CLAIMS

1. 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.

2. The apparatus of claim 1, 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.

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

4. The apparatus of claim 3, 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.

5. The apparatus of claim 4, wherein an optic axis of the imager extends through the vessel substantially orthogonal to and intersecting with the longitudinal axis of the vessel.

6. The apparatus of claim 3, 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.

7. 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.

8. The method of claim 7, 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.

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

10. The method of claim 9, 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.

11. The method of claim 10, wherein an optic axis of the imager extends through the vessel substantially orthogonal to and intersecting with the longitudinal axis of the vessel.

12. The method of claim 11, 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.