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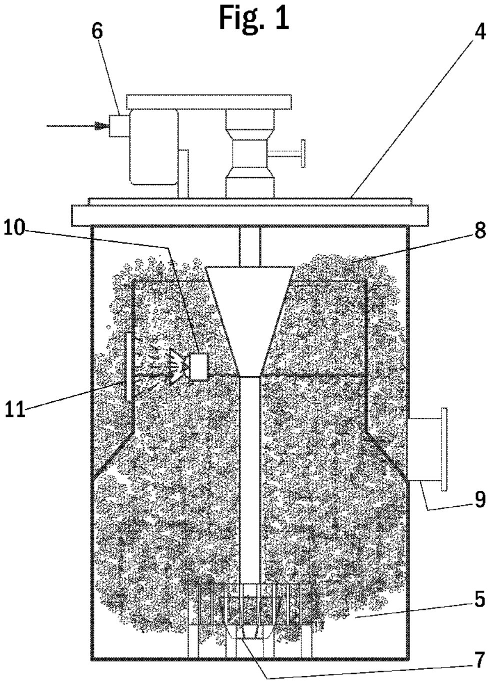
[Continued on next page]

(54) **Title**: A METHOD AND AN ARRANGEMENT FOR MONITORING OF A METALLURGICAL FROTH FLOTATION PROCESS IN A METALLURGICAL FLOTATION CELL

Fig. 1



(57) **Abstract**: The present invention relates to the field of mineral engineering and metallurgy and metallurgical technologies in general and to extraction of metal compounds from ores or concentrates by metallurgical processes, and more particularly to a method and an arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell. An arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell (4) according to the present invention comprises at least one X-ray tube (10), (12), (14), (16), said at least one X-ray tube (10), (12), (14), (16) being arranged to transmit X-ray radiation into said metallurgical flotation cell (4); at least one X-ray sensor unit (11), (13), (15), (17) arranged to detect X-ray radiation travelling inside said metallurgical flotation cell (4); and a sensor data processing unit, which said sensor data processing unit provides a two- or three dimensional image related to the attenuation of X-rays by the process slurry (5) and metallurgical flotation froth (8) inside said metallurgical flotation cell (4) based on the detected X-ray radiation data; wherein at least one of said at least one X-ray tube (10), (12), (14), (16) and at least one X-ray sensor unit (11), (13), (15), (17) is arranged inside said metallurgical flotation cell (4).

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A METHOD AND AN ARRANGEMENT FOR MONITORING OF A METALLURGICAL FROTH FLOTATION PROCESS IN A METALLURGICAL FLOTATION CELL

FIELD OF THE INVENTION

The present invention relates to the field of mineral engineering and metallurgy and metallurgical technologies in general and to extraction of metal compounds from ores or concentrates by metallurgical processes, and more particularly to a method and an arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell.

BACKGROUND OF THE INVENTION

Metallurgical flotation, such as e.g. metallurgical froth flotation is a method of performing a separation of valuable minerals from gangue or ore by taking advantage of differences in their hydrophobicity. According to known methods of controlling and operating a flotation cell in a metallurgical froth flotation process, there can be an operator observing the flotation cell and manually or otherwise adjusting the different inputs to the flotation cell. This can be for example adding additional chemicals and/or changing the gas flow rate into the cell, according to his or her observations. Typically the mentioned adjustments are empirical, based particularly on observation of the froth surface and its behavior. It is also known from prior art that instead of human visual observation an optical image analysis system based on a video camera can be used to measure froth characteristics on the surface of the flotation froth layer. However, such methods of adjustment are often very imprecise. Furthermore, changes in certain visual aspects of flotation froth do not correspond necessarily to variation in quality or performance of the froth flotation process.

In general, there are several problems with the prior art solutions for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell. So far, the measuring solutions are relatively troublesome and difficult to process. Also the measurement reliability with the prior art measuring solutions has not been adequate enough.

The problem therefore is to find a solution for an adequate measuring arrangement in a metallurgical froth flotation process which can provide continuously reliable measurement data for monitoring the metallurgical froth flotation process in a metallurgical flotation cell.

There is a demand in the market for a method for monitoring the metallurgical froth flotation process in a metallurgical flotation cell which method would be continuous, reliable and informative measurement when compared to the prior art solutions. Likewise, there is a demand in the market for an arrangement for monitoring the metallurgical froth flotation process in a metallurgical flotation cell which arrangement would be reliable and informative measurement when compared to the prior art solutions.

BRIEF DESCRIPTION OF THE INVENTION

An object of the present invention is thus to provide a method and an apparatus for implementing the method so as to overcome the above problems and to alleviate the above disadvantages.

The objects of the invention are achieved by a method for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell, which method comprises the steps of:

- transmitting X-ray radiation into said metallurgical flotation cell by at least one X-ray tube;

- detecting X-ray radiation travelled inside said metallurgical flotation cell by at least one X-ray sensor unit; and

- providing a two- or three-dimensional image related to the attenuation of X-rays by the process slurry and/or metallurgical flotation froth inside said metallurgical flotation cell based on the detected X-ray radiation data;

wherein at least one of said at least one X-ray tube and said at least one X-ray sensor unit is arranged inside said metallurgical flotation cell.

Preferably, the method comprises the step of:

- controlling said metallurgical froth flotation process based on the detected X-ray radiation data.

Preferably, the method comprises the step of:

-feeding a gas stream to the bottom part of the metallurgical flotation cell.

Further preferably, said gas stream is an air stream, a nitrogen stream, an oxygen enriched air stream or a depleted air stream.

Furthermore, the objects of the invention are achieved by an arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell, which said arrangement comprises:

- at least one X-ray tube, said at least one X-ray tube being arranged to transmit X-ray radiation into said metallurgical flotation cell, and

- at least one X-ray sensor unit arranged to detect X-ray radiation travelling inside said metallurgical flotation cell; and

- a sensor data processing unit, which said sensor data processing unit provides a two- or three-dimensional image related to the attenuation of X-rays by the process slurry and metallurgical flotation froth inside said metallurgical flotation cell based on the detected X-ray radiation data;

wherein at least one of said at least one X-ray tube or at least one X-ray sensor unit is arranged inside said metallurgical flotation cell.

Preferably, said arrangement comprises a sensor data processing unit, which said sensor data processing unit controls said metallurgical froth flotation process based on the detected X-ray radiation data.

Preferably, phase boundaries, solids densities and/or bubble sizes in the process slurry and metallurgical flotation froth inside said metallurgical flotation cell is/are calculated based on the detected X-ray radiation data. Preferably, the water content and/or solids content of the process slurry and metallurgical flotation froth at different heights in said metallurgical flotation cell is/are calculated based on the detected X-ray radiation data

Preferably, the X-rays from said at least one X-ray tube are collimated into a narrow beam in at least one dimension when propagating inside said metallurgical flotation cell. Further preferably, said at least one X-ray tubeis arranged to move or turn in order to transmit X-ray radiation in multiple directions. Preferably, said at least one X-ray sensor unit is arranged to move or turn.

Preferably, at least one of said at least one X-ray tube and said at least one X-ray sensor unit is attached at a frame structure of said metallurgical flotation cell. Further preferably, at least one of said at least one X-ray tube and said at least one X-ray sensor unit is attached outside said frame structure of said metallurgical flotation cell and that said frame structure is manufactured of material, which does not absorb the X-rays and allows at least 1 %, preferably at least 5 %, more preferably at least 30 %, of the X-ray radiation to travel through said frame structure of said metallurgical flotation cell. Alternatively, at least one of said at least one X-ray tube and said at least one X-ray sensor unit is attached outside said frame structure of said metallurgical flotation cell and that the frame structure of said metallurgical flotation cell comprises one or more window portions, which said one or more window portions are manufactured of material, which does not absorb the X-rays and allows at least 1 %, preferably at least 5 %, more preferably at least 30 %, of the X-ray radiation to travel through the frame structure of said metallurgical flotation cell.

Preferably, said at least one X-ray tube and said at least one X-ray sensor unit are realized as at least one X-ray measurement unit. Alternatively, said at least one X-ray tube and said at least one X-ray sensor unit are realized as at least one movable X-ray measurement unit.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a cross-sectional view of one embodiment of a metallurgical flotation cell according to the present invention;

Figure 2 shows a cross-sectional view of another embodiment of a metallurgical flotation cell according to the present invention;

Figure 3 shows a cross-sectional view of a third embodiment of a metallurgical flotation cell according to the present invention; and

Figure 4 shows a cross-sectional view of a fourth embodiment of a metallurgical flotation cell according to the present invention.

The prior art drawings of Figure 1 has been presented earlier. In the following, the invention will be described in greater detail by means of preferred embodiments with reference to the accompanying drawings of Figures 1 to 4.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a method and an arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell.

Metallurgical froth flotation is a method of performing a separation of valuable minerals from gangue by taking advantage of differences in their hydrophobicity. Mineral particles, ground to suitable fineness and flowing in aqueous slurry, are conditioned using chemicals that enhance the hydrophobicity differences between valuable minerals and waste gangue. The conditioned slurry is led to a metallurgical flotation cell where air is dispersed into the slurry as small bubbles. The hydrophobic particles selectively adhere to the bubbles and are carried to the surface and removed as a froth overflow from the flotation machine, while the particles that remain wetted stay in the slurry phase. Metallurgical froth flotation can be adapted to a broad range of mineral separations, as it is possible to use various chemical treatments to alter mineral surfaces so that they have the necessary properties for the separation.

Figure 1 shows a cross-sectional view of one embodiment of a metallurgical flotation cell according to the present invention. A metallurgical flotation cell 4 according to the present embodiment is a large container having a diameter ranging from 1 meter to 10 meters. In a froth flotation process according to the present embodiment process slurry 5 containing e.g. crushed and ground ore is fed to said metallurgical flotation cell 4. In the metallurgical flotation cell 4 according to the present embodiment there is a gas feed 6 for feeding gas, e.g. air or nitrogen to the slurry 5 from the bottom part of said metallurgical flotation cell 4. Said gas feed 6, e.g. air feed 6 can be arranged through a rotating impeller and a stationary stator arranged in the bottom part of said metallurgical flotation cell 4. In said gas feed 6 the shearing forces between said rotating impeller and said stationary stator break the gas feed 6 into small bubbles of dispersed gas stream 7, e.g. dispersed air stream 7.

As said small bubbles of dispersed gas stream 7, e.g. dispersed air stream 7 travels upwards in the process slurry 5 the particles in the process slurry 5 that have a hydrophobic surface will stick to the gas bubbles and rise to the surface. Respectively the particles in the process slurry 5 that have a hydrophilic surface will not stick to the gas bubbles and will remain in the slurry.

Said small bubbles of dispersed gas carrying said particles having hydrophobic surfaces rise on top of the process slurry 5 and form a froth layer 8 on the top part of said metallurgical flotation cell 4. Said froth layer 8 extends from a pulp-froth interface to a bursting surface, which is typically above an overflow lip of said metallurgical flotation cell 4. A term “froth depth” can be defined as the distance between said pulp-froth interface and said overflow lip. Respectively a term “froth height” can be defined as the distance from said overflow lip to said bursting surface.

The froth in said froth layer 8 can be arranged to overflow over said overflow lip and through a froth collecting outlet 9 of said metallurgical flotation cell 4. There can be both hydrophobic and hydrophilic particles present in said collected froth. Typically, in mineral froth flotation, it is the hydrophobic particles which are the desired product, and are intended to be recovered from said collected froth.

The remaining underflow of the process slurry 5 in said metallurgical flotation cell 4 is commonly referred to as the tailings of the froth flotation process. It is known that several controllable parameters can contribute to the performance quality of a froth flotation process. These controllable parameters include the tailings flow rate from the flotation cell 4, pH of the froth flotation process slurry 5, the concentration of various chemicals added to the flotation cell 4, solids concentration in the froth flotation process slurry 5 and gas flow rate into the flotation cell 4. However, the presence of this many controllable parameters make quantitative control of froth flotation processes difficult.

One of the most important parameters affecting the performance of the froth flotation process is the depth of the froth layer 8. Also the consistence of the froth layer 8, in particular the amount of hydrophobic and hydrophilic particles present in said froth layer 8 affects the performance of the froth flotation process.

In the arrangement for monitoring a metallurgical froth flotation process in a metallurgical flotation cell according to the present embodiment said metallurgical flotation cell 4 comprises process slurry 5 mixed with an air stream 7 or with a gas stream 7. Furthermore, the arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell 4 comprises at least one X-ray tube 10. In the present embodiment said at least one X-ray tube 10 is arranged inside said metallurgical flotation cell 4. Said at least one X-ray tube 10 is arranged to transmit X-ray radiation into said metallurgical flotation cell 4. Said X-ray tube 10 is an X-ray tube suitable for X-ray imaging. Said X-ray tube 10 may have a point focus and may be equipped with a collimator that limits the X-ray beam to a desired direction and minimizes radiation to other directions.

The arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell according to the present embodiment comprises at least one X-ray sensor unit 11, said at least one X-ray sensor unit 11 opposing said at least one X-ray tube 10. In the present embodiment said at least one X-ray sensor unit 11 is attached at a frame structure of said metallurgical flotation cell 4. Said at least one X-ray sensor unit 11 is arranged to detect X-ray radiation travelling inside said metallurgical flotation cell 4. Said X-ray sensor unit 11 is an X-ray sensor unit suitable for X-ray imaging. Said X-ray sensor unit 11 may comprise at least two, preferably more than 31, more preferably more than 127, detectors that measure the intensity of X-ray radiation.

In the arrangement for monitoring a metallurgical froth flotation process in a metallurgical flotation cell according to the present embodiment said at least one X-ray sensor unit 11 is attached to said frame structure so that said at least one X-ray sensor unit 11 is outside said metallurgical flotation cell 4. The frame structure of said metallurgical flotation cell 4 may be manufactured of material, which does not absorb the X-rays and allows at least 1 %, preferably at least 5 %, more preferably at least 30 %, of the X-ray radiation to travel through the frame structure of said metallurgical flotation cell 4. Alternatively, the frame structure of said metallurgical flotation cell 4 may comprise one or more window portions, which said one or more window portions are manufactured of material, which does not absorb the X-rays and allows at least 1 %, preferably at least 5 %, more preferably at least 30 %, of the X-ray radiation to travel through the frame structure of said metallurgical flotation cell 4. Said one or more window portions may be manufactured of polymeric material, glass, aluminium, ceramics or composite.

In an alternative embodiment of an arrangement for monitoring a metallurgical froth flotation process in a metallurgical flotation cell said at least one X-ray sensor unit 11 is arranged inside said metallurgical flotation cell 4 and said at least one X-ray tube 10 is attached at a frame structure of said metallurgical flotation cell 4.

In the arrangement for monitoring a metallurgical froth flotation process in a metallurgical flotation cell according to the present embodiment the X-rays from said at least one X-ray tube 10 may be collimated into a narrow beam in at least one dimension when propagating inside said metallurgical flotation cell 4 thus minimizing the amount of radiation to other directions than the detector. Furthermore, said at least one X-ray tube10 may be arranged to move or turn in order to transmit X-ray radiation in multiple directions.

In the embodiment presented in Figure 1 at least one X-ray sensor unit 11 of said metallurgical flotation cell 4 detects X-ray radiation transmitted by said opposing at least one X-ray tube 10, said X-ray radiation travelling inside said metallurgical flotation cell 4.

From the detected X-ray radiation data a sensor data processing unit can provide a two-dimensional image related to the attenuation of X-rays by the metallurgical slurry inside said metallurgical flotation cell 4. Furthermore, said at least one X-ray sensor unit 11 may be arranged to move or turn in order to sense and provide a two- or three-dimensional image based on the detected X-ray radiation data.

Said image provided by said at least one X-ray sensor unit 11 gives information for the calculation, monitoring and controlling of process, e.g. tailings flow rate from the flotation cell 4, pH of the froth flotation process slurry 5, the concentration of various chemicals added to the flotation cell 4, solids concentration in the froth flotation process slurry 5 and gas flow rate into the flotation cell 4. Furthermore, said image provided by said at least one X-ray sensor unit 11 gives information for the calculation for measurement of the phase boundaries, particle densities and/or particle sizes in the process slurry 5 and metallurgical flotation froth 8 inside said metallurgical flotation cell 4.

Furthermore, the water content and/or solids content of the process slurry 5 and metallurgical flotation froth at different heights in said metallurgical flotation cell 4 may be calculated based on the information provided by said at least one X-ray sensor unit 11. Determining the water content and/or solids content of the process slurry 5 online with the help of said image provided by said at least one X-ray sensor unit 11 gives an opportunity to follow the process behaviour, to detect abnormal situations and to make corrective actions in time. Online measurement will also give a long time average measurement result instead of an instantaneous indication.

In order to monitor and control the process, e.g. tailings flow rate from the flotation cell 4, pH of the froth flotation process slurry 5, the concentration of various chemicals added to the flotation cell 4, solids concentration in the froth flotation process slurry 5 and gas flow rate into the flotation cell 4, it is useful to measure the phase boundary between the process slurry 5 and the metallurgical flotation froth 8. The diameter of the metallurgical flotation cell 4 may range from 2 meters to 100 meters, typically from 5 meters to 40 meters. The bed height of the metallurgical flotation cell 4 may range from 2 meters to 10 meters, typically from 3 meters to 5 meters.

Figure 2 shows a cross-sectional view of another embodiment of a metallurgical flotation cell according to the present invention. A metallurgical flotation cell 4 according to the present another embodiment is a large container having a diameter ranging from 2 meters to 100 meters. In a froth flotation process according to the present another embodiment process slurry 5 containing e.g. crushed and ground ore is fed to said metallurgical flotation cell 4. There is a gas feed 6 for feeding gas, e.g. air or nitrogen to the slurry 5 from the bottom part of said metallurgical flotation cell 4 arranged through a rotating impeller and a stationary stator arranged in the bottom part of said metallurgical flotation cell 4. In said gas feed 6 the shearing forces between said rotating impeller and said stationary stator break the gas feed 6 into small bubbles of dispersed gas stream 7, e.g. dispersed air stream 7. As said small bubbles of dispersed gas stream 7, e.g. dispersed air stream 7 travels upwards in the process slurry 5 the particles in the process slurry 5 that have a hydrophobic surface will stick to the gas bubbles and rise to the surface and the particles in the process slurry 5 that have a hydrophilic surface will not stick to the gas bubbles and will remain in the slurry.

Said small bubbles of dispersed gas carrying said particles having hydrophobic surfaces rise on top of the process slurry 5 and form a froth layer 8 on the top part of said metallurgical flotation cell 4. Said froth layer 8 extends from a pulp-froth interface to a bursting surface, which is typically above an overflow lip of said metallurgical flotation cell 4. The froth in said froth layer 8 can be arranged to overflow over said overflow lip and through a froth collecting outlet 9 of said metallurgical flotation cell 4.

The arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell 4 comprises at least one X-ray tube 12. In the present another embodiment said at least one X-ray tube 12 is arranged inside said metallurgical flotation cell 4. Said at least one X-ray tube 12 is arranged to transmit X-ray radiation into said metallurgical flotation cell 4. Said X-ray tube 12 is an X-ray tube suitable for X-ray imaging. Said X-ray tube 12 may have a point focus and may be equipped with a collimator that limits the X-ray beam to a desired direction.

The arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell according to the present another embodiment comprises at least one X-ray sensor unit 13, said at least one X-ray sensor unit 13 opposing said at least one X-ray tube 12. In the present another embodiment said at least one X-ray sensor unit 13 is attached at a frame structure of said metallurgical flotation cell 4. Said at least one X-ray sensor unit 13 is arranged to detect X-ray radiation travelling inside said metallurgical flotation cell 4. Said X-ray sensor unit 13 is an X-ray sensor unit suitable for X-ray imaging. Said X-ray sensor unit 13 may comprise at least two, preferably more than 31, more preferably more than 127, detectors that measure the intensity of X-ray radiation.

In the arrangement for monitoring a metallurgical froth flotation process in a metallurgical flotation cell according to the present another embodiment said at least one X-ray sensor unit 13 is attached to said frame structure so that said at least one X-ray sensor unit 13 is outside said metallurgical flotation cell 4. In an alternative embodiment of an arrangement for monitoring a metallurgical froth flotation process in a metallurgical flotation cell said at least one X-ray sensor unit 13 is arranged inside said metallurgical flotation cell 4 and said at least one X-ray tube 12 is attached at a frame structure of said metallurgical flotation cell 4.

In the arrangement for monitoring a metallurgical froth flotation process in a metallurgical flotation cell according to the present another embodiment the X-rays from said at least one X-ray tube 12 may be collimated into a narrow beam in at least one dimension when propagating inside said metallurgical flotation cell 4 thus minimizing the amount of radiation other directions than the detector. Furthermore, said at least one X-ray tube12 may be arranged to move or turn in order to transmit X-ray radiation in multiple directions.

In the another embodiment presented in Figure 2 at least one X-ray sensor unit 13 of said metallurgical flotation cell 4 detects an X-ray radiation transmitted by said opposing at least one X-ray tube 12, said X-ray radiation travelling inside said metallurgical flotation cell 4. From the detected X-ray radiation data a sensor data processing unit can provide a two-dimensional image related to the attenuation of X-rays by the metallurgical slurry inside said metallurgical flotation cell 4. Furthermore, said at least one X-ray sensor unit 13 may be arranged to move or turn in order to sense and provide a two- or three-dimensional image based on the detected X-ray radiation data.

Said image provided by said at least one X-ray sensor unit 13 gives information for the calculation, monitoring and controlling of process, e.g. tailings flow rate from the flotation cell 4, pH of the froth flotation process slurry 5, the concentration of various chemicals added to the flotation cell 4, solids concentration in the froth flotation process slurry 5 and gas flow rate into the flotation cell 4. Furthermore, said image provided by said at least one X-ray sensor unit 13 gives information for the calculation for measurement of the phase boundaries, particle densities and/or particle sizes in the process slurry 5 and metallurgical flotation froth 8 inside said metallurgical flotation cell 4.

Furthermore, the water content and/or solids content of the process slurry 5 and metallurgical flotation froth at different heights in said metallurgical flotation cell 4 may be calculated based on the information provided by said at least one X-ray sensor unit 13. Determining the water content and/or solids content of the process slurry 5 online with the help of said image provided by said at least one X-ray sensor unit 13 gives an opportunity to follow the process behaviour, to detect abnormal situations and to make corrective actions in time. Online measurement will also give a long time average measurement result instead of an instantaneous indication.

In order to monitor and control the process, e.g. tailings flow rate from the flotation cell 4, pH of the froth flotation process slurry 5, the concentration of various chemicals added to the flotation cell 4, solids concentration in the froth flotation process slurry 5 and gas flow rate into the flotation cell 4, it is useful to measure the phase boundary between the process slurry 5 and the metallurgical flotation froth 8. The diameter of the metallurgical flotation cell 4 may range from 2 meters to 100 meters, typically from 5 meters to 40 meters. The bed height of the metallurgical flotation cell 4 may range from 2 meters to 10 meters, typically from 3 meters to 5 meters.

Figure 3 shows a cross-sectional view of a third embodiment of a metallurgical flotation cell according to the present invention. A metallurgical flotation cell 4 according to the present a third embodiment is a large container having a diameter ranging from 2 meters to 100 meters. In a froth flotation process according to the present a third embodiment process slurry 5 containing e.g. crushed and ground ore is fed to said metallurgical flotation cell 4. There is a gas feed 6 for feeding gas, e.g. air or nitrogen to the slurry 5 from the bottom part of said metallurgical flotation cell 4 arranged through a rotating impeller and a stationary stator arranged in the bottom part of said metallurgical flotation cell 4. In said gas feed 6 the shearing forces between said rotating impeller and said stationary stator break the gas feed 6 into small bubbles of dispersed gas stream 7, e.g. dispersed air stream 7. As said small bubbles of dispersed gas stream 7, e.g. dispersed air stream 7 travels upwards in the process slurry 5 the particles in the process slurry 5 that have a hydrophobic surface will stick to the gas bubbles and rise to the surface and the particles in the process slurry 5 that have a hydrophilic surface will not stick to the gas bubbles and will remain in the slurry.

Said small bubbles of dispersed gas carrying said particles having hydrophobic surfaces rise on top of the process slurry 5 and form a froth layer 8 on the top part of said metallurgical flotation cell 4. Said froth layer 8 extends from a pulp-froth interface to a bursting surface, which is typically above an overflow lip of said metallurgical flotation cell 4. The froth in said froth layer 8 can be arranged to overflow over said overflow lip and through a froth collecting outlet 9 of said metallurgical flotation cell 4.

The arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell 4 comprises at least one X-ray tube 14. In the present a third embodiment said at least one X-ray tube 14 is arranged inside said metallurgical flotation cell 4. Said at least one X-ray tube 14 is arranged to transmit X-ray radiation into said metallurgical flotation cell 4. Said X-ray tube 14 is an X-ray tube suitable for X-ray imaging. Said X-ray tube 14 may have a point focus and may be equipped with a collimator that limits the X-ray beam to a desired direction.

The arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell according to the present a third embodiment comprises at least one X-ray sensor unit 15, said at least one X-ray sensor unit 15 opposing said at least one X-ray tube 14. In the present a third embodiment said at least one X-ray sensor unit 15 is also arranged inside said metallurgical flotation cell 4. Said at least one X-ray sensor unit 15 is arranged to detect X-ray radiation travelling inside said metallurgical flotation cell 4. Said X-ray sensor unit 15 is an X-ray sensor unit suitable for X-ray imaging. Said X-ray sensor unit 15 may comprise at least two, preferably more than 31, more preferably more than 127, detectors that measure the intensity of X-ray radiation.

In the arrangement for monitoring a metallurgical froth flotation process in a metallurgical flotation cell according to the present a third embodiment the X-rays from said at least one X-ray tube 14 may be collimated into a narrow beam in at least one dimension when propagating inside said metallurgical flotation cell 4 thus minimizing the amount of radiation other directions than the detector. Furthermore, said at least one X-ray tube14 may be arranged to move or turn in order to transmit X-ray radiation in multiple directions.

In the a third embodiment presented in Figure 3 at least one X-ray sensor unit 15 of said metallurgical flotation cell 4 detects an X-ray radiation transmitted by said opposing at least one X-ray tube 14, said X-ray radiation travelling inside said metallurgical flotation cell 4. From the detected X-ray radiation data a sensor data processing unit can provide a two-dimensional image related to the attenuation of X-rays by the metallurgical slurry inside said metallurgical flotation cell 4 based on the detected X-ray radiation data. Furthermore, said at least one X-ray sensor unit 15 may be arranged to move or turn in order to sense and provide a two- or three-dimensional image. Said at least one X-ray tube 10 and the at least one X-ray sensor unit 11 may be realized as at least one X-ray measurement unit.

Said image provided by said at least one X-ray sensor unit 15 gives information for the calculation, monitoring and controlling of process, e.g. tailings flow rate from the flotation cell 4, pH of the froth flotation process slurry 5, the concentration of various chemicals added to the flotation cell 4, solids concentration in the froth flotation process slurry 5 and gas flow rate into the flotation cell 4. Furthermore, said image provided by said at least one X-ray sensor unit 15 gives information for the calculation for measurement of the phase boundaries, particle densities and/or particle sizes in the process slurry 5 and metallurgical flotation froth 8 inside said metallurgical flotation cell 4.

Furthermore, the water content and/or solids content of the process slurry 5 and metallurgical flotation froth at different heights in said metallurgical flotation cell 4 may be calculated based on the information provided by said at least one X-ray sensor unit 15. Determining the water content and/or solids content of the process slurry 5 online with the help of said image provided by said at least one X-ray sensor unit 15 gives an opportunity to follow the process behaviour, to detect abnormal situations and to make corrective actions in time. Online measurement will also give a long time average measurement result instead of an instantaneous indication.

In order to monitor and control the process, e.g. tailings flow rate from the flotation cell 4, pH of the froth flotation process slurry 5, the concentration of various chemicals added to the flotation cell 4, solids concentration in the froth flotation process slurry 5 and gas flow rate into the flotation cell 4, it is useful to measure the phase boundary between the process slurry 5 and the metallurgical flotation froth 8. The diameter of the metallurgical flotation cell 4 may range from 2 meters to 100 meters, typically from 5 meters to 40 meters. The bed height of the metallurgical flotation cell 4 may range from 2 meters to 10 meters, typically from 3 meters to 5 meters.

Figure 4 shows a cross-sectional view of a fourth embodiment of a metallurgical flotation cell according to the present invention. A metallurgical flotation cell 4 according to the present a fourth embodiment is a large container having a diameter ranging from 2 meters to 100 meters. In a froth flotation process according to the present a fourth embodiment process slurry 5 containing e.g. crushed and ground ore is fed to said metallurgical flotation cell 4. There is a gas feed 6 for feeding gas, e.g. air or nitrogen to the slurry 5 from the bottom part of said metallurgical flotation cell 4 arranged through a rotating impeller and a stationary stator arranged in the bottom part of said metallurgical flotation cell 4. In said gas feed 6 the shearing forces between said rotating impeller and said stationary stator break the gas feed 6 into small bubbles of dispersed gas stream 7, e.g. dispersed air stream 7. As said small bubbles of dispersed gas stream 7, e.g. dispersed air stream 7 travels upwards in the process slurry 5 the particles in the process slurry 5 that have a hydrophobic surface will stick to the gas bubbles and rise to the surface and the particles in the process slurry 5 that have a hydrophilic surface will not stick to the gas bubbles and will remain in the slurry.

Said small bubbles of dispersed gas carrying said particles having hydrophobic surfaces rise on top of the process slurry 5 and form a froth layer 8 on the top part of said metallurgical flotation cell 4. Said froth layer 8 extends from a pulp-froth interface to a bursting surface, which is typically above an overflow lip of said metallurgical flotation cell 4. The froth in said froth layer 8 can be arranged to overflow over said overflow lip and through a froth collecting outlet 9 of said metallurgical flotation cell 4.

The arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell 4 comprises at least one X-ray tube 16. In the present a fourth embodiment said at least one X-ray tube 16 is arranged inside said metallurgical flotation cell 4. Said at least one X-ray tube 16 is arranged to transmit X-ray radiation into said metallurgical flotation cell 4. Said X-ray tube 16 is an X-ray tube suitable for X-ray imaging. Said X-ray tube 16 may have a point focus and may be equipped with a collimator that limits the X-ray beam to a desired direction.

The arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell according to the present a fourth embodiment comprises at least one X-ray sensor unit 17, said at least one X-ray sensor unit 17 opposing said at least one X-ray tube 16. In the present a fourth embodiment said at least one X-ray sensor unit 17 is also arranged inside said metallurgical flotation cell 4. Said at least one X-ray sensor unit 17 is arranged to detect X-ray radiation travelling inside said metallurgical flotation cell 4. Said X-ray sensor unit 17 is an X-ray sensor unit suitable for X-ray imaging. Said X-ray sensor unit 17 may comprise at least two, preferably more than 31, more preferably more than 127, detectors that measure the intensity of X-ray radiation.

In the arrangement for monitoring a metallurgical froth flotation process in a metallurgical flotation cell according to the present a fourth embodiment the X-rays from said at least one X-ray tube 16 may be collimated into a narrow beam in at least one dimension when propagating inside said metallurgical flotation cell 4 thus minimizing the amount of radiation to other directions than the detector. Furthermore, said at least one X-ray tube16 may be arranged to move or turn in order to transmit X-ray radiation in multiple directions.

In the a fourth embodiment presented in Figure 4 at least one X-ray sensor unit 17 of said metallurgical flotation cell 4 detects X-ray radiation transmitted by said opposing at least one X-ray tube 16, said X-ray radiation travelling inside said metallurgical flotation cell 4. From the detected X-ray radiation data a sensor data processing unit can provide a two-dimensional image related to the attenuation of X-rays by the metallurgical slurry inside said metallurgical flotation cell 4 based on the detected X-ray radiation data. Furthermore, said at least one X-ray sensor unit 17 may be arranged to move or turn in order to sense and provide a two- or three-dimensional image. Said at least one X-ray tube 10 and the at least one X-ray sensor unit 11 may be realized as at least one movable X-ray measurement unit.

Said image provided by said at least one X-ray sensor unit 17 gives information for the calculation, monitoring and controlling of process, e.g. tailings flow rate from the flotation cell 4, pH of the froth flotation process slurry 5, the concentration of various chemicals added to the flotation cell 4, solids concentration in the froth flotation process slurry 5 and gas flow rate into the flotation cell 4. Furthermore, said image provided by said at least one X-ray sensor unit 17 gives information for the calculation for measurement of the phase boundaries, particle densities and/or particle sizes in the process slurry 5 and metallurgical flotation froth 8 inside said metallurgical flotation cell 4.

Furthermore, the water content and/or solids content of the process slurry 5 and metallurgical flotation froth at different heights in said metallurgical flotation cell 4 may be calculated based on the information provided by said at least one X-ray sensor unit 17. Determining the water content and/or solids content of the process slurry 5 online with the help of said image provided by said at least one X-ray sensor unit 17 gives an opportunity to follow the process behaviour, to detect abnormal situations and to make corrective actions in time. Online measurement will also give a long time average measurement result instead of an instantaneous indication.

In order to monitor and control the process, e.g. tailings flow rate from the flotation cell 4, pH of the froth flotation process slurry 5, the concentration of various chemicals added to the flotation cell 4, solids concentration in the froth flotation process slurry 5 and gas flow rate into the flotation cell 4, it is useful to measure the phase boundary between the process slurry 5 and the metallurgical flotation froth 8. The diameter of the metallurgical flotation cell 4 may range from 2 meters to 100 meters, typically from 5 meters to 40 meters. The bed height of the metallurgical flotation cell 4 may range from 2 meters to 10 meters, typically from 3 meters to 5 meters.

The solution for monitoring of a metallurgical froth flotation process according to the present invention provides a continuous measurement of a metallurgical froth flotation in a metallurgical flotation cell, which is highly insensitive to dirt or contamination. The solution for monitoring of a metallurgical froth flotation process according to the present invention provides reliable, online measurement data for the monitoring of the metallurgical froth flotation process.

With the help of the solution according to the present invention the manufacturers and owners of metallurgical flotation cells will be able to provide a metallurgical flotation cell with a measurement arrangement producing more reliable measurement data for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell. The solution according to the present invention may be utilised in any kind of a metallurgical flotation cell.

It will be obvious to a person skilled in the art that, as the technology advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.

CLAIMS

1. A method for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell (4) **characterized** by that the method comprises the steps of:

- transmitting X-ray radiation into said metallurgical flotation cell (4) by at least one X-ray tube (10), (12), (14), (16); and

- detecting X-ray radiation travelled inside said metallurgical flotation cell (4) by at least one X-ray sensor unit (11), (13), (15), (17); and

- providing a two- or three-dimensional image related to the attenuation of X-rays by the process slurry (5) and/or metallurgical flotation froth (8) inside said metallurgical flotation cell (4) based on the detected X-ray radiation data;

wherein at least one of said at least one X-ray tube (10), (12), (14), (16) and said at least one X-ray sensor unit (11), (13), (15), (17) is arranged inside said metallurgical flotation cell (4).

2. A method according to claim 1, **characterized** in that the method comprises the step of:

- controlling said metallurgical froth flotation process based on the detected X-ray radiation data.

3. A method according to claim 1 or to claim 2, **characterized** in that the method comprises the step of:

- feeding said metallurgical flotation cell (4) with process slurry (5).

4. A method according to any one of claims 1 to 3, **characterized** in that the method comprises the step of:

- feeding a gas stream (7) to the bottom part of the metallurgical flotation cell (4).

5. A method according to claim 4, **characterized** in that said gas stream (7) is an air stream (7), a nitrogen stream (7), an oxygen enriched air stream (7) or a depleted air stream (7).

6. An arrangement for monitoring of a metallurgical froth flotation process in a metallurgical flotation cell (4), **characterized** in that said arrangement comprises:

- at least one X-ray tube (10), (12), (14), (16), said at least one X-ray tube (10), (12), (14), (16) being arranged to transmit X-ray radiation into said metallurgical flotation cell (4),

- at least one X-ray sensor unit (11), (13), (15), (17) arranged to detect X-ray radiation travelling inside said metallurgical flotation cell (4); and

- a sensor data processing unit, which said sensor data processing unit provides a two- or three dimensional image related to the attenuation of X-rays by the process slurry (5) and metallurgical flotation froth (8) inside said metallurgical flotation cell (4) based on the detected X-ray radiation data;

wherein at least one of said at least one X-ray tube (10), (12), (14), (16) or at least one X-ray sensor unit (11), (13), (15), (17) is arranged inside said metallurgical flotation cell (4).

7. An arrangement according to claim 6, **characterized** in that said arrangement comprises a sensor data processing unit, which said sensor data processing unit controls said metallurgical froth flotation process based on the detected X-ray radiation data.

8. An arrangement according to claim 6 or to claim 7, **characterized** in that phase boundaries, solids densities and/or bubble sizes in the process slurry (5) and metallurgical flotation froth (8) inside said metallurgical flotation cell (4) is/are calculated based on the detected X-ray radiation data.

9. An arrangement according to any one of claims 6 to 8, **characterized** in that the water content and/or solids content of the process slurry (5) and metallurgical flotation froth (8) at different heights in said metallurgical flotation cell (4) is/are calculated based on the detected X-ray radiation data.

10. An arrangement according to any one of claims 6 to 9, **characterized** in that the X-rays from said at least one X-ray tube (10), (12), (14), (16) are collimated into a narrow beam in at least one dimension when propagating into said metallurgical flotation cell (4).

11. An arrangement according to claim 10, **characterized** in that said at least one X-ray tube(10), (12), (14), (16) is arranged to move or turn in order to transmit X-ray radiation in multiple directions.

12. An arrangement according to any one of claims 6 to 11, **characterized** in that said at least one X-ray sensor unit (11), (13), (15), (17) is arranged to move or turn.

13. An arrangement according to any one of claims 6 to 12, **characterized** in that at least one of said at least one X-ray tube (10),

(12), (14), (16) and said at least one X-ray sensor unit (11), (13), (15), (17) is attached at a frame structure of said metallurgical flotation cell (4).

14. An arrangement according to claim 13, **c h a r a c t e r i z e d** in that at least one of said at least one X-ray tube (10), (12), (14), (16) and said at least one X-ray sensor unit (11), (13), (15), (17) is attached outside said frame structure of said metallurgical flotation cell (4) and that said frame structure is manufactured of material, which does not absorb the X-rays and allows at least 1 %, preferably at least 5 %, more preferably at least 30 %, of the X-ray radiation to travel through said frame structure of said metallurgical flotation cell (4).

15. An arrangement according to claim 13, **c h a r a c t e r i z e d** in that at least one of said at least one X-ray tube (10), (12), (14), (16) and said at least one X-ray sensor unit (11), (13), (15), (17) is attached outside said frame structure of said metallurgical flotation cell (4) and that the frame structure of said metallurgical flotation cell (4) comprises one or more window portions, which said one or more window portions are manufactured of material, which does not absorb the X-rays and allows at least 1 %, preferably at least 5 %, more preferably at least 30 %, of the X-ray radiation to travel through the frame structure of said metallurgical flotation cell (4).

16. An arrangement according to any one of claims 6 to 15, **c h a r a c t e r i z e d** in that said at least one X-ray tube (10), (12), (14), (16) and said at least one X-ray sensor unit (11), (13), (15), (17) are realized as at least one X-ray measurement unit.

17. An arrangement according to any one of claims 6 to 15, **c h a r a c t e r i z e d** in that said at least one X-ray tube (10), (12), (14), (16) and said at least one X-ray sensor unit (11), (13), (15), (17) are realized as at least one movable X-ray measurement unit.

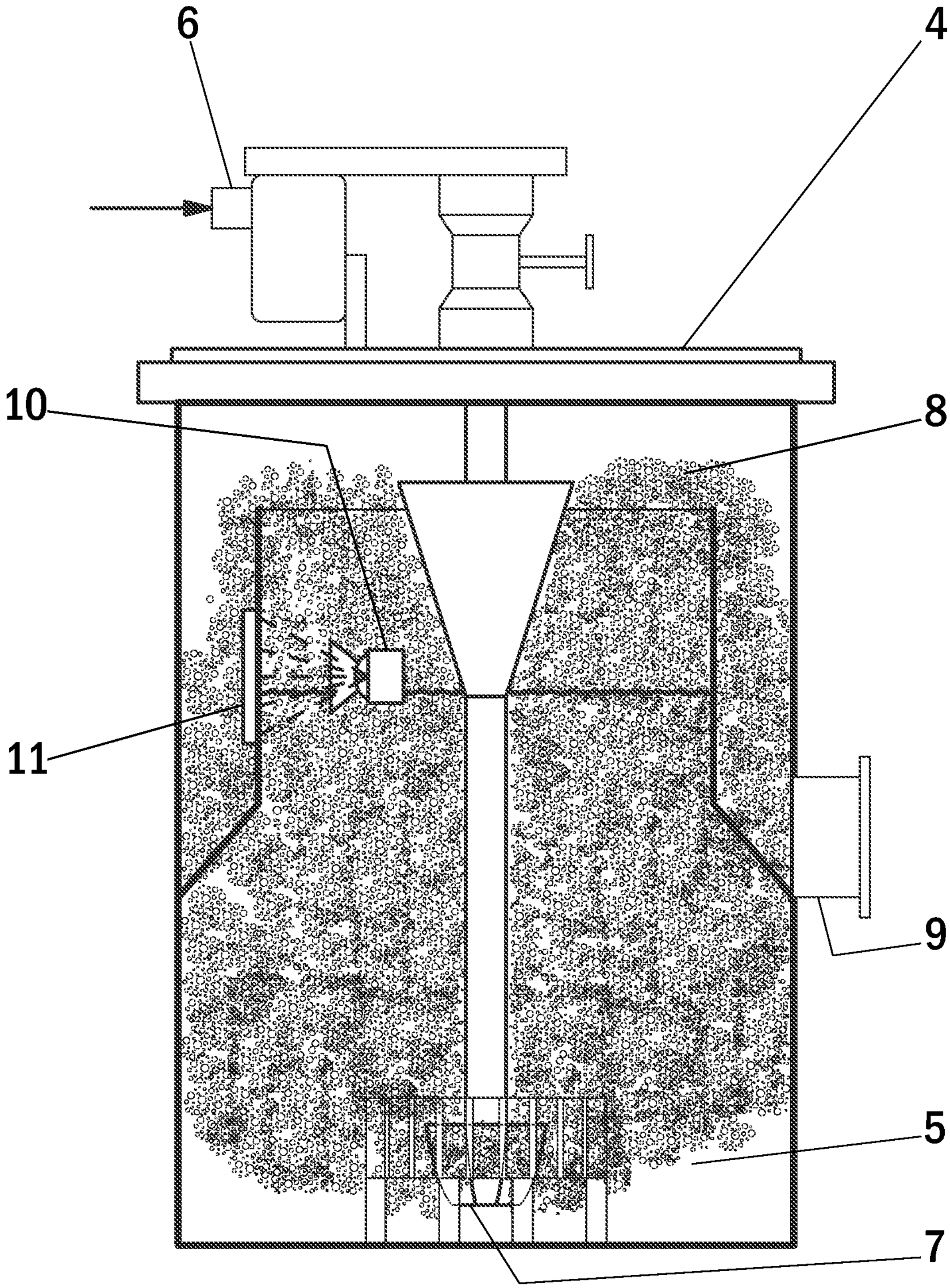

Fig. 1

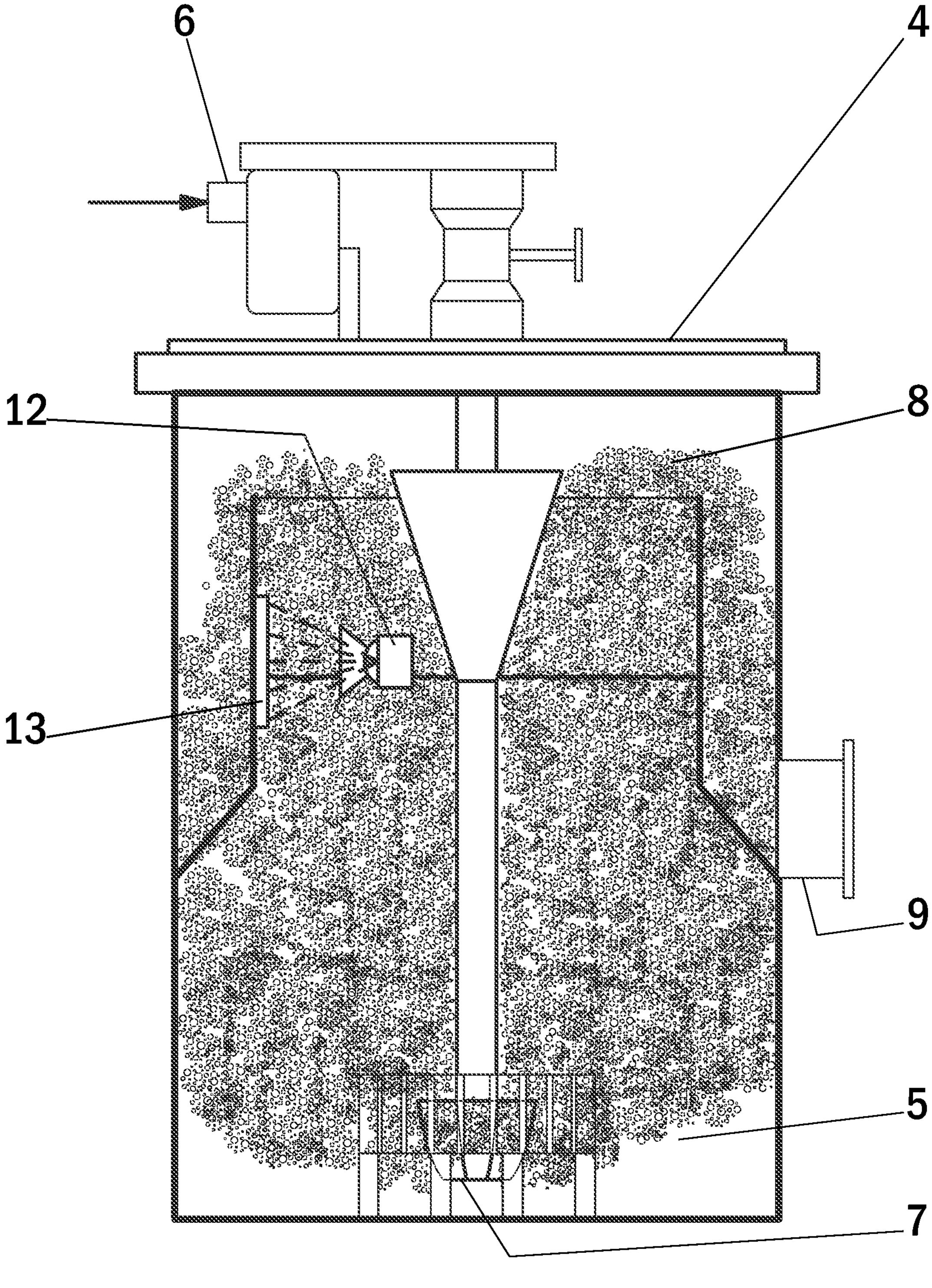

Fig. 2

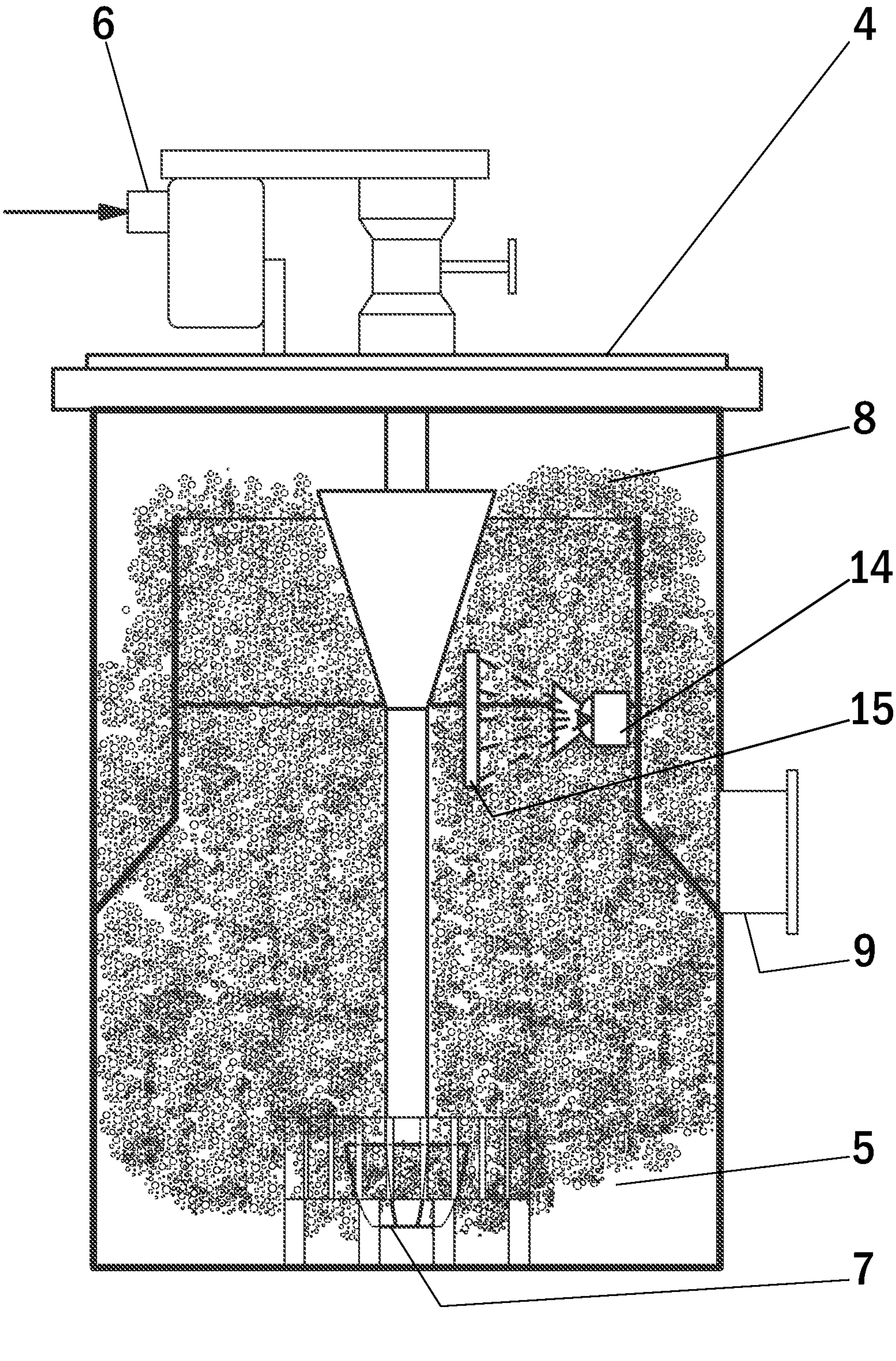

Fig. 3

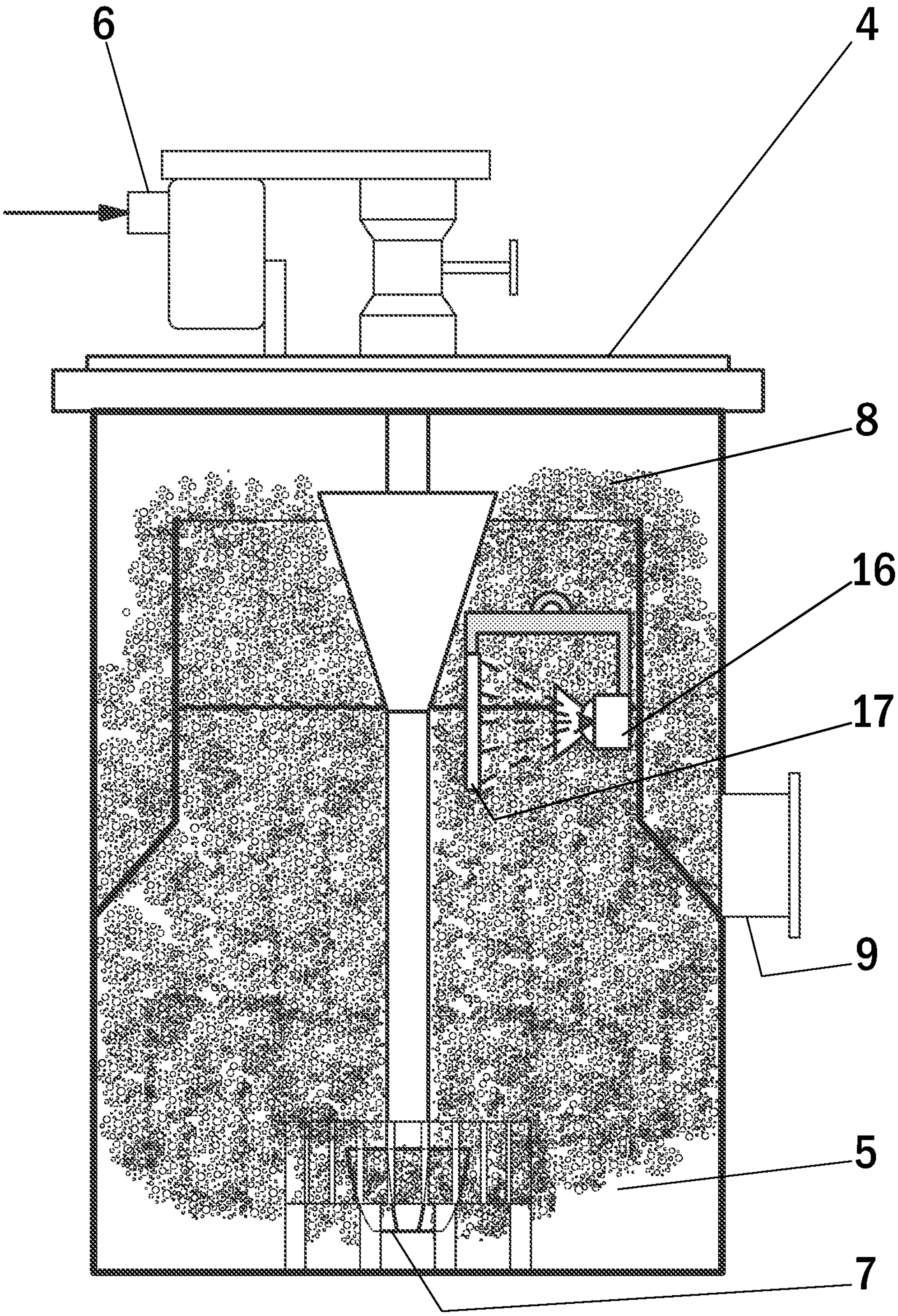

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2016/050924

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N33/20 C22B3/02 G01N23/04 G01N23/083
ADD. B03D1/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01N B03D C22B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/074002 A1 (SIEMENS AG [DE]) 15 May 2014 (2014-05-15) column 5, line 8 - column 7, line 18; figures 1-3	6-17
A	EP 2 481 482 A1 (ABB RESEARCH LTD [CH]) 1 August 2012 (2012-08-01) paragraph [0018] - paragraph [0021]; figure 1	1-17
A	EP 2 952 259 A1 (ABB RESEARCH LTD [CH]) 9 December 2015 (2015-12-09) paragraphs [0005], [0068] - paragraph [0079]; figure 1	1-17

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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 April 2017	18/04/2017

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	L.G. BERGH ET AL: "The long way toward multivariate predictive control of flotation processes", JOURNAL OF PROCESS CONTROL, vol. 21, no. 2, 15 December 2010 (2010-12-15), pages 226-234, XP055001381, ISSN: 0959-1524, DOI: 10.1016/j.jprocont.2010.11.001 thw whole document, in particular chapter 4.2 -----	1-17
A	WO 97/45203 A1 (BAKER HUGHES INC [US]) 4 December 1997 (1997-12-04) the whole document -----	1-17

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/FI2016/050924

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