth multiple of the frequency of said ultrasonic waves being applied to said liquid is larger than the vibration strength of said liquid at said fourth-order frequency.

3. The ultrasonic cleaning method according to claim 1 or 2, further comprising the step of measuring the vibration strength of said liquid at said fourth-order frequency.

4. The ultrasonic cleaning method according to claim 1 or 2, further comprising the steps of:
- measuring the vibration strength of said liquid at said fourth-order frequency and the vibration strength of said liquid at said ~~fundamental~~ frequency; and
- calculating the ratio between the vibration strength of said liquid at said fourth-order frequency and the vibration strength of said liquid at said ~~fundamental~~ frequency.

5. The ultrasonic cleaning method according to claim 3 or 4, wherein in said step of cleaning the object ~~(W)~~ to be cleaned, said object to be cleaned is cleaned in ~~liquid is adjusted, based on the vibration strength of said liquid at said fourth-order frequency, so that~~ a state where bubbles containing said gas continue to be generated in said liquid ~~is realized~~.

6. The ultrasonic cleaning method according to any one of claims 1 to 5, wherein said step of cleaning the object ~~(W)~~ to be cleaned includes the step in which sonoluminescence occurs.

7. The ultrasonic cleaning method according to any one of claims 1 to 6, wherein said gas is nitrogen and the dissolved gas concentration of said liquid is 5 ppm or more.

8. An ultrasonic cleaning apparatus ~~(100)~~ for cleaning an object ~~(W)~~ to be cleaned in a liquid in which a gas is dissolved, by irradiating said liquid with ultrasonic waves, the apparatus comprising:

irradiation means ~~(30)~~ capable of irradiating said liquid with said ultrasonic waves;

a container ~~(20)~~ capable of containing said liquid; ~~and~~

a device ~~(71)~~ capable of measuring a vibration strength of said liquid at a fourth-order frequency that is fourth multiple of a frequency of said ultrasonic waves being applied to said liquid; and

an adjusting mechanism capable of adjusting said liquid so that a ratio determined by dividing the vibration strength of said liquid at said fourth-order frequency of said ultrasonic waves by a vibration strength of said liquid at the frequency of said ultrasonic waves is larger than 0.8/1000.

9. The ultrasonic cleaning apparatus ~~(100)~~ according to claim 8, ~~comprising an~~wherein said adjusting mechanism ~~(45)~~ is

capable of realizing a state where bubbles containing said gas continue to be generated in said liquid~~, based on the vibration strength of said liquid at said fourth order frequency~~.