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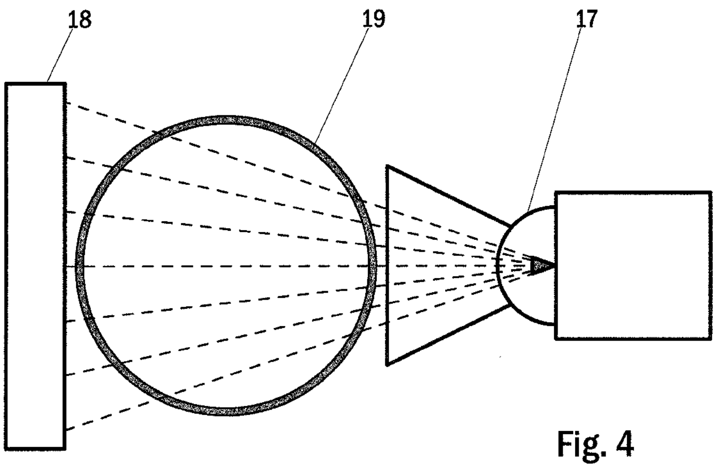

Fig. 4

(57) **Abstract**: The present invention relates to the field of mineral engineering and metallurgy and hydrometallurgical technologies in general and to extraction of metal com¬ pounds from ores or concentrates by wet processes, and more particularly to a method and an arrangement for monitoring of a hydrometallurgical process. An arrangement for monitoring of a hydrometallurgical process according to the present invention comprises one or more hydrometallurgical pipe measurement modules (30-35), (45-50), each of the one or more hydrometallurgical pipe measurement modules (30-35), (45-50) comprising at least one X-ray tube unit (14), (17), (23), (38), (223), said at least one X-ray tube unit (14), (17), (23), (38), (223) being arranged to transmit X-ray radiation into a hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or into an analyzer pipe (225), and at least one X-ray sensor unit (15), (18), (24), (39) arranged to detect X-ray radiation transmitted by said at least one X-ray tube unit (14), (17), (23) (38), (223), said X-ray radiation having travelled through said hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or through said analyzer pipe (225).

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A METHOD AND AN ARRANGEMENT FOR MONITORING OF A HYDROMETALLURGICAL PROCESS

FIELD OF THE INVENTION

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

BACKGROUND OF THE INVENTION

Hydrometallurgical technologies are used for obtaining or extracting metal compounds from their ores. Typical for hydrometallurgical streams is that they usually contain solids, the solutions are not transparent for visible light and all surfaces tend to be covered by scaling. This disables the use of any optical methods that are sensitive for fouling in such industrial conditions.

Very often the hydrometallurgical fluid stream contains suspended solids such as ore, precipitates, silica and gypsum which tend to accumulate in the process in various places such as hydrometallurgical pipe surfaces. The accumulated solid material may also suddenly continue downstream in the process and cause disturbances in the operation of the process. Currently there are no suitable arrangements for measuring the characteristics of the incoming or the outgoing hydrometallurgical fluid stream or for measuring the characteristics of the hydrometallurgical fluid streams inside the pipes between the equipment or for a proper monitoring of said process block or the entire hydrometallurgical process

Entrainment consists of isolated droplets of the other liquid phase that settle slowly by gravity due to the very small size of the droplets or due to solids. Under normal operating conditions the amount of entrainment is quite low but in the event of process disturbances, which can take place for several possible reasons, the phase disengagement rate in the settler may decrease and result in an increase in entrainment. In extraction process there is currently no automated online measurement used for acquiring adequate measurement data for monitoring the extraction process .

A typical practice for providing measurement data for monitoring of a hydrometallurgical process is that the plant personnel take samples manually from the process and use a centrifuge in the laboratory to measure the water content. Also the content of solids is measured based on samples. These methods, however, are time consuming, prone to human errors and, as being based on a single sample taken from a single point will only give an instantaneous indication of the status of the hydrometallurgical process.

In general, there are several problems with the prior art solutions for monitoring the hydrometallurgical process. So far, the measuring solutions are relatively troublesome and difficult to process. The presence of solids has been difficult to detect. Also the measurement reliability with the prior art measuring solutions has not been adequate enough. Previously there has not been any means for the monitoring of accumulation of solids and the scaling of hydrometallurgical pipe surfaces in the hydrometallurgical process.

The problem therefore is to find a solution for an adequate measuring arrangement in a hydrometallurgical process which can provide continuously reliable measurement data from inside the various process pipes for monitoring the hydrometallurgical process.

There is a demand in the market for a method for monitoring the hydrometallurgical process 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 hydrometallurgical process which arrangement would be more 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 hydrometallurgical process, said hydrometallurgical process comprising one or more hydrometallurgical pipes, said one or more hydrometallurgical pipes used for carrying a hydrometallurgical process stream, which method comprises the steps of:

- transmitting X-ray radiation into a hydrometallurgical pipe or into an analyzer pipe by at least one X-ray tube unit;

- detecting X-ray radiation transmitted by said at least one X-ray tube unit, said X-ray radiation having travelled through said hydrometallurgical pipe or through said analyzer pipe by an at least one X-ray sensor unit; and

- providing a two- or three-dimensional image related to the attenuation of X-rays by the hydrometallurgical process stream inside said hydrometallurgical pipe or inside said analyzer pipe based on said detected X-ray radiation data.

Preferably, the method comprises the step of:

- controlling said hydrometallurgical process based on the detected X-ray radiation data.

Preferably in the method, said hydrometallurgical pipe is a riser outlet pipe of at least one hydrometallurgical plant reactor.

Furthermore, the objects of the invention are achieved by an arrangement for monitoring of a hydrometallurgical process, said hydrometallurgical process comprising one or more hydrometallurgical pipes, which arrangement comprises one or more hydrometallurgical pipe measurement modules, each of the one or more hydrometallurgical pipe measurement modules comprising:

- at least one X-ray tube unit, said at least one X-ray tube unit being arranged to transmit X-ray radiation into a hydrometallurgical pipe or into an analyzer pipe, and

- an at least one X-ray sensor unit arranged to detect X-ray radiation transmitted by said at least one X-ray tube unit, said X-ray radiation having travelled through said hydrometallurgical pipe or through said analyzer pipe.

Preferably, said analyzer pipe is arranged in fluid communication with hydrometallurgical pipes of said hydrometallurgical process. Preferably, said analyzer pipe is secured with flange elements. Preferably, said hydrometallurgical pipe or said analyzer pipe is manufactured at least partially of polymeric material, glass, aluminium, ceramics or composite. Preferably, said hydrometallurgical pipe or said analyzer pipe has window portions, which window portions are manufactured of polymeric material, glass, aluminium, ceramics or composite.

Preferably, said at least one X-ray tube unit and said at least one X-ray sensor unit are attached to a hydrometallurgical pipe or to said analyzer pipe. Preferably, at least one of said one or more hydrometallurgical pipe measurement modules has at least one movable X-ray tube unit and at least one movable X-ray sensor unit.

Preferably, said at least one of said one or more hydrometallurgical pipe measurement modules comprises rails, wherein:

- said at least one movable X-ray tube unit is arranged to move parallel to said hydrometallurgical pipe along a first rail of said rails; and

- said at least one movable X-ray sensor unit is arranged to move parallel to said hydrometallurgical pipe along a second rail of said rails.

Preferably, said at least one of said one or more hydrometallurgical pipe measurement modules comprises flanges attached to said hydrometallurgical pipe.

Preferably, said at least one X-ray tube unit and said at least one X-ray sensor unit are integrated to a flange element, said flange element being arranged around said hydrometallurgical pipe.

Preferably, said arrangement comprises 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 the hydrometallurgical fluid stream inside said hydrometallurgical pipe or inside said analyzer pipe. Alternatively, said arrangement comprises a sensor data processing unit, which sensor data processing unit controls said hydrometallurgical process based on the detected X-ray radiation data.

Preferably, phase volumes, particle densities and/or particle sizes in the hydrometallurgical process stream is/are calculated based on the detected X-ray radiation data. Preferably, crud formation inside said hydrometallurgical pipe or inside said analyzer pipe is 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 hydrometallurgical pipe or inside said analyzer pipe. Preferably, said at least one X-ray tube unit is 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, said one or more hydrometallurgical pipe measurement modules are arranged for measuring the characteristics of the hydrometallurgical fluid stream in the hydrometallurgical pipe, wherein said hydrometallurgical pipe is a riser outlet pipe of at least one hydrometallurgical plant reactor. Alternatively, said at least one hydrometallurgical plant reactor is a leaching reactor, a precipitation reactor, a crystallization reactor, an oxidation reactor, a reduction reactor, a liquid-liquid reactor, a chemical reactor, a storage tank or a buffer tank.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a flow diagram of a hydrometallurgical process according to the present invention;

Figure 2 shows a flow diagram with hydrometallurgical pipes in another hydrometallurgical process according to the present invention;

Figure 3 shows a cross-sectional view of one embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process according to the present invention;

Figure 4 shows a cross-sectional view of another embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process ac-cording to the present invention;

Figure 5 shows a cross-sectional view of a third embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process ac-cording to the present invention;

Figure 6 shows a cross-sectional view of a fourth embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process according to the present invention;

Figure 7 shows a side view of a fifth embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process according to the present invention;

Figure 8 shows a side view of a sixth embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process according to the present invention;

Figure 9 shows a flow diagram with hydrometallurgical pipes in one embodiment of a hydrometallurgical process according to the present invention;

Figure 10 shows a partial cross-sectional view of one embodiment of a hydrometallurgical plant reactor according to the present invention;

Figure 11 shows a top view of one embodiment of a hydrometallurgical plant according to the present invention.

The invention will be described in greater detail by means of preferred embodiments with reference to the accompanying drawings of Figures 1 to 11.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a method and an arrangement monitoring of a hydrometallurgical process. In the context of the present invention a hydrometallurgical pipe is defined as a pipe in a hydrometallurgical process, which pipe is used for carrying a hydrometallurgical process stream, said stream containing one or more phases, at least one of said one or more phases being in liquid state.

Furthermore, the hydrometallurgical pipes according to the present invention are used in hydrometallurgical processes containing various types of process equipment such as reactors, crystallizers, storage tanks, ponds, thickeners, flotation cells, electrolysis cells, filters, adsorption columns and membrane modules which process equipment are typically connected with hydrometallurgical pipes. In these hydrometallurgical pipes different hydrometallurgical fluid streams are fed to or from various types of process equipments or alternatively transported within different parts of various types of process equipment.

Hydrometallurgical technologies are used for obtaining or extracting metal compounds from their ores. Hydrometallurgical processes involve the use of aqueous chemistry for the recovery of metals from ores, concentrates, and recycled or residual materials. Here hydrometallurgy is understood to include also all the wet mineral grinding and separation processes prior to leaching, solution purification, recovery and effluent treatment technologies.

Leaching involves the use of aqueous solutions, which contain a lixiviant brought into contact with a material containing a valuable metal. There are a number of leaching process options available for the hydrometallurgical treatment of ores and concentrates. In the leaching process, oxidation potential, temperature, and pH of the solution are important parameters. There are several leaching methods utilizing lixiviants such as sulfuric acid, chloride and cyanide at atmospheric or elevated pressure. Leaching technologies include the leaching of e.g. zinc, copper, nickel, cobalt, gold, silver, rare earth elements, molybdenum, manganese and synthetic rutile.

After the leaching process, there are several options to do the solution purification and recovery. For those purposes various separation technologies such as liquid-liquid extraction, ion-exchange as well as precipitation e.g. as metal sulfides or hydroxides may be used. In the hydrometallurgical process various equipment are connected with pipes or launders. For the control of the process it is important to be able to continuously monitor the content inside the pipes without taking samples. Such pipes may be located not only between equipment but also inside the equipment.

The solution purification can for example be a liquid-liquid extraction process, in which process the pregnant leach solution is first mixed with an organic stream to form a liquid-liquid dispersion when the metal ion is transferred to the organic phase. After mixing the phase disengagement takes place in a settler. The resulting streams will be a loaded organic phase stream and a raffinate stream. After the liquid-liquid extraction loading process, is the liquid-liquid extraction stripping process, where the loaded organic phase is then mixed as liquid-liquid dispersion with stripping liquor and allowed to separate in a settler. In stripping the metal will be transferred from the organic phase to the stripping liquor. The resulting streams will be a stripped organic phase stream and a rich stripping liquor stream.

Figure 1 shows a flow diagram of a hydrometallurgical process according to the present invention. A hydrometallurgical process according to the present invention comprises the process blocks for leaching process 1, liquid-liquid extraction process 2, and recovery process 3.

In a hydrometallurgical process according to the present invention the leaching process 1 is carried out first. The leaching process provides a pregnant leach solution for the liquid-liquid extraction process 2. In the loading stage of the liquid-liquid extraction process 2 the pregnant leach solution is first mixed into liquid-liquid dispersion with an organic stream in a mixer tank. The resulting mixed liquid-liquid dispersion is taken from the mixer tank to a settler of the liquid-liquid extraction process 2 for separation. The loading stage of the liquid-liquid extraction process provides a loaded organic phase stream and a raffinate stream as output of the loading process.

The loaded organic phase stream from the loading stage of the liquid-liquid extraction process 2 is provided as an input for the stripping stage of the liquid-liquid extraction process 2. In the stripping stage the loaded organic phase is then mixed into liquid-liquid dispersion with e.g. a lean electrolyte in a mixer tank. The resulting mixed liquid-liquid dispersion is taken to a stripping settler for separation. The stripping stage of the liquid-liquid extraction process provides a stripped organic phase stream and a rich electrolyte stream as output of the stripping process.

In a hydrometallurgical process there is typically different hydrometallurgical fluid streams carried in hydrometallurgical pipes from one process step to another. These hydrometallurgical fluid streams in hydrometallurgical pipes may be multiphase fluid streams, i.e. they may contain several different phases. In regard to the proper outcome of the hydrometallurgical process it is very important have each process step functioning optimally. In order for a proper monitoring of a hydrometallurgical process it would be beneficial to get more information from the output of a one process step carried in a hydrometallurgical pipe as an input to another process step.

Figure 2 shows a flow diagram with hydrometallurgical pipes in another hydrometallurgical process according to the present invention. Another hydrometallurgical process according to the present invention comprises the process blocks for a leaching process 4, an extraction process 5, a stripping process 6, and an electrowinning process 7.

In another hydrometallurgical process according to the present invention the leaching process 4 is carried out first. Leaching 4 involves the use of aqueous solutions, which contain a lixiviant brought into contact with a material containing a valuable metal. There are a number of leaching process options available for the hydrometallurgical treatment of ores and concentrates. In the leaching process, oxidation potential, temperature, and pH of the solution are important parameters. There are several versatile leaching methods ranging from sulfuric acid to chloride leaching and from atmospheric to pressure leaching. Leaching technologies include the leaching of e.g. zinc, copper, nickel, cobalt, gold, silver, rare earth elements, molybdenum, manganese and synthetic rutile. The leaching process 4 provides a pregnant leach solution, which pregnant leach solution is carried in a hydrometallurgical pipe 8 to the extraction process 5.

In the extraction process 5 the pregnant leach solution is typically first mixed with an organic stream in a mixer tank to form a liquid-liquid dispersion when the metal ion is transferred to the organic phase. The resulting liquid-liquid dispersion is taken from the mixer tank to a liquid-liquid extraction settler of the extraction process 5 for separation. The loading stage of the extraction process 5 provides a loaded organic phase stream and a barren leach solution stream as output of the loading stage of the extraction process 5. The loaded organic phase stream is carried in a hydrometallurgical pipe 9 to the stripping process 6 and the barren leach solution stream is returned in a hydrometallurgical pipe 10 back to the leaching process 4.

In the stripping process 6 the loaded organic phase is then mixed into liquid-liquid dispersion with e.g. a lean electrolyte in a mixer tank. The resulting mixed liquid-liquid dispersion is taken to a stripping settler of the stripping process 6 for separation. The stripping stage of the stripping process 6 provides a stripped organic phase stream and a rich electrolyte stream as output of the stripping process 6. The rich electrolyte stream is carried in a hydrometallurgical pipe 11 to the electrowinning process 7 and the stripped organic phase stream is returned in a hydrometallurgical pipe 12 back to the extraction process 5.

In the electrowinning process 7 the rich electrolyte is taken to an electrowinning settler of the electrowinning process 7. In the electrowinning process 7, a current is passed from an inert anode through the rich electrolyte solution containing the metal so that the metal is extracted as it is deposited in an electroplating process onto the cathode. The electrowinning process 7 provides cathodes containing the metal and a spent electrolyte stream as output of the electrowinning process 7. The cathodes containing the metal are taken out as the output of the hydrometallurgical process and the spent electrolyte stream is returned in a hydrometallurgical pipe 13 back to the stripping process 6.

In addition to the hydrometallurgical process according to the present invention presented in Figure 2 hydrometallurgical pipes are used in hydrometallurgical processes containing various types of process equipments such as reactors, crystallizers, storage tanks, ponds, thickeners, flotation cells, electrolysis cells, filters, adsorption columns and membrane modules which process equipments are typically connected with hydrometallurgical pipes. In these hydrometallurgical pipes different hydrometallurgical fluid streams are fed to or from various types of process equipments or alternatively transported within different parts of various types of process equipments.

For example, in the extraction process 5 the liquid-liquid extraction settler separates the phases in the liquid-liquid dispersed pregnant leach solution. The phases exiting the liquid-liquid extraction settler, i.e. the separated loaded organic phase and the separated barren leach solution aqueous phase, should be clean of the other liquid phase and solids but in practice some residue of the other phase, commonly called entrainment, will remain in the solutions.

Entrainment consists of isolated droplets of the other liquid phase that settle slowly by gravity due to the very small size of the droplets or due to solids. The entrained aqueous liquid in the separated loaded organic phase typically contains impurities which can impair the purity of the product, cause degradation of the organic phase and lower the current efficiency of the electrowinning process 7 following the extraction process 5 and the stripping process 6.

Figure 3 shows a cross-sectional view of one embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process according to the present invention. The hydrometallurgical process according to the presented embodiment may comprise one or more hydrometallurgical pipe measurement modules. A hydrometallurgical pipe measurement module according to the presented embodiment comprises an at least one X-ray tube unit 14 and an at least one X-ray sensor unit 15.

In the hydrometallurgical pipe measurement module according to the present embodiment said at least one X-ray tube unit 14 and said at least one X-ray sensor unit 15 are attached to a hydrometallurgical pipe 16, said at least one X-ray sensor unit 15 opposing said at least one X-ray tube unit 14 so that said at least one X-ray tube unit 14 is arranged to transmit X-ray radiation into of said hydrometallurgical pipe 16 and so that said at least one X-ray sensor unit 15 is arranged to detect X-ray radiation transmitted by said at least one X-ray tube unit 14, said X-ray radiation having travelled through said hydrometallurgical pipe 16. Said hydrometallurgical pipe 16 may be manufactured at least partially of such pipe material, e.g. polymeric material, glass, aluminium, ceramics or composite, that said pipe material does not absorb the X-rays and allows the X-rays travel through said hydrometallurgical pipe 16.

In the hydrometallurgical pipe measurement module according to the present embodiment the X-rays from said at least one X-ray tube 14 may may be collimated into a narrow beam in at least one dimension when propagating inside said hydrometallurgical pipe 16 thus minimizing the amount of radiation to other directions than the detector. Furthermore, said at least one X-ray tube of said at least one X-ray tube unit 14 may be arranged to move or turn in order to transmit X-ray radiation in multiple directions.

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 hydrometallurgical process stream, e.g. the hydrometallurgical fluid stream, and the crud formation inside said hydrometallurgical pipe 16 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.

Figure 4 shows a cross-sectional view of another embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process according to the present invention. The hydrometallurgical process according to the presented embodiment may comprise one or more hydrometallurgical pipe measurement modules. A hydrometallurgical pipe measurement module according to the present embodiment comprises an at least one X-ray tube unit 17 and an at least one X-ray sensor unit 18.

In the hydrometallurgical pipe measurement module according to the another embodiment said at least one X-ray tube unit 17 and said at least one X-ray sensor unit 18 are arranged so that said at least one X-ray sensor unit 18 is opposing said at least one X-ray tube unit 17. In the presented embodiment said at least one X-ray tube unit 17 is arranged to transmit X-ray radiation into the of said hydrometallurgical pipe 19 and so that said at least one X-ray sensor unit 18 is arranged to detect X-ray radiation transmitted by said at least one X-ray tube unit 17, said X-ray radiation having travelled through said hydrometallurgical pipe 19. Said hydrometallurgical pipe 19 may be manufactured at least partially of such pipe material, e.g. polymeric material, glass, aluminium, ceramics or composite, that said pipe material does not absorb the X-rays and allows the X-rays travel through said hydrometallurgical pipe 19.

In the hydrometallurgical pipe measurement module according to the another embodiment the X-rays from said at least one X-ray tube 17 may may be collimated into a narrow beam in at least one dimension when propagating inside said hydrometallurgical pipe 16 thus minimizing the amount of radiation to other directions than the detector. Furthermore, said at least one X-ray tube of said at least one X-ray tube unit 17 may be arranged to move or turn in order to transmit X-ray radiation in multiple directions.

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 hydrometallurgical process stream, e.g. the hydrometallurgical fluid stream, and the crud formation inside said hydrometallurgical pipe 19 based on the detected X-ray radiation data. Furthermore, said at least one X-ray sensor unit 18 may be arranged to move or turn in order to sense and provide a two- or three-dimensional image.

Figure 5 shows a cross-sectional view of a third embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process according to the present invention. The hydrometallurgical process according to the presented embodiment may comprise one or more hydrometallurgical pipe measurement modules. A hydrometallurgical pipe measurement module according to the present embodiment comprises an at least one X-ray tube unit 17 and an at least one X-ray sensor unit 18.

In the hydrometallurgical pipe measurement module according to the third embodiment said at least one X-ray tube unit 17 and said at least one X-ray sensor unit 18 are arranged so that said at least one X-ray sensor unit 18 is opposing said at least one X-ray tube unit 17. In the presented embodiment said at least one X-ray tube unit 17 is arranged to transmit X-ray radiation into the of said hydrometallurgical pipe 20 and so that said at least one X-ray sensor unit 18 is arranged to detect X-ray radiation transmitted by said at least one X-ray tube unit 17, said X-ray radiation having travelled through said hydrometallurgical pipe 20. Said hydrometallurgical pipe 20 has window portions 21, 22, which window portions 21, 22 are manufactured of such window material, e.g. polymeric material, glass, aluminium, ceramics or composite, that said window material does not absorb the X-rays and allows the X-rays travel through said hydrometallurgical pipe 20.

In the hydrometallurgical pipe measurement module according to the third embodiment the X-rays from said at least one X-ray tube 17 may be collimated into a narrow beam in at least one dimension when propagating inside said hydrometallurgical pipe 20 thus minimizing the amount of radiation to other directions than the detector. Furthermore, said at least one X-ray tube unit 17 may be arranged to move or turn in order to transmit X-ray radiation in multiple directions.

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 hydrometallurgical process stream, e.g. the hydrometallurgical fluid stream, and the crud formation inside said hydrometallurgical pipe 20 based on the detected X-ray radiation data. Furthermore, said at least one X-ray sensor unit 18 may be arranged to move or turn in order to sense and provide a two- or three-dimensional image.

Figure 6 shows a cross-sectional view of a fourth embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process according to the present invention. The hydrometallurgical process according to the presented embodiment may comprise one or more hydrometallurgical pipe measurement modules. A hydrometallurgical pipe measurement module according to the present embodiment comprises an at least one X-ray tube unit 17, an at least one X-ray sensor unit 18 and a flange element 220.

In the hydrometallurgical pipe measurement module according to the fourth embodiment said at least one X-ray tube unit 17 and said at least one X-ray sensor unit 18 are integrated to said flange element 220, said flange element 220 being arranged around a hydrometallurgical pipe 19. Said at least one X-ray sensor unit 18 is arranged opposing said at least one X-ray tube unit 17 so that said at least one X-ray tube unit 17 is arranged to transmit X-ray radiation into the of said hydrometallurgical pipe 19 and so that said at least one X-ray sensor unit 18 is arranged to detect X-ray radiation transmitted by said at least one X-ray tube unit 17, said X-ray radiation having travelled through said hydrometallurgical pipe 19.

Said hydrometallurgical pipe 19 may be manufactured at least partially of such pipe material, e.g. polymeric material, glass, aluminium, ceramics or composite, that said pipe material does not absorb the X-rays and allows the X-rays travel through said hydrometallurgical pipe 19.

In the hydrometallurgical pipe measurement module according to the fourth embodiment the X-rays from said at least one X-ray tube unit 17 may be collimated into a narrow beam in at least one dimension when propagating inside said hydrometallurgical pipe 19 thus minimizing the amount of radiation to other directions than the detector. Furthermore, said at least one X-ray tube unit 17 may be arranged to move or turn in order to transmit X-ray radiation in multiple directions.

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 hydrometallurgical process stream, e.g. the hydrometallurgical fluid stream, and the crud formation inside said hydrometallurgical pipe 19 based on the detected X-ray radiation data. Furthermore, said at least one X-ray sensor unit 18 may be arranged to move or turn in order to sense and provide a two- or three-dimensional image.

Said image provided by said at least one X-ray sensor unit 15, 18 gives measurement information for the calculation of valuable hydrometallurgical process information, e.g. phase volumes, particle densities and particle sizes in the hydrometallurgical process stream. Determining the valuable hydrometallurgical process information online with the help of said image provided by said at least one X-ray sensor unit 15, 18 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.

Figure 7 shows a side view of a fifth embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process according to the present invention. The hydrometallurgical process according to the presented embodiment may comprise one or more hydrometallurgical pipe measurement modules. A hydrometallurgical pipe measurement module according to the present embodiment is arranged between hydrometallurgical pipes 191, 192, said hydrometallurgical pipes 191, 192 having pipe flange elements 193, 194. The presented hydrometallurgical pipe measurement module according to the present embodiment comprises flange elements 221, 222 for securing said hydrometallurgical pipe measurement module to the pipe flange elements 193, 194 of said hydrometallurgical pipes 191, 192. The presented hydrometallurgical pipe measurement module according to the present embodiment comprises an at least one X-ray tube unit 223 and an at least one X-ray sensor unit 224. Said at least one X-ray tube unit 223 and said at least one X-ray sensor unit 224 may also be integrated to said flange elements 221, 222.

The presented hydrometallurgical pipe measurement module according to the present embodiment comprises an analyzer pipe 225, said analyzer pipe 225 arranged in fluid communication with said hydrometallurgical pipes 191, 192. Said analyzer pipe 225 of the presented hydrometallurgical pipe measurement module may be secured with said flange elements 221, 222.

Said at least one X-ray sensor unit 224 is arranged opposing said at least one X-ray tube unit 223 so that said at least one X-ray tube unit 223 is arranged to transmit X-ray radiation into the of said analyzer pipe 225 and so that said at least one X-ray sensor unit 224 is arranged to detect X-ray radiation transmitted by said at least one X-ray tube unit 223, said X-ray radiation having travelled through said analyzer pipe 225. Said flange elements 221, 222 enable a fast installation of the module between two pipe sections of said hydrometallurgical pipes 191, 192.

Said analyzer pipe 225 may be manufactured at least partially of such pipe material, e.g. polymeric material, glass, aluminium, ceramics or composite, that said pipe material does not absorb the X-rays and allows the X-rays travel through said analyzer pipe 225.

In the hydrometallurgical pipe measurement module according to the fourth embodiment the X-rays from said at least one X-ray tube unit 223 may be collimated into a narrow beam in at least one dimension when propagating inside said analyzer pipe 225 thus minimizing the amount of radiation to other directions than the detector. Furthermore, said at least one X-ray tube unit 223 may be arranged to move or turn in order to transmit X-ray radiation in multiple directions.

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 hydrometallurgical process stream, e.g. the hydrometallurgical fluid stream, and the crud formation inside said analyzer pipe 225 based on the detected X-ray radiation data. Furthermore, said at least one X-ray sensor unit 224 may be arranged to move or turn in order to sense and provide a two- or three-dimensional image.

Said image provided by said at least one X-ray sensor unit 224 gives measurement information for the calculation of valuable hydrometallurgical process information, e.g. phase volumes, particle densities and particle sizes in the hydrometallurgical process stream. Determining the valuable hydrometallurgical process information online with the help of said image provided by said at least one X-ray sensor unit 224 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.

Figure 8 shows a side view of a sixth embodiment of a hydrometallurgical pipe measurement module of a hydrometallurgical process according to the present invention. The hydrometallurgical process according to the presented embodiment may comprise one or more hydrometallurgical pipe measurement modules. A hydrometallurgical pipe measurement module according to the present embodiment comprises an at least one X-ray tube unit 23 and an at least one X-ray sensor unit 24. A hydrometallurgical pipe measurement module according to the present embodiment is arranged as having an at least one movable X-ray tube unit 23 and an at least one movable X-ray sensor unit 24.

The hydrometallurgical pipe measurement module according to the sixth embodiment comprises flanges 25, 26 attached to a hydrometallurgical pipe 27 and rails 28, 29, a first rail 28 of said rails 28, 29 being arranged for said at least one X-ray tube unit 23, and a second rail 29 of said rails 28, 29 being arranged for said at least one X-ray sensor unit 24. Said at least one X-ray tube unit 23 is arranged on said first rail 28 and is further arranged as a movable X-ray tube unit 23 arranged to move along said first rail 28 parallel to said hydrometallurgical pipe 27. Likewise, said at least one X-ray sensor unit 24 is arranged on said second rail 29 and is further arranged as a movable X-ray sensor unit 24 arranged to move along said second rail 29 parallel to said hydrometallurgical pipe 27.

In the hydrometallurgical pipe measurement module according to the sixth embodiment said at least one X-ray sensor unit 24 on said second rail 29 is arranged opposing said at least one X-ray tube unit 23 on said first rail 28 so that said at least one X-ray tube unit 23 is arranged to transmit X-ray radiation into the of said hydrometallurgical pipe 27 and so that said at least one X-ray sensor unit 24 is arranged to detect X-ray radiation transmitted by said at least one X-ray tube unit 23, said X-ray radiation having travelled through said hydrometallurgical pipe 27.

Said hydrometallurgical pipe 27 may be manufactured at least partially of such pipe material, e.g. polymeric material, glass, aluminium, ceramics or composite, that said pipe material does not absorb the X-rays and allows the X-rays travel through said hydrometallurgical pipe 27. Said hydrometallurgical pipe 27 may also have window portions, which window portions are manufactured of such window material, e.g. polymeric material, glass, aluminium, ceramics or composite, that said window material does not absorb the X-rays and allows the X-rays travel through said hydrometallurgical pipe 27.

In the hydrometallurgical pipe measurement module according to the sixth embodiment the X-rays from said at least one X-ray movable transmission unit 23 may be collimated into a narrow beam in at least one dimension when propagating inside said hydrometallurgical pipe 27 thus minimizing the amount of radiation to other directions than the detector. Furthermore, said at least one X-ray movable transmission unit 23 may be arranged to move or turn in order to transmit X-ray radiation in multiple directions.

From the detected X-ray radiation data a sensor data processing unit can provide a two- or three-dimensional image related to the attenuation of X-rays by the hydrometallurgical process stream, e.g. the hydrometallurgical fluid stream, and the crud formation inside said hydrometallurgical pipe 27 based on the detected X-ray radiation data. Furthermore, said at least one X-ray sensor unit 24 may be arranged to move or turn in order to sense and provide a two- or three-dimensional image.

Said image provided by said at least one movable X-ray sensor unit 24 gives measurement information for the calculation of valuable hydrometallurgical process information, e.g. phase volumes, particle densities and particle sizes in the hydrometallurgical process stream. Determining the valuable hydrometallurgical process information online with the help of said image provided by said at least one movable X-ray sensor unit 24 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.

Figure 9 shows a flow diagram with hydrometallurgical pipes in one embodiment of a hydrometallurgical process according to the present invention. A hydrometallurgical process according to the presented embodiment comprises the process blocks for a leaching process 4, an extraction process 5, a stripping process 6, and an electrowinning process 7.

In the hydrometallurgical process according to the presented embodiment the leaching process 4 is carried out first. Leaching 4 involves the use of aqueous solutions, which contain a lixiviant brought into contact with a material containing a valuable metal. There are a number of leaching process options available for the hydrometallurgical treatment of ores and concentrates. In the leaching process, oxidation potential, temperature, and pH of the solution are important parameters. There are several versatile leaching methods ranging from chloride to sulphate leaching and from atmospheric to pressure leaching. Leaching technologies include the leaching of e.g. zinc, copper, nickel, cobalt, gold, arsenic, silver, molybdenum, manganese and synthetic rutile. The leaching process 4 provides a pregnant leach solution, which pregnant leach solution is carried in a hydrometallurgical pipe 8 to the extraction process 5.

In the hydrometallurgical process according to the presented embodiment the hydrometallurgical pipe 8 carrying the pregnant leach solution stream from the leaching process 4 to the extraction process 5 is accompanied with a hydrometallurgical pipe measurement module 30 for measuring the characteristics of the hydrometallurgical fluid stream in the hydrometallurgical pipe 8.

In the hydrometallurgical process according to the presented embodiment the extraction process 5 is carried out after the leaching process 4. In the extraction process 5 the pregnant leach solution is typically first mixed into emulsion with an organic stream in a mixer tank. The resulting mixed liquid-liquid dispersion is taken from the mixer tank to a solvent extraction settler of the extraction process 5 for separation. The loading stage of the extraction process 5 provides a loaded organic phase stream and a barren leach solution stream as output of the loading stage of the extraction process 5. The loaded organic phase stream is carried in a hydrometallurgical pipe 9 to the stripping process 6 and the barren leach solution stream is returned in a hydrometallurgical pipe 10 back to the leaching process 4.

In the hydrometallurgical process according to the presented embodiment the hydrometallurgical pipe 9 carrying the loaded organic phase stream from the extraction process 5 to the stripping process 6 is accompanied with a hydrometallurgical pipe measurement module 31 for measuring the characteristics of the hydrometallurgical fluid stream in the hydrometallurgical pipe 9. Likewise, the the hydrometallurgical pipe 10 carrying the barren leach solution stream from the extraction process 5 back to the leaching process 4 is accompanied with a hydrometallurgical pipe measurement module 32 for measuring the characteristics of the hydrometallurgical fluid stream in the hydrometallurgical pipe 10.

In the hydrometallurgical process according to the presented embodiment the stripping process 6 is carried out after the extraction process 5. In the stripping process 6 the loaded organic phase is then mixed into emulsion emulsification with e.g. a lean electrolyte in a mixer tank. The resulting mixed liquid-liquid dispersion is taken to a stripping settler of the stripping process 6 for separation. The stripping stage of the stripping process 6 provides a stripped organic phase stream and a rich electrolyte stream as output of the stripping process 6. The rich electrolyte stream is carried in a hydrometallurgical pipe 11 to the electrowinning process 7 and the stripped organic phase stream is returned in a hydrometallurgical pipe 12 back to the extraction process 5.

In the hydrometallurgical process according to the presented embodiment the hydrometallurgical pipe 11 carrying the rich electrolyte stream from the stripping process 6 to the electrowinning process 7 is accompanied with a hydrometallurgical pipe measurement module 33 for measuring the characteristics of the hydrometallurgical fluid stream in the hydrometallurgical pipe 11. Likewise, the hydrometallurgical pipe 12 carrying the stripped organic phase stream from the stripping process 6 back to the extraction process 5 is accompanied with a hydrometallurgical pipe measurement module 34 for measuring the characteristics of the hydrometallurgical fluid stream in the hydrometallurgical pipe 12.

In the hydrometallurgical process according to the presented embodiment the electrowinning process 7 is carried out after the stripping process 6. In the electrowinning process 7 the rich electrolyte is taken to an electrowinning settler of the electrowinning process 7. In the electrowinning process 7, a current is passed from an inert anode through the rich electrolyte solution containing the metal so that the metal is extracted as it is deposited in an electroplating process onto the cathode. The electrowinning process 7 provides cathodes containing the metal and a spent electrolyte stream as output of the electrowinning process 7. The cathodes containing the metal are taken out as the output of the hydrometallurgical process and the spent electrolyte stream is returned in a hydrometallurgical pipe 13 back to the stripping process 6.

In the hydrometallurgical process according to the presented embodiment the hydrometallurgical pipe 13 carrying the spent electrolyte stream from the electrowinning process 7 back to the stripping process 6 is accompanied with a hydrometallurgical pipe measurement module 35 for measuring the characteristics of the hydrometallurgical fluid stream in the hydrometallurgical pipe 13.

The hydrometallurgical process according to the present invention may also have side flow or side stream portions within said hydrometallurgical process. The hydrometallurgical pipe measurement module according to the present invention may be arranged also for measuring the characteristics of the hydrometallurgical fluid stream in said side flow or side stream portions within said hydrometallurgical process.

Figure 10 shows a partial cross-sectional view of one embodiment of a hydrometallurgical plant reactor according to the present invention. A hydrometallurgical plant reactor 36 according to the present embodiment comprises a hydrometallurgical pipe 37, i.e. a riser outlet pipe 37, said hydrometallurgical pipe 37 carrying the riser hydrometallurgical fluid stream out from said hydrometallurgical plant reactor 36.

In the hydrometallurgical plant reactor according to the presented embodiment the hydrometallurgical pipe 37 carrying the riser hydrometallurgical fluid stream out from said hydrometallurgical plant reactor 36 is accompanied with a hydrometallurgical pipe measurement module for measuring the characteristics of the riser hydrometallurgical fluid stream in the hydrometallurgical pipe 37, i.e. in the riser outlet pipe 37. Said hydrometallurgical pipe measurement module comprises an at least one X-ray tube unit 38 and an at least one X-ray sensor unit 39. Said hydrometallurgical plant reactor 36 according to the presented embodiment may be a leaching reactor 36, a precipitation reactor 36, a crystallization reactor 36, an oxidation reactor 36, a reduction reactor 36, a liquid-liquid reactor 36, a chemical reactor 36, a storage tank 36 or a buffer tank 36.

Figure 11 shows a top view of one embodiment of a hydrometallurgical plant according to the present invention. A hydrometallurgical plant according to the present embodiment comprises one or more hydrometallurgical plant reactor 36, 40-44, i.e. a reactor cascade 36, 40-44, an at least one hydrometallurgical plant reactor 36, 40-44 of said one or more hydrometallurgical plant reactor 36, 40-44 comprising one or more hydrometallurgical pipes, an at least one hydrometallurgical pipe of said one or more hydrometallurgical pipes being a riser outlet pipe, said riser outlet pipe carrying the riser hydrometallurgical fluid stream out from said at least one hydrometallurgical plant reactor 36, 40-44.

In the hydrometallurgical plant according to the presented embodiment the at least one hydrometallurgical pipe carrying the riser hydrometallurgical fluid stream out from said at least one hydrometallurgical plant reactor 36, 40-44 is accompanied with a hydrometallurgical pipe measurement module 45-50 for measuring the characteristics of the riser hydrometallurgical fluid stream in the at least one hydrometallurgical pipe, i.e. in the riser outlet pipe. Said at least one said hydrometallurgical plant reactor 36, 40-44 according to the presented embodiment may be a leaching reactor 39-44, a precipitation reactor

36, 40-44, a crystallization reactor 36, 40-44, an oxidation reactor 36, 40-44, a reduction reactor 36, 40-44, a liquid-liquid reactor 36, 40-44, a chemical reactor 36, 40-44, a storage tank 36, 40-44 or a buffer tank 36, 40-44.

The solution for monitoring of a hydrometallurgical process according to the present invention provides a continuous measurement of the inside of a hydrometallurgical pipe, which is highly insensitive to dirt or contamination. The solution for monitoring of a hydrometallurgical process according to the present invention provides reliable, online measurement data for the monitoring of the hydrometallurgical process.

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

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 hydrometallurgical process, said hydrometallurgical process comprising one or more hydrometallurgical pipes (8-13), said one or more hydrometallurgical pipes (8-13) used for carrying a hydrometallurgical process stream, **characterized** in that the method comprising the steps of:

- transmitting X-ray radiation into a hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or into an analyzer pipe (225) by at least one X-ray tube unit (14), (17), (23), (38), (223);

- detecting X-ray radiation transmitted by said at least one X-ray tube unit (14), (17), (23), (38), (223), said X-ray radiation having travelled through said hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or through said analyzer pipe (225) by an at least one X-ray sensor unit (15), (18), (24), (39), (224); and

- providing a two- or three-dimensional image related to the attenuation of X-rays by the hydrometallurgical process stream inside said hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or inside said analyzer pipe (225) based on said detected X-ray radiation data.

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

- controlling said hydrometallurgical process based on the detected X-ray radiation data.

3. A method according to claim 1 or to claim 2, **characterized** in that said hydrometallurgical pipe (37) is a riser outlet pipe (37) of at least one hydrometallurgical plant reactor (36), (40-44).

4. An arrangement for monitoring of a hydrometallurgical process, said hydrometallurgical process comprising one or more hydrometallurgical pipes (8-13), **characterized** in that said arrangement comprises one or more hydrometallurgical pipe measurement modules (30-35), (45-50), each of the one or more hydrometallurgical pipe measurement modules (30-35), (45-50) comprising:

- at least one X-ray tube unit (14), (17), (23), (38), (223), said at least one X-ray tube unit (14), (17), (23), (38), (223) being arranged to transmit X-ray radiation into a hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or into an analyzer pipe (225), and

- at least one X-ray sensor unit (15), (18), (24), (39) arranged to detect X-ray radiation transmitted by said at least one X-ray tube unit (14), (17), (23), (38), (223), said X-ray radiation having travelled through said hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or through said analyzer pipe (225).

5. An arrangement according to claim 4, **characterized** in that said analyzer pipe (225) is arranged in fluid communication with hydrometallurgical pipes (191), (192) of said hydrometallurgical process.

6. An arrangement according to claim 4 or to claim 5, **characterized** in that said analyzer pipe (225) is secured with flange elements (221), (222).

7. An arrangement according to any one of claims 4 to 6, **characterized** in that said hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or said analyzer pipe (225) is manufactured at least partially of polymeric material, glass, aluminium, ceramics or composite.

8. An arrangement according to any one of claims 4 to 7, **characterized** in that said hydrometallurgical pipe (8-13), (20), (27), (37) or said analyzer pipe (225) has window portions (21), (22), which window portions (21), (22) are manufactured of polymeric material, glass, aluminium, ceramics or composite.

9. An arrangement according to any one of claims 4 to 8, **characterized** in that said at least one X-ray tube unit (14), (23), (38), (223) and said at least one X-ray sensor unit (15), (24), (39), (224) are attached to said hydrometallurgical pipe (8-13), (16), (27), (37) or to said analyzer pipe (225).

10. An arrangement according to any one of claims 4 to 9, **characterized** in that at least one of said one or more hydrometallurgical pipe measurement modules (30-35), (45-50) has at least one movable X-ray tube unit (23) and at least one movable X-ray sensor unit (24).

11. An arrangement according to claim 10, **characterized** in that said at least one of said one or more hydrometallurgical pipe measurement modules (30-35), (45-50) comprises rails (28), (29), wherein:

- said at least one movable X-ray tube unit (23) is arranged to move parallel to said hydrometallurgical pipe (8-13), (27) along a first rail (28) of said rails (28), (29); and

- said an at least one movable X-ray sensor unit (24) is arranged to move parallel to said hydrometallurgical pipe (8-13), (27) along a second rail (29) of said rails (28), (29).

12. An arrangement according to claim 11, **characterized** in that said at least one of said one or more hydrometallurgical pipe measurement modules (30-35), (45-50) comprises flanges (25), (26) attached to said hydrometallurgical pipe (8-13), (27).

13. An arrangement according to claim 4, **characterized** in that said at least one X-ray tube unit (17) and said at least one X-ray sensor unit (18) are integrated to a flange element (220), said flange element (220) being arranged around said hydrometallurgical pipe (8-13), (19).

14. An arrangement according to any one of claims 4 to 13, **characterized** in that said arrangement comprises 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 hydrometallurgical process stream inside said hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or inside said analyzer pipe (225).

15. An arrangement according to any one of claims 4 to 13, **characterized** in that said arrangement comprises a sensor data processing unit, which sensor data processing unit controls said hydrometallurgical process based on the detected X-ray radiation data.

16. An arrangement according to any one of claims 4 to 15, **characterized** in that phase volumes, particle densities and/or particle sizes in the hydrometallurgical fluid stream is/are calculated based on the detected X-ray radiation data.

17. An arrangement according to any one of claims 4 to 16, **characterized** in that crud formation inside said hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or inside said analyzer pipe (225) is calculated based on the detected X-ray radiation data.

18. An arrangement according to any one of claims 4 to 17, **characterized** in that the X-rays from said at least one X-ray tube unit (14), (17), (23), (38), (223) are collimated into a narrow beam in at least one dimension when propagating inside said hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37) or inside said analyzer pipe (225).

19. An arrangement according to any one of claims 4 to 18, **characterized** in that said at least one X-ray tube unit (14), (17), (23),

(38), (223) is arranged to move or turn in order to transmit X-ray radiation in multiple directions.

20. An arrangement according to any one of claims 4 to 19, **c h a r a c t e r i z e d** in that said at least one X-ray sensor unit (15), (18), (24), (39), (224) is arranged to move or turn.

21. An arrangement according to any one of claims 4 to 20, **c h a r a c t e r i z e d** in that said one or more hydrometallurgical pipe measurement modules (45-50) are arranged for measuring the characteristics of the hydrometallurgical fluid stream in the hydrometallurgical pipe (8-13), (16), (19), (20), (27), (37), wherein said hydrometallurgical pipe (37) is a riser outlet pipe (37) of at least one hydrometallurgical plant reactor (36), (40-44).

22. An arrangement according to claim 21, **c h a r a c t e r i z e d** in that said at least one hydrometallurgical plant reactor (36), (40-44) is a leaching reactor (36), (40-44), a precipitation reactor (36), (40-44), a crystallization reactor (36), (40-44), an oxidation reactor (36), (40-44), a reduction reactor (36), (40-44), a liquid-liquid reactor (36), (40-44), a chemical reactor (36), (40-44), a storage tank (36), (40-44) or a buffer tank (36), (40-44).

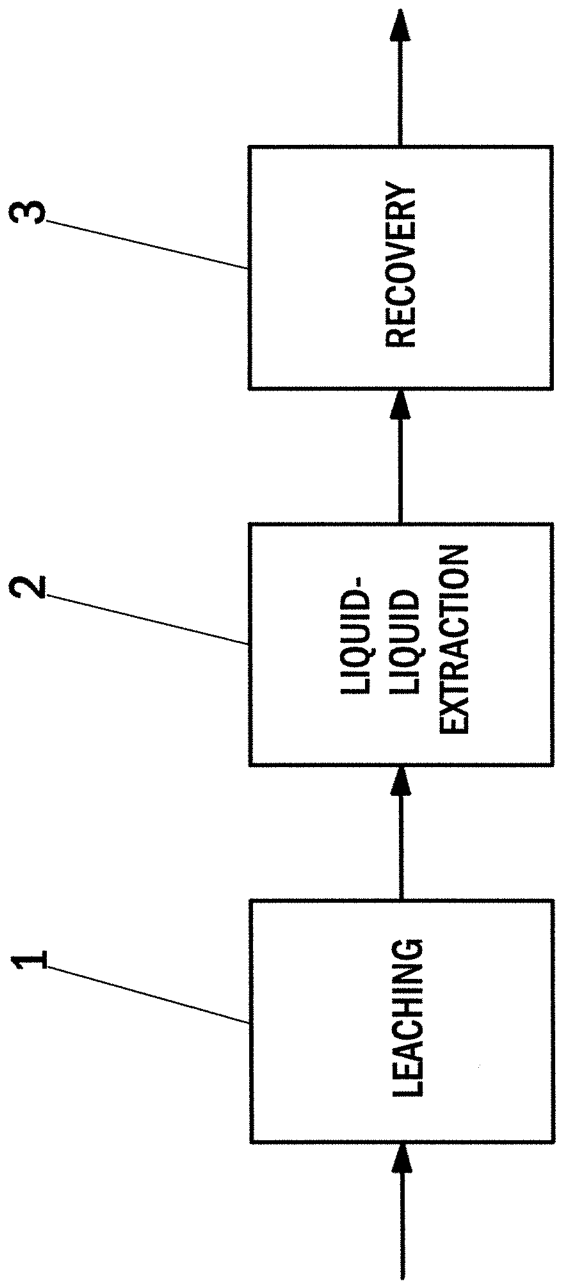

Fig. 1

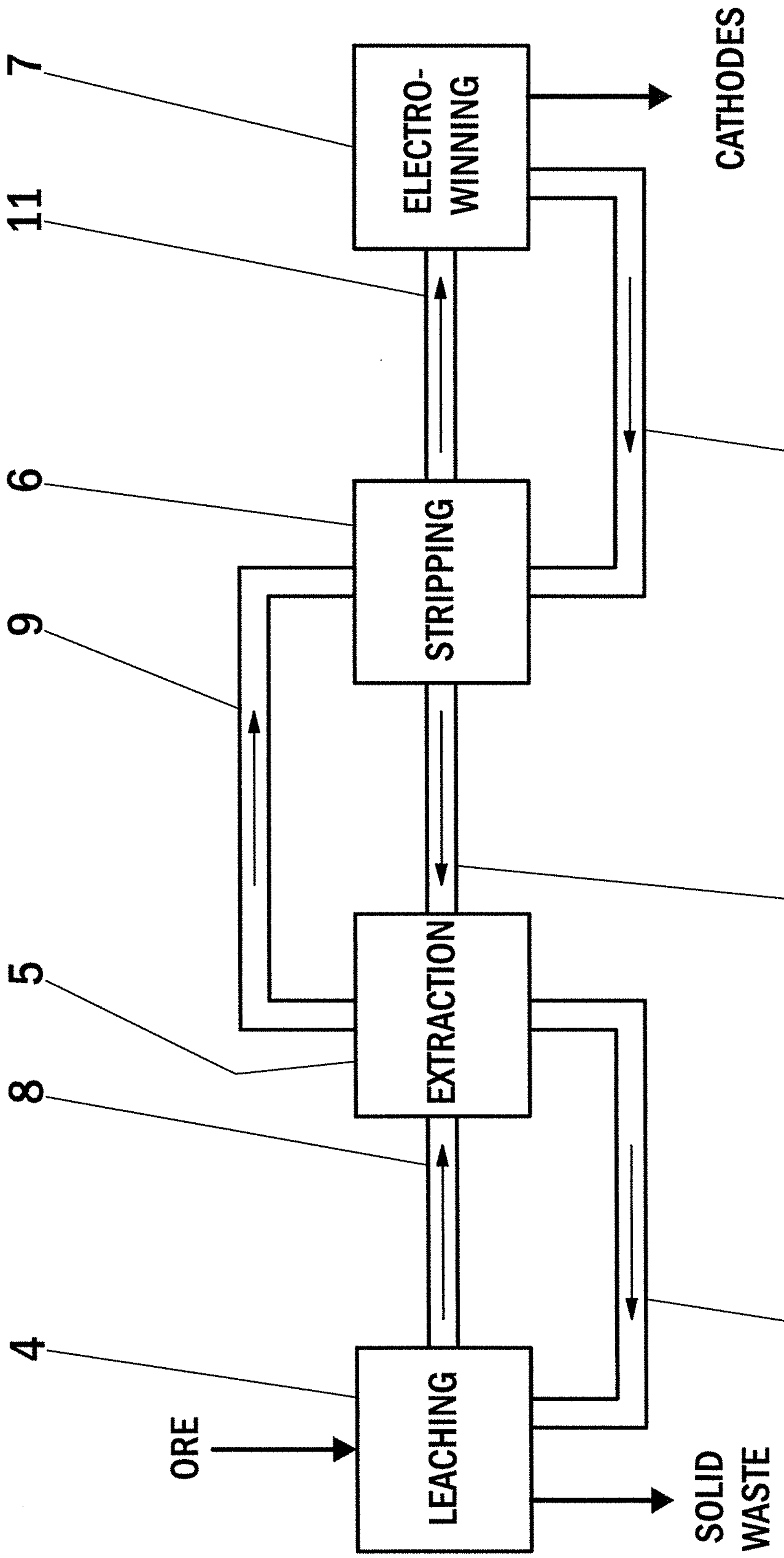
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Fig. 2

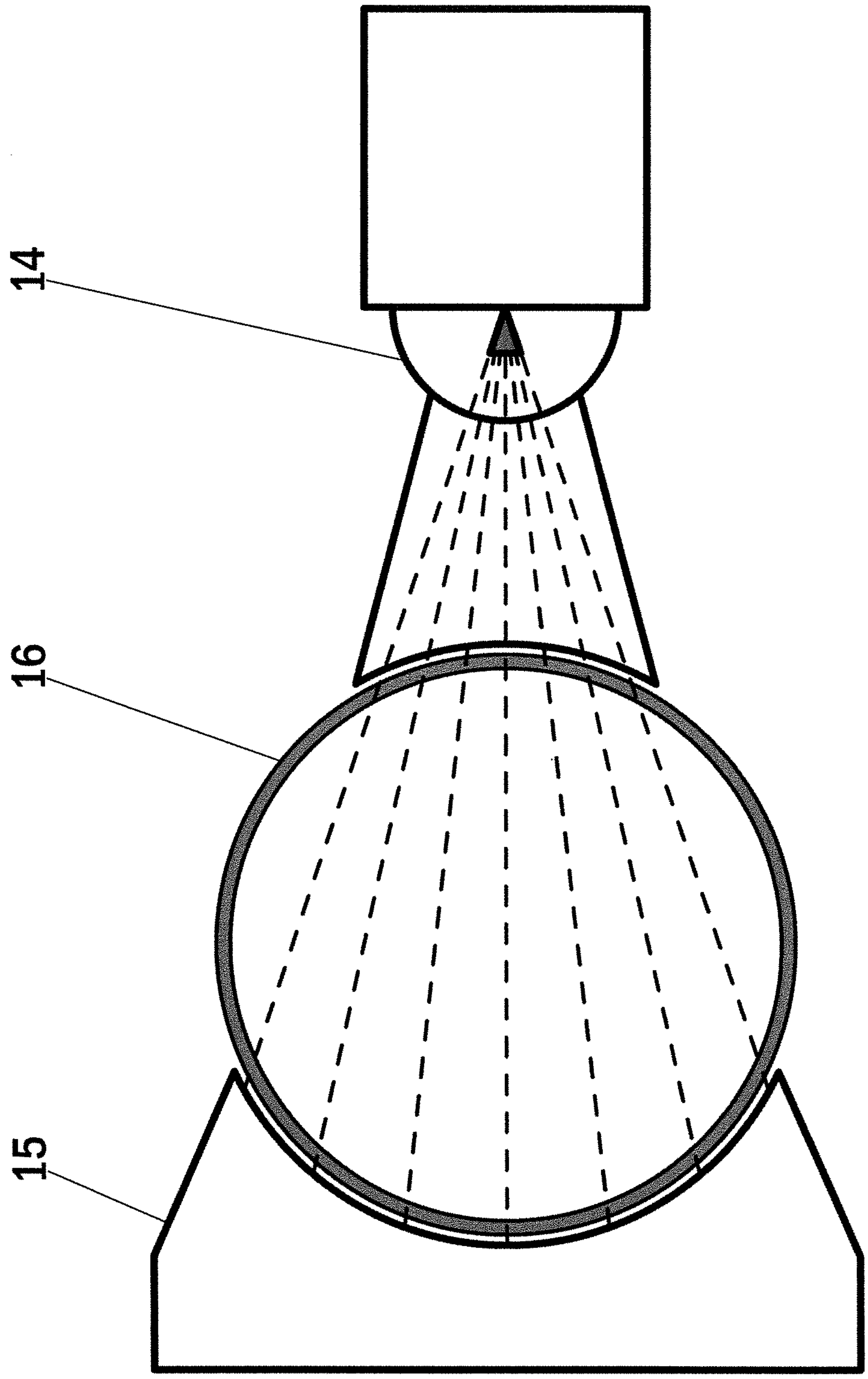

Fig. 3

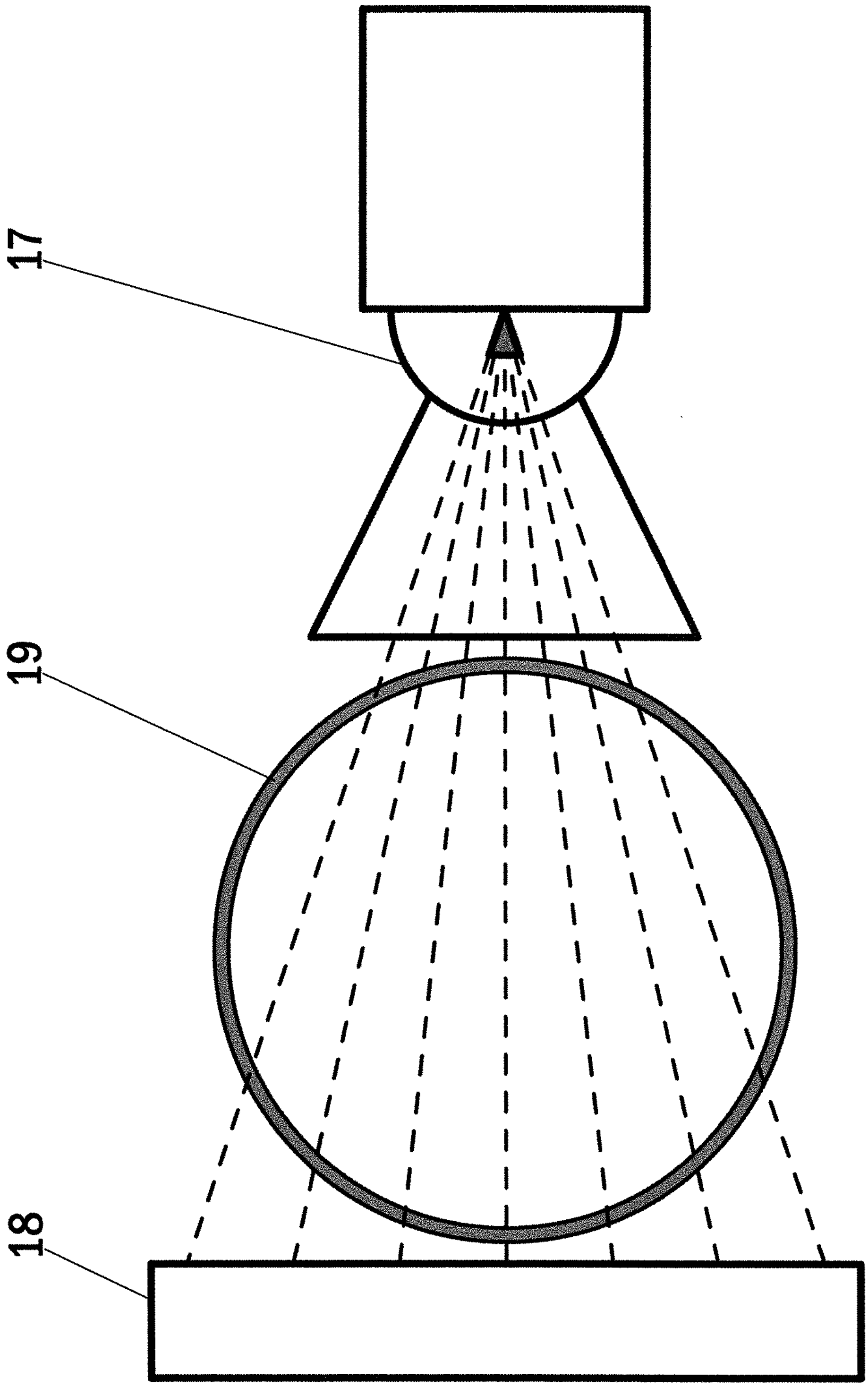

Fig. 4

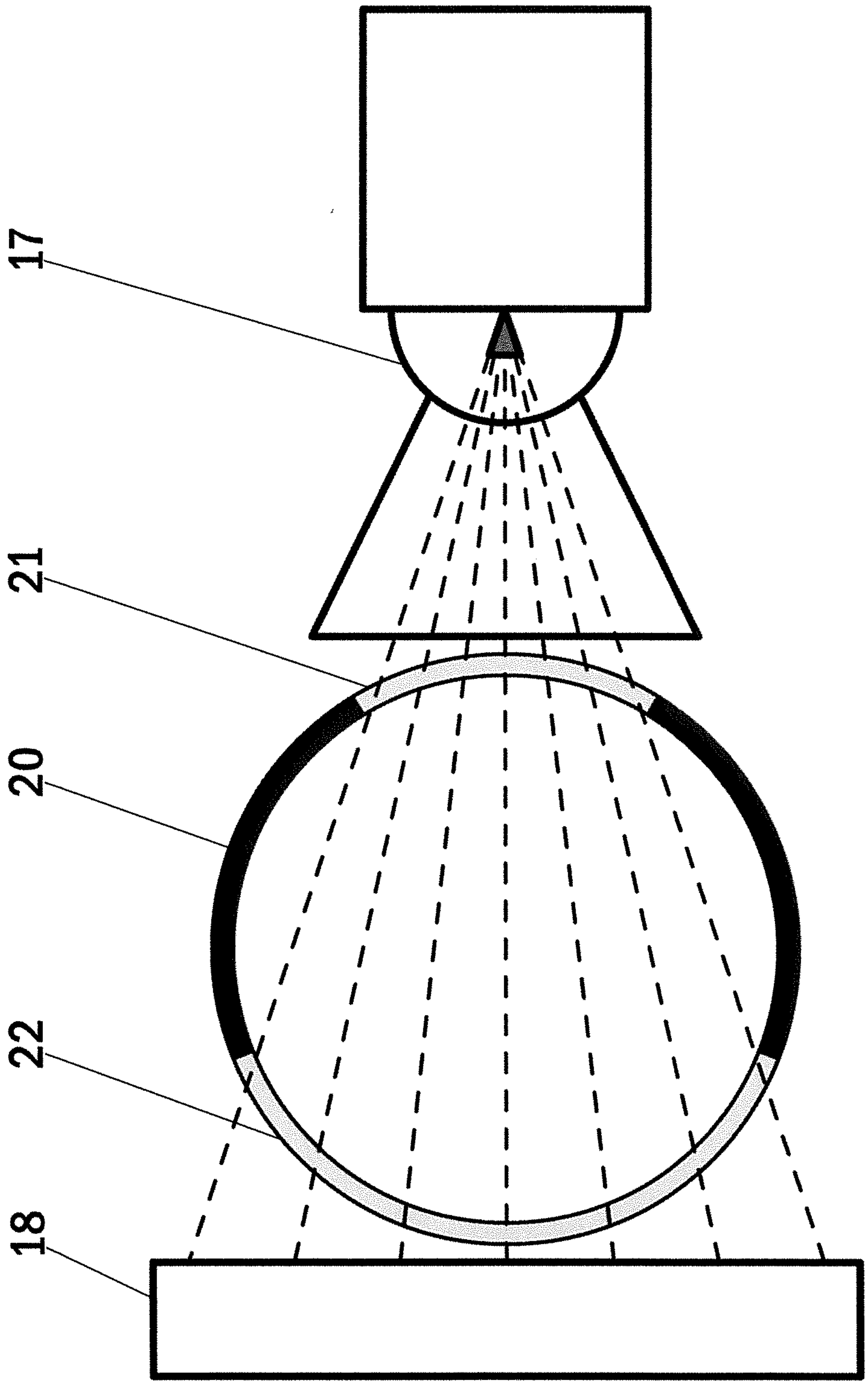

Fig. 5

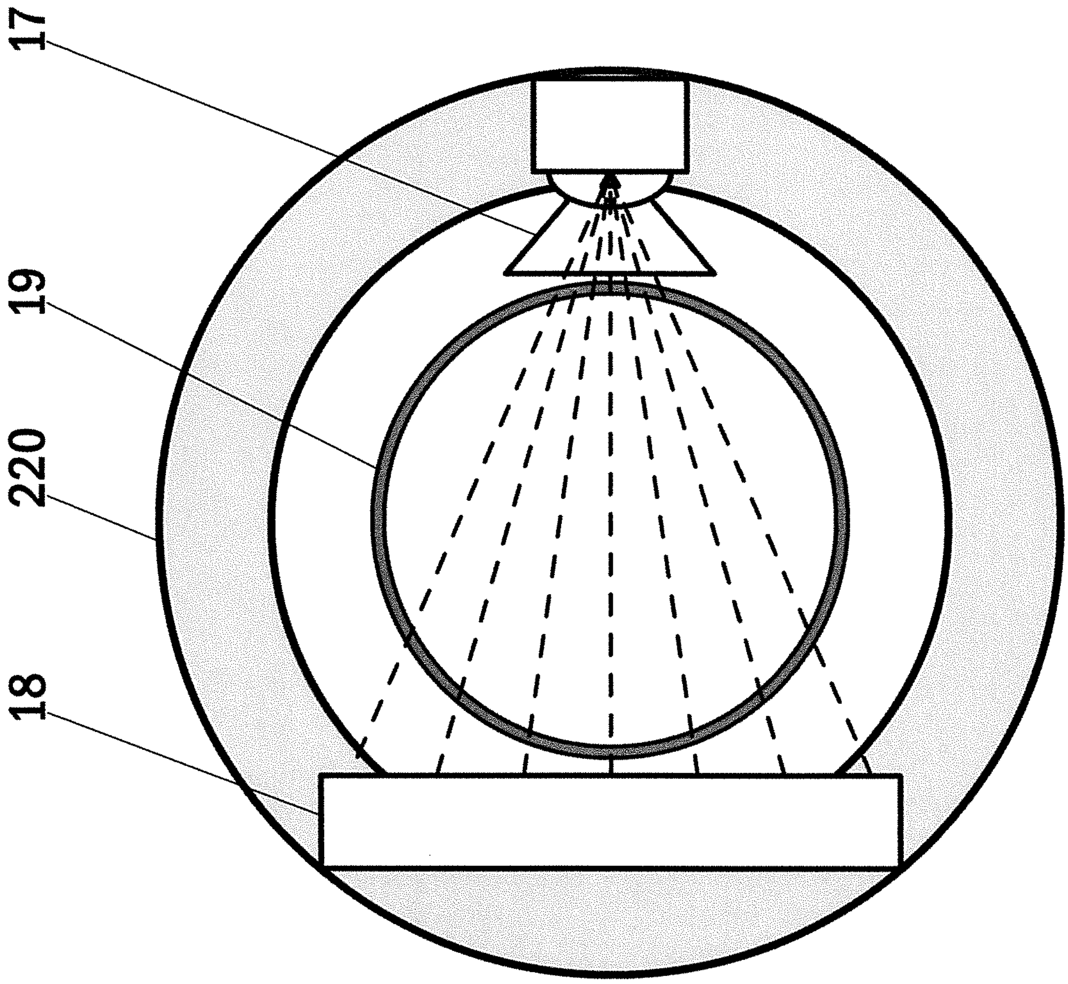

Fig. 6

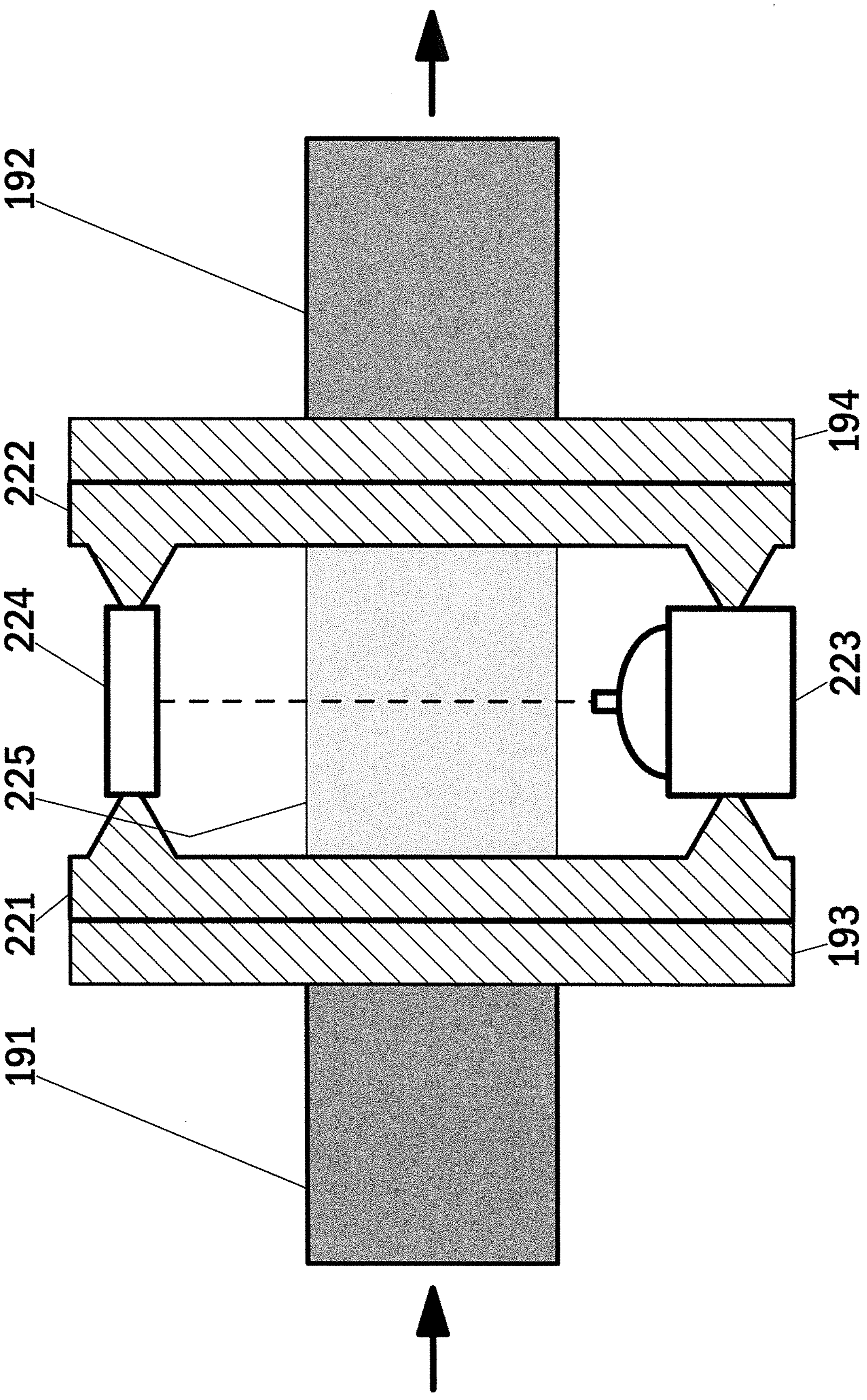

Fig. 7

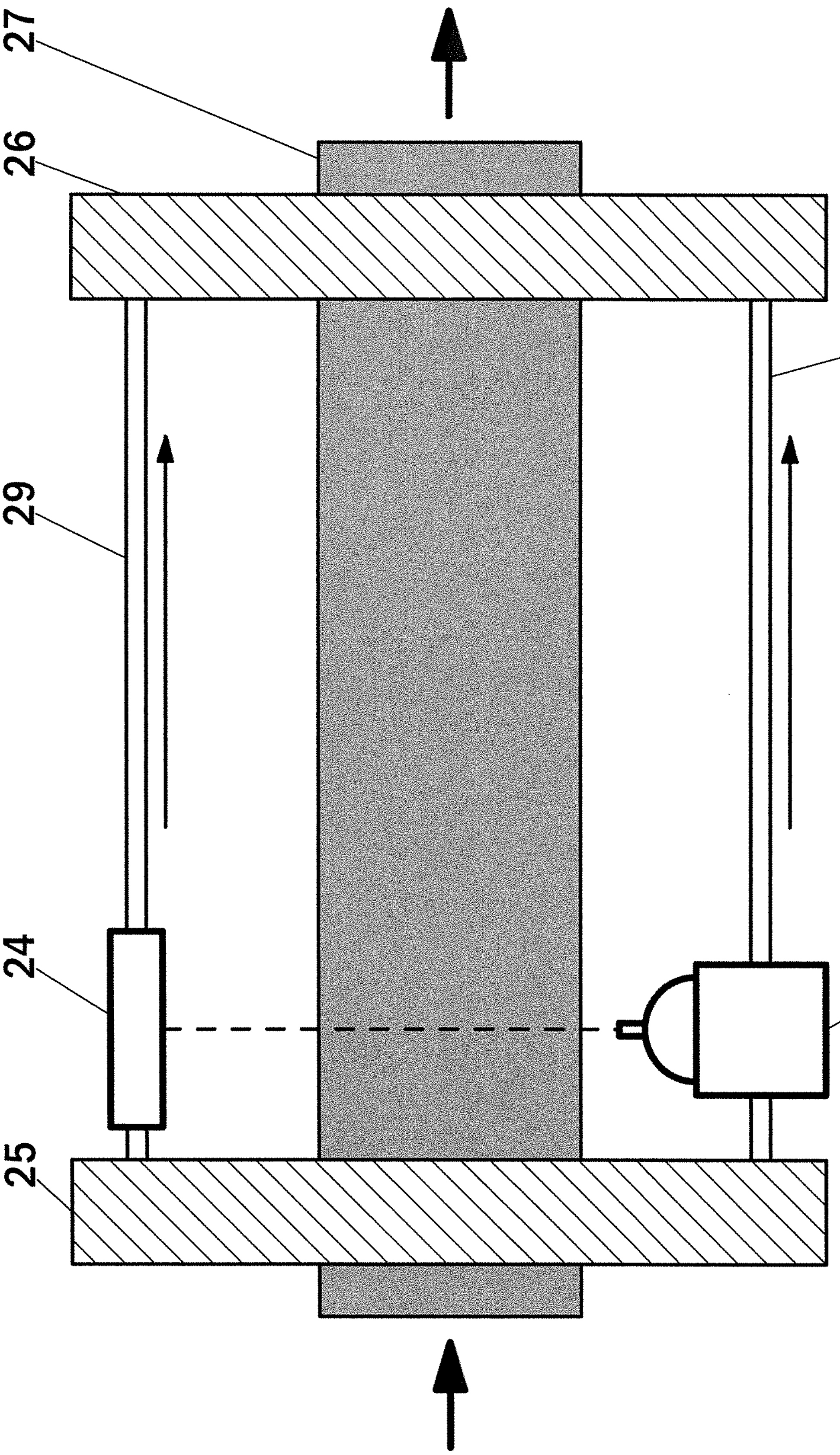

Fig. 8

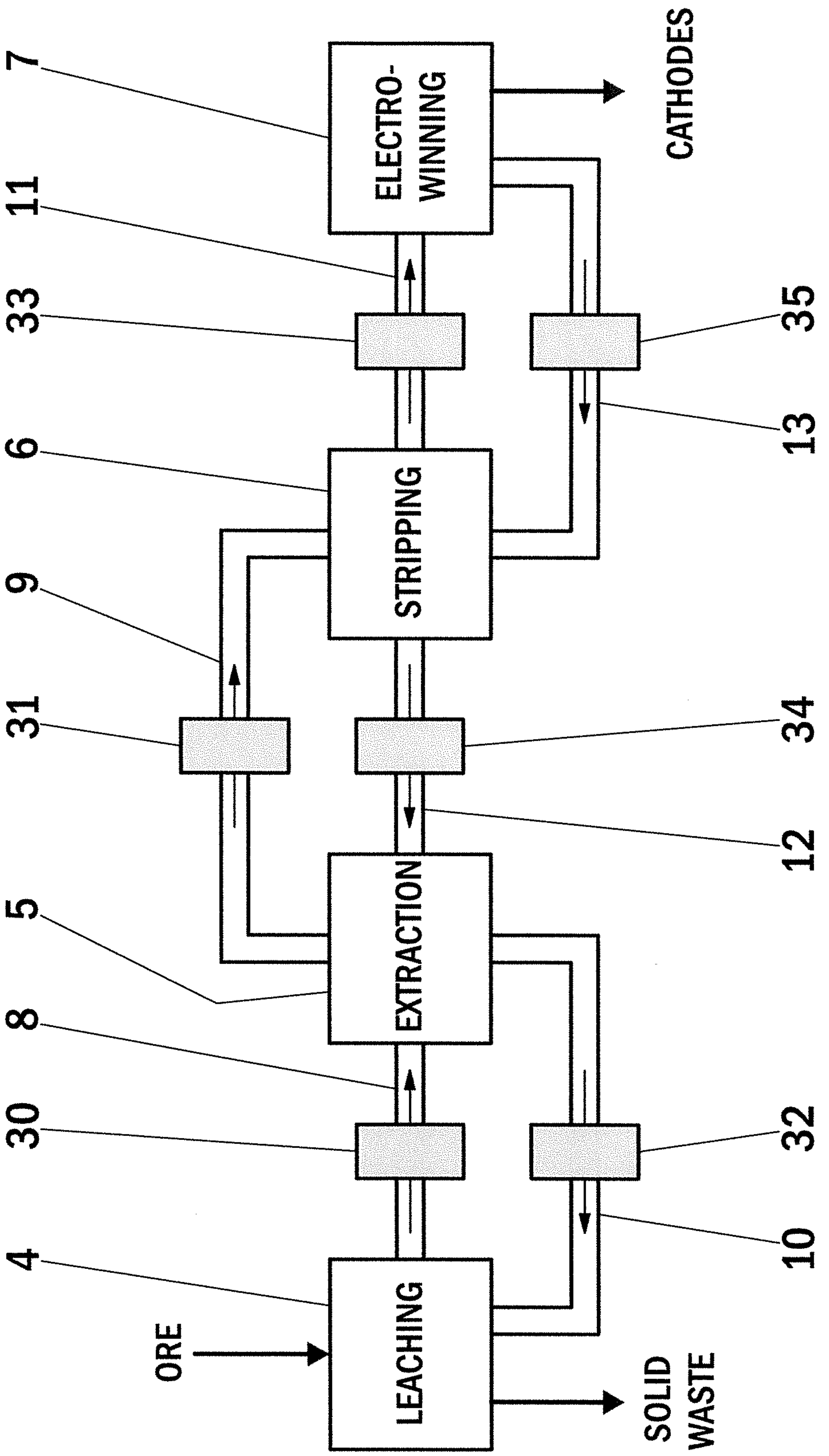
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Fig. 9

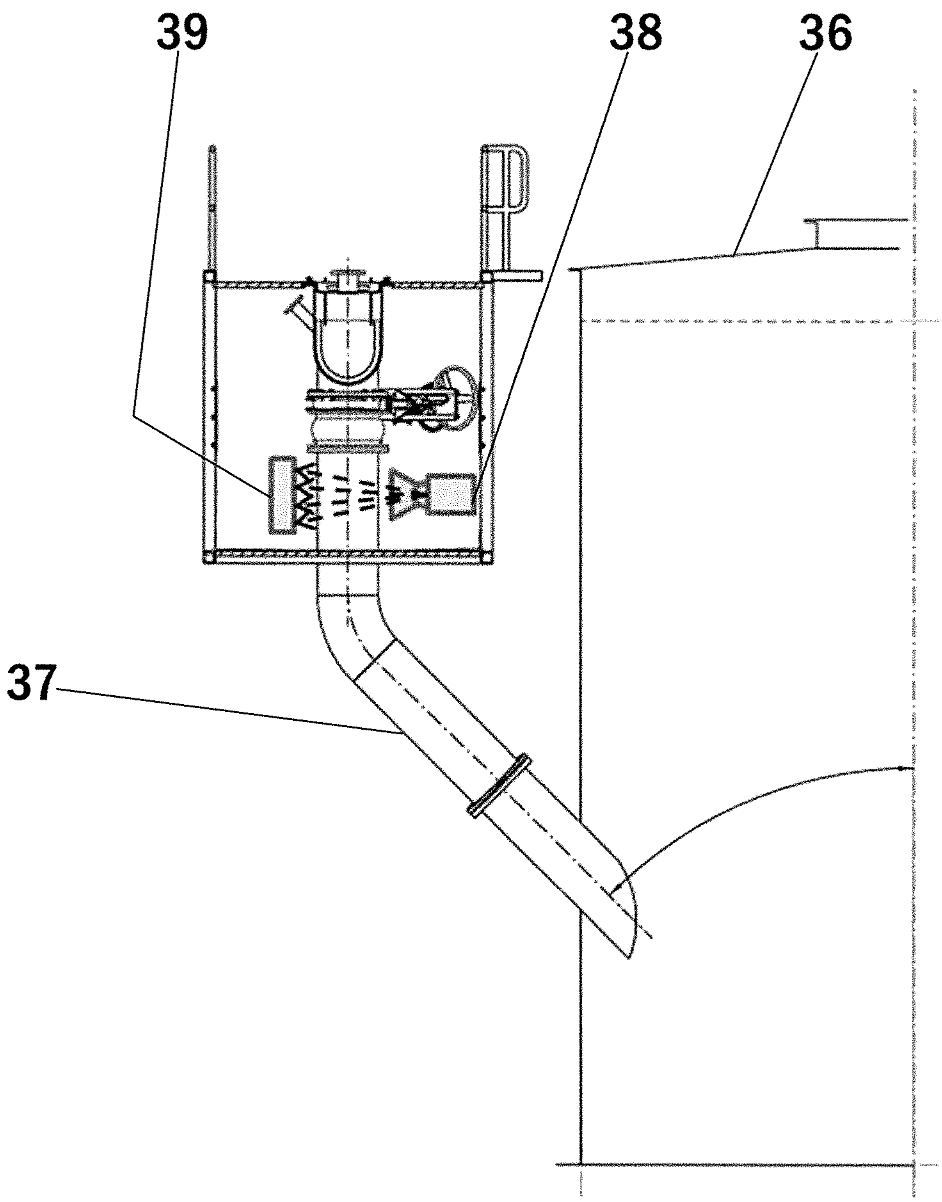

Fig. 10

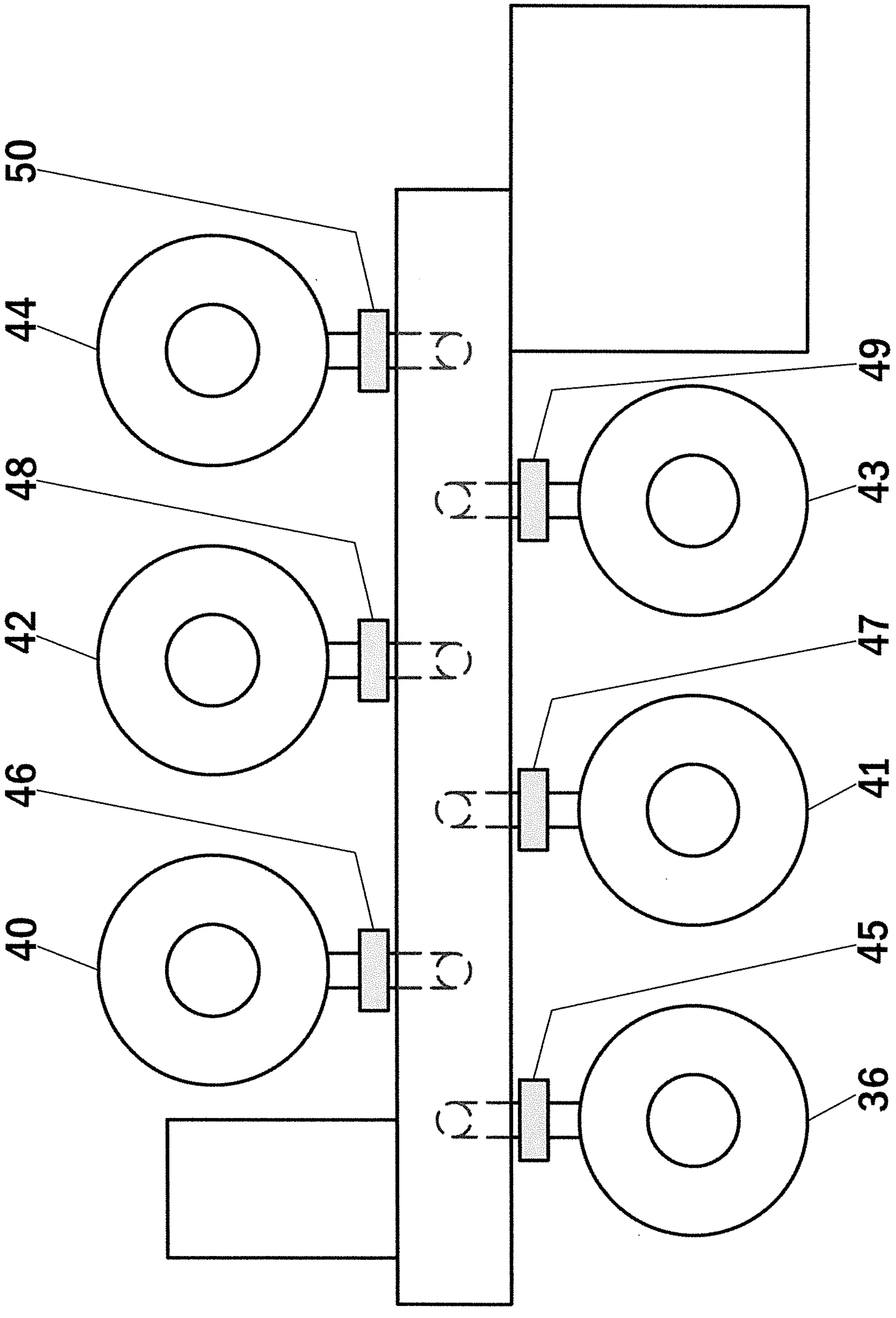

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2016/050921

A. CLASSIFICATION OF SUBJECT MATTER
INV. C22B3/02 C22B3/04
ADD.

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)
C22B G01N

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, COMPENDEX, 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 A	US 7 440 543 B2 (MORTON EDWARD J [GB]) 21 October 2008 (2008-10-21) the whole document	1-12, 14-22 13
X	JP S59 174744 A (TOSHIBA KK) 3 October 1984 (1984-10-03) abstract; figure 1	4-12, 14-22
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
16 March 2017	29/03/2017

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INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2016/050921

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