CLAIMS

1. An apparatus for nondestructive detection of an undissolved particle in a vessel that is at least partially filled with a fluid, comprising:

a sensor;

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; and

an illumination source positioned to illuminate contents of the vessel for imaging by the imager while substantially eliminating a presence of light rays emitted from the illumination source that reflect or refract from a surface of the vessel and are imaged by the at least one optical element onto the sensor.

2. The apparatus of claim 1, wherein the illumination source is located in a region that is substantially free of back-propagating rays extending from the sensor, through the at least one imaging optical element, and subsequently through the vessel.

3. The apparatus of claim 2, wherein the at least one optical element comprises a telecentric lens.

4. The apparatus of claim 1, wherein an optical axis of the imager is positioned to extend through the vessel substantially orthogonal to and intersecting with a longitudinal axis of the vessel, the longitudinal axis corresponding to an axis of symmetry of the vessel.

5. The apparatus of claim 1, 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 and 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 trajectory.

6. A method for nondestructive detection of an undissolved particle in a vessel that is at least partially filled with a fluid, 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 a sensor; and

illuminating the vessel with an illumination source positioned to illuminate contents of the vessel for imaging by the imager while substantially eliminating a presence of light rays emitted from the illumination source that reflect or refract from a surface of the vessel and are imaged by the at least one optical element onto the sensor.

7. The method of claim 6, wherein the illumination source is located in a region that is substantially free of back-propagating rays extending from the sensor, through the at least one optical element, and subsequently through the vessel.

8. The method of claim 7, wherein the at least one optical element comprises a telecentric lens.

9. The method of claim 6, wherein an optical axis of the imager extends through the vessel substantially orthogonal to and intersecting with a longitudinal axis of the vessel, the longitudinal axis corresponding to an axis of symmetry of the vessel.

10. The method of claim 6, further 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 trajectory.

11. A non-transitory computer-readable medium storing instructions that, when executed by a processor, cause the processor to perform nondestructive detection of an undissolved particle in a vessel that is at least partially filled with a fluid by:

causing 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 a sensor; and

causing illumination of the vessel via an illumination source positioned to illuminate contents of the vessel for imaging by the imager while substantially eliminating a presence of light rays emitted from the illumination source that reflect or refract from a surface of the vessel and are imaged by the at least one optical element onto the sensor.

12. The non-transitory computer-readable medium of claim 11, wherein the illumination source is located in a region that is substantially free of back-propagating rays extending from the sensor, through the at least one optical element, and subsequently through the vessel.

13. The non-transitory computer-readable medium of claim 12, wherein the at least one optical element comprises a telecentric lens.

14. The non-transitory computer-readable medium of claim 11, wherein an optical axis of the imager extends through the vessel substantially orthogonal to and intersecting with a longitudinal axis of the vessel, the longitudinal axis corresponding to an axis of symmetry of the vessel.

15. The non-transitory computer-readable medium of claim 11, further including instructions that, when executed by the processor, cause the imager to acquire time-series data representing a trajectory of the particle in the fluid, and 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 trajectory.