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(54) Titre : DETECTION D'UNE USURE OU D'UN DOMMAGE D'UN SEPARATEUR A CYCLONE A L'AIDE D'UNE
MESURE DE DEBORDEMENT D'UN SEPARATEUR A CYCLONE INDIVIDUEL
(54) Title: DETECTION OF CYCLONE WEAR OR DAMAGE USING INDIVIDUAL CYCLONE OVERFLOW
MEASUREMENT

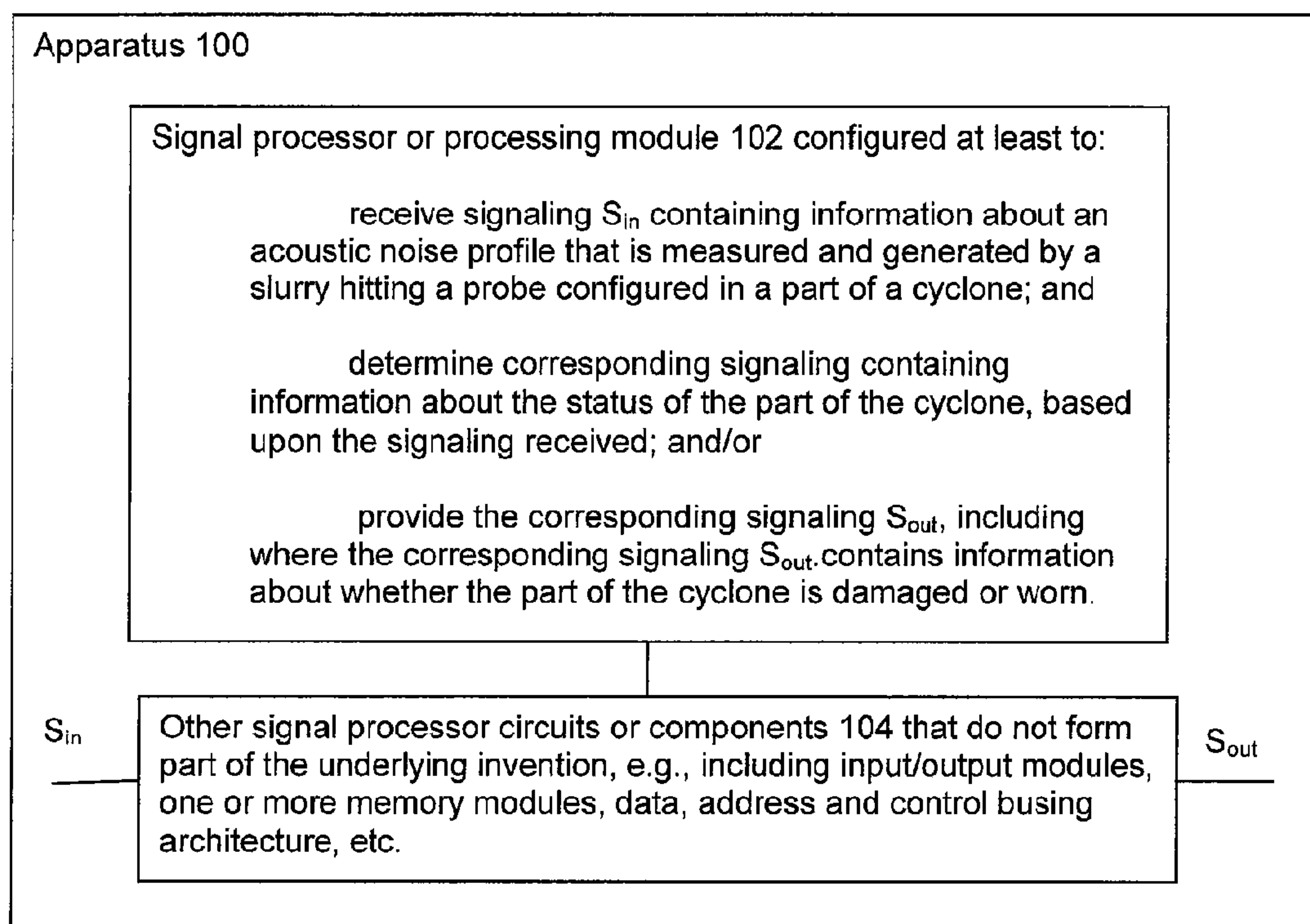


Figure 4A: The Basic Apparatus

(57) Abrégé/Abstract:

Apparatus features a signal processor or signal processing module configured to: receive signaling containing information about an acoustic noise profile that is directly measured and generated by a slurry hitting a probe configured in a part of a cyclone; and



(57) **Abrégé(suite)/Abstract(continued):**

determine corresponding signaling containing information about the status of the part of the cyclone, based upon the signaling received. The signal processor or signal processing module is configured to provide the corresponding signaling, including where the corresponding signaling provided contains information about whether the part of the cyclone is damaged or worn. The part of the cyclone is an apex of the cyclone, and the corresponding signaling contains information about the status of the apex of the cyclone.

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(54) Title: DETECTION OF CYCLONE WEAR OR DAMAGE USING INDIVIDUAL CYCLONE OVERFLOW MEASUREMENT

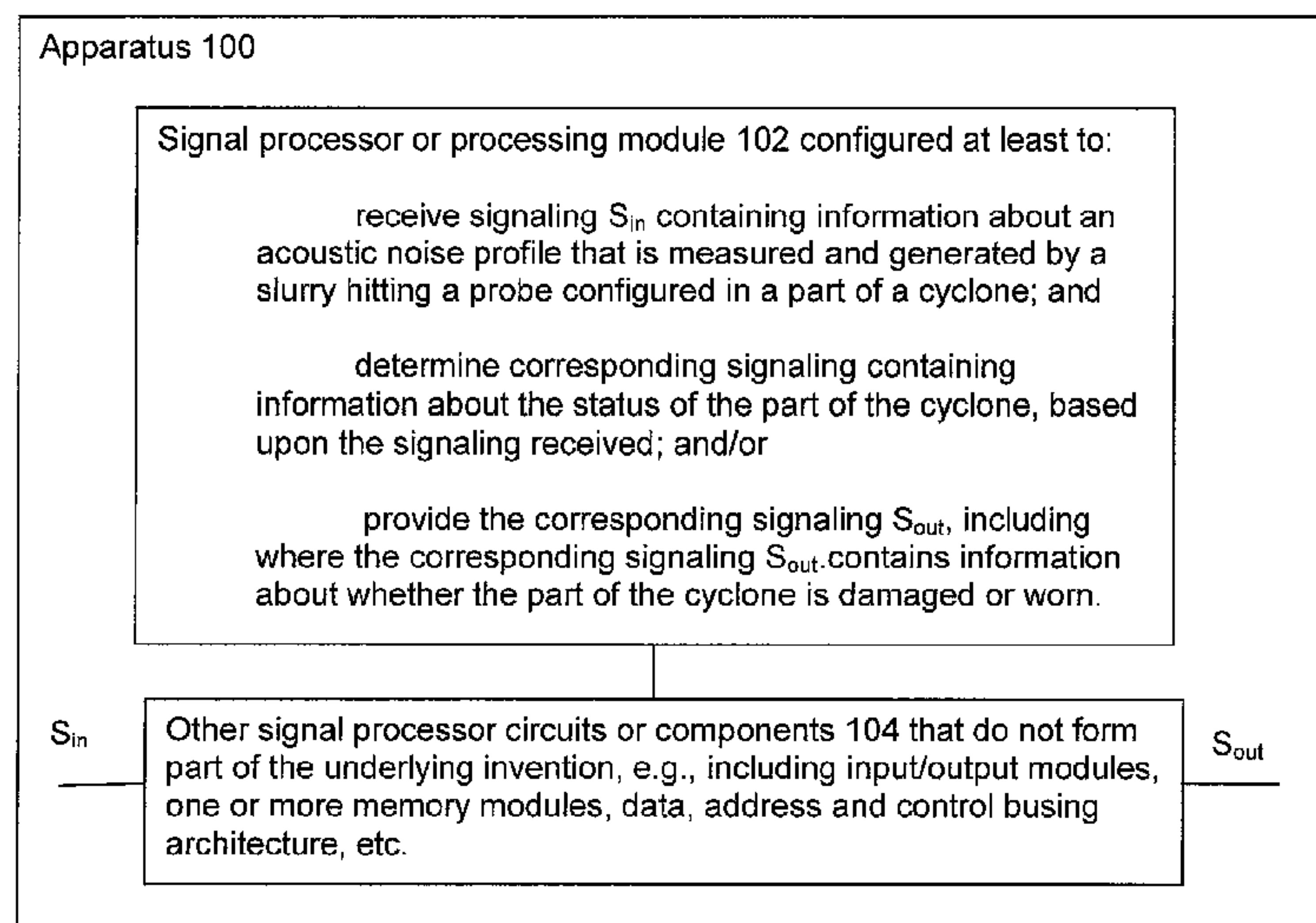


Figure 4A: The Basic Apparatus

(57) Abstract: Apparatus features a signal processor or signal processing module configured to: receive signaling containing information about an acoustic noise profile that is directly measured and generated by a slurry hitting a probe configured in a part of a cyclone; and determine corresponding signaling containing information about the status of the part of the cyclone, based upon the signaling received. The signal processor or signal processing module is configured to provide the corresponding signaling, including where the corresponding signaling provided contains information about whether the part of the cyclone is damaged or worn. The part of the cyclone is an apex of the cyclone, and the corresponding signaling contains information about the status of the apex of the cyclone.

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**DETECTION OF CYCLONE WEAR OR DAMAGE
USING INDIVIDUAL CYCLONE OVERFLOW MEASUREMENT**

CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application claims benefit to provisional patent application serial no. 62/108,689 (712-2.418//CCS-0134), filed 28 January 2015; which is incorporated by reference in its entirety.

 This application is related to PCT patent application serial no. PCT/US14/52628 (712-2.410-1//CCS-0124), filed 26 August 2014, which claims
10 benefit to provisional patent application serial no. 61/869,901 (712-2.410-1//CCS-0124), filed 26 August 2013, which are both incorporated by reference in their entirety.

 This application is related to patent application serial no. 13/389,546 (712-2.330-1-1), which corresponds to PCT/US10/45178, filed 11 August 2010, claiming
15 benefit to provisional patent application serial nos. 61/232,875 (CCS-0026), filed 11 August 2009; serial no. 61/400,819 (CCS-0044), filed 2 August 2010; and serial no. 61/370,154 (CCS-0043), filed 3 August 2010, which are all incorporated by reference in their entirety.

 This application is also related to patent application serial no. 13/377,083
20 (712-2.326-1-1//CCS-0027), which corresponds to PCT/US10/38281, filed 11 June 2010, claiming benefit to provisional patent application serial nos. 61/186,502, 12 June 2009, which are all incorporated by reference in their entirety.

 This application is related to patent application serial no. 12/991,636 (712-2.322-1-1//CC-0962), which corresponds to PCT/US09/43438, filed 11 May 2009,
25 claiming benefit to provisional patent application serial nos. 61/051,775 (CC-0962P), 61/051,781 (CCS-0963P), and 61/051,803 (CCS-0964P), all filed 9 May 2008, which are all incorporated by reference in their entirety.

The aforementioned applications were all assigned to the assignee of the present application, which builds on this family of technology.

BACKGROUND OF THE INVENTION

5 1. Field of Invention

This invention relates to a technique for optimizing the performance of cyclones, e.g., operating in a hydrocyclone battery in a mineral extraction processing system, including extracting a mineral from ore.

10 2. Description of Related Art

General Background

In many industrial processes the sorting, or classification, of product by size is critical to overall process performance. A minerals processing plant, or beneficiation plant, is no exception. In the case of a copper concentrator as shown in Figure 1A, 15 the input to the plant is water and ore (of a particular type and size distribution) and the outputs are copper concentrate and tailings. The process consists of a grinding, classification, floatation, and thickening, as shown in Figure 1B. The grinding and classification stage produces a fine slurry of water and ore, to which chemicals are added prior to being sent to the flotation stage. Once in the flotation stage, air is 20 used to float the copper mineral while the gangue (tailings) is depressed. The recovered copper is cleaned and dried. The tailings are thickened and sent to the tailings pond. The classification stage is critical to the performance of two areas of the process. These areas are the grinding throughput and flotation recovery, grade and throughput.

A grinding operation may include a screens and crusher stage and a mill stage, that is typically configured mills in closed circuit with a hydrocyclone battery.

A hydrocyclone is a mechanical device that will separate a slurry stream whereby the smaller particles will exit out the overflow line and the larger particles will exit out the underflow line. The overflow is sent to the flotation circuit and the underflow is sent back to the mill for further grinding. A collection of these devices is called a battery.

A hydrocyclone will be sized based on the particular process requirements. The performance of the hydrocyclone is dependent on how well it is matched to the process conditions. Once the proper hydrocyclone has been chosen and installed, it

must be operated within a specific range in order to maintain the proper split between the overflow and the underflow. The split is dependent on slurry feed density and volumetric flow into the device. A typical control system will use a combination of volumetric flow, feed density and pressure across the hydrocyclone to control the split. Because of the harsh environmental and process conditions all of

these measurements suffer from maintenance and performance issues. This can result in reduced classification performance and reduced mill throughput. Flotation performance is highly dependent on the particle size distribution in the feed which comes from the battery overflow, thus it is dependent on the hydrocyclone classification performance. The mill throughput is highly dependent on the

circulation load which comes from the battery underflow. Traditionally hydrocyclone performance has been determined by evaluating manually collected samples from the consolidated hydrocyclone battery overflow stream. This technique is time consuming; the accuracy is subject to sampling techniques; the sample is a summation of all the hydrocyclones from the battery; and has a typical 24 hour

turnaround time. Therefore it is not possible to implement a real time control algorithm to monitor, control, and optimize the each individual hydrocyclone.

Real time monitoring of each individual hydrocyclone would provide the ability to track the performance of individual hydrocyclones. This would enable the following:

- The detection of hydrocyclones that require maintenance or have become plugged.
- The detection of operational performance instabilities that cause extended periods of roping or surging.
- The detection of chronic problems with certain hydrocyclones.
- Tighter classification control with changing throughput demands and feed densities.
- Increased up time or availability of the hydrocyclone battery.

Moreover, Figure 2 shows a classification stage generally indicated as 10 that may form part of a mineral extraction processing system, like the one shown in Figure 1A and 1B for extracting minerals from ore. The classification stage 10 includes a hydrocyclone battery 12 that receives a feed from a grinding stage, as shown in Figure 1B. The hydrocyclone battery 12 is configured to respond to signaling from a signal processor or processor control module 14, and provide an effluent, e.g., a fine slurry or slurry feed, to a flotation stage shown in Figure 1B. The classification stage 10 also may include a hydrocyclone split 16 that receives the slurry from the hydrocyclone battery 12, and also may receive signaling from the signal processor or processor control module 14, and may provide some portion of the slurry back to the mill stage shown in Figure 1B, and may also provide another portion of the slurry as a flotation feed to a flotation stage shown in Figure 1B. The

signal processor or processor control module 14 may also send to or receive from one or more signals with a control room computer 50 (see Figure 3A). The technique to track the flow performance of individual cyclones operating in parallel on a single battery is described in relation to the hydrocyclone battery 12 (i.e. the single battery), the signal processor or processor control module 14 and the cooperation of these two components.

Figure 3 shows the hydrocyclone battery 12 (i.e. the single battery), the signal processor or processor control module 14 and the cooperation of these two components according to some embodiments of the present invention. For example, the hydrocyclone battery 12 may include a first and second hydrocyclone pair 12a, 12b. The first hydrocyclone pair 12a includes a first hydrocyclone 20 and a second hydrocyclone 30. The first hydrocyclone 20 has a cylindrical section 22 with an inlet portion 22a for receiving via a feed pipe 9 the feed from the grinding stage shown in Figure 1B, an overflow pipe 24 for providing one portion of the fine slurry or slurry feed to either the flotation stage shown in Figure 1B, or the hydrocyclone split 16 shown in Figure 2, and has a conical base section 26 with underflow outlet 26a for providing a remaining portion of the fine slurry or slurry feed.

Similarly, the second hydrocyclone 30 has a cylindrical section 32 with an inlet portion 32a for receiving the feed from the grinding stage shown in Figure 1B, an overflow pipe 34 for providing one portion of the fine slurry or slurry feed to either the flotation stage shown in Figure 1B, or the hydrocyclone split 16 shown in Figure 2, and has a conical base section 36 with underflow outlet 36a for providing a remaining portion of the fine slurry or slurry feed.

As one skilled in the art would appreciate, the first and second hydrocyclones 20, 30 classify, separate and sort particles in the feed from the grinding stage based

at least partly on a ratio of their centripetal force to fluid resistance. This ratio is high for dense and course particles, and low for light and fine particles. The inlet portion 22a, 32a receives tangentially the feed from the grinding stage shown in Figure 1B, and the angle and the length of the conical base section 26, 36 play a role in determining its operational characteristics, as one skilled in the art would also appreciate.

In the example shown in 3, at least one sensor 28 may be mounted on the overflow pipe 24 that is configured to respond to sound propagating in the overflow pipe 24 of the cyclone 20, and to provide at least one signal containing information about sound propagating through the slurry flowing in the overflow pipe 24 of the cyclone 20. Similarly, at least one corresponding sensor 38 is mounted on the overflow pipe 34 that is configured to respond to sound propagating in the overflow pipe 34 of the cyclone 30, and to provide at least one corresponding signal containing information about sound propagating through the slurry flowing in the overflow pipe 34 of the cyclone 30. By way of example, the at least one sensors 28, 38 may take the form of a SONAR-based clamp-around flow meter, which is known in the art consistent with that described below. The SONAR-based clamp-around flow meters 28, 38 may be clamped in whole or in part around some portion of the overflow pipes 24, 34. For example, the at least one sensor or meter 28, 38 may be mounted on the top of the overflow pipes 24, 34, or the at least one sensor or meter 28, 38 may be mounted on the bottom of the overflow pipe 24, 34. Alternatively, a pair of at least one sensor or meter 28, 38 may be mounted on the overflow pipes 24, 34, e.g., with one sensor or meter mounted on the top of the overflow pipes 24, 34, and with another sensor or meter mounted on the bottom of the overflow pipe 24, 34.

By way of example, in operation the SONAR-based clamp-around flow meters 28, 38 may be configured to respond to a strain imparted by the slurry, e.g., made up of water and fine particles, flowing in the overflow pipes 24, 34 of the cyclones 20, 30, and provide the signals along signal paths or lines 28a, 38a containing
5 information about sound propagating through the slurry flowing in the overflow pipes 24, 34 of the cyclones 20, 30.

The Problem Addressed by the Present Application

Consistent with that set forth above, classification in industrial processing
10 circuits is often performed using such hydrocyclones as shown in Figures 2-3. Hydrocyclones are inherently simple devices with no moving parts and are typically arranged in a cluster or pack of multiple units. Each individual cyclone unit is fed from a common distribution header and it is assumed that each individual cyclone unit receives an equal feed flow and the performance of each is similar. However,
15 in practice this is not the case due to a number of factors including wear of the cyclone apex and/or vortex finder and damage to the hydrocyclone.

As the cyclone apex wears over time and becomes larger, there is an increase in the fraction of material reporting to the underflow. Furthermore, the percent solids of the underflow decreases and the excess water carries fine
20 particles to the underflow. In a closed circuit ball mill, this can have significant impact to grinding efficiency since particles that are of product size are returning to the ball mill and taking up volume which could be otherwise used to grind larger particles. In some cases, the wear can be significant enough to impact the particle size distribution and flow pattern of the overflow stream.

As the cyclone vortex finder wears over time, the cut point of the cyclone will increase leading to a larger particle size distribution in the overflow stream. This negatively impacts the performance of the downstream process since the material size is too large for efficient valuable mineral recovery.

5 With no moving parts, the hydrocyclone relies heavily on its internal dimensions and geometry to achieve the desired classification. Any damage to the internal structure of the hydrocyclone (i.e. liner coming free, missing liner piece or holes) will lead to sub-optimal performance. Furthermore, hydrocyclones are assembled in sections and a misalignment of two or more sections can create a step
10 change in the internal wall which in turn leads to a drop in performance.

Currently, the method of determining cyclone wear or damage is through physical measurements of the cyclone dimensions which require at least the cyclone to be offline and in some cases the whole cyclone cluster.

In view of this, there is a need in the industry for a better way for determining
15 cyclone wear or damage, especially by eliminating the requirement that at least one cyclone be offline and in some cases the whole cyclone cluster in order to make such a determination.

SUMMARY OF THE INVENTION

20 The Present Invention

The present invention provides a new and unique technique for determining cyclone wear or damage, e.g., through measurement of the cyclone overflow stream in real time, individual cyclone wear or damage can be inferred providing a maintenance and operational efficiency benefit. By way of example, this can be
25 accomplished by directly measuring the acoustic noise generated by the slurry hitting

a probe, e.g., including a particle size tracking (PST) probe developed by the assignee of the present invention and known in the industry as CYCLONEtrac™.

This acoustic noise profile can be correlated to the slurry flow pattern which in turn indicates the status of the hydrocyclone apex diameter. This diagnostic capability is

5 provided while the hydrocyclone is operating so the cyclone does not have to be taken out of operation for manual inspection. This new trending capability enables new predictive maintenance strategies based on condition based monitoring as opposed to time based replacement, e.g., that is known in the art.

10 Particular Embodiments

In its broadest sense, the new and unique techniques, e.g., may include, or take the form of, a method and/or an apparatus, to optimize the performance of individual cyclones operating in a battery of cyclones.

According to some embodiments of the present invention, the apparatus may
15 comprise at least one signal processor or signal processing module configured at least to:

receive signaling containing information about an acoustic noise profile that is measured and generated by a slurry hitting a probe configured in a part of a cyclone; and

20 determine corresponding signaling containing information about the status of the part of the cyclone, based upon the signaling received.

The apparatus may also include one or more of the following features:

The signal processor or signal processing module may be configured to provide the corresponding signaling, including where the corresponding signaling

provided contains information about whether the part of the cyclone is damaged or worn.

The part of the cyclone may be an apex of the cyclone, and the corresponding signaling contains information about the status of the apex of the cyclone.

5 The part of the cyclone may be the cyclone vortex finder, and the corresponding signaling contains information about the status of the cyclone vortex finder.

10 The signal processor or signal processing module may be configured to correlate the acoustic noise profile to a slurry flow pattern which indicates the status of the part of the cyclone.

15 The signal processor or signal processing module may be configured to determine the status of the part of the cyclone based upon fluctuations in the acoustic noise profile, including the acoustic noise profile of a worn or damaged part of the cyclone has higher or less stable statistical fluctuations in probe measurements, and a corresponding acoustic noise profile of a non-worn or non-damaged part of the cyclone has lower or more stable statistical fluctuations in the probe measurements than the acoustic noise profile of the worn or damaged part of the cyclone.

20 The corresponding signaling provided may contain an indication about the status of the part of the cyclone, including where the indication is a graph showing the statistical fluctuations in the probe measurements for visual interpretation by a plant manager about the status of the part of the cyclone, or including where the indication is an alarm signal alerting the plant manager about the status of the part of the cyclone. The alarm signal may be an audio signal, or a visual signal (e.g., a
25 blinking light), or some combination thereof.

The signal processor or signal processing module may be configured, through measurements of a cyclone overflow stream in real time, to determine individual cyclone wear or damage.

The signal processor or signal processing module may be configured to
5 determine trending capability of cyclone wear or damage that enables predictive maintenance strategies based on condition monitoring instead of time-based replacement, based upon the signaling received. For example, based upon trending capability of cyclone wear or damage determined, the signal processor or signal processing module may be configured to implement predictive maintenance
10 algorithms to determine predictive maintenance strategies to manage the replacement of the part of the cyclone. The predictive maintenance algorithms may be based upon developing a forward-moving database that includes data containing information about cyclones, cyclone parts, wear patterns of cyclone parts, replacement events of cyclone parts in the past, predicted replacement events of
15 cyclone parts in the future, cyclone running times, types of slurry being processed, amount of slurry being processed, etc.

The signal processor or signal processing module may be configured to provide diagnostic capability in real time while the cyclone is operating so the cyclone does not have to be taken out of operation for manual inspection, based
20 upon the signaling received.

The apparatus may include the probe. The probe may be a particle size tracking probe.

The apparatus may include the cyclone having a cyclone part, like an apex, with the probe configured therein.

According to some embodiments, the present invention may take the form of apparatus for detection of cyclone wear or damage using individual cyclone overflow measurement, featuring a signal processor or signal processing module configured to: receive signaling containing information about an acoustic noise profile that is

5 directly measured and generated by a slurry hitting a probe configured in an apex of a cyclone; and determine corresponding signaling containing information about the diameter of the apex of the cyclone in real time based upon fluctuations in the acoustic noise profile in the signaling received. The signal processor or signal processing module may be configured to provide the corresponding signaling,

10 including where the corresponding signaling contains information about whether the apex of the cyclone is damaged or worn. The corresponding signaling may contain information for generating a graph showing statistical fluctuations in probe measurements over time for visual interpretation by a plant manager in order to assess the status of the diameter of the apex of cyclone. Alternatively, the

15 corresponding signaling may contain information for generating an alarm signal alerting a plant manager about the status of the diameter of the apex of the cyclone, including where the alarm signal is an audio signal, or a visual signal, or some combination thereof.

According to some other embodiments, the present invention may take the

20 form of a method featuring steps for receiving in a signal processor or signal processing module signaling containing information about an acoustic noise profile that is measured and generated by a slurry hitting a probe configured in a part of a cyclone; and determining in the signal processor or signal processing module corresponding signaling containing information about the status of the part of the

25 cyclone, based upon the signaling received.

The signal processor or signal processor module may take the form of a signal processor and at least one memory including a computer program code, where the signal processor and at least one memory are configured to cause the apparatus to implement the functionality of the present invention, e.g., to respond to signaling received and to determine the corresponding signaling, based upon the signaling received.

According to some embodiment, the present invention may take the form of apparatus comprising means for responding to signaling containing information about an acoustic noise profile that is measured and generated by a slurry hitting a probe configured in a part of a cyclone; and means for determining corresponding signaling containing information about the status of the part of the cyclone, based upon the signaling received, consistent with that set forth herein.

According to some embodiments of the present invention, the apparatus may also take the form of a computer-readable storage medium having computer-executable components for performing the steps of the aforementioned method. The computer-readable storage medium may also include one or more of the features set forth above.

One advantage of the present invention is that it provides a better way for determining cyclone wear or damage, especially by eliminating the requirement that at least one cyclone be offline and in some cases the whole cyclone cluster.

BRIEF DESCRIPTION OF THE DRAWING

The drawing includes Figures 1A - 13, which are not necessarily drawn to scale, as follows:

Figure 1A is a block diagram of a mineral extraction processing system in the form of a copper concentrator that is known in the art.

Figure 1B is a block diagram showing typical processing stages of a mineral extraction processing system that is known in the art.

Figure 2 is a block diagram showing a classification stage that is known in the art.

Figure 3 is a diagram showing a cyclone battery, sensors, a signal processor and a remote computer processor that is known in the art.

Figure 4A shows a block diagram of apparatus, e.g., having a signal processor or signal processing module for implementing signal processing functionality, according to some embodiments of the present invention.

Figure 4B is a diagram showing a cyclone having a probe arranged on one or more parts of the cyclone, including underflow portion, according to some embodiments of the present invention.

Figure 5 shows a block diagram of a flowchart for a method, according to some embodiments of the present invention.

Figure 6 shows a graph for application 1 of cyclone acoustic readings over time a 12 hour time span taken, according to some embodiments of the present invention.

Figure 7 shows photos of an acoustic measurement probe for the application 1 after an inspection, including Fig. 7A that shows a photo of an upside of the acoustic measurement probe for the application 1, Fig. 7B that shows a photo of a

right side of the acoustic measurement probe for the application 1, and Fig. 7C that shows a photo of a downside of the acoustic measurement probe for the application 1.

Figure 8 shows photos of an inside of an overflow (O/F) pipe that forms part of the cyclone in the application 1, including Fig. 8A that shows an original photo of the O/F pipe for the application 1, and Fig. 8B that shows an edge-filtered photo of the O/F pipe for the application 1.

Figure 9 shows graphs (% + 150 microns vs. time) of PST measurements in 1 minute intervals of the cyclone before (Fig. 9A) and after (Fig. 9B) replacement.

Figure 10 shows a graph for application 2 of cyclone acoustic readings over time a 12 hour time span taken, according to some embodiments of the present invention.

Figure 11 shows photos of an acoustic measurement probe for the application 2 after an inspection, including Fig. 11A that shows a photo of an downside of the acoustic measurement probe for the application 2, Fig. 11B that shows a photo of a right side of the acoustic measurement probe for the application 2, and Fig. 11C that shows a photo of a upside of the acoustic measurement probe for the application 2.

Figure 12 shows two photos of inside portions of an overflow (O/F) pipe at two pipe locations that forms part of the cyclone in the application 2 and a photo of an outside of the O/F pipe with the two pipe locations identified, including Fig. 12A that shows a photo of the O/F pipe at a first pipe location (see left side arrow in Fig. 12C) for the application 2, and Fig. 12B that shows a photo of the O/F pipe at a second pipe location (see right side arrow in Fig. 12C) for the application 2, and Fig. 12C that shows the photo of an outside of the O/F pipe with the two locations,

Figure 13 shows a graph (% + 150 microns vs. time) of PST measurements in 5 minute intervals of the cyclone before replacement.

DETAILED DESCRIPTION OF BEST MODE OF THE INVENTION

5 Summary of Basic Invention

In general, the present invention provides new and unique techniques for determining cyclone wear or damage, e.g., through measurement of the cyclone overflow stream in real time, individual cyclone wear or damage can be inferred providing a maintenance and operational efficiency benefit. This will be
10 accomplished by directly measuring the acoustic noise generated by the slurry hitting a probe, e.g., including a particle size tracking (PST) probe developed by the assignee of the present invention and known in the industry as CYCLONEtrac™. This acoustic noise profile can be correlated to the slurry flow pattern which in turn indicates the status of the hydrocyclone apex diameter. This diagnostic capability is
15 provided while the hydrocyclone is operating so the cyclone does not have to be taken out of operation for manual inspection. This new trending capability enables new predictive maintenance strategies based on condition based monitoring as opposed to the known time based replacement strategies.

20 Figure 4A

By way of example, Figure 4A shows apparatus generally indicated as 100, e.g. having at least one signal processor or signal processing module 102 for implementing the signal processing functionality according to the present invention. In operation, the at least one signal processor or signal processing module 102 may
25 be configured at least to:

receive signaling S_{in} containing information about an acoustic noise profile that is measured and generated by a slurry hitting a probe (e.g., see probe 128a (Fig. 4B)) configured in a part of a cyclone; and

5 determine corresponding signaling S_{out} containing information about the status of the part of the cyclone, based upon the signaling received.

By way of example, the signaling S_{in} may be received from a CYCLONEtracTM PST probe 128a that may be mounted on the part of the cyclone. (See Figures 7-8 and 11 that show photos of the probe arranged in the part of the cyclone.)

10 The at least one signal processor or signal processing module 102 may also be configured to determine the corresponding signaling containing information about the status of the part of the cyclone, based upon the signaling received. A person skilled in the art would appreciate and understanding without undue experimentation, especially after reading the instant patent application together with that known in the art, e.g., how to implement suitable signaling suitable processing functionality to
15 make one or more such determinations.

The at least one signal processor or signal processing module 102 may be configured to provide the corresponding signaling S_{out} . By way of example, the corresponding signaling S_{out} provided may include, take the form of, or contain information about whether the part of the cyclone is damaged or worn.

20 According to some embodiments of the present invention, the apparatus 100 may also include, e.g., one or more probes like element 128a, a cyclone like element 120, the battery of cyclones like element 120, etc., e.g., consistent with that set forth herein.

Figure 4B

By way of example, Figure 4B shows a cyclone 120 according to some embodiments of the present invention, e.g., that may form part of the hydrocyclone battery shown in Figure 3 or some other hydrocyclone battery for implementing the present invention. The cyclone 120 has a cylindrical section 122 with an inlet portion 122a for receiving via the feed pipe 9 (see Fig. 2) the feed from the grinding stage (see Fig. 1B), has an overflow pipe 124 for providing some portion of the fine slurry or slurry feed to either the flotation stage (Fig. 1B), or the hydrocyclone split 16 (Fig. 2), and has a conical base section 126 with an underflow outlet 126a for providing a remaining portion of the fine slurry or slurry feed, e.g., back for reprocessing in the grinding stage (Fig. 2).

In Figure 4B, the cyclone 120 has at least one probe labeled 128a arranged in relation to the underflow portion 126a of the cyclone 120. The probe 128a is known in the art, and may take the form of a CYCLONEtracTM PST probe that was developed by the assignee of the instant patent application. In operation, the probe 128a may be configured to provide the signaling S_{in} to the signal processor or processing module 102, e.g., containing information about the acoustic noise profile that is directly measured and generated by the slurry hitting the probe configured in relation to the underflow portion 126a of the cyclone.

In Figure 4B, the cyclone 120 may include other probes labeled 128b, 128c, 128d, 128e, e.g., arranged in relation to other parts or portions of the cyclone 120, including the cylindrical section 122, the inlet portion 122a, the overflow pipe 124 and/or the conical base section 126. The scope of the invention is not intended to be limited to any particular arrangement of any particular number of probes like element 128a, 128b, 128c, 128d, 128e on any particular parts or portion of the cyclone 120

like elements the cylindrical section 122, the inlet portion 122a, the overflow pipe 124, the conical base section 126 and/or the underflow portion 126a.

It is note that a person skilled in the art would appreciate and understanding without undue experimentation, especially after reading the instant patent application together with that known in the art, e.g., how to implement suitable signaling processing functionality in the signal processor or signal processing module 102 (Fig. 4A) to receive such signaling containing such information from such a CYCLONEtracTM PST probe like element 128a, as well as how to adapt such a CYCLONEtracTM PST probe like element 128a to implement suitable signaling processing functionality to provide such signaling containing such information to the signal processor or signal processing module 102.

The Signal Processor or Processor Module 102

The functionality of the signal processor or processor module 102 may be implemented using hardware, software, firmware, or a combination thereof. In a typical software implementation, the processor module may include one or more microprocessor-based architectures having a microprocessor, a random access memory (RAM), a read only memory (ROM), input/output devices and control, data and address buses connecting the same, e.g., consistent with that shown in Figure 4A, e.g., see element 104. A person skilled in the art would be able to program such a microprocessor-based architecture(s) to perform and implement such signal processing functionality described herein without undue experimentation. The scope of the invention is not intended to be limited to any particular implementation using any such microprocessor-based architecture or technology either now known or later developed in the future.

By way of example, the apparatus 100 may also include, e.g., other signal processor circuits or components 104 that do not form part of the underlying invention, e.g., including input/output modules, one or more memory modules, data, address and control busing architecture, etc. In operation, the at least one signal processor or signal processing module 102 may cooperation and exchange suitable data, address and control signaling with the other signal processor circuits or components 104 in order to implement the signal processing functionality according to the present invention. By way of example, the signaling S_{in} may be received by such an input module, provided along such a data bus and stored in such a memory module for later processing, e.g., by the at least one signal processor or signal processing module 102. After such later processing, processed signaling resulting from any such determination may be stored in such a memory module, provided from such a memory module along such a data bus to such an output module, then provided from such an output module as the corresponding signaling S_{out} , e.g., by the at least one signal processor or signal processing module 102.

Figure 5

Figure 5 shows a method generally indicated as 110 having steps 110a, 110b and 110c for implementing the signal processing functionality, e.g., with at least one signal processor or signal processing module like element 102 in Figure 4, according to some embodiments of the present invention.

The method 100 may include a step 110a for responding with at least one signal processor or signal processing module to signaling containing information about an acoustic noise profile that is measured and generated by a slurry hitting a probe configured in a part of a cyclone; and a step 110b for determining with the at

least one signal processor or signal processing module corresponding signaling containing information about the status of the part of the cyclone, based upon the signaling received. The method 100 may also include a step 110c for providing the corresponding signaling the corresponding signaling, including where the

5 corresponding signaling provided contains information about whether the part of the cyclone is damaged or worn.

The method may also include one or more steps for implementing other features of the present invention set forth herein, including steps for making the various determinations associated with the statistical algorithm or technique, e.g.,

10 consistent with that set forth herein.

Figure 6:

Figure 6 shows a graph for application 1 of cyclone acoustic readings over time a 12 hour time span taken, according to some embodiments of the present invention. The graph includes indications showing statistical fluctuations in the probe measurements, e.g., which once generated according to the present invention may be visually interpreted to determine the status of the part of the cyclone. In Figure 6, the statistical fluctuations in the probe measurements include fluctuations designated by the term "Bad" that includes fluctuations identified by white diamonds, a shaded

15

20 square, an unfilled triangle.

Figure 7

Figure 7 shows photos of an acoustic measurement probe for the application 1 after an inspection. For example, Fig. 7A shows a photo of an upside of the acoustic measurement probe for the application 1; Fig. 7B shows a photo of a right

25

side of the acoustic measurement probe for the application 1; and Fig. 7C shows a photo of a downside of the acoustic measurement probe for the application 1. The photo in Figure 7 show that, when the acoustic measurement (PST) probe in the application 1 was inspected, buildup was found on the upside and downside of the probe, only the end of the upside area was clean, therefore only the end of the probe was hit by the slurry passing through the cyclone overflow line.

Figure 8

Figure 8 shows photos of an inside of an overflow (O/F) pipe that forms part of the cyclone in the application 1. By way of example, Fig. 8A shows an original photo of the O/F pipe for the application 1; and Fig. 8B shows an edge-filtered photo of the O/F pipe for the application 1. The photo in Figure 8 show that slurry flow lines inside the cyclone overflow pipe confirming that slurry was only touching the end of the PST probe. In addition, during experimentation, the apex diameter of the hydrocyclone was measured by maintenance crew and determined to be out of specification. Based upon this, the hydrocyclone was replaced.

Figure 9

Figure 9 shows graphs (% + 150 microns vs. time) of PST measurements in 1 minute intervals of the cyclone before (Fig. 9A) and after (Fig. 9B) replacement. The graphs in Figure 9 show that PST measurements with the hydrocyclone before replacement had a higher fluctuation (i.e., identified by a broader signal fluctuation range), and the PST measurements with a new hydrocyclone are more stable (i.e., identified by a narrower signal fluctuation range).

Figure 10: Application 2

Figure 10 shows a graph for application 2 of cyclone acoustic readings taken over a 12 hour time span, according to some embodiments of the present invention. The graph shows that the application 2 also demonstrated poor performance due to a worn apex. In Figure 10, the graph includes indications showing statistical fluctuations in the probe measurements, e.g., which once generated according to the present invention may be visually interpreted to determine the status of the part of the cyclone. In Figure 10, the statistical fluctuations in the probe measurements include fluctuations designated by the term "Bad" that includes fluctuations identified by white diamonds, a shaded square, an unfilled triangle.

Figure 11

Figure 11 shows photos of an acoustic measurement probe for the application 2 after an inspection, including Fig. 11A that shows a photo of an downside of the acoustic measurement probe for the application 2, Fig. 11B that shows a photo of a right side of the acoustic measurement probe for the application 2, and Fig. 11C that shows a photo of a upside of the acoustic measurement probe for the application 2.

The photos in Figure 11 show that atypical buildup was found on the downside of the probe, and that the thickness of the buildup was greater than the buildup thickness found in other PST probes. Based upon this, it appears that the PST probe is not impacted by slurry all the time or the hydrocyclone was operating sporadically.

Figure 12

Figure 12 shows two photos of inside portions of an overflow (O/F) pipe at two pipe locations that forms part of the cyclone in the application 2 and a photo of an outside of the O/F pipe with the two pipe locations identified, including Fig. 12A that shows a photo of the O/F pipe at a first pipe location (see left side arrow in Fig. 12C) for the application 2, and Fig. 12B that shows a photo of the O/F pipe at a second pipe location (see right side arrow in Fig. 12C) for the application 2, and Fig. 12C that shows the photo of an outside of the O/F pipe with the two pipe locations. In summary, during experimentation the photos in Figure 12 show that the O/F pipe didn't have slurry flow lines.

Figure 13

Figure 13 shows a graph (% + 150 microns vs. time) of PST measurements for application 2 in 5 minute intervals of the cyclone before replacement. The graph in Figure 13 shows that the PST measurements before hydrocyclone replacement had a high fluctuation.

Comments and Conclusions

Based on literature known in the prior art, if the apex diameter of a cyclone is too large, then there is an increment in the ratio of underflow flow rate to overflow flow rate. Also, the % solids of the underflow decreases and the excess of water carries unclassified fine particles to the underflow affecting the performance of the hydrocyclone.

When the apex diameter of the hydrocyclones is too large, the overflow flow rate decreases, this flow rate decrement affects the flow path of slurry in the O/F pipe and slurry is not hitting the PST probe causing fluctuation in the PST readings.

PST measurement readings according to the present invention are able to
5 provide an indication of cyclone wear.

The Determination of a Damaged/Worn Cyclone Part

By way of example, the determination of a damaged or worn cyclone part may take the form of one or more of the following techniques:

10 For example, the corresponding signaling provided from the signal processor or processing module 102 may contain an indication about the status of the part of the cyclone, including where the part is an apex of the cyclone. The indication may take the form of a graph showing the statistical fluctuations in the probe measurements for visual interpretation by a plant manager about the status of the
15 part of the cyclone. Alternatively, the indication may take the form of an alarm signal alerting the plant manager about the status of the part of the cyclone. The alarm signal may be an audio signal, or a visual signal (e.g., one or more blinking lights), or some combination thereof.

20 CYCLONEtrac™ PST Probe like Element 128a

As one skilled in the art would appreciate, the CYCLONEtrac™ Particle Size Tracking (PST) Probe like element 128a was developed by the assignee of the present invention and is known in the art. The reader is referred to the aforementioned patent application serial no. PCT/US14/52628 (712-2.410-1//CCS-

0124) for a more comprehensive discussion of the same, e.g., including that set forth in relation to Figure 3C therein.

The Classification Stage 10

5 By way of example, the present invention as it relates to the classification stage 10 is described in relation to the mineral extraction processing system shown, e.g., in Figures 1A and 1B, which takes the form of a copper concentrator, although the scope of the invention is not intended to be limited to any particular type or kind of mineral process or mineral extraction processing system either now known or later
10 developed in the future.

The classification stage 10 may also include one or more elements, devices, apparatus or equipment that are known in the art, do not form part of the underlying invention, and are not disclosed herein or described in detail for that reason.

The scope of the invention re classification stage and/or hydrocyclone
15 applications is not intended to be limited to the type or kind of mineral being processed, or the type of mineral process, either now known or later developed in the future. By way of example, the scope of the invention is intended to include hydrocyclone applications include Molybdenum, Lead, Zinc, Iron, Gold, Silver, Nickel, Fluorite, Tantalum, Tungsten, Tin, Lithium, Coal, as well as, e.g. diamonds,
20 etc.

Figure 3: The Cyclone or Hydrocyclone 20, 30

The cyclone or hydrocyclone, e.g., like elements 20, 30 in Figure 3, are known in the art, and the scope of the invention is not intended to be limited to any
25 particular type or kind thereof either now known or later developed in the future. The

scope of the invention is intended to include implementing the present invention in relation to cyclone or hydrocyclone, e.g., like elements 20, 30, that are now known, as well as those later developed in the future.

5 Applications Re Other Industrial Processes

By way of example, the present invention is described in relation to, and part of, a mineral extraction processing system for extracting minerals from ore.

However, the scope of the invention is intended to include other types or kinds of industrial processes either now known or later developed in the future, including any
10 mineral process, such as those related to processing substances or compounds that result from inorganic processes of nature and/or that are mined from the ground, as well as including either other extraction processing systems or other industrial processes, where the sorting, or classification, of product by size is critical to overall industrial process performance.

15

Hydrocyclone Performance Monitoring Products and Patents

By way of example, the assignee of the instant patent application has developed hydrocyclone performance monitoring products, which are disclosed in one or more of the following granted U.S. Patent(s): 6,354,147; 6,435,030;
20 6,587,798; 6,601,458; 6,609,069; 6,691,584; 6,732,575; 6,813,962; 6,862,920; 6,889,562; 6,988,411; 7,032,432; 7,058,549; 7,062,976; 7,086,278; 7,110,893; 7,121,152; 7,127,360; 7,134,320; 7,139,667; 7,146,864; 7,150,202; 7,152,003; 7,152,460; 7,165,464; 7,275,421; 7,359,803; 7,363,800; 7,367,240; 7,343,820; 7,437,946; 7,529,966; and 7,657,392, which are all incorporated by reference in their
25 entirety. The disclosure herein related to the present invention is intended to be

interpreted consistent with the family of technologies disclosed in all the issued patents incorporated by reference herein.

The Scope of the Invention

5 While the invention has been described with reference to an exemplary embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, may modifications may be made to adapt a particular situation or material to the teachings of the invention

10 without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed herein as the best mode contemplated for carrying out this invention.

WHAT IS CLAIMED IS:

1. Apparatus comprising:

a signal processor or signal processing module configured to:

receive signaling containing information about an acoustic noise profile

5 that is measured and generated by a slurry hitting a probe configured in a part of a cyclone; and

determine corresponding signaling containing information about the status of the part of the cyclone, based upon the signaling received.

10 2. Apparatus according to claim 1, wherein the signal processor or signal processing module is configured to provide the corresponding signaling, including where the corresponding signaling provided contains information about whether the part of the cyclone is damaged or worn.

15 3. Apparatus according to claim 1, wherein the part of the cyclone is an apex of the cyclone, and the corresponding signaling contains information about the status of the apex of the cyclone.

20 4. Apparatus according to claim 1, wherein the signal processor or signal processing module is configured to correlate the acoustic noise profile to a slurry flow pattern which indicates the status of the part of the cyclone.

5. Apparatus according to claim 1, wherein the signal processor or signal processing module is configured to determine the status of the part of the cyclone based upon fluctuations in the acoustic noise profile, including where the acoustic noise profile of a worn or damaged part of the cyclone has higher or less stable statistical fluctuations in probe measurements, and a corresponding noise profile of a non-worn or non-damaged part of the cyclone has lower or more stable statistical fluctuations in the probe measurements than the acoustic noise profile of the worn or damaged part of the cyclone.

6. Apparatus according to claim 1, wherein the signal processor or signal processing module is configured, through measurements of a cyclone overflow stream in real time, to determine individual cyclone wear or damage.

7. Apparatus according to claim 1, wherein the signal processor or signal processing module is configured to determine trending capability of cyclone wear or damage that enables predictive maintenance strategies based on condition monitoring instead of time-based replacement.

8. Apparatus according to claim 1, wherein the signal processor or signal processing module is configured to provide diagnostic capability in real time while the cyclone is operating so the cyclone does not have to be taken out of operation for manual inspection.

9. Apparatus according to claim 1, wherein the apparatus comprises the probe.

10. Apparatus according to claim 1, wherein the probe is a particle size tracking probe.

5 11. A method comprising:

receiving in a signal processor or signal processing module signaling containing information about an acoustic noise profile that is measured and generated by a slurry hitting a probe configured in a part of a cyclone; and

determining in the signal processor or signal processing module
10 corresponding signaling containing information about the status of the part of the cyclone, based upon the signaling received.

12. A method according to claim 11, wherein the signal processor or signal processing module is configured to provide the corresponding signaling, including
15 where the corresponding signaling provided contains information about whether the part of the cyclone is damaged or worn.

13. A method according to claim 11, wherein the part of the cyclone is an apex of the cyclone, and the corresponding signaling contains information about the
20 status of the apex of the cyclone.

14. A method according to claim 11, wherein the signal processor or signal processing module is configured to correlate the acoustic noise profile to a slurry flow pattern which indicates the status of the part of the cyclone.

25

15. A method according to claim 14, wherein the acoustic noise profile of a worn or damaged part of the cyclone has higher or less stable statistical fluctuations in probe measurements, and a corresponding acoustic noise profile of a non-worn or non-damaged part of the cyclone has lower or more stable statistical fluctuations in the probe measurements than the acoustic noise profile of the worn or damaged part of the cyclone.

16. A method according to claim 11, wherein the method comprises configuring the signal processor or signal processing module, through measurements of a cyclone overflow stream in real time, to determine individual cyclone wear or damage.

17. A method according to claim 11, wherein the signal processor or signal processing module is configured to determine trending capability of cyclone wear or damage that enables predictive maintenance strategies based on condition monitoring instead of time-based replacement.

18. A method according to claim 11, wherein the signal processor or signal processing module is configured to provide diagnostic capability in real time while the cyclone is operating so the cyclone does not have to be taken out of operation for manual inspection.

19. A method according to claim 11, wherein the method further comprises configuring the probe to provide the signaling to the signal processor or signal processing module.

20. A method according to claim 19, wherein the probe is a particle size tracking probe.

5 21. Apparatus for detection of cyclone wear or damage using individual cyclone overflow measurement, comprising:

a signal processor or signal processing module configured to:

receive signaling containing information about an acoustic noise profile that is directly measured and generated by a slurry hitting a probe configured

10 in an apex of a cyclone; and

determine corresponding signaling containing information about the diameter of the apex of the cyclone in real time based upon fluctuations in the acoustic noise profile in the signaling received.

15 22. Apparatus according to claim 21, wherein the signal processor or signal processing module is configured to provide the corresponding signaling, including where the corresponding signaling contains information about whether the apex of the cyclone is damaged or worn.

20 23. Apparatus according to claim 22, wherein the corresponding signaling contains information for generating a graph showing statistical fluctuations in probe measurements over time for visual interpretation by a plant manager in order to assess the status of the diameter of the apex of cyclone.

24. Apparatus according to claim 22, wherein the corresponding signaling contains information for generating an alarm signal alerting a plant manager about the status of the diameter of the apex of the cyclone, including where the alarm signal is an audio signal, or a visual signal, or some combination thereof.

5

25. Apparatus comprising:

means for receiving signaling containing information about an acoustic noise profile that is measured and generated by a slurry hitting a probe configured in a part of a cyclone; and

10 means for determining corresponding signaling containing information about the status of the part of the cyclone, based upon the signaling received.

26. Apparatus according to claim 25, wherein the apparatus comprises means for providing the corresponding signaling, including where the corresponding
15 signaling provided contains information about whether the part of the cyclone is damaged or worn.

27. Apparatus, including a computer-readable storage medium having computer-executable components, configured to perform the steps of the method
20 recited in claim 11.

28. Apparatus according to claim 1, wherein the apparatus comprises the cyclone having a cyclone part with the probe configured therein.

FIGURE 1A: Mineral Extraction Processing System - Prior Art

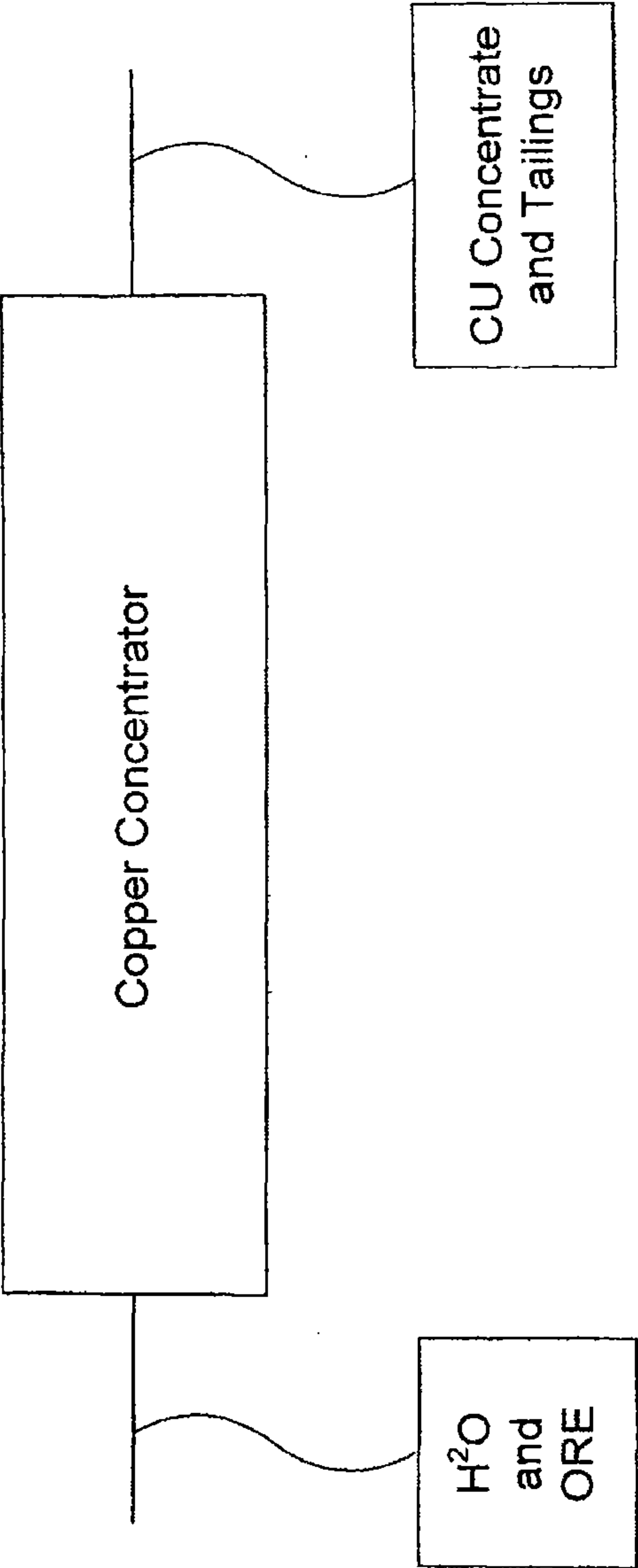
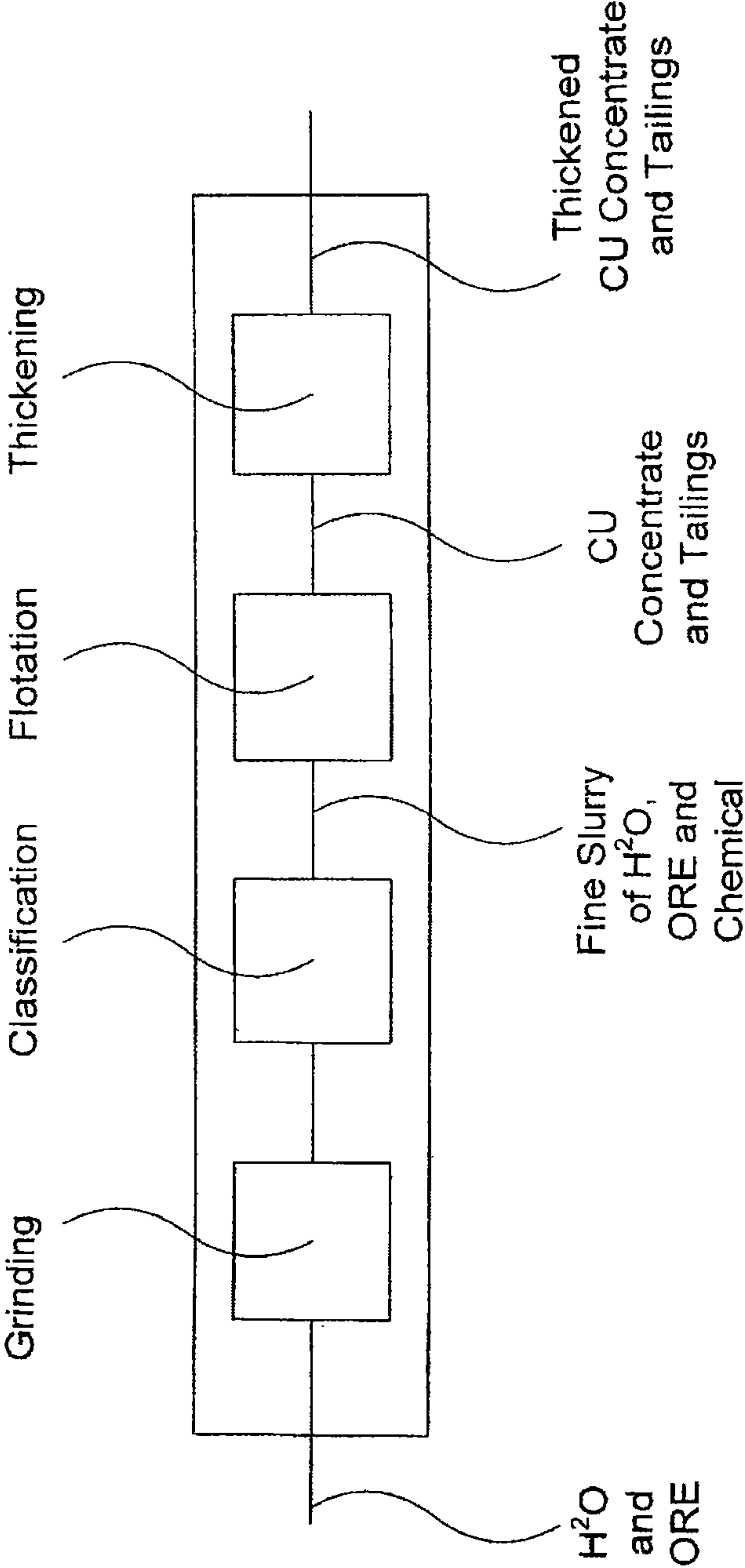


FIGURE 1B: - Prior Art



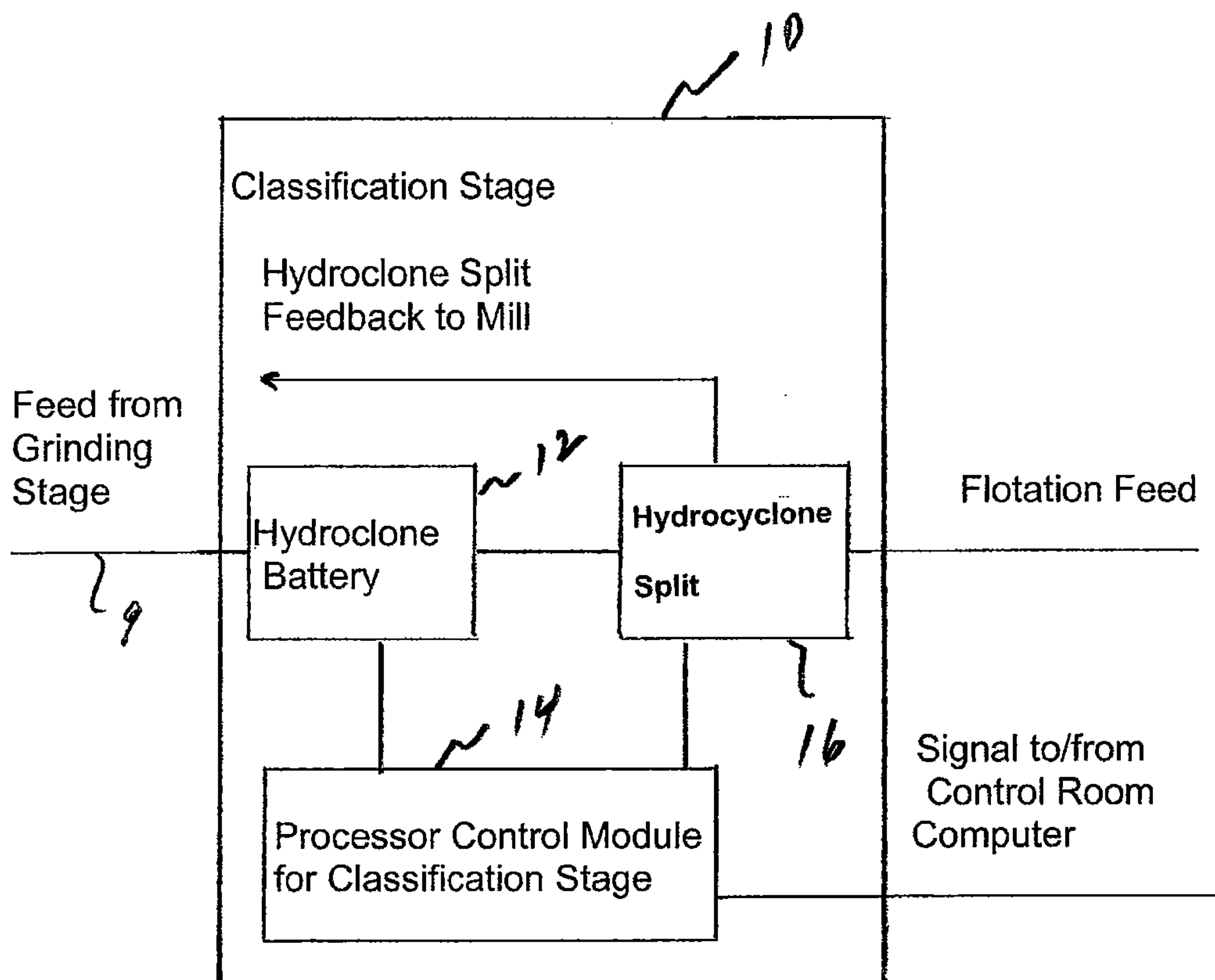


FIGURE 2: Classification Stage - Prior Art

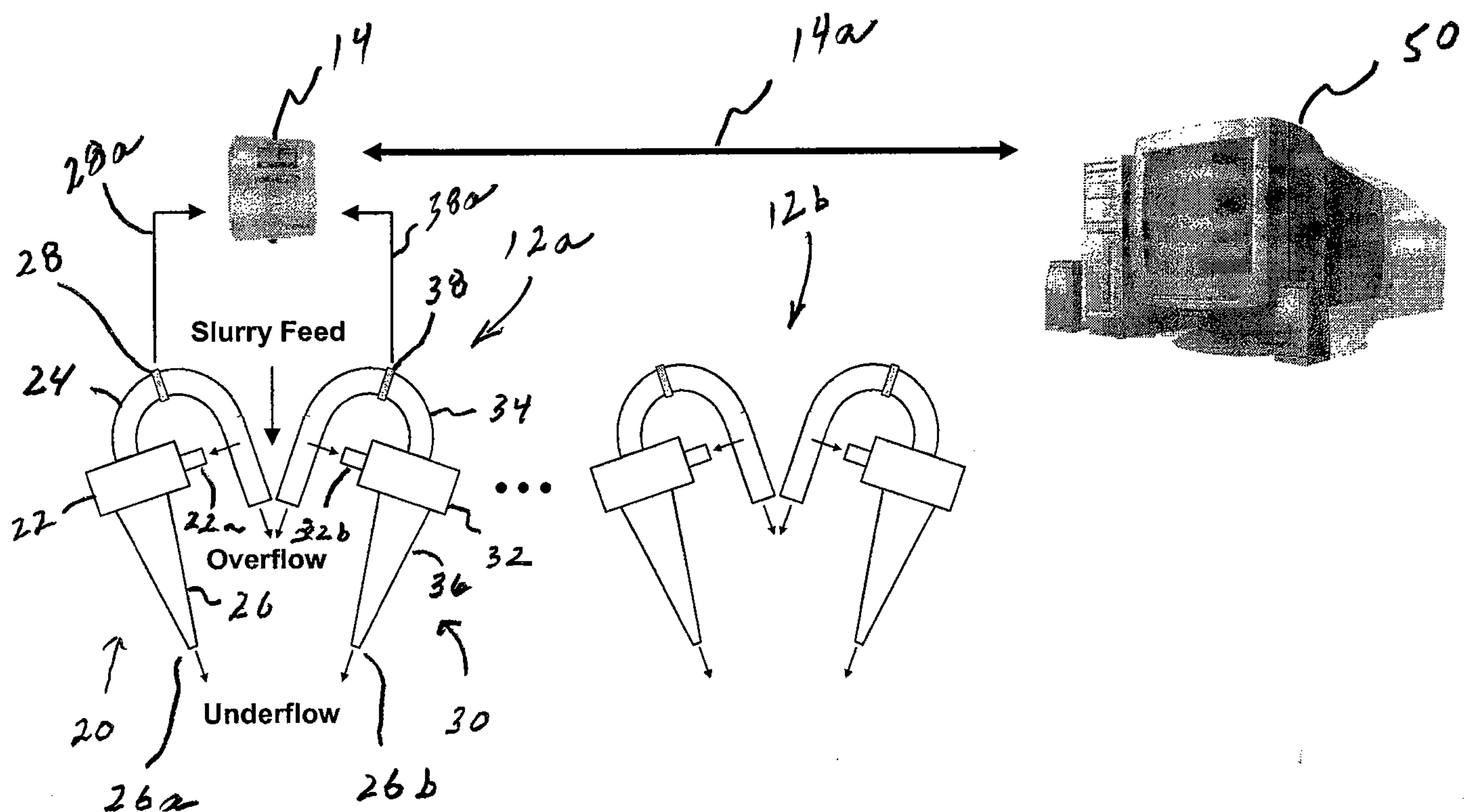


Figure 3 - PRIOR ART

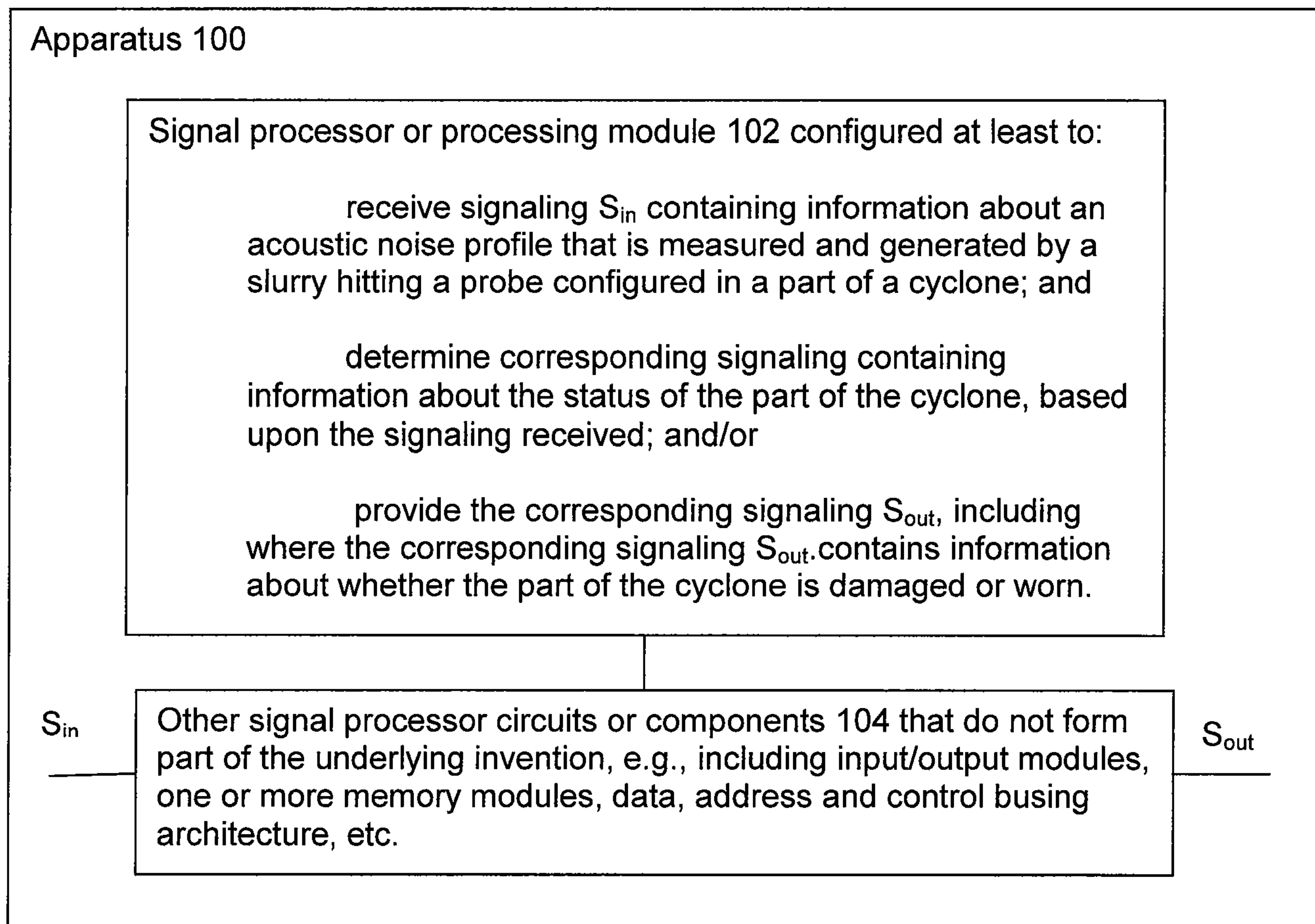
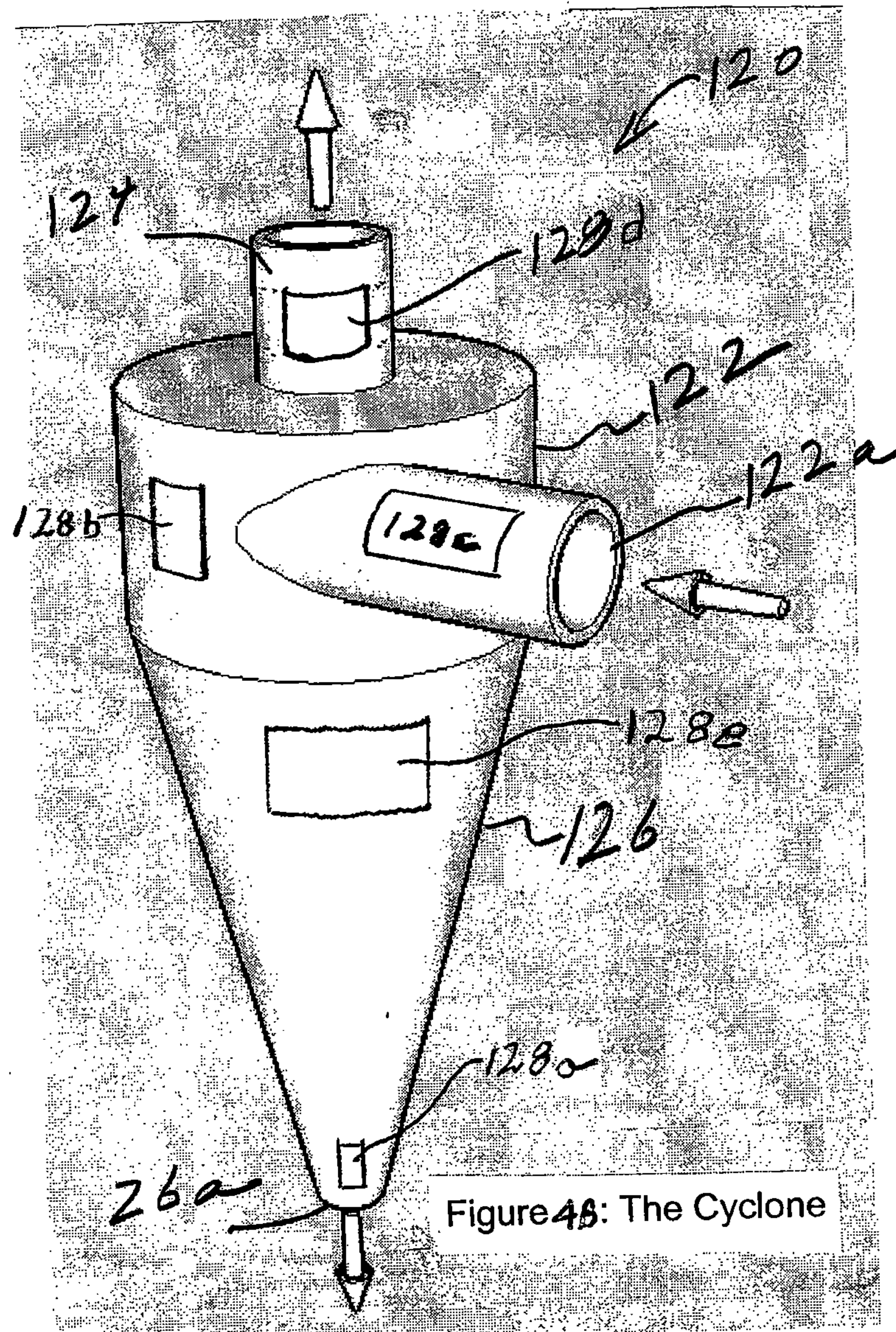
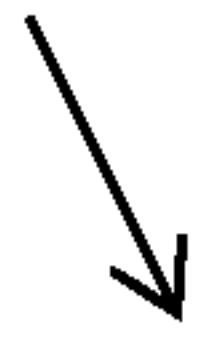


Figure 4A: The Basic Apparatus



110



110a, Respond to signaling S_{in} containing information about an acoustic noise profile that is directly measured and generated by a slurry hitting a probe configured in a part of a cyclone

110b, Determine corresponding containing information about the status of the part of the cyclone, based upon the signaling received, based upon the signaling received

110c, Provide corresponding signaling S_{out} , including where the corresponding signaling S_{out} contains information about whether the part of the cyclone is damaged or worn

Figure 5

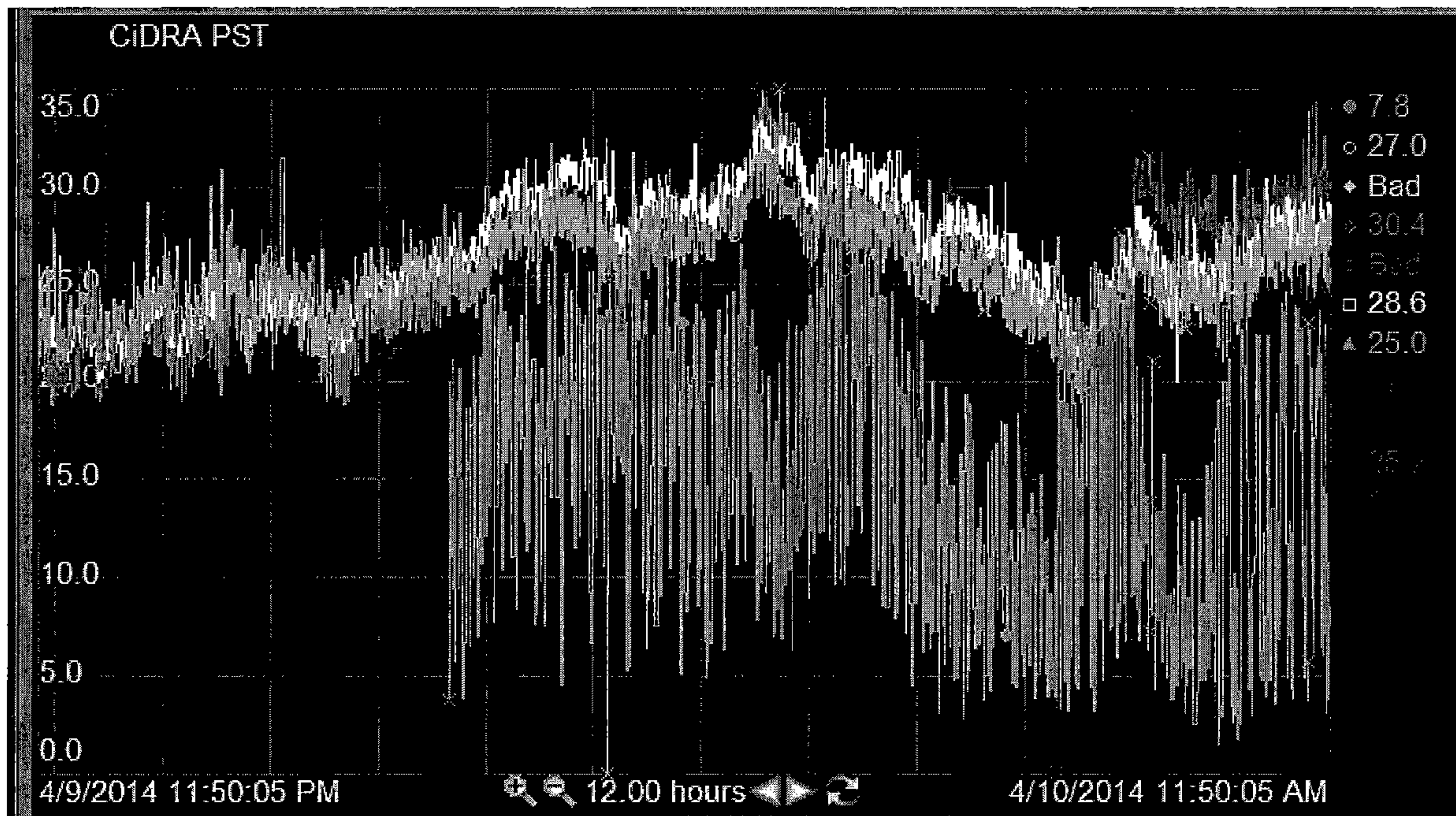


Figure 6: Cyclone Performance Monitoring - Detecting Wear Characteristics
(Note: Erratic Cyclone readings)

Fig. 7A: Upside



Fig. 7B: Right side

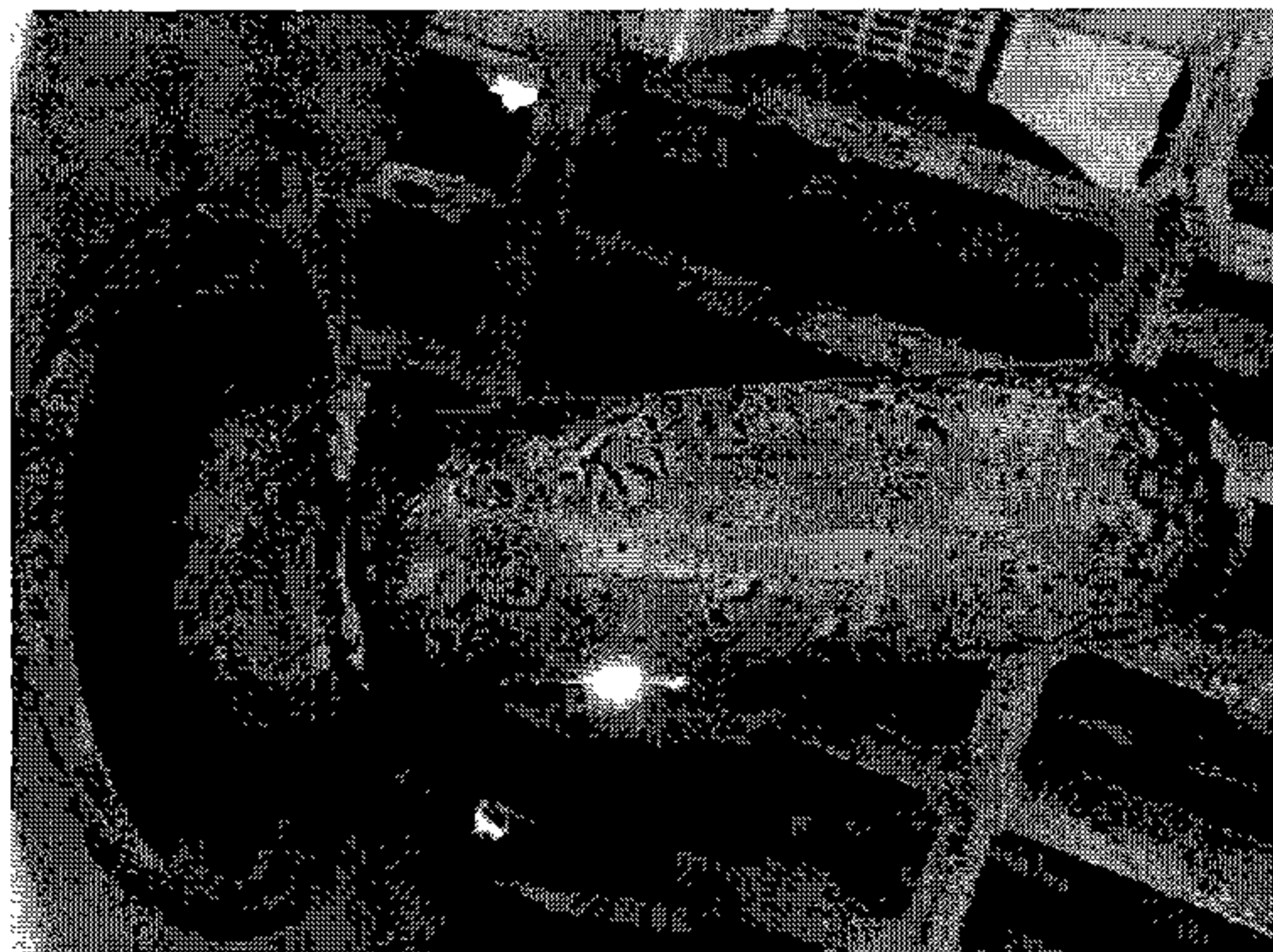


Fig. 7C: Downside

Figure 7: Application 1

Fig 8A: Photo of inside of the O/F pipe



Slurry flow lines

Edge-filtered photo



Fig 8B: Photo of inside of the O/F pipe

Figure 8: Photos of inside of O/F pipe

10/13

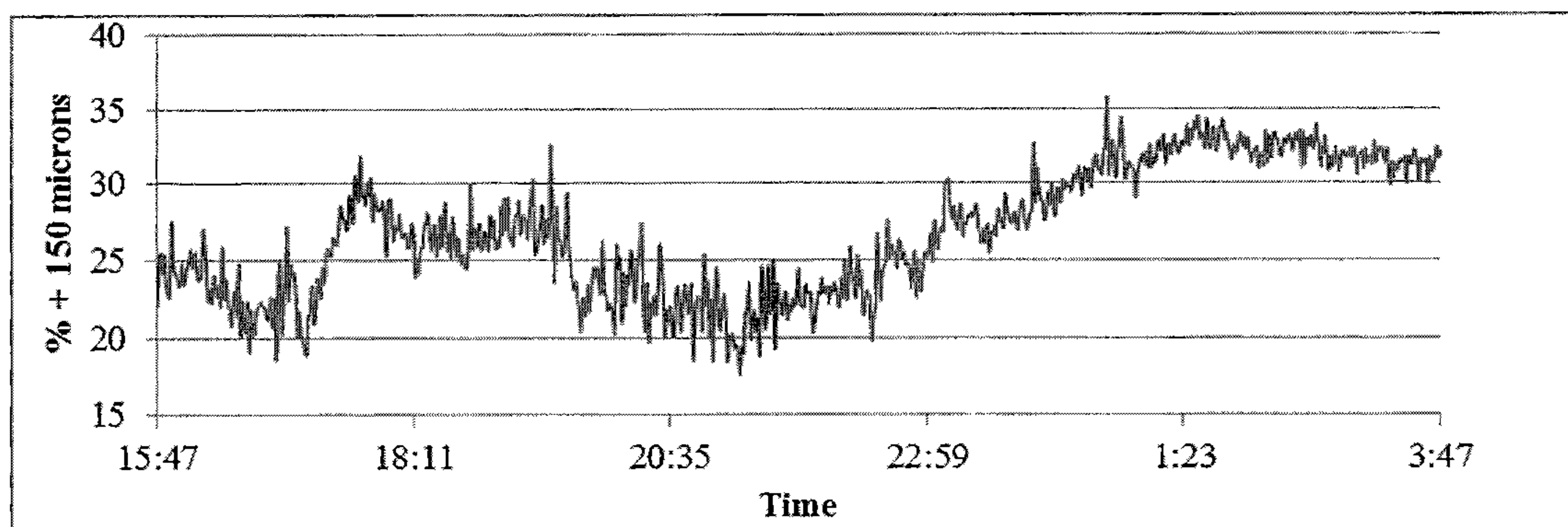


Fig.9A: Hydrocyclone before replacement

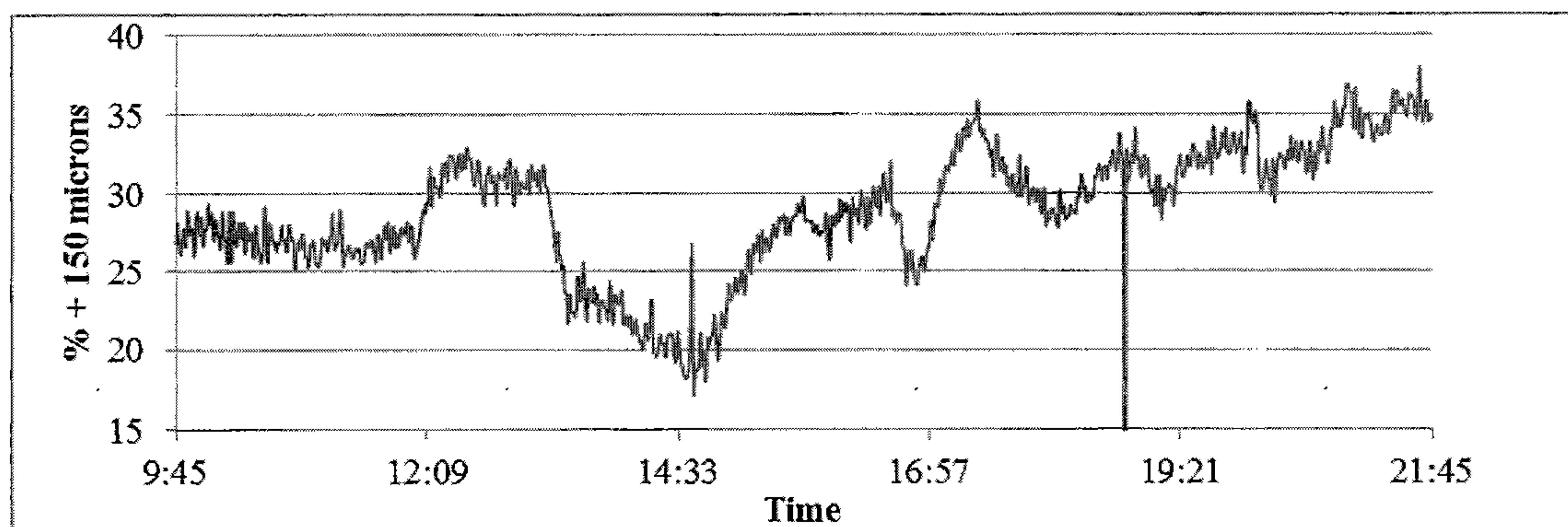


Fig.9B: Hydrocyclone after replacement

Figure 9

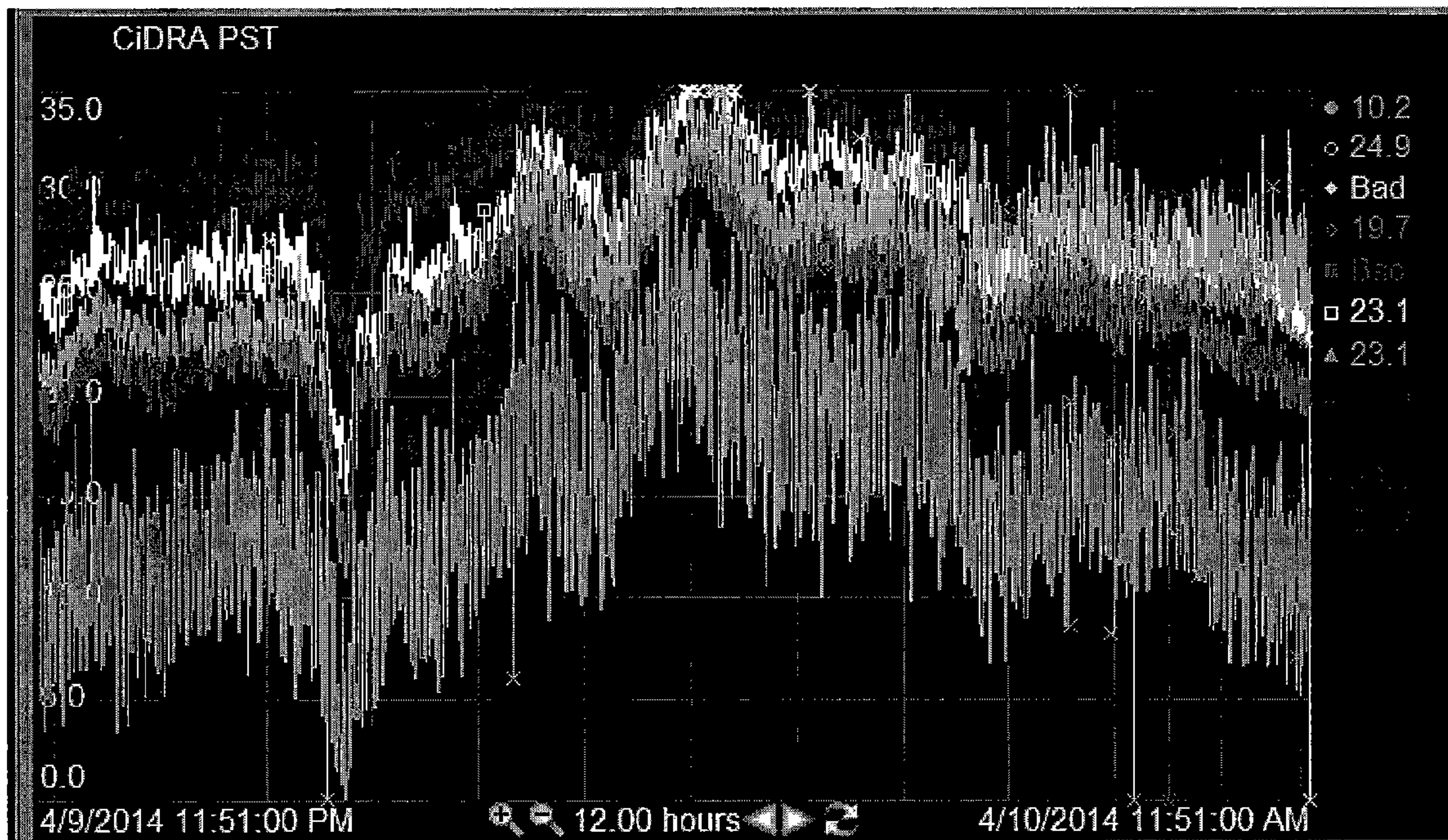


Figure 10

Fig. 11A: Downside

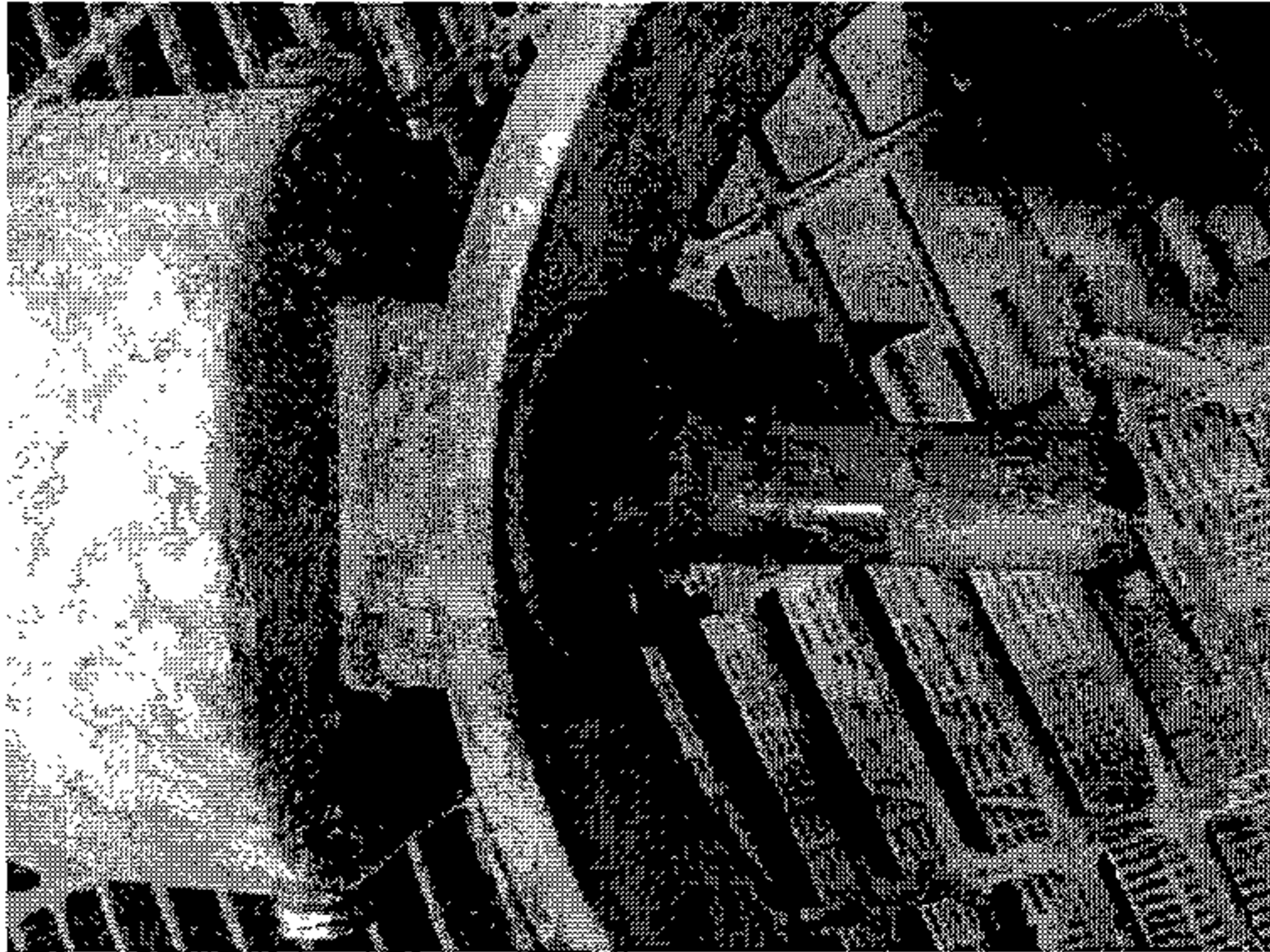


Fig. 11B Right side

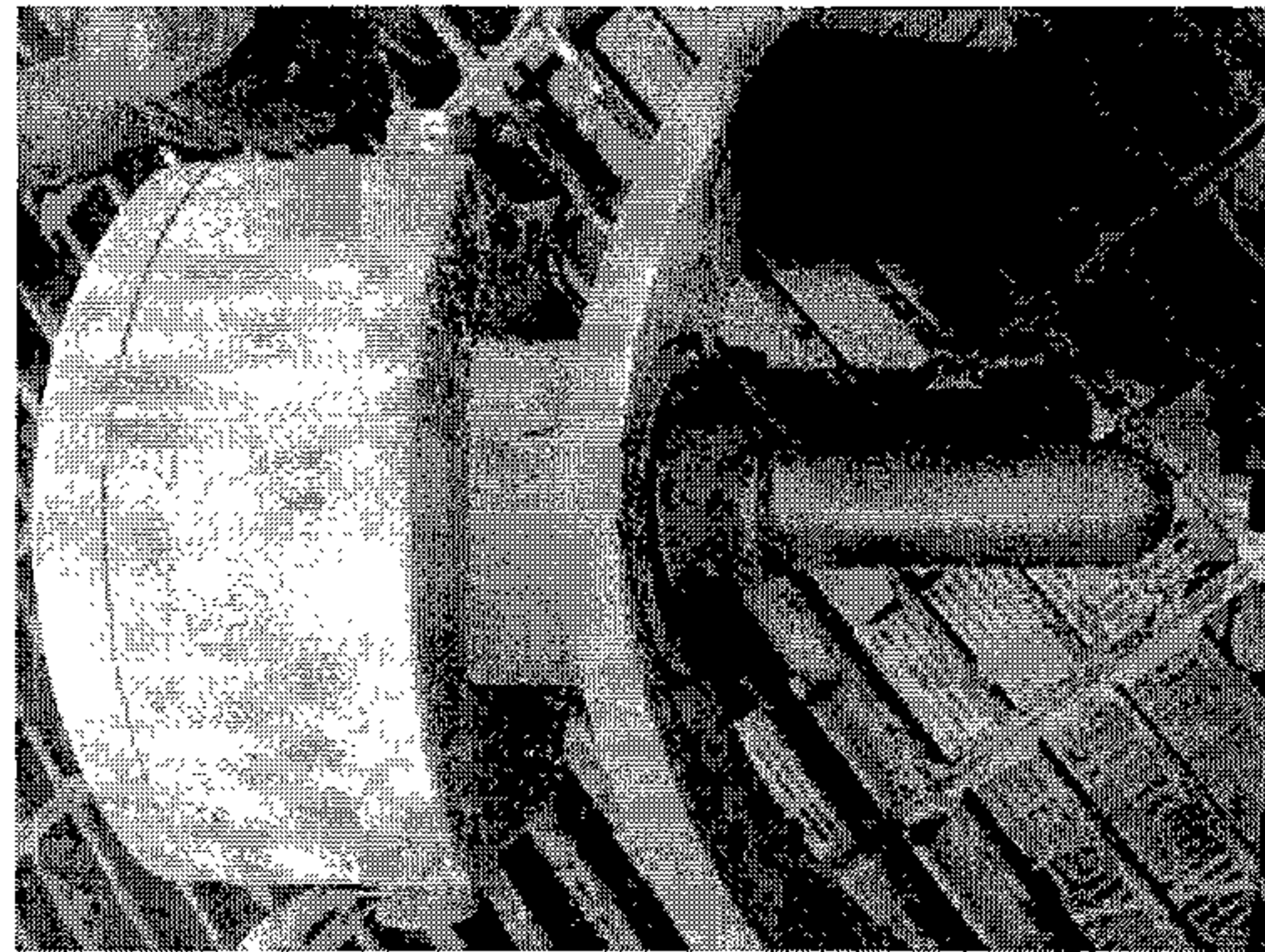


Fig. 11C: Upside

Figure 11: Photos of PST Probe

Fig. 12C

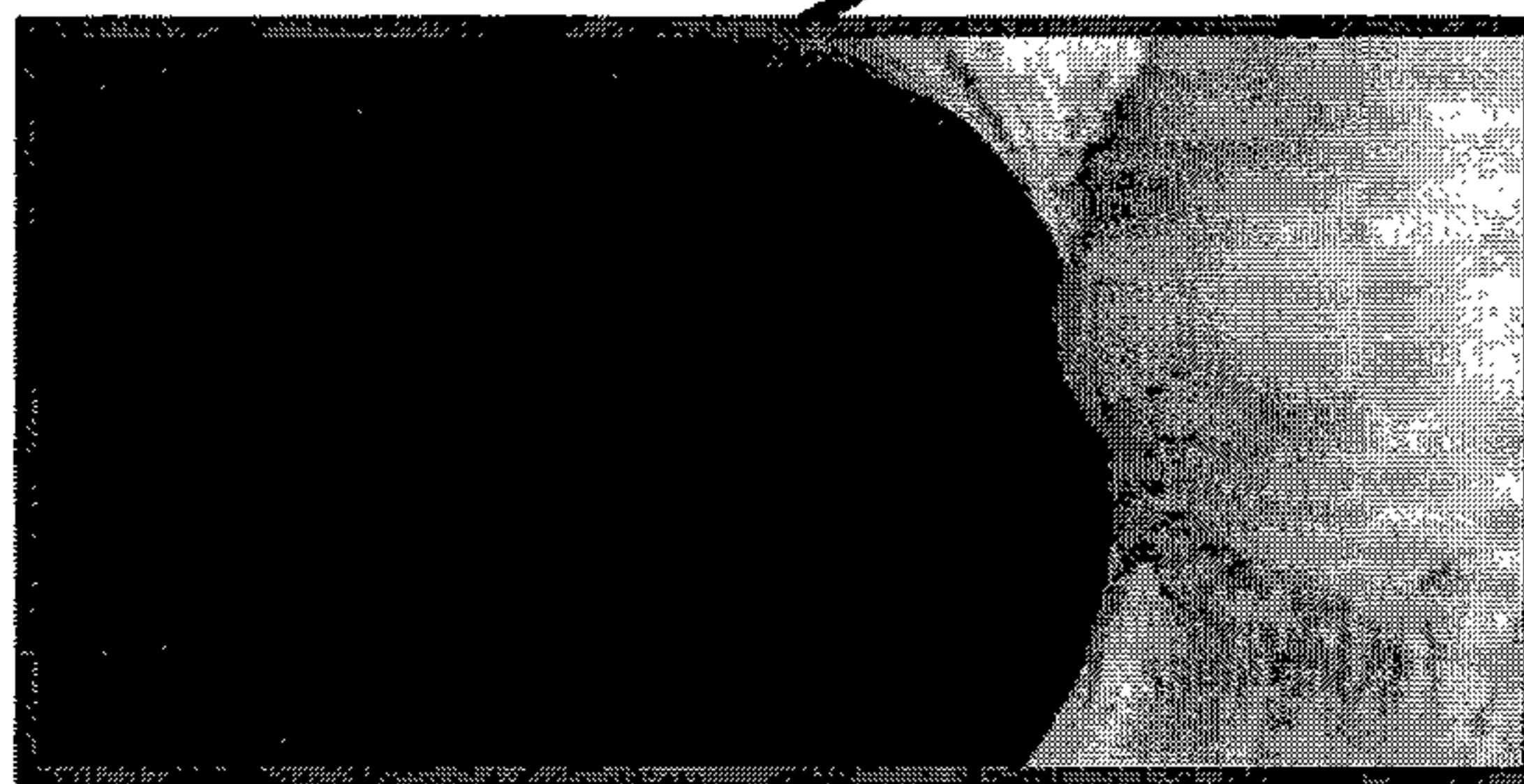
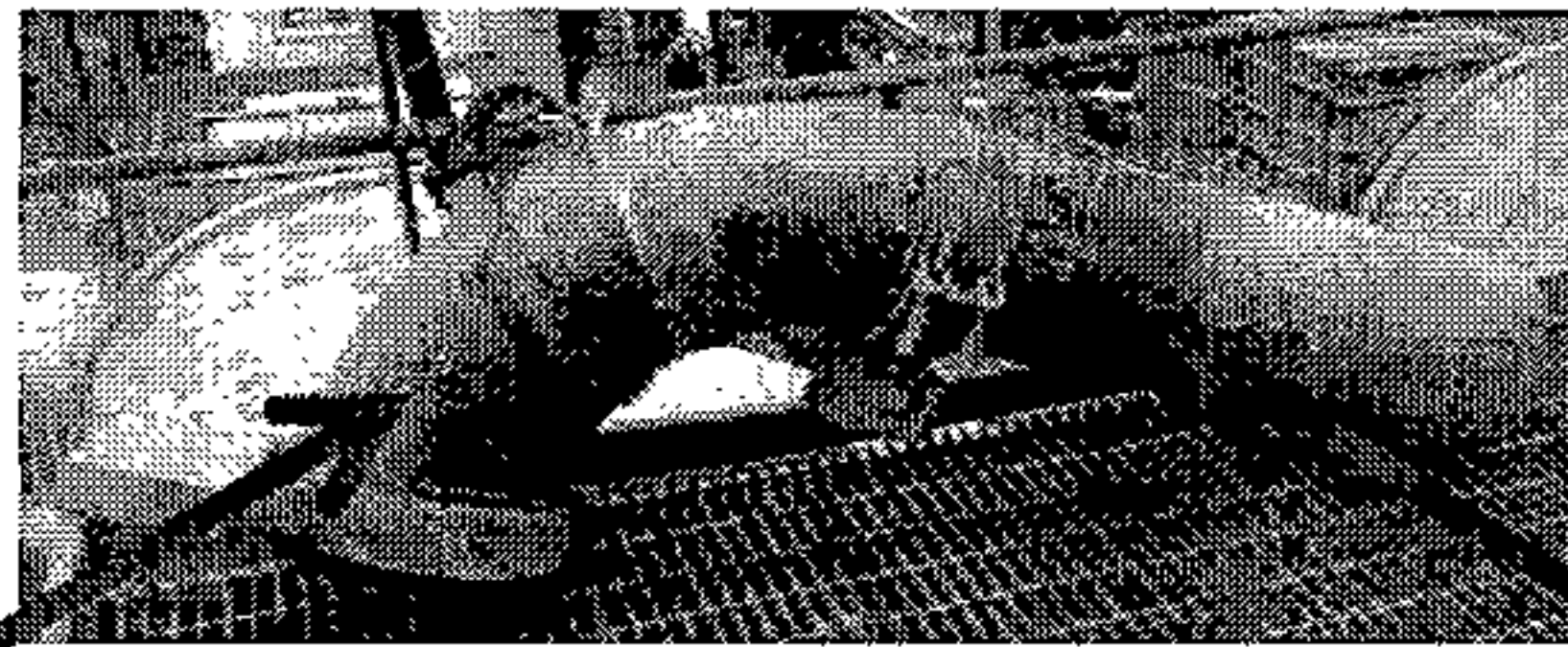


Fig. 12A

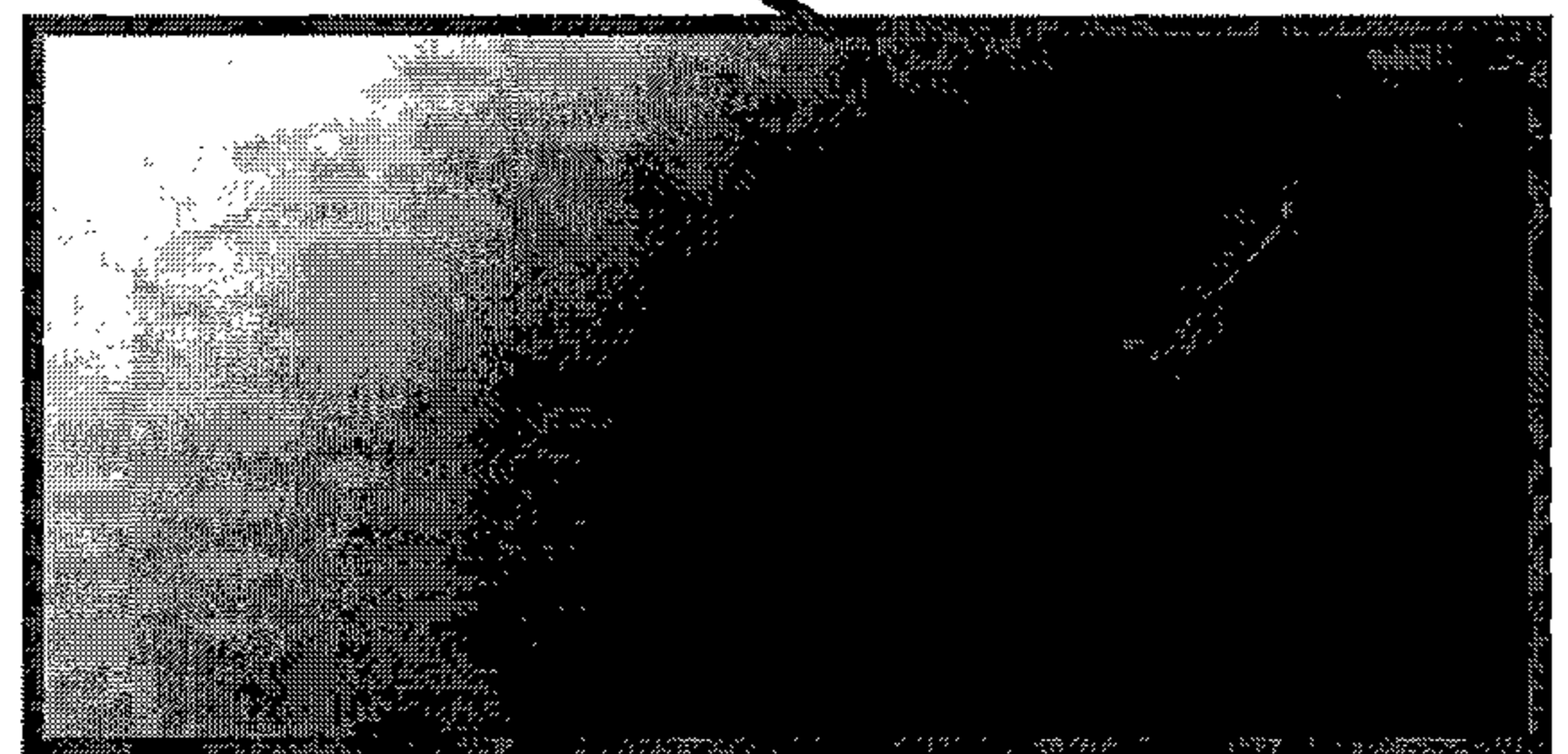


Fig. 12B

Figure 12: Photos of inside of the O/F pipe

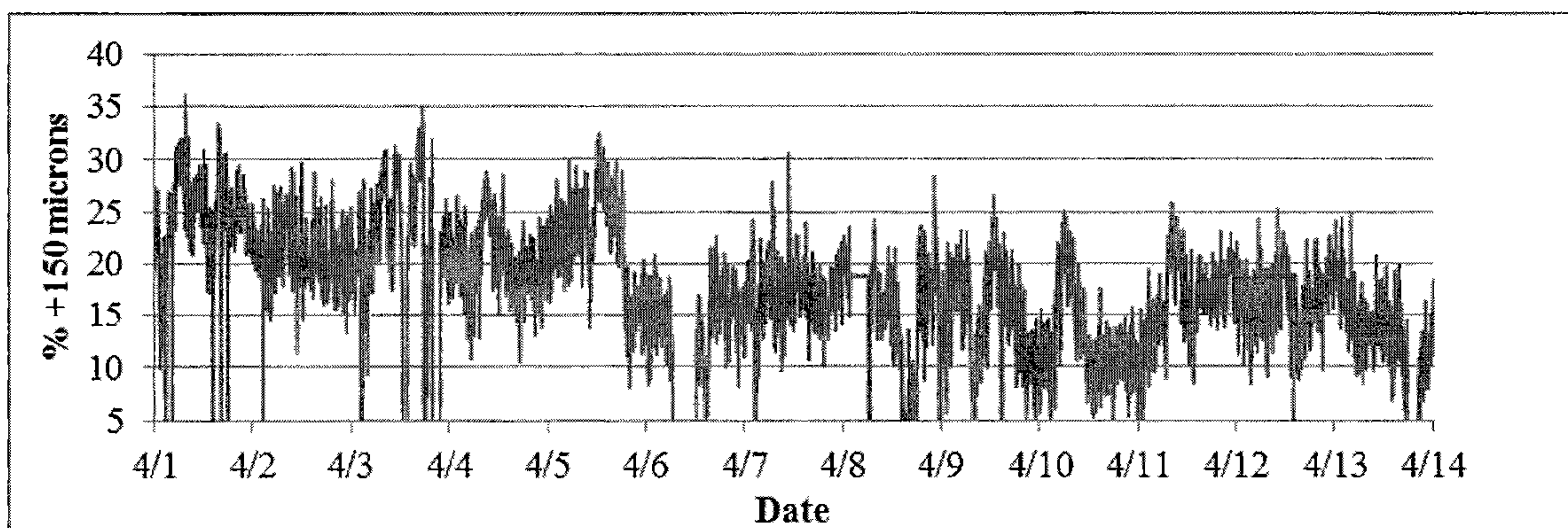


Figure 13

Apparatus 100

Signal processor or processing module 102 configured at least to:

receive signaling S_{in} containing information about an acoustic noise profile that is measured and generated by a slurry hitting a probe configured in a part of a cyclone; and

determine corresponding signaling containing information about the status of the part of the cyclone, based upon the signaling received; and/or

provide the corresponding signaling S_{out} , including where the corresponding signaling S_{out} contains information about whether the part of the cyclone is damaged or worn.

S_{in}

Other signal processor circuits or components 104 that do not form part of the underlying invention, e.g., including input/output modules, one or more memory modules, data, address and control busing architecture, etc.

S_{out}

Figure 4A: The Basic Apparatus