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 have earnestly studied a relationship between the refractive index of the liquid and the particle removal rate, and as a result, have obtained the following findings. Specifically, the inventors of the present invention 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 region, where a spatial rate of change of the refractive index of the liquid is large relative to a case where ultrasonic waves are not applied, appears along a direction in which the ultrasonic waves travel. 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. An object to be cleaned is cleaned while the liquid is irradiated with the ultrasonic waves so that a region, where a spatial rate of change of the refractive index of the liquid in which the gas is dissolved is large relative to a case where the ultrasonic waves are not applied, appears along the direction in which the ultrasonic waves travel. In the step of preparing the liquid, a dissolved gas concentration in the liquid is adjusted so that a region, where a spatial rate of change of a refractive index of the liquid in which said gas is dissolved is large relative to a case where the ultrasonic waves are not applied, appears along a direction in which the ultrasonic waves travel. Accordingly, a high particle removal rate can be obtained in a stable manner.

Accordingly, the liquid having a high particle removal rate in a stable manner can efficiently be adjusted.

Preferably, in the ultrasonic cleaning method, the step of cleaning the object to be cleaned includes the step in which 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 applying / irradiating ultrasonic waves to the liquid. The container is capable of containing the liquid. The adjusting mechanism is capable of adjusting the liquid so that a region, where a spatial rate of change of a refractive index of the liquid in which said gas is dissolved is large relative to a case where the ultrasonic waves are not applied, appears along a direction in which the ultrasonic waves travel. The device is capable of measuring a spatial rate of change of a refractive index of the liquid.

The ultrasonic cleaning apparatus according to embodiments of the present invention has the device capable of measuring the spatial rate of change of the refractive index of the liquid. 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. Accordingly, the liquid having a high particle removal rate in a stable manner can efficiently be adjusted.

Effects of the Invention

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 irradiating said liquid with ultrasonic waves so that a region, where a spatial rate of change of a refractive index of said liquid in which said gas is dissolved is large relative to a case where ultrasonic waves are not applied, appears along a direction in which the ultrasonic waves travel.

2. The ultrasonic cleaning method according to claim 1, comprising the step of measuring the spatial rate of change of the refractive index of said liquid.

3. The ultrasonic cleaning method according to claim 2, wherein said step of measuring the spatial rate of change of the refractive index of said liquid includes the step of observing transmitted light having passed through said liquid while applying parallel rays to said liquid, in a state where ultrasonic waves are applied to said liquid.

4. The ultrasonic cleaning method according to claim 2, wherein said step of measuring the spatial rate of change of the refractive index of said liquid includes the steps of:
- observing first transmitted light having passed through said liquid while applying parallel rays to said liquid, in a state where ultrasonic waves are applied to said liquid; and
- observing second transmitted light having passed through said liquid while applying parallel rays to said liquid, in a state where ultrasonic waves are not applied to said liquid.

5. The ultrasonic cleaning method according any one of claims 2 to 4, wherein in said step of cleaning the object (W) to be cleaned, said liquid is adjusted based on said spatial rate of change 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 a 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 ultrasonic waves;
- a container (20) capable of containing said liquid; and
- a device (71) capable of measuring a spatial rate of change of a refractive index of said liquid.

9. The ultrasonic cleaning apparatus (100) according to claim 8, comprising an adjusting mechanism (45) capable of realizing a state where bubbles containing said gas continue to be generated in said liquid, based on said spatial rate of change.

Claims

1. An ultrasonic cleaning method for cleaning an object 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 to be cleaned while irradiating said liquid with said ultrasonic waves so that a region, where a spatial rate of change of a refractive index of said liquid in which said gas is dissolved is large relative to a case where said ultrasonic waves are not applied, appears along a direction in which said ultrasonic waves travel, wherein

in said step of preparing said liquid, a dissolved gas concentration in said liquid is adjusted so that a region, where a spatial rate of change of a refractive index of said liquid in which said gas is dissolved is large relative to a case where said ultrasonic waves are not applied, appears along a direction in which said ultrasonic waves travel.

2. The ultrasonic cleaning method according to claim 1, comprising the step of measuring the spatial rate of change of the refractive index of said liquid.

3. The ultrasonic cleaning method according to claim 2, wherein said step of measuring the spatial rate of change of the refractive index of said liquid includes the step of observing transmitted light having passed through said liquid while applying parallel rays to said liquid, in a state where said ultrasonic waves are applied to said liquid.

4. The ultrasonic cleaning method according to claim 2, wherein said step of measuring the spatial rate of change of the refractive index of said liquid includes the steps of:

- observing first transmitted light having passed through said liquid while applying parallel rays to said liquid, in a state where said ultrasonic waves are applied to said liquid;
- observing second transmitted light having passed through said liquid while applying parallel rays to said liquid, in a state where said ultrasonic waves are not applied to said liquid; and
- comparing brightness of said first transmitted light and brightness of said second transmitted light.

5. The ultrasonic cleaning method according any one of claims 2 to 4, wherein in said step of cleaning the object to be cleaned, said object to be cleaned is cleaned in a state where bubbles containing said gas continue to be generated in said liquid.

6. The ultrasonic cleaning method according to any one of claims 1 to 5, wherein said step of cleaning the object to be cleaned includes a 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 for cleaning an object to be cleaned in a liquid in which a gas is dissolved, by irradiating said liquid with ultrasonic waves, the apparatus comprising:

- irradiation means capable of irradiating said liquid with said ultrasonic waves;
  a container capable of containing said liquid;
  a device capable of measuring a spatial rate of change of a refractive index of said liquid; and
  an adjusting mechanism capable of adjusting said liquid so that a region, where a spatial rate of change of a refractive index of said liquid in which said gas is dissolved is large relative to a case

where said ultrasonic waves are not applied, appears along a direction in which said ultrasonic waves travel.

9. The ultrasonic cleaning apparatus according to claim 8, wherein said adjusting mechanism is capable of realizing a state where bubbles containing said gas continue to be generated in said liquid.