CLAIMS

1. An apparatus for nondestructive detection of one or more transparent or reflective objects in a vessel that is at least partially filled with a fluid, the apparatus comprising:

(a) an imager configured to acquire data that represent light reflected from a plurality of spatial locations in the vessel as a function of time;

(b) a memory operably coupled to the imager and configured to store the data;

and

(c) a processor operably coupled to the memory, the processor configured to detect the objects based on the data by:

(i) identifying a respective maximum amount of reflected light for each location in the plurality of locations, and

(ii) determining a presence or absence of the objects in the vessel based on the number of spatial locations whose respective maximum amount of reflected light exceeds a predetermined value.

2. The apparatus of claim 1, wherein the vessel has a bottom, and further comprising:

a light source configured to illuminate the bottom of the vessel.

3. The apparatus of claim 1, wherein the vessel contains a protein aggregate, and wherein the processor is further configured to distinguish the objects from the protein aggregate based on the data.

4. The apparatus of claim 1, wherein the processor is further configured to estimate at least one of an average size of the objects, a size distribution of the objects, and a number of the objects.

5. The apparatus of claim 1, wherein the processor is further configured to distinguish the object from other types of particles based on a variation in the amount of reflected light as a function of time.

6. The apparatus of claim 5, wherein the processor is further configured to identify at least one other type of particle in the vessel using the data and additional data representing light transmitted through the vessel.

7. The apparatus of claim 1, wherein the objects comprise glass lamellae.

8. A method of nondestructive detection of transparent or reflective objects in a vessel that is at least partially filled with a fluid, the method comprising:

(a) identifying a respective maximum amount of reflected light for each location in a plurality of locations in the vessel based on data representing light reflected from a plurality of spatial locations as a function of time; and

(b) determining a presence or absence of the objects in the vessel based on the number of spatial locations whose respective maximum amount of reflected light exceeds a predetermined value.

9. The method of claim 8, wherein the vessel has a bottom, and further comprising:

illuminating the bottom of the vessel; and

acquiring the data representing light reflected from the plurality of spatial locations.

10. The method of claim 8, wherein the vessel contains a protein aggregate, and further comprising:

distinguishing the objects from the protein aggregate on the basis of the data.

11. The method of claim 8, further comprising:

estimating at least one of an average size of the objects, a size distribution of the objects, and a number of the objects.

12. The method of claim 8, further comprising:

distinguishing the objects from another type of particle based on a variation in the amount of reflected light as a function of time.

13. The method of claim 8, further comprising:

identifying at least one other type of particle in the vessel using the data and additional data representing light transmitted through the vessel.

14. The method of claim 8, wherein the objects comprise glass lamellae.

15. A computer program product for nondestructive detection of transparent or reflective objects in a vessel that is at least partially filled with a fluid, the computer program product comprising nonvolatile, machine-readable instructions, which, when executed by a processor, cause the processor to:

(a) identify a respective maximum amount of reflected light for each location in a plurality of locations in the vessel based on data representing light reflected from a plurality of spatial locations as a function of time; and

(b) determine a presence or absence of the objects in the vessel based on the number of spatial locations whose respective maximum amount of reflected light exceeds a predetermined value.

16. An apparatus for nondestructive detection of an undissolved particle in a vessel that is at least partially filled with a fluid, wherein the vessel comprises a transparent tubular vessel wall disposed about a longitudinal axis, the apparatus comprising:

an imager configured to acquire one or more images of the particle in the fluid, the imager comprising at least one imaging optical element positioned to image the particle onto the sensor;

an illumination source positioned at least partially within a plane passing through the vessel and substantially orthogonal to the longitudinal axis of the vessel, the illumination source arranged to substantially eliminate the presence of light rays emitted from the source that reflect or refract from a surface of the vessel wall and are imaged by the at least one optical element onto the sensor.

17. The apparatus of claim 16, wherein the illumination source is located in a region outside of the vessel that would be substantially free of any back-propagating rays extending

from the sensor, through the at least one imaging optical element, and subsequently through the vessel.

18. The apparatus of claim 17 wherein the at least one optical element comprises a telecentric lens.

19. The apparatus of claim 18, wherein the transparent tubular vessel wall comprises a cylindrical wall, and wherein the longitudinal axis corresponds to an axis of symmetry of the cylindrical wall.

20. The apparatus of claim 19, wherein an optic axis of the imager extends through the vessel substantially orthogonal to and intersecting with the longitudinal axis of the vessel.

21 The apparatus of claim 18, wherein the imager is configured to acquire time-series data representing a trajectory of the particle in the fluid, the apparatus further comprising:

(a) a memory operably coupled to the imager and configured to store the time-series data; and

(b) a processor operably coupled to the memory, the processor configured to detect the particle by:

(i) reversing a time ordering of the time-series data to form reversed time-series data;

(ii) estimating the trajectory of the particle from the reversed time-series data; and

(iii) determining a presence or type of the particle based on the estimated trajectory of the particle.

22. A method for nondestructive detection of an undissolved particle in a vessel that is at least partially filled with a fluid, wherein the vessel comprises a transparent tubular vessel wall disposed about a longitudinal axis, the method comprising:

using an imager to acquire one or more images of the particle in the fluid, the imager comprising at least one imaging optical element positioned to image the particle onto the sensor; and

illuminating the vessel with an illumination source positioned at least partially within a plane passing through the vessel and substantially orthogonal to the longitudinal axis of the vessel, the illumination source arranged to substantially eliminate the presence of light rays emitted from the source that reflect or refract from a surface of the vessel wall and are imaged by the at least one optical element onto the sensor.

23. The method of claim 22, wherein illuminating the vessel includes illuminating the vessel using the illumination source located in a region outside of the vessel that is substantially free of any back-propagating rays extending from the sensor, through the at least one optical element, and subsequently through the vessel.

24. The method of claim 23, wherein the at least one optical element comprises a telecentric lens.

25. The method of claim 24, wherein the transparent tubular vessel wall comprises a cylindrical wall, and wherein the longitudinal axis corresponds to an axis of symmetry of the cylindrical wall.

26. The method of claim 25, wherein an optic axis of the imager extends through the vessel substantially orthogonal to and intersecting with the longitudinal axis of the vessel.

27. The method of claim 26, comprising:

using the imager to acquire time-series data representing a trajectory of the particle in the fluid; and

detecting the particle by:

(i) reversing a time ordering of the time-series data to form reversed time-series data;

(ii) estimating the trajectory of the particle from the reversed time-series data; and

(iii) determining a presence or type of the particle based on the estimated trajectory of the particle.