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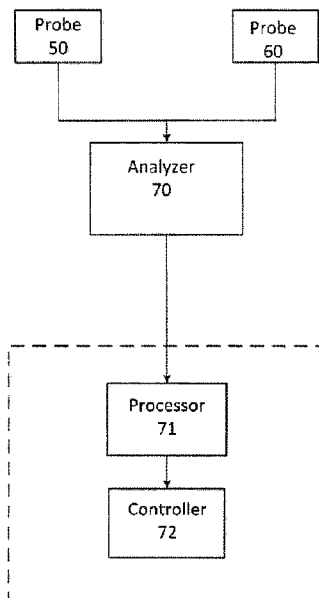
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(54) Title: MINED ORE ANALYSIS AND CONTROL OF RELATED MINING AND EXTRACTION PROCESSES



(57) **Abrégé/Abstract:**

In a surface mining operation, real-time ore composition analysis can be used to direct ongoing mining processes, and in blending ore feed streams to achieve a blended dry ore stream that meets operational specifications for downstream processing. Further, the analysis data can be used to control downstream processing steps, for example in determining appropriate volumes and temperature of water and chemicals added to the ore to form a suitable slurry composition for efficient operation of a downstream hydrocarbon extraction process, or to optimize specific processing steps in the extraction of hydrocarbons from oil sands ore, based on the analysis data. The ore analysis data can also be used to update a mine or reservoir map. Ore analysis can be accomplished by infrared reflectance analysis using NIR probes installed on ore transport or processing equipment that come into direct contact with the ore to be analyzed.

ABSTRACT

In a surface mining operation, real-time ore composition analysis can be used to direct ongoing mining processes, and in blending ore feed streams to achieve a blended dry ore stream that meets operational specifications for downstream processing. Further, the analysis data can be used to control downstream processing steps, for example in determining appropriate volumes and temperature of water and chemicals added to the ore to form a suitable slurry composition for efficient operation of a downstream hydrocarbon extraction process, or to optimize specific processing steps in the extraction of hydrocarbons from oil sands ore, based on the analysis data. The ore analysis data can also be used to update a mine or reservoir map. Ore analysis can be accomplished by infrared reflectance analysis using NIR probes installed on ore transport or processing equipment that come into direct contact with the ore to be analyzed.

MINED ORE ANALYSIS AND CONTROL OF RELATED MINING AND EXTRACTION PROCESSES

TECHNICAL FIELD

[0001] The following relates to the mining and extraction of hydrocarbons from oil sands and to methods of ore analysis and related control processes.

BACKGROUND

[0002] Alberta's oil sands are considered to be one of the world's largest remaining oil reserves. The McMurray Formation hosts the majority of the bitumen resource in the region, containing oil sands typically composed of about seventy to ninety percent by weight mineral solids (including sand and clay), about one to ten percent by weight water, with a bitumen or heavy oil content of up to twenty one percent by weight.

[0003] In Alberta, only about twenty percent of the oil sands are sufficiently shallow to be recovered by surface mining, typically accomplished using large shovels to excavate ore from the mine face. The other 80% of oil sands reserves can be recovered using in situ recovery techniques, for example, Steam-Assisted Gravity Drainage (SAGD).

[0004] Due to the highly viscous nature of bitumen, recovering the hydrocarbons from mined oil sand ore generally requires various physical processing steps in combination with hot water and/or chemical treatment. In a typical hot water extraction process, hot process water is mixed with comminuted oil sands ore to form a slurry, and other agents such as flotation aids can be added. The slurry is agitated or conditioned for a period of time to form a bitumen-containing froth that can be separated from higher density tailings. The bitumen froth is processed and directed to downstream upgrading and refining operations.

Extraction of bitumen from mined oil sand ore is most efficiently accomplished when variations in ore quality and composition are minimal, allowing long term process optimization. When ore feeds varies, extraction processing irregularities can result, compromising product quality the economics of the extraction operation.

SUMMARY

[0005] In a first aspect, there is provided a method for estimating the composition of surface-mined oil sands ore, the method comprising the steps of:

providing an ore analysis device comprising a near infrared light source, an infrared light detector, and an infrared permeable window;

positioning the ore analysis device in a sampling location in proximity to a path of moving oil sands ore such that the infrared permeable window comes into direct contact with mined oil sands ore;

operating the ore analysis device to emit and detect infrared light through the window to obtain a reflectance spectrum associated with an oil sands ore sample in direct contact with the window, wherein the window is positioned between (i) the ore sample and (ii) the infrared light source and light detector such that a fixed distance is maintained between the two during operation of the analysis device to emit and collect infrared signals; and

correlating the magnitude of the reflectance spectrum at one or more wavenumbers of infrared light to a calibration curve to estimate at least one composition parameter of the ore sample.

[0006] In an implementation, the magnitude of the reflectance spectrum is correlated at one or more wavenumbers of infrared light to estimate two or more composition parameters of the ore sample.

[0007] In some implementations, the composition parameter comprises: bitumen content, solids content, fine solids content, connate water content, chloride content, solid particle size distribution, methylene blue index, Ca^{+2} concentration, Na^{+} concentration, K^{+} concentration, CO_3^{-2} concentration, or SO_4^{-2} concentration.

[0008] In some implementations, the composition parameter is bitumen content and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 9380 to 7417, 6102 to 5446 or 4790 to 4026 cm^{-1} .

[0009] In some implementations the composition parameter is solids content and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 8092 to 7621 or 6456 to 5442 cm^{-1} .

[0010] In some implementations the composition parameter is fine solids content and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 7891 to 6996 or 5550 to 5130 cm^{-1}

[0011] In some implementations the composition parameter is connate water content and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about 7506 to 4713 cm^{-1} .

[0012] In some implementations the composition parameter is chloride content and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 10348 to 7621, 5716 to 5342 or 4455 to 4026 cm^{-1} .

[0013] In some implementations the composition parameter is particle size distribution and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 10348 to 7621, 5716 to 5342 or 4455 to 4026 cm^{-1} .

[0014] In some implementations the composition parameter is Ca^{+2} concentration and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 9403 to 6094 or 5454 to 4952 cm^{-1} .

[0015] In some implementations the composition parameter is Na^{+} concentration and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 9403 to 7498 or 5778 to 5446 cm^{-1} .

[0016] In some implementations the composition parameter is K^{+} concentration and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 7506 to 6094 or 5207 to 4952 cm^{-1} .

[0017] In some implementations the composition parameter is CO_3^{-2} concentration and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 9403 to 6094 or 5454 to 4968 cm^{-1} .

[0018] In some implementations the composition parameter is SO_4^{2-} concentration and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 9403 to 7498 or 5454 to 4952 cm^{-1} .

[0019] In some implementations the composition parameter is clay content and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about 9403 to 4944 cm^{-1} .

[0020] In some implementations the composition parameter is methylene blue index and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about: 7506 to 6094 or 5454 to 4952 cm^{-1} .

[0021] In some implementations the composition parameter is pH and the magnitude of the reflectance spectrum is correlated to a calibration curve at one or more wavenumbers between about 7506 to 4983 cm^{-1} .

[0022] In an implementation, the method further comprises correlating a plurality of reflectance spectra corresponding to a plurality of ore samples to obtain composition parameter data for the plurality of ore samples; and based on the composition parameter data for the plurality of ore samples, determining an estimated quality of a volume of mined oil sand ore that includes the plurality of ore samples as a fraction of the volume.

[0023] In an implementation, the infrared light detector captures infrared light reflected and scattered by the ore sample in response to the infrared incident light.

[0024] In an implementation, the infrared light detected through the window is clarified, filtered or processed using a scattered light model to generate the reflectance spectrum for use in the correlating step.

[0025] In an implementation, the method further comprises processing the composition data associated with the oil sands ore sample to detect if the oil sands ore was not in direct contact with the window when sampled.

[0026] In an implementation, the method further comprises correlating a plurality of reflectance spectra, corresponding to a plurality of ore samples, to a calibration curve to obtain composition data for each ore sample, and processing the composition parameter data for each ore sample in accordance with a model to select composition data that

meets criteria of the model, while excluding composition data that does not meet criteria of the model.

[0027] In an implementation, the method further comprises providing the selected data to a controller.

[0028] In an implementation, the ore analysis device is a near-infra red (NIR) probe.

[0029] In some implementations, positioning the ore analysis device in a sampling location comprises positioning the device on or in proximity to equipment used for mining or processing of the oil sands ore such that direct contact between the NIR probe and the oil sands ore will occur.

[0030] In some implementations, equipment comprises: an apron feeder, conveyor, hopper, haul truck, excavation shovel or crusher.

[0031] In some implementations the ore analysis device is positioned such that the infrared permeable window is flush with an ore contacting surface of the equipment.

[0032] In some implementations the ore analysis device is positioned such that the infrared permeable window is positioned in a path of moving oil sands ore.

[0033] In accordance with a further aspect, there is provided a surface mining method for extraction of bitumen from oil sands, the method comprising:

excavating a volume of oil sands ore and transporting the volume of excavated ore to an ore processing facility;

prior to arrival of the volume of ore at the ore processing facility, obtaining an estimate of a composition parameter of the volume of ore by near-infrared (NIR) spectral analysis using an NIR analysis device comprising a near-infrared light source, an infrared detector and an infrared permeable window, wherein the window is positioned in direct contact with ore samples and between (i) the ore samples and (ii) the infrared light source and light detector such that a fixed distance is maintained between the two during operation of the analysis device to emit and collect infrared signals; and

controlling a mining, ore processing or bitumen extraction operation based on the estimated composition parameter.

[0034] In an implementation, the ore processing facility comprises a slurry preparing facility.

[0035] In an implementation, the ore processing operation comprises a slurry preparation operation or an ore blending operation.

[0036] In an implementation, the composition parameter is bitumen content, solids content, fine solids content, connate water content, chloride content, solid particle size distribution, methylene blue index, pH, Ca^{+2} concentration, Na^{+} concentration, K^{+} concentration, CO_3^{-2} concentration or SO_4^{-2} concentration.

[0037] In an implementation, the NIR analysis device is an NIR probe analyzer installed in a sampling location on or in proximity of equipment in a system for mining or processing of oil sands ore.

[0038] In an implementation, the NIR probe analyzer is installed in proximity to or in contact with an apron feeder, conveyor, hopper, haul truck, excavation shovel, or crusher.

[0039] In an implementation, the probe is installed such that the window of the NIR probe is flush with an ore contacting surface.

[0040] In an implementation, the probe is installed such that an analysis window of the probe is placed into the path of moving ore.

[0041] In an implementation, the method further comprises processing the estimated composition parameters for each sample to derive an estimated quality of the mined oil sand ore.

[0042] In an implementation, the controlled operation is a mining operation that is controlled to change an excavation location based on the composition parameter estimate.

[0043] In an implementation, the controlled operation is an ore blending operation that blends ore from two or more volumes of oil sands ore from different mine faces.

[0044] In an implementation, the controlled operation is an ore blending operation that blends ore from two or more volumes of oil sands ore excavated from one or more mines.

[0045] In an implementation, the method further comprises obtaining a composition parameter estimate of blended ore prior to arrival of the ore at a slurry preparation location, wherein the estimate is obtained by near infrared spectral analysis using an NIR analysis device in direct contact with the blended ore.

[0046] In an implementation, the controlled operation is a slurry preparation operation and wherein controlling the operation comprises controlling an amount of water, solvent, or other processing aid added to ore during slurry preparation.

[0047] In an implementation, the controlled operation is a slurry preparation operation and wherein controlling the operation comprises controlling the temperature of water added to the ore when preparing a slurry.

[0048] In an implementation, the rate of slurry preparation is controlled.

[0049] In an implementation, a bitumen extraction operation is controlled.

[0050] In an implementation, a separation or flotation step in the extraction operation is controlled.

[0051] In an implementation, the residence time in a separation or flotation vessel is controlled.

[0052] In an implementation, the composition parameter estimate is used to update a mine map.

[0053] In accordance with a further aspect, there is provided a system for estimating composition parameters of ore moving through an ore processing operation, the system comprising:

one or more near infrared analysis devices, each infrared analysis device comprising an infrared light source, an infrared light detector, and an infrared permeable window;

each analysis device installed in a sampling location in proximity to a path of moving oil sands ore such that the infrared permeable window comes into direct contact with mined oil sands ore moving through the ore processing operation;

the ore analysis device operable to emit and detect infrared light through the window to obtain a reflectance spectrum associated with an oil sands ore sample in direct contact with the window, wherein the window is positioned between (i) the ore sample and (ii) the infrared light source and light detector such that a fixed distance is maintained between the two during operation of the analysis device to emit and collect infrared signals; and

a processor for processing the magnitude of the reflectance spectrum at one or more wavenumbers in accordance with a model to estimate at least one composition parameter of the ore sample.

[0054] In an implementation, the system further comprises a controller configured to receive composition data from the processor and transmit signals to ore processing equipment in the ore processing operation in response to the estimated composition parameters.

[0055] In an implementation, the controller is further configured to transmit signals to an upstream mining operation.

[0056] In an implementation, the controller is further configured to transmit signals to a downstream extraction operation.

[0057] In an implementation, the ore processing operation is an oil sands ore processing operation for preparing ore to recover hydrocarbons from the ore.

[0058] In accordance with another aspect, there is provided a method for estimating the composition of oil sands ore samples, the method comprising the steps of:

emitting infrared light onto a plurality of oil sands ore samples in succession, where the distance between the emitted light and each oil sands sample is consistent for each oil sands sample;

collecting infrared light reflected from each oil sands ore sample, where the distance between the oil sands ore sample and a detector is consistent for each oil sands sample;

processing the reflected light collected by the detector to obtain a reflectance spectrum for each sample; and

correlating the reflectance spectra to a calibration curve to estimate at least one composition parameter of the oil sands ore samples.

[0059] In an implementation, the light is emitted and detected by a NIR reflectance probe in direct contact with each oil sands ore sample.

[0060] In an implementation, the oil sands ore sample is a core sample, is obtained from a core sample, or is a portion of a core sample.

[0061] In an implementation, the oil sands ore sample is ore moving through a mining or ore processing operation.

[0062] In an implementation, the estimated composition parameter is used to create or update a mine map or reservoir map.

[0063] In an implementation, the method further comprises detecting and processing infrared incident light scattered by the sample.

[0064] In some implementations, the sample is a mined ore sample.

[0065] In some implementations, the composition parameter comprises bitumen content, solids content, fine solids content, connate water content, chloride content, solid particle size distribution, methylene blue index, pH, Ca^{+2} concentration, Na^{+} concentration, K^{+} concentration, CO_3^{-2} concentration, or SO_4^{-2} concentration.

[0066] In accordance with another aspect, there is provided a process for obtaining a blended mined oil sands ore feed comprising:

providing at least two feed streams of mined ore;

analyzing each feed stream using an infrared spectral analysis process in which an infrared analysis probe is placed in direct contact with mined ore samples to estimate two or more composition parameters of the mined ore;

processing the composition parameter estimates to determine a blend ratio for the feed streams, wherein the blend ratio results in a blended ore composition that meets a pre-determined specification; and

blending the mined ore from the feed streams in accordance with the blend ratio.

[0067] In an implementation, the pre-determined specification is based on feed requirements for a downstream ore processing step.

[0068] In an implementation, the pre-determined specification is based on feed requirements of a downstream slurry preparation process or a downstream bitumen extraction process.

[0069] In an implementation, the bitumen extraction process is a hot water extraction process, solvent extraction process, flotation-based extraction process, or mechanical separation process.

[0070] In an implementation, an infrared analysis probe is installed in a sampling location in proximity to each feed stream such that ore moving within the feed stream comes into direct contact with the probe.

[0071] In an implementation, the probe is operated to emit and detect infrared light through a window to obtain a reflectance spectrum associated with an oil sands ore sample in direct contact with the window, wherein the window is positioned between (i) the ore sample and (ii) the infrared light source and light detector such that a fixed distance is maintained between the two during operation of the analysis device to emit and collect infrared signals.

[0072] In an implementation, the method further comprises a controller configured to receive composition estimates for each feed stream and control blending of the mined ore from the feed streams in accordance with the blend ratio.

[0073] In accordance with one aspect, there is provided a system comprising:
a mining facility configured to excavate mined ore from a mine face;
a transportation system configured to transport the mined ore to an ore processing facility;
an ore processing facility configured to receive and process the mined ore;

a plurality of near-infra red (NIR) analysis devices, each device comprising an NIR light source, an NIR light detector and an infrared permeable window positioned between the NIR light source and light detector, and an ore sample in direct contact with the window, wherein each device is positioned at a location in the system where the window comes into direct contact with the mined ore or a derivative thereof, providing a plurality of ore samples; and

a controller configured to:

receive signals from the plurality of NIR analysis devices;

correlate the signals to a calibration curve to estimate at least one composition parameter of the plurality ore samples;

transmit signals to locations in the system to control one or more operating parameters of the system in response to the estimated composition parameters.

[0074] In an implementation, the system further comprises an extraction facility configured to receive a slurry derived from the mined ore from the ore processing facility and to extract a resource from the slurry.

[0075] In an implementation, the controller is further configured to control an extraction process within the extraction facility based on the composition of the mined ore.

[0076] In an implementation, the extraction facility is a bitumen extraction facility and the extraction process comprises a flotation step.

[0077] In an implementation, the controller transmits signals to control the addition of hot water, chemicals, or other process aids at the flotation step.

[0078] In an implementation, the controller transmits signals to control retention time, flushing conditions, interface level, or withdrawal rates associated with the flotation step.

[0079] In an implementation, at least one of the NIR analysis devices is located in the mining or transportation system; and composition parameters estimated for ore samples that were analyzed by said NIR analysis device are used by the controller to transmit signals to the mining facility, transportation facility, or extraction facility to control one or more operating parameters of the system.

[0080] In an implementation, said NIR analysis device is located within an excavator used to mine ore, or within a haul truck used to haul the mined ore from the mining facility to the ore processing facility; and the operating parameter of the system is an excavation location.

[0081] In an implementation, said NIR analysis device is located within an excavator used to mine ore, or within a haul truck used to haul the mined ore from the mining facility to the ore processing facility; and the operating parameter of the system is an excavation rate.

[0082] In an implementation, said NIR analysis device is located within an excavator used to mine ore, or within a haul truck used to haul the mined ore from the mining facility to the ore processing facility; and the operating parameter of the system is a hopper or blend location for delivery of mined ore to the ore processing facility.

[0083] In an implementation, at least one of the NIR analysis devices is located in the ore processing system; and composition parameters estimated for ore samples that were analyzed by said NIR analysis device are used by the controller to transmit signals to the mining facility, transportation facility, or extraction facility to control one or more operating parameters of the system.

[0084] In an implementation, said NIR analysis device is located in proximity to a hopper or conveyor used to transport mined ore; and the operating parameter of the system is a mined ore blending.

[0085] In an implementation, said NIR analysis device is located in proximity to a hopper or conveyor used to transport mined ore; and the operating parameter of the system relates to a processing step within the extraction facility.

[0086] In an implementation, the mining facility is an oil sands mining facility for recovery of hydrocarbons from the mined ore.

[0087] In an implementation, the controller is further configured to compare the ore composition to an expected ore composition prior to transmitting control signals.

[0088] In an implementation, the controller is further configured to update a mine map or reservoir map based on the ore composition data.

[0089] Implementations of the invention can realize some or none of the following advantages. The methods and systems described herein sample mined ore that is in direct contact with an infrared permeable window, behind which is an infrared light source and detector. The distance from the infrared light source and detector to the window is a constant, fixed distance. By only using samples that were taken when the mined ore is in direct contact with the window, the sample therefore is also a fixed distance from the infrared light source and detector when sampling occurs. The magnitude of the distance is selected based on the desired composition data for which the sample is being collected. Advantageously, having the sample a fixed, known and pre-set distance from the infrared light source and detector during sampling provides improved reliability of composition analysis and data.

[0090] Being able to collect composition data for mined ore in near-real time at one or more locations in a mining and processing operation advantageously allows the operation to be controlled – in near-real time – to account for variations in mined ore feed to the processing operation. Processing and extraction operations typically are optimized for ore feed having composition parameters falling within a particular range. When ore feed enters the system outside these ranges, there can be adverse consequences to the efficiency and economics of the processing and downstream operations. Advantageously, these adverse consequences can be mitigated in at least two ways using the methods and systems described herein. Mining and transportation operations can be controlled based on the real-time composition data to optimize ore blending systems, to minimize variations in ore feed, thereby reducing instances of the problem. Additionally or alternatively, downstream operations (i.e., ore processing and/or extraction operations) can be controlled to account for the variations in ore feed, thereby mitigating the adverse consequences.

BRIEF DESCRIPTION OF THE DRAWINGS

[0091] Various aspects and implementations will now be described by way of example only with reference to the appended drawings wherein:

[0092] FIG. 1 is a process flow diagram of an example oil sands mining and extraction system;

[0093] FIG. 2a and 2b show implementations of NIR probes for use in estimating ore composition;

[0094] Fig. 3 is a flow diagram of an implementation of an NIR reflectance data processing and control system

[0095] FIGs. 4a through 4m provide validation comparison scatter plots comparing an NIR predicted estimation to a laboratory measurement for multiple composition parameters;

[0096] FIG. 5 is a schematic representation of a surface mining and slurry preparation system, in one embodiment;

[0097] FIG. 6 is a process flow diagram of an extraction system, in one embodiment; and

[0098] FIG. 7 is a process flow diagram of an oil sands mining and extraction system, in one implementation.

DETAILED DESCRIPTION

[0099] In a surface mining process and corresponding mined ore processing system, the composition of mined ore can be determined by real-time analysis of the mined ore during transportation or processing. Analysis equipment can be installed on mining, transport, or processing equipment, and the resulting ore composition data can be used to both adjust upstream mining operations and optimize downstream processes for extraction of valuable resources from the mined ore.

[00100] Real-time NIR analysis of ore composition can be used to direct ongoing mining processes, and in blending mined ore feed streams to achieve a blended ore stream that meets operational specifications, e.g., for slurry preparation. Further, the analysis data can be used to advise downstream processing steps, for example in determining appropriate volumes and temperature of water and chemicals added to the ore to form a suitable slurry composition for efficient operation of a downstream extraction process, or to optimize specific processing steps in the extraction of valuable resources (e.g., hydrocarbons) from the ore, based on the analysis data.

[00101] In one implementation, ore analysis is accomplished by infrared reflectance analysis using NIR reflectance probes installed on ore transport or processing equipment. When installed at one or more ore analysis locations, each NIR probe makes direct contact with mined ore moving past the analysis location, permitting periodic or continuous analysis of ore samples by the probe. The resulting NIR reflectance spectra are processed and correlated to a standard to determine the composition of each ore sample contacted and analyzed by the probe. This valuable composition data can be compared to expected or historical ore composition data. The analysis data is further useful in directing ongoing mining efforts or processing steps.

[00102] For illustrative purposes, the methods and systems are described below in the context of an oil sands mining operation for the purpose of extracting bitumen from the mined ore. However, it should be understood that the methods and systems described herein can be used in other operations for mining ore and are not limited to oil sands mining.

Surface Mining Overview

[00103] Referring to Figure 1, a simplified process flow diagram illustrating an example oil sands surface mining operation is provided, although recovery of other resources from mined ore using the methods described herein is also contemplated.

[00104] In the mining stage 100, oil sand ore is mined by excavation, which can be accomplished by suitable equipment as is known in the art, such as an electric shovel or excavator. Locations for excavation within the mine are typically determined based on a pre-determined mine map, generated using core sample laboratory analysis data that is extrapolated across the reservoir or geographical location to be mined. Accordingly, based on the mine map, the mine is generally represented by a grid in which each cell is assigned an estimated ore composition. For example, the estimated composition for a particular mine grid location may include estimated bitumen content, fines content, D50 (representative of the grain size of sand, wherein a high D50 means the sand is more coarse), number of recoverable barrels of bitumen, ore grade, and other parameters. As the mine face is excavated and ore is loaded into haul trucks, an automated system can assign estimated composition data to each truckload of ore, based on the mine map grid location from which the ore was mined. For example, a GPS system associated with the shovel bucket can be used to estimate the composition of the truckload based on the various bucket positions while excavating ore from the mine face.

[00105] The mined oil sand ore is conveyed 102 to ore processing 104, for example by trucks and/or conveyors. The ore processing step 104 can include a crusher or comminutor to reduce the mined ore into a comminuted ore, and can further include a series of operations to blend and convert the mined oil sand ore into a pumpable oil sand slurry comprised of oil sand ore and process fluid. The pumpable oil sand slurry can be conveyed by hydrotransport 106 to an extraction facility 108. Conveyance by hydrotransport 106 may aid in conditioning the slurry, which improves separation of the bitumen in later processing steps. If conditioning is not required and the extraction 108 facility is co-located with the ore processing 104 facility, hydrotransport 106 may not be present. The process fluid can be a solvent such as water that has been heated to a process temperature, and optionally can include one or more additives such as a diluent, caustic, or other process aids. The slurry can be further diluted with process fluids or

additional additives at later stages in the operations, such as during extraction 108, where the pumpable oil sand slurry is processed and separated into a diluted bitumen product stream 110 and a tailings stream 111.

[00106] The diluted bitumen product stream 110 is transported to subsequent downstream processing steps such as upgrading and refining 112, converting the bitumen to various hydrocarbon products.

[00107] Tailings operations 114, serve to dispose of the tailings stream 111 that results from the extraction process. For example, tailings can be deposited in settling ponds or can be subject to solid-liquid separation or other processing steps leading to disposal of solid waste and recycling of process water.

[00108] Ore processing 104 interfaces the inconsistent operation of mining 100 (due to variations in volumes and composition of ore feed) and the continuous operations of extraction 108. Extraction processes operate most efficiently when ore feed and process steps can be consistently maintained within set operating parameters.

Ore Analysis

[00109] An ore analysis device can be installed in close proximity to, in direct contact with, or inserted into, oil sands ore during mining or ore processing, to provide ore composition data. Based on this composition data, mining operations and ore processing operations can be adjusted to minimize variations in slurry composition fed to the extraction process. Further, the data can be used to make adjustments to optimize downstream operations such as extraction, upgrading, and refining, based on the expected slurry composition. The ore composition data can also be used to generate or update a mine map or reservoir map.

[00110] The ore analysis device is provided for analyzing ore composition at one or more locations in the mining 100 or ore processing 104 operations, to obtain estimated composition data for various parameters of interest within the ore. Ore composition parameters for estimation in oil sands ore can include, for example, bitumen content, fines content, solids content, water (connate) content, concentration of chlorides, conductivity, D50 (a measure of particle size distribution), ore grade, degradation state of the bitumen, clay content, naphtha content, sulfate content, or bicarbonate content. In

some implementations, the content of chlorides, potassium, calcium, sodium, sulfates, and/or carbonates, can be expressed as a concentration, e.g., in mg/L, and the content of bitumen, fines, minerals (solids), water, and clay can be expressed as a percentage by weight.

[00111] In some implementations, certain combinations of composition parameters can be estimated. For example, when the composition estimates will be used to assign an ore grade to the ore, the composition parameters estimated by NIR analysis can include bitumen, clay, and particle size distribution. Depending on the purpose of the data collection, various combinations of ore composition parameters can be estimated. The parameters can be used to advise downstream extraction operations, for example to estimate or model the recovery of bitumen using various extraction processes, and to predict recovery of bitumen, solids, and fines during each stage of extraction 108.

[00112] The ore analysis device can include one or more reflectance infrared spectrometers that direct infrared light toward an ore sample from a controlled or fixed distance, capture reflected light from a controlled or fixed distance, and process the captured light to obtain a reflectance spectrum. These functions can be accomplished by a single device, or each function can be carried out by independent devices operating as a system.

[00113] In some implementations, the ore analysis device includes a probe-type spectrometer that is placed in direct contact with the ore sample. The probe can be, for example, a reflectance near infrared probe spectrometer that can emit infrared light and capture infrared light that is reflected and/or scattered by the sample back onto the probe. An example of an NIR probe is shown in Figure 2a and 2b. In the implementation shown in Figure 2a, the probe 50 includes a steel flange portion 52 connected to a steel shaft portion 54. An infrared light-permeable window 55, such as a sapphire window, is located at a distal end 56 of the shaft portion 54. In Figure 2b, the shaft 64 of probe 60 extends through an equipment surface 61 and is held in place by anchoring flange portion 62 against the equipment surface. The infrared light-permeable window 65 makes direct contact with ore 90.

[00114] Placement of a probe in direct contact with the ore sample during analysis allows the distance for infrared reflectance analysis to be controlled and consistent from one sample to the next.

[00115] The beam of infrared light emitted onto the sample can include near infrared light, for example infrared light with a wavelength between about 800nm – 2500nm. In some implementations, the ore analysis device is a Near Infrared Reflectance spectroscopy (NIR) probe, or a collection of such probes, operable to direct a beam of infrared light through one or more infrared-permeable, impact resistant windows (such as a sapphire glass window) onto the ore. In embodiments in which the probe is intended to directly contact, to abut, or to be inserted into a moving or stationary source of oil sands ore, the window provides a consistent analysis distance between the light source/detector and the ore sample, allowing controlled conditions for precise and reliable spectral analysis of samples moving past the window. Infrared light reflected by the ore is captured back through the window, and scattered light may also be captured through the window. Captured light (reflected or scattered or both) is analyzed to obtain a reflectance spectrum, which can be evaluated based on one or more models to generate an estimate as to one or more composition parameters of the ore.

[00116] Each probe may include an analyzer for conversion of optical signals, corresponding to the collected infrared light reflected by an ore sample, to a reflectance spectrum. With reference to Figure 3, one or more probes 50, 60 can each be operatively associated with an analyzer 70 that can receive optical signals from each probe corresponding to the infrared light reflected and/or scattered by samples contacting the window of the probe. The optical signals can be processed by the analyzer 70 to generate a reflectance spectrum, which is output as data indicating the magnitude of the infrared light reflected by the sample at various wavenumbers. The data can be sent to a processor 71 for correlation to a standard calibration curve or model, to provide ore composition data. The ore composition data can be averaged over a period of time to provide an estimated average ore composition. The ore composition information is transmitted to a controller 72 (either by wired or wireless communication) and can be used by the controller 72 to direct ongoing mining operations, ore processing, and/or extraction operations. In some implementations, the probe and

analyzer are integrated as one device. In some implementations, the processor and analyzer are integrated as one device. In some implementations, the processor and controller are integrated as one device. Other configurations are possible, and the configuration shown in Fig. 3 is but one example.

[00117] Each cycle of illumination and light capture can be referred to as an analysis interval. The analysis interval can be automated to take place at a desired rate, for example one analysis interval per second. During each analysis interval, infrared light is emitted through the window and light is captured through the window, whether or not an ore sample was in contact with the probe window during the analysis interval. The captured light from each analysis interval can be analyzed to generate a reflectance spectrum that is filtered or processed to determine whether the spectrum is acceptable for evaluation of ore composition. Alternatively, captured light from each analysis interval can be correlated to a calibration curve to determine the ore composition, and the ore composition data can be processed or filtered to determine whether the data is acceptable.

[00118] The reflectance spectrum can be processed by applying chemometrics to evaluate the spectrum and to compare features of the spectrum to at least one multivariate model. The model is calibrated off-line by collecting multiple process stream samples, and capturing spectra of each of the samples along with corresponding reference laboratory results. Multivariate calibration techniques, such as partial-least squares regression (PLS regression), principal component analysis (PCA), neural networks (NNs), or other known means, can be used to construct a mathematical model that relates the spectrum to the content of a particular component of the sample. The spectrum can then be evaluated with reference to the model to obtain an estimate of the content of that component.

[00119] A separate model can be calibrated for each composition parameter of interest, and a set of models is used to evaluate more than one composition parameter of a bitumen-containing process stream. A separate set of models can be calibrated for each of different locations of interest.

[00120] Once a spectrum has been evaluated to generate an estimate of various composition parameters, the composition parameter estimates can be used to inform

upstream or downstream operations. For example, further to receiving the ore composition estimates, proactive or remedial actions can be taken to optimize mining, ore processing, blending, and extraction processes. The efficiency of downstream froth treatment, upgrading, and refining processes can also be improved as a result of this information.

Ore composition Parameters

[00121] Table 1 provides a list of ore composition parameters that can be estimated using near infrared spectral analysis, and corresponding filter windows (wavenumber ranges) for estimation of each parameter. As discussed above, the analysis can be completed using an NIR probe in direct contact with oil sands ore, which contact provides a consistent analysis distance between the sample light spot of the probe.

TABLE 1: Wavenumber Ranges for Estimation of Ore Composition Laboratory Parameters Using NIR Analysis

Parameter	Wavenumber range (cm ⁻¹)
Bitumen	9380-7417, 6102-5446, 4790-4026
Solids	8092-7621, 6456-5442
Fines	7891-6996, 5550-5130
Connate water	7506-4713
Chlorides	10348-7621, 5716-5342, 4455-4026
Particle Size Distribution: for example, D45	6996-6102, 5550-4042, 6102-4520
Ca ⁺²	9403-6094, 5454-4952
K ⁺	7506-6094, 5207-4952
Methylene Blue	7506-6094, 5454-4952

Na ⁺	9403-7498, 5778-5446
SO ₄ ⁻²	9403-7498, 5454-4952
pH	7506-4983
CO ₃ ⁻²	9403-6094, 5454-4968
Clay	9403-4944

[00122] The above wavenumber ranges are examples of wavenumbers that can be used to process a reflectance spectrum and arrive at composition estimates. That is, the magnitude of the reflectance spectrum at one or more wavenumbers within the above ranges can be used for correlation to a standard curve/model for determination of an estimated content of the composition parameter within the ore. The magnitude of the reflectance spectrum at wavenumbers outside these ranges can also be correlated to composition parameters of interest.

[00123] With reference to Figures 4a through 4m, validation studies were carried out to compare ore composition results obtained using NIR analysis with conventional laboratory analysis.

[00124] Oil sand ore samples were obtained and analyzed in accordance with standard laboratory practices. NIR analysis of the same samples was conducted using a Bruker Albedo probe. The probe was placed in direct contact with each ore sample, and a spectrum was collected across an 800-2500nm wavelength range.

[00125] With reference to Figure 4a, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the bitumen content of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual bitumen content (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R² of 98.06%.

[00126] Referring to Figure 4b, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the mineral (solid) content (wt%) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual mineral content (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 95.16.

[00127] Referring to Figure 4c, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the connate water content (%) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual connate water content (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 96.91.

[00128] Referring to Figure 4d, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the chloride content (mg/L) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual chloride content (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 96.71.

[00129] Referring to Figure 4e, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the Methylene Blue index to characterize clay content (ml/100g) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual Methylene Blue results (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 98.46.

[00130] Referring to Figure 4f, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the pH of the ore as estimated by NIR

analysis is indicated on the Y axis, and the corresponding actual pH (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 94.24.

[00131] Referring to Figure 4g, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the Ca^{+2} content (mg/L) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual Ca^{+2} content (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 97.96.

[00132] Referring to Figure 4h, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the CO_3^{-2} content (mg/L) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual CO_3^{-2} content (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 96.29.

[00133] Referring to Figure 4i, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the K^+ content (mg/L) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual K^+ content (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 98.29.

[00134] Referring to Figure 4j, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the Na^+ content (mg/L) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual Na^+ content (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 97.44.

[00135] Referring to Figure 4k, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the SO_4^{2-} content (mg/L) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual SO_4^{2-} content (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 97.77.

[00136] Referring to Figure 4l, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the Particle Size Distribution <45 μm (%) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding PSD (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 91.99.

[00137] Referring to Figure 4m, a validation model is shown, with the sloped line representing the ideal reference line between lab analysis and corresponding NIR analysis. As is observed from the model, in which the clay content (%) of the ore as estimated by NIR analysis is indicated on the Y axis, and the corresponding actual clay content (as determined by laboratory analysis) indicated on the X axis, there is reasonable correspondence between the two methods of measurement, with an R^2 of 98.86.

Analysis Locations

[00138] In some implementations, an ore analysis device, such as a probe-type spectrometer, is installed on transport or processing equipment that is continuously exposed to moving bodies or samples of mined ore. For example, one or more spectrometers can be installed within the wall of a conveyor, hopper or crusher, to rapidly and continually analyze ore moving past the analysis location during ore processing.

[00139] In some implementations, an ore analysis device can be installed on transport or processing equipment that is periodically exposed to moving or stationary

loads, bodies or samples of mined ore. For example, an ore analysis device can be placed in a haul truck or in contact with a surge pile to provide composition analysis of samples of mined ore.

[00140] Each spectrometer can be set to emit infrared light and obtain a spectrum at particular intervals to generate a representative sampling of the ore composition being mined and processed over time. The probe can be installed such that ore continually or periodically comes in direct contact with the ore as it advances through ore processing.

[00141] In some implementations, ore analysis devices can be installed on mining equipment, for example, the probe can be fixed in place through a wall of an excavation bucket or haul truck bed. The probe can be located such that ore falls past the probe window during loading/unloading, allowing many sample analyses to be taken during a single loading or unloading event. As a bucket is dumped into the haul truck, a steady stream of mined ore can make contact with the probe as it passes. Depending on the location and number of probes installed, and the analysis rate and interval that can be achieved with each probe, many composition measurement intervals, or samples, can be analyzed during the unloading of a single bucket into the haul truck, allowing multiple measurements to be taken while loading a single truck with ore. The measurements for a single truckload can be averaged to estimate the ore composition of the entire truckload of ore.

[00142] Alternatively, or in addition to analysis during loading, one or more probes can be installed within the lower side walls or bottom surface of the haul truck bed to provide composition analysis of the stationary mined ore in the truck bed during hauling. Such probes can again be activated for analysis of ore during unloading of the mined ore from the truck bed, with continual rapid analysis during unloading as ore moves past the ore analysis location.

[00143] In some implementations, ore analysis devices can be installed on various types of equipment during ore processing. When installed within the wall of a hopper, crusher, or conveyor, an analysis device such as a NIR probe can be continually exposed to ore moving past the probe location. During some sampling intervals, ore may be in direct contact with the probe window, while in other intervals, ore may not be in direct contact with the window. Ore composition data can be filtered to exclude data from

analysis, where the data is based only on an interval in which an ore sample was not in direct contact with the probe, to improve reliability of the ore composition estimates.

[00144] A high sampling rate will generally allow increased reliability in estimating ore composition, particularly in sampling locations where a large proportion of samples are expected to be discarded due to lack of direct contact between the ore sample and the probe.

[00145] As the ore analysis device can be installed in a high impact environment, with many tonnes of material moving past the analysis location within minutes, as mentioned above, the online measurement apparatus can include a durable, infrared-permeable window, such as a sapphire optical window, positioned between the infrared incident light and the sample. Such window can form the end of a probe or be used to cover the end of a probe. The window can directly contact the sample, thereby controlling the analysis distance of the sample from the incident light, and also controlling the distance of the sample from the reflected and scattered light collector(s). Such probes are readily available, for example the “Albedo” type probe from Bruker Inc.

[00146] With reference to Figure 2b, in one implementation, the ore analysis device is an NIR probe-type analysis device. Such devices can include a fibre bundle 67 containing at least one NIR transmission fibre and at least one light collection fibre. The ends of these fibres are generally aligned so as to be the same distance from the sample. The end of the fibre bundle is termed a “light spot”. When the fibre bundle is installed within an NIR analysis device for use in the analysis of oil sands ore, the fibres are positioned behind an infrared-permeable window 65 of appropriate thickness and durability to protect the fibres from contact with the ore, and to provide an appropriate and consistent analysis distance A between the light spot and the ore to be analyzed.

[00147] In some implementations for use in analysis of mined oil sands ore, the infrared-permeable window can be flat or convex for easy installation and alignment within an equipment surface such as a hopper wall, to ensure that ore passing the analysis location will make contact with the window to permit analysis from a controlled distance. As mentioned, the window can be formed of infrared permeable, impact-resistant glass, such as sapphire glass or sapphire crystal, for durability. Repeated

contact of ore with the window serves the additional function of clearing dust, bitumen, clay, or debris from the impact-resistant window.

[00148] In some implementations, the ore analysis device is an NIR probe having one or more NIR transmission fibres, one or more light collection fibres, and a window between the fibres and the sample to be analyzed. Depending on the desired installation location, the ore analysis device can extend into the path of moving or stationary ore such that the probe is inserted into a volume of ore, with the window (flat, curved, etc.) providing a controlled analysis distance between the light spot and the sample.

[00149] The light transmission and capture functions can be accomplished by separate devices or probes, or separate fibre bundles, positioned behind a common window or behind separate protective windows. Each can be independently programmed to operate under specific conditions. For example, the incident light can be provided consistently at a particular rate, while the spectral analysis can be processed at a different rate based on independent criteria such as the degree of ore contact or proximity with the probe or window.

[00150] With reference to a light spot of an NIR analysis device, the most reliable and precise ore composition estimates will be obtained when the distance between the light spot and the ore sample is consistent for every sample. It should be noted that the distance of the light spot from the sample will, to some extent, determine which ore composition parameters can be reliably obtained. Certain parameters, such as particle size distribution, are more accurately estimated when the probe is in very close proximity to the sample, while estimation of other parameters do not require close proximity to the sample. Accordingly, the probe should be in direct contact with the ore samples during analysis, in order to maintain a consistent spacing of each ore sample from the light spot. The probe should be selected or designed with a window of an appropriate spacing or thickness to provide a sample spacing from the light spot that will provide accurate and consistent estimation of all composition parameters that are desired.

[00151] For any data point, light reflected by the sample and light scattered by the sample can be collected and processed. As distance from the sample increases, the reflected light alone may not provide a crisp spectrum for modelling of some properties, such as particle size distribution. For these parameters, the spectrum can be clarified,

filtered, or further processed using a scattered light model. The need for filtering or processing can be determined based on the strength of the reflectance signal, clarity of the spectral shape compared to a standard, or other standard correlation methods known in the art.

[00152] Referring to Figures 2a and 2b, an NIR probe 50 is adapted for insertion through or within a wall opening 60 within a retention wall 61, for example a retention wall adjacent an apron feeder. As shown in Figure 2b, the probe can thereby be secured behind the wall 61 while extending through the wall to a position flush with the wall or extending into the ore conveying or processing area to contact ore 90.

[00153] In the implementation shown in Figure 2a, the probe 50 includes a steel flange portion 52 connected to a steel shaft portion 54. An infrared light-permeable window 55, such as a sapphire window, is located at a distal end 56 of the shaft portion 54.

[00154] In some implementations, the probe embodiment can include a lengthened shaft portion for extending into the bitumen processing area and allowing more direct contact within the ore 90. In an implementation, the shaft portion 54 has a surface metal coating to protect the portions of the probe exposed to the ore during processing. The coating provides increased strength to resist abrasion and corrosion, and to assist in preventing bitumen from adhering to the exposed portions of the probe. In some implementations, the surface coating is a Nickel/Molybdenum based CK45 steel metal alloy.

Ore Processing

[00155] With reference to Figure 5, an example ore processing system 201 for use in ore processing 104 is illustrated. As will be appreciated, the exact layout and number of conveyors and processing equipment can vary from site to site and the embodiment of Figure 5 is intended to provide an exemplary layout of equipment for processing mined oil sand ore for explanatory purposes. A truck 202 can be used to supply mined oil sands ore to a hopper 204, which receives and delivers loads of mined oil sands ore to a hopper apron feed conveyor 206. The ore is conveyed to a comminutor 208, e.g., a roll crusher or other means known in the art. The hopper apron feed conveyor 206 is

typically a variable speed conveyor to allow control over the rate of deposition of ore into the comminutor 208.

[00156] The comminutor 208 crushes the received loads of ore into comminuted ore that is deposited onto a comminuted ore feed conveyor 210 and conveyed to an optional surge pile 212 that retains a store of ore. The comminuted ore feed conveyor 210 is typically a constant velocity conveyor that provides a feed of comminuted ore to the surge pile 212.

[00157] The surge pile 212 stores the comminuted ore to allow for constant delivery of ore to a downstream slurry apparatus 218, as well as to provide buffer capacity to ensure a steady supply of ore during periods of upstream downtime (e.g. shift change, maintenance, etc.). The surge pile 212 can vary in volume and composition according to the supply of ore from the hopper apron feed conveyor 206 and comminutor 208.

[00158] The stored ore can be delivered from the surge pile 212 to a reclaim apron feed conveyor 214. The reclaim apron feed conveyor 214 is typically a variable speed conveyor that can convey the ore to a slurry apparatus feed conveyor 216. The slurry apparatus feed conveyor 216 is typically a constant velocity conveyor that supplies ore delivered from the reclaim apron feed conveyor 214 to a slurry apparatus 218, such as a rotary breaker. In the implementation shown, delivery of the stored ore from the surge pile 212 to the slurry apparatus 218 is effectively controlled by the variable speed reclaim apron feed conveyor 214.

[00159] Various ore analysis locations are possible within the ore processing system 201. In some implementations, one or more ore analysis devices can be installed at hopper 204, adjacent apron feed conveyor 206 or comminuted ore feed conveyor 210, at the feed or outlet end of the surge pile 212, and/or along reclaim surge apron feed conveyor 214.

Slurry Preparation

[00160] Referring to the implementation shown in Figure 5, a slurry apparatus 218 receives ore from the slurry feed conveyor 216, and converts it into a slurry with the addition of process fluid 217. The slurry apparatus 218 provides a sizing operation to limit ore components of the slurry to a pre-determined maximum size. The slurry

apparatus 218 provides the slurry to a slurry pump box 220 that feeds the slurry to hydrotransport pump 222. The slurry apparatus typically further includes oversize rejection 219 for diverting rejected rock and other mineral material that cannot be sized by the slurry apparatus 218. Oversize rejection 219 diverts the rejected material, typically to a reject pile, for temporary storage and then conveyance for disposal as backfill material. Hydrotransport pump 222 pumps the oil sand slurry through hydrotransport 106 to extraction 108.

[00161] The ore processing system 201 can include other inputs such as process fluids 217 added to the slurry apparatus 218, process fluids 221 added to the slurry pump box 220, and process fluids 223 added at an outlet of the slurry pump box 220 to control a composition of the oil sand slurry conveyed by hydrotransport 106. Such process fluids can include hot and/or cold process water, diluents, or other conditioning or flotation aids.

[00162] In various implementations, one or more ore analysis devices can be installed along slurry feed conveyor 216, or at other locations within the slurry preparation portion of the ore processing system 201.

Ore Blending

[00163] Typical bitumen mining extraction operations are designed based on an expected ore grade, and the operational parameters are optimized as experience is gained in mining and processing the ore. It is expected that the ore grade, quality, or composition can vary to some degree between loads and gradually shifts over time as new areas of the mine are excavated. Significant variability in the ore composition has the potential to upset operational equilibrium and reduce performance, resulting in bitumen recovery losses, increased processing time, and reduced efficiency. Notably, by the time the out-of-specification ore composition would be flagged by a standard laboratory analysis or by visual observation of off-spec processing parameters during extraction, there may already be significant impact on economic returns of the extraction process. In addition, further processing steps may also be impacted in dealing with this off-spec feed to downstream operations.

[00164] In order to control variability in ore composition and maintain consistent feed quality, ores from different sources or of differing grades can be blended together to achieve a desired feed grade or specification.

[00165] As described below, ore blending can be determined based on real-time estimated ore composition analysis. For example, ore composition may be analyzed at the stage of hauling the mined ore 102, or at the ore processing stage 104.

[00166] With reference to Figure 5, the ore processing system 201 can include multiple hoppers 204 for receiving mined oil sand ore from a multiple trucks 202 at different locations at the mine site. Truckloads of mined ore are thereby combined at each hopper 204 and become blended during ore processing to form a blended supply of ore at each surge pile 212.

[00167] The composition of mined oil sand ore delivered to each of the hoppers 204 can be monitored in real-time using NIR analysis to estimate the blended ore composition downstream of the hoppers 204. Further, when ore analysis devices are installed at the excavators and/or on the haul trucks, the blend of ore at each hopper can be controlled by directing each truck to a particular hopper based on the estimated ore composition of the mined oil sands ore in the truck.. By subsequent analysis of ore composition at an ore processing location downstream of the hopper 204 (such as at conveyor 210 or 214, or at the surge pile 212) the desired ore blend can be verified prior to the ore reaching the slurry apparatus 218.

[00168] The use of multiple hoppers 204 in parallel may be a preferred arrangement to accommodate blending of ore from various sources or of varying quality, and blending at each hopper may be controlled to achieve a different blended ore composition downstream of each hopper, if desired. By operating multiple hoppers 204 in parallel, estimates of the ore quality or composition at each hopper may be monitored and controlled independently. Installation of an ore analysis device at the point of excavation, at each hopper 204, and at other locations within the ore processing system 201 can provide real-time monitoring of ore composition parameters to optimize blending at the parallel hopper locations.

[00169] Conventionally, if ore blending is implemented, it is based on estimated bitumen content, which is determined from the mine map. However, since the mine map is itself estimated and subject to a standard of error, and the excavation process is also imprecise, the estimates upon which the ore blending are typically based do not allow sufficient optimization of bitumen recovery. Real-time analysis of mined ore and/or blended ore can provide current actionable information about the ore as it is fed into the ore processing system 201. Providing reliable composition information allows adjustments to be made to the ore processing and bitumen extraction processes, to optimize the efficiency and economics of bitumen recovery. For example, extraction processes can be optimized to use less process water, reduced volumes of chemical process aids, and reduced energy inputs while allowing higher throughput, reduced maintenance and improved product quality.

Extraction

[00170] Referring to Figure 6, a simplified diagram of an extraction system 300 is provided. The simplified system shown excludes many additional operations that can be involved in extraction, and focuses on high level systems that produce a product stream of interest. As will be appreciated, a working facility can include multiple copies of elements contained in the Figure, as well as additional recycling and processing systems not shown. In Figure 6, an oil sand slurry is received for primary extraction by a Primary Separation Vessel (PSV) 306 from hydrotransport line 106. The PSV 306 operates to separate the oil sand slurry into three layers: a bitumen froth layer that includes bitumen froth and some process fluid that floats to the top of the cell 306; a middlings layer that includes some froth, a mineral component and process fluid; and, a lower tailings layer that predominantly includes a heavier mineral component and some process fluid.

[00171] The bitumen froth layer is separated from the top of the PSV 306 as a bitumen froth stream 315 and can be provided to a storage tank 316 for further extraction processing. The middlings layer is typically separated through middlings output stream 309 for processing, such as in flotation tank 308, to separate a bitumen rich middlings component from a tailings component. As illustrated, the flotation tank 308 separates the bitumen rich middlings component, which can be returned to the PSV 306 for further processing through middlings return stream 310, and the tailings component is output through middlings

tailings stream 312 for processing or disposal as tailings 114. A tailings stream 311 is extracted from the tailings layer of the PSV 306 .

[00172] Samples are typically taken at various locations during the extraction process, which are subject to laboratory analysis. The laboratory analysis can be used to adjust operation of the PSV 306. However, a limitation of this adjustment method is the delay between mining the ore, collecting the samples during extraction, obtaining a laboratory analysis and, in response, adjusting operating parameters. A typical laboratory analysis can take 24 hours to obtain – by which time the sample upon which the analysis was based has long since passed through the extraction system 300, and later-mined ore, potentially having quite a different composition, may be currently processing. Accordingly, conventional operations tend to default to using excess process inputs such as water, diluent, and other process aids to ensure bitumen recovery stays above a minimum acceptable threshold, since reliable ore blends and/or composition estimates have not been available.

[00173] When ore analysis devices are used to monitor mined ore composition at one or more ore analysis locations throughout the ore processing system 201, the slurry feed 106 to the extraction process can be controlled and off-spec parameters can be managed by modification of extraction process operating parameters. For example, the clay content of ore included in the slurry feed can be used to determine an appropriate amount of process water to add to the PSV 206; the bitumen content or ore quality of the slurry feed can be used to adjust the PSV residence time; and the fines content and degree of ore degradation can be used to determine whether additional reagents, e.g., caustic, should be added. The bitumen residence time in the PSV can be adjusted by raising or lowering the froth/middlings interface height in the PSV to provide increased or decreased residence time. This can be accomplished, for example, by adjusting the underflow withdrawal rate. Generally, the froth interface level in the PSV can be raised when bitumen content or ore quality is high, reducing the residence time; or lowered when excessive fines are expected to require more time to achieve separation.

[00174] Operation of the extraction process in response to ore analysis can also be effected by adjusting the process fluids added at various locations or stages of extraction. Hot process water can be added as froth underwash within the upper portion

of the PSV below the interface when increased fines concentration in the ore feed is detected. A conical flush of the lower portion of the PSV with hot or cold water can be implemented in combination with reduced intake of slurry into the PSV 206, to increase the bitumen recovery rate when the ore feed is of lower quality.

[00175] Referring again to Fig. 5, hot process water and additives can be added to the hydrotransport line or at the rotary breaker during slurry preparation when poor quality ore is detected. The temperature of the process water can also be adjusted in response.

[00176] When the ore quality is recognized as being out of specification, adjustments can be made in extraction and/or by adjusting the ore blend from various locations, and/or adjusting shovel locations. However, to date, adjustments in blend or in mining location have only been possible based on the mine map, which is subject to a degree of error as discussed previously. Ore composition analysis during mining and/or ore processing provides increased reliability in quickly identifying the need to adjust mining locations or ore blend. Updates can be made to the mine map based on the real-time analysis of the mined ore.

[00177] Accordingly, ore quality or processing conditions can be determined based on real time ore composition analysis.

Core Analysis and Reservoir Mapping

[00178] The analysis of ore by NIR can also be useful in generation of a mine map or reservoir map. Prior to recovery of bitumen or other resources from a geographic location, core samples are obtained and subjected to laboratory-based composition analysis. The number and location of core samples are typically selected to allow geologists to gain insight into the geological structures and resource content. While a larger number of core samples is desirable, the time and cost of analyzing core samples ultimately limits the number of core samples that can be taken, and geologists must generate a reservoir map based on limited core sample data, in combination with data that may be available from other sources or observations. Inherently, mine maps generated using these conventional techniques have inaccuracies.

[00179] NIR-based composition analysis of core samples can be used to reduce the cost of core sample analysis by avoiding costly laboratory services, and further allows a greater number of samples to be analyzed without increasing costs. The analysis of a large number of samples, or analysis of additional core samples in areas of the reservoir where there is some uncertainty in structure or composition, improves reliability of the reservoir map. Analysis of the core samples can be completed on site when a core sample is obtained: portions of the core sample of particular interest can be collected and analyzed using a portable NIR analyzer in real time. This real-time analysis of core samples on site can inform selection of the next core sample location, and whether a suitable number of samples have been collected for a particular geographic region. It is also contemplated that data from real-time NIR composition analysis can be collected by a controller and processed in accordance with pre-determined schemes or operational algorithms to automate certain aspects of the system. The controller can also collect additional data from complementary systems for integration across the mining and ore processing functions. For example, in a mining operation that includes mine face analysis, the mine face analysis data may be correlated with the NIR –based composition estimates of the mined ore from that mine face, to provide more robust data regarding ore analysis and ore composition within the mine. Such integration can, over time, reduce reliance on prior core sample data (which may be inaccurate), in favor of actual data obtained during mining operations. An updated mine map can then be generated for the excavated portion of the mine and extrapolated to the unexcavated areas of the mine, which can advise further mining efforts in the region.

System Control Based on Composition Parameter Estimates

[00180] In an implementation, mined ore composition estimates can be processed in real-time, or near real-time, allowing for efficient remedial or preventative action to be taken in an upstream or downstream location to mitigate impact of varying ore feed parameters. Online NIR slurry analysis within the extraction system can be used to evaluate the effectiveness of process changes made on the basis of ore composition analysis.

Bitumen Content / Ore Grade

[00181] In some implementations, the bitumen content and/or ore grade of mined ore being transported during mining or ore processing is estimated by NIR analysis. The estimated bitumen content can be used to determine whether remedial or preventative action should be taken at upstream or downstream operational steps. For example, when the bitumen content of a mined ore stream – as estimated by NIR at a particular hopper or conveyor - is below a lower threshold level, blending of the ore stream can be adjusted. For example, the low bitumen ore stream can be blended at a lower rate with another ore stream that meets the threshold, or the low bitumen ore stream can be blended at the same rate or even a higher rate with an ore stream that is higher in bitumen content, or that is even above an upper threshold bitumen content. Excavation from amine face with undesirable ore quality can be quickly recognized and halted, avoiding further costs of unwanted mining activity. Truckloads of low quality ore that has already been excavated can be discarded or reassigned to non-extraction purposes.

[00182] Other adjustments that can be made based on a low bitumen content might include increasing the amount of process water or caustic during slurry preparation. When the estimated bitumen content of a mined ore stream is below the threshold for a prolonged period, the mined ore can be segregated and used as fill, and the excavation site can be reviewed while directing excavation efforts to other areas of the mine.

[00183] When bitumen content is above an upper threshold, this may cause the ore to become difficult to handle and process, especially during warm ambient temperatures. Accordingly, ore blending can be adjusted, conveyor speed can be adjusted to speed transport of the ore, and extraction can be optimized to reduce the amount of water and process aids added. The estimated bitumen content data can further be used to update the mine map accordingly.

Fines Content / Clay content

[00184] In an implementation, the fines and/or clay content of the ore being transported or processed is estimated by NIR analysis, and the estimated fines content can be used to proactively adjust downstream extraction steps. For example, when the fines content of a mined ore stream – as estimated by NIR at a particular hopper or

conveyor - is below a lower threshold level, blending of the ore stream can be adjusted (manually or automatically) to bring the fines content of the blended ore stream into a desired range. In another example, high fines content may warrant withdrawal of middlings from the primary separation cell at an increased rate, and/or increased addition of water during flotation-based separation to allow the bitumen to separate from the fines and float to the surface of the cell. The estimated fines content can be used to control the middlings withdrawal and/or rate of water addition accordingly.

Other Parameters

[00185] In various implementations, one or more of many typical oil sands composition parameters are estimated by NIR analysis, and can be used to determine whether remedial or preventative action should be taken at upstream or downstream steps in the extraction system. For example, estimation of the particle size distribution can allow the hydrotransport process to be efficiently managed to avoid sanding out of the hydrotransport line. Examples of measurements conventionally determined by laboratory analysis that can be estimated using the ore analysis methods described above include: bitumen content, fines content (e.g. particle size <45 µm), mineral (solids) content, water content, clay content, chloride content, sulfate content, potassium content, calcium content, sodium content, carbonate content, particle size distribution, pH value, and methylene blue index. Other measurements can also be estimated. With reference to Figure 7, ore composition estimates obtained during the course of mining, transport, processing, and extraction operations can be used by a controller 710 to modify ongoing system operations. During mining efforts within mining facility 702, ore composition can be estimated using conventional methods, such as consulting a mine map based on core sample data. In addition, real-time analysis of ore composition can be completed as discussed above. For example, ore analysis devices can be installed in excavators to analyze samples of ore as it is mined, with the resulting composition estimates provided to the controller 710, which can be a centralized system for collection of mining data and control of mining equipment. Ore analysis devices can be installed on haul trucks of the transportation system 704, providing ore composition data for loads of ore 712 transported by haul trucks. The ore composition data is provided to the controller, which can control mining and transportation efforts based on ore composition

and truck availability. For example, based on the ore composition data received at the controller 710, the controller 710 can control truck movement to optimize efficiency of the transportation operation and/or to optimize ore blending at hoppers included in the ore processing facility 706. Trucks can be directed by the controller 710 to an appropriate hopper within the ore processing facility 706 to achieve a desired ore blend within each hopper stream of the ore processing facility. Ore analysis devices can be installed within the ore processing facility 706, such as adjacent conveyors, to verify the composition of the ore present within the ore processing facility 706. Installation of one or more ore analysis devices just prior to the slurry preparation step within the ore processing facility 706 can provide verification of the ore blend used to prepare an oil sand slurry 714, thereby providing reliable ore composition to the extraction facility 708.

[00186] Should the ore composition estimates at any location indicate that the ore at a particular stage is not of appropriate composition, the controller 712 can adjust any steps within the mining, transportation, ore processing, or extraction operations accordingly.

[00187] The examples and corresponding diagrams used herein are for illustrative purposes only. The principles discussed herein with reference to oil sands mining can be implemented in other mining systems, and for analysis of other types of mined ore. Different configurations and terminology can be used without departing from the principles expressed herein. For instance, steps, equipment, components, and modules can be added, deleted, modified, or re-arranged without departing from these principles.

[00188] Although the above principles have been described with reference to certain specific examples, various modifications thereof will be apparent to those skilled in the art, as outlined in the appended claims.

CLAIMS:

1. A process for obtaining a blended mined oil sands ore feed comprising:
providing at least two feed streams of mined ore;
analyzing each feed stream using an infrared spectral analysis process in which an infrared analysis probe is placed in direct contact with mined ore samples to estimate two or more composition parameters of the mined ore;
processing the composition parameter estimates to determine a blend ratio for the feed streams, wherein the blend ratio results in a blended ore composition that meets a predetermined specification; and
blending the mined ore from the feed streams in accordance with the blend ratio.
2. The process of claim 1, wherein the pre-determined specification is based on feed requirements for a downstream ore processing step.
3. The process of claim 1, wherein the pre-determined specification is based on feed requirements of a downstream slurry preparation process or a downstream bitumen extraction process.
4. The process of claim 3, wherein the bitumen extraction process is a hot water extraction process, solvent extraction process, flotation-based extraction process, or mechanical separation process.
5. The process of claim 1, wherein the infrared analysis probe is installed in a sampling location in proximity to each feed stream such that ore moving within the feed stream comes into direct contact with the infrared analysis probe.
6. The process of claim 5, wherein the infrared analysis probe includes an infrared light source, a light detector, and a window, and is operated to emit, from the infrared light source, and detect, from the light detector, infrared light through the window to obtain a reflectance spectrum associated with each mined ore sample in direct contact with the window, wherein the window is positioned between (i) the mined ore sample and (ii) the infrared light source and light detector such that a fixed distance is maintained between the two of (i) and (ii) during operation of the infrared analysis probe to emit and collect infrared signals.

7. The process of any one of claims 1-6, further comprising using a controller configured to receive the composition parameter estimates for each feed stream and control blending of the mined ore from the feed streams in accordance with the blend ratio.

8. The process of any one of claims 1-7, wherein the two or more composition parameters are any combination of the following: bitumen content, solids content, fine solids content, connate water content, chloride content, solid particle size distribution, methylene blue index, pH, Ca^{+2} concentration, Na^{+} concentration, K^{+} concentration, CO_3^{-2} concentration, or SO_4^{-2} concentration.

9. The process of claim 8, wherein the two or more composition parameters comprise any combination of any of the following: bitumen content, fine solids content, or solid particle size distribution.

10. The process of claim 8 or 9, wherein the combination includes bitumen content.

11. A process for obtaining a blended mined oil sands ore feed comprising: providing at least two feed streams of mined ore;

analyzing each feed stream using an infrared spectral analysis process in which an infrared analysis probe is placed in direct contact with mined ore samples to estimate at least one composition parameter of the mined ore;

processing the composition parameter estimates to determine a blend ratio for the feed streams, wherein the blend ratio results in a blended ore composition that meets a predetermined specification; and

blending the mined ore from the feed streams in accordance with the blend ratio.

12. The process of claim 11, wherein the at least one composition parameter is bitumen content, solids content, fine solids content, connate water content, chloride content, solid particle size distribution, methylene blue index, pH, Ca^{+2} concentration, Na^{+} concentration, K^{+} concentration, CO_3^{-2} concentration, or SO_4^{-2} concentration.

13. The process of claim 12, wherein the at least one composition parameter is bitumen content.

14. The process of any one of claims 1 and 11-13, wherein the step of analyzing each feed stream includes emitting infrared light onto the mined ore samples of the feed stream in succession and collecting infrared light reflected from the mined ore samples of the feed stream; and the infrared light is emitted and collected by the infrared analysis probe.
15. The process of claim 14, wherein the collected infrared light is processed to obtain a reflectance spectrum for each of the mined ore samples of the feed stream.
16. The process of claim 15, wherein the reflectance spectrum for each of the mined ore samples of the feed stream is correlated to a calibration curve to estimate the given composition parameter.
17. The process of any one of claims 14-16, wherein the infrared analysis probe is a NIR reflectance probe.
18. The process of any one of claims 14-17, further comprising detecting and processing infrared incident light scattered by the mined ore samples.
19. The process of any one of claim 14-18, wherein the infrared analysis probe is installed in a sampling location in proximity to each feed stream such that ore moving within the feed stream comes into direct contact with the infrared analysis probe.
20. The process of claim 14-19, wherein the infrared analysis probe includes an infrared light source and an infrared detector, where the infrared light is emitted onto the mined ore samples from the infrared light source and the infrared light reflected from the mined ore samples is collected by the infrared light detector.
21. The process of claim 20, wherein a window is provided in the infrared analysis probe; the infrared light is emitted and collected through a window; and the infrared analysis probe maintains the direct contact with the mined ore samples via the window.
22. The process of claim 21, wherein the window is positioned between (i) each mined ore sample and (ii) the infrared light source and light detector, such that a fixed distance is maintained between the two of (i) and (ii) during operation of the infrared analysis probe.

23. The process of any one of claims 14-19, wherein the infrared analysis probe includes a reflectance infrared spectrometer for emission and collection of infrared light.
24. The process of any one of claims 14-19, wherein the infrared analysis probe includes an analyzer for conversion of optical signals, corresponding to the collected infrared light, to a reflectance spectrum.
25. The process of any one of claims 14-24, wherein the pre-determined specification is based on feed requirements for a downstream ore processing step.
26. The process of any one of claims 14-24, wherein the pre-determined specification is based on feed requirements of a downstream slurry preparation process or a downstream bitumen extraction process.
27. The process of claim 26, wherein the bitumen extraction process is a hot water extraction process, solvent extraction process, flotation-based extraction process, or mechanical separation process.
28. The process of any one of claims 14-27, further comprising using a controller configured to receive the composition parameter estimates for each feed stream and control blending of the mined ore from the feed streams in accordance with the blend ratio.
29. The process of claim 28, wherein the step of analyzing each feed stream is performed at a stage of excavation, haulage, or processing of the mined ore.
30. The process of claim 28, wherein the blend ratio for the feed streams is determined in real time.
31. The process of claim 30, wherein the feed streams of the mined ore are provided by multiple haulage trucks from different locations at a mine site, and blended in a hopper to form a blended supply of the mined ore at a location downstream of the hopper.

32. The process of claim 31, wherein the infrared analysis probe is installed at excavation or haulage equipment in order to direct each haulage truck to the hopper such that the blended supply of the mined ore is obtained in accordance with the blend ratio.
33. The process of claim 32, wherein the controller directs each haulage truck to the hopper based on the composition parameter estimates received.
34. The process of any one of claims 31-33, wherein a subsequent analysis is performed at the location of downstream of the hopper to verify that the blended ore composition meets the pre-determined specification.
35. The process of any one of claims 14-34, wherein the process functions as an interface between a mining operation for mining oil sands ore and an extraction operation for extracting oil sands from the mined ore, in that the process provides the blended mined ore that meets the pre-determined specification required in the extraction operation.
36. The process of claim 35, wherein the extraction operation uses less process water, reduced volumes of chemical-process aids, or reduced energy inputs than when without the interface.
37. A process for obtaining multiple blended feeds of mined oil sands ore, wherein each blended feed is obtained by implementing the process of any one of claims 1-36.
38. The process of claim 37, wherein at least two of the multiple blended feeds are obtained by the processes in which the pre-determined specifications are different.

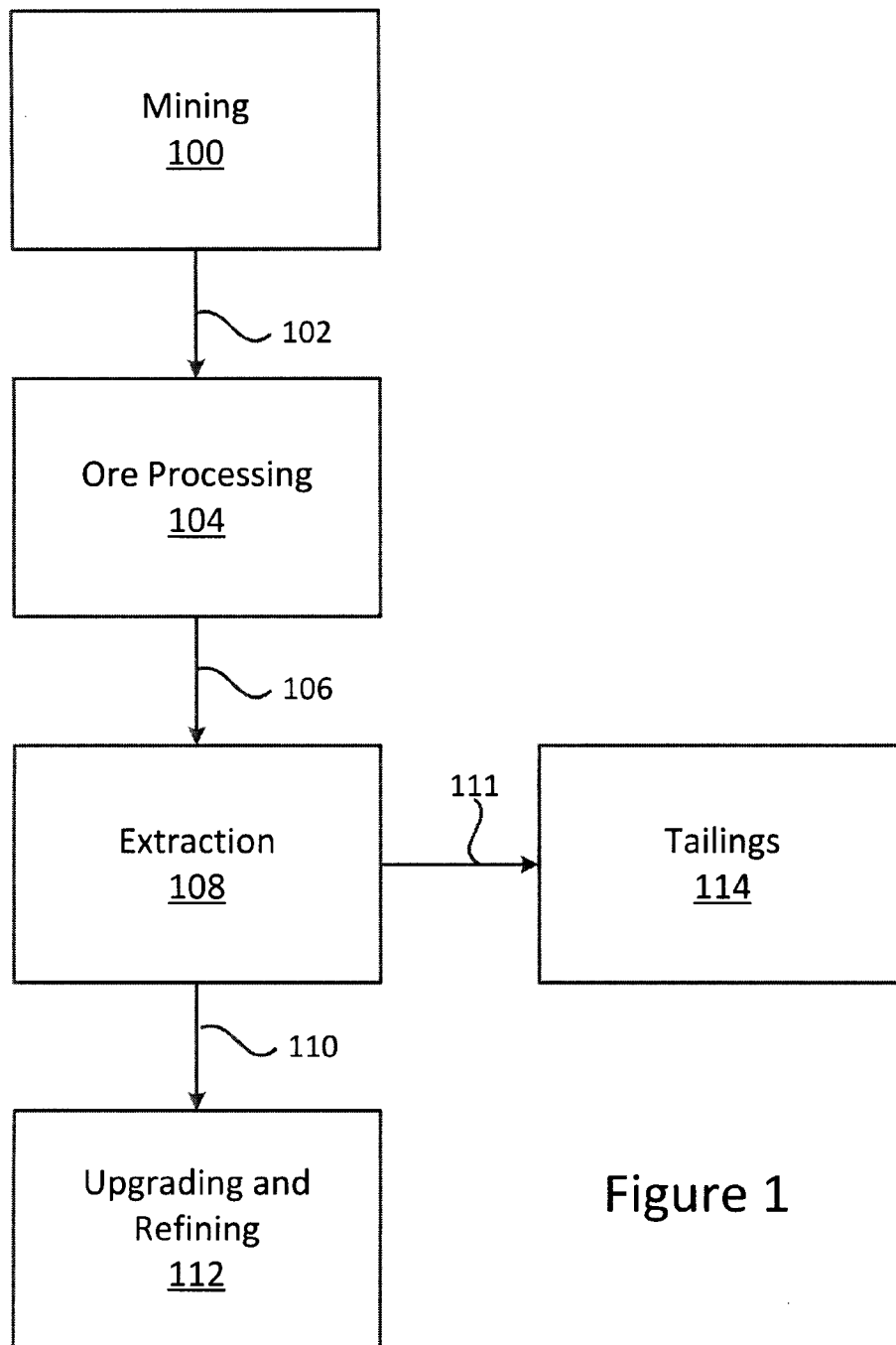
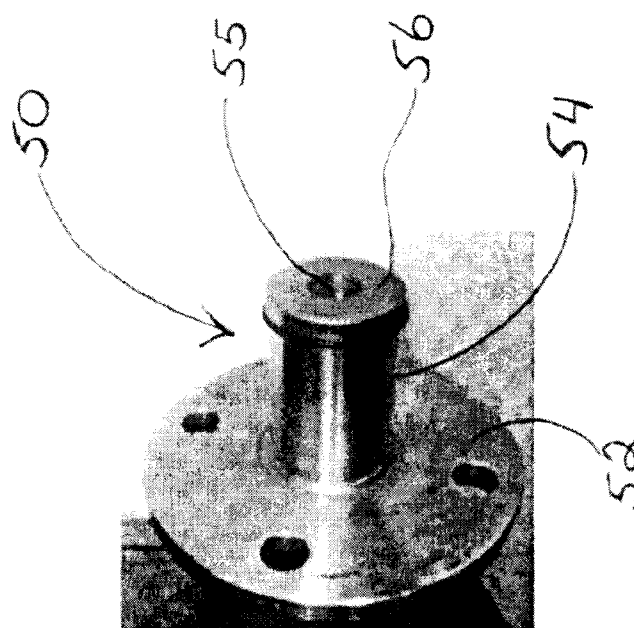
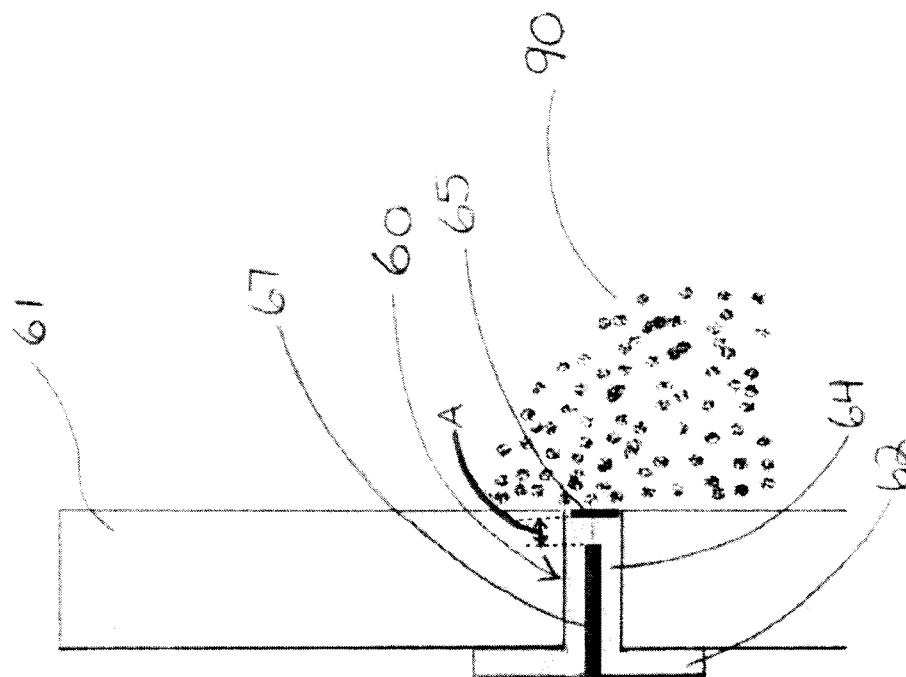


Figure 1



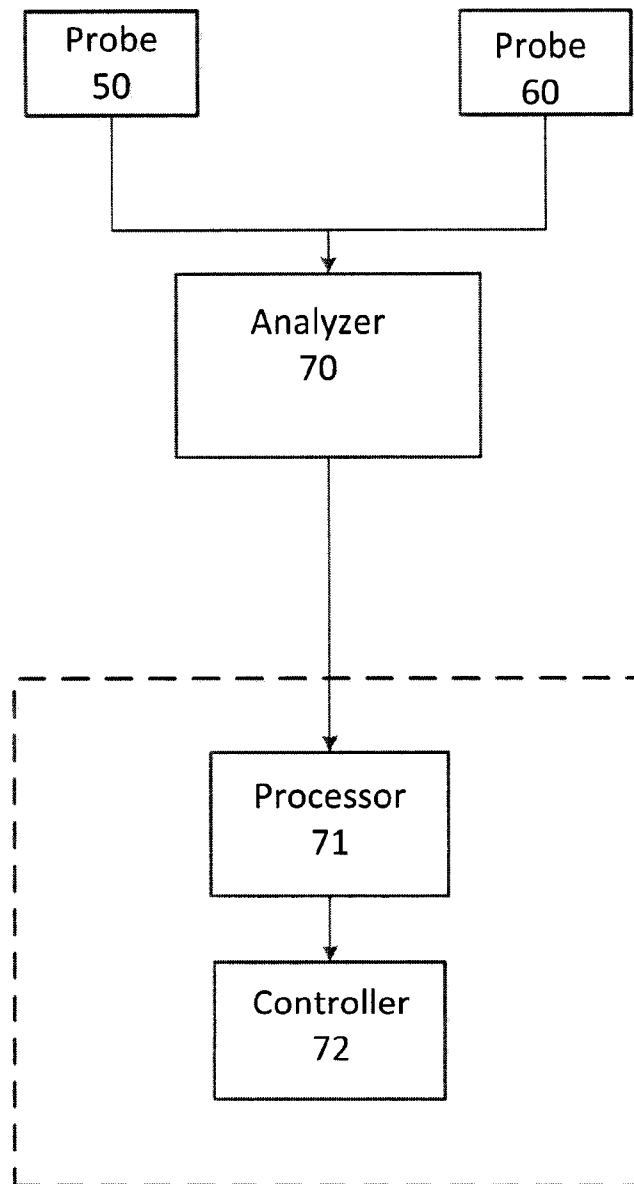
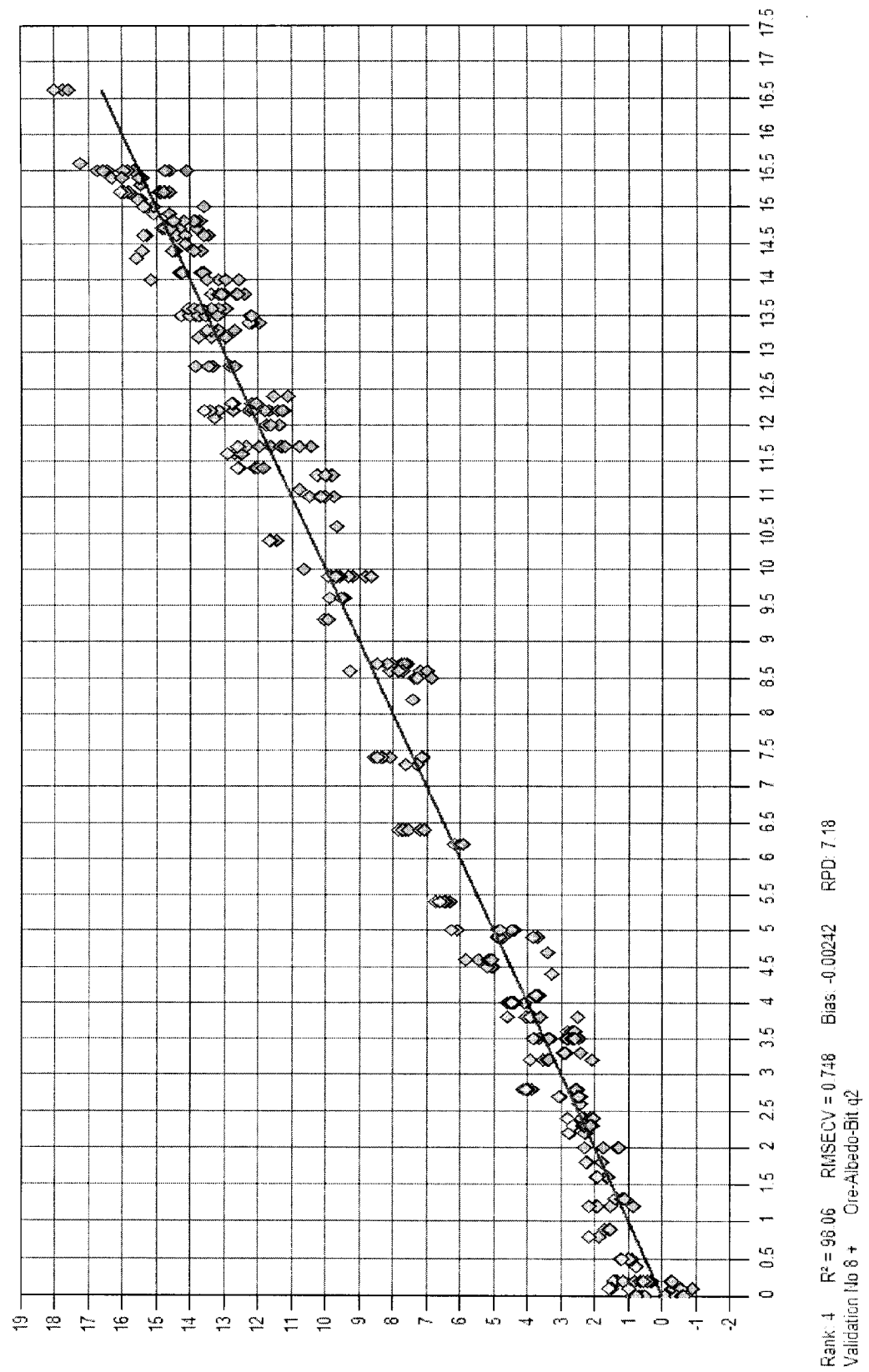


Figure 3

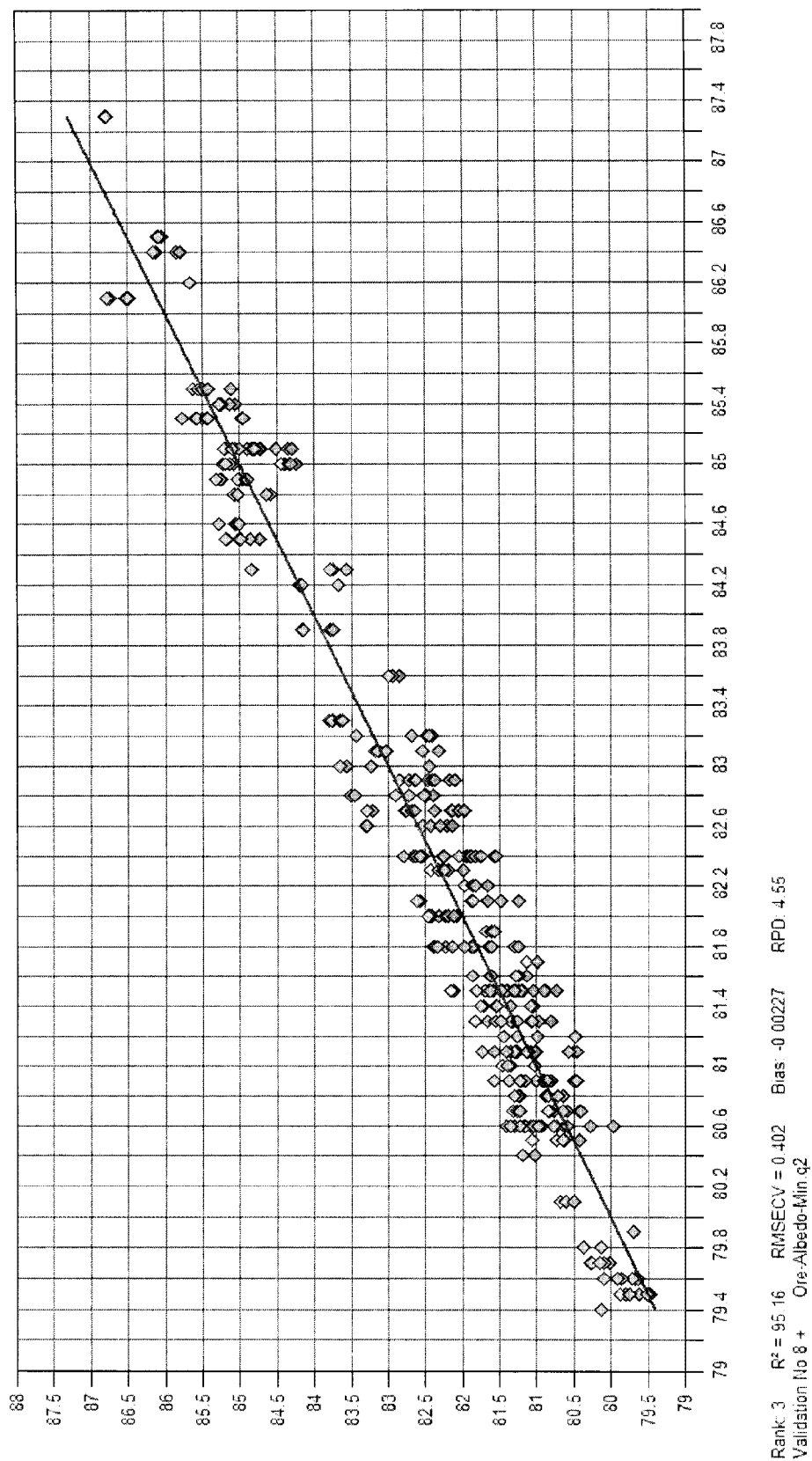
Bitumen - Fig. 4a

Prediction vs True / BIT [%] / Cross Validation



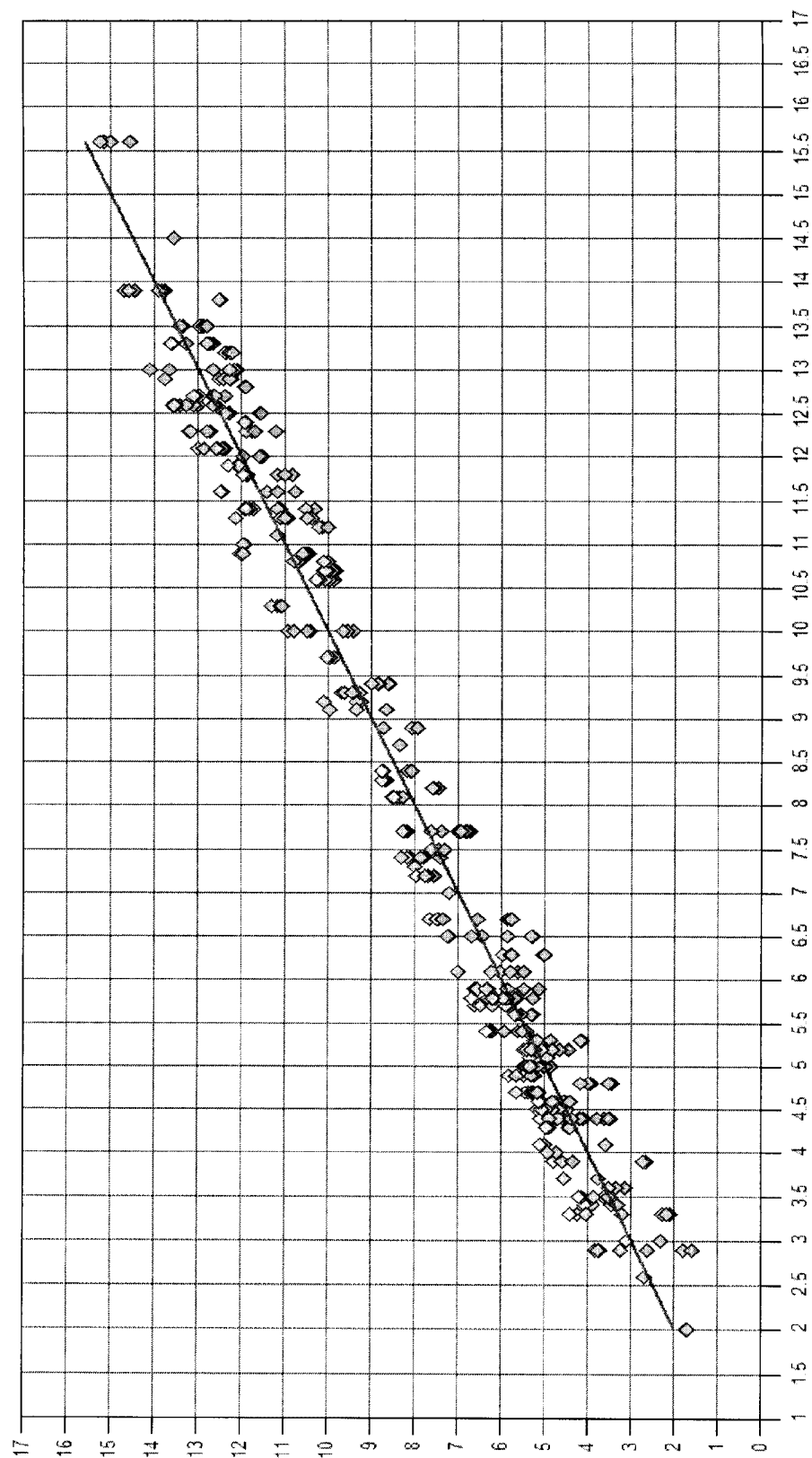
Mineral (solid) - Fig. 4b

Prediction vs True / MIN [%] / Cross Validation



Connate water - Fig. 4c

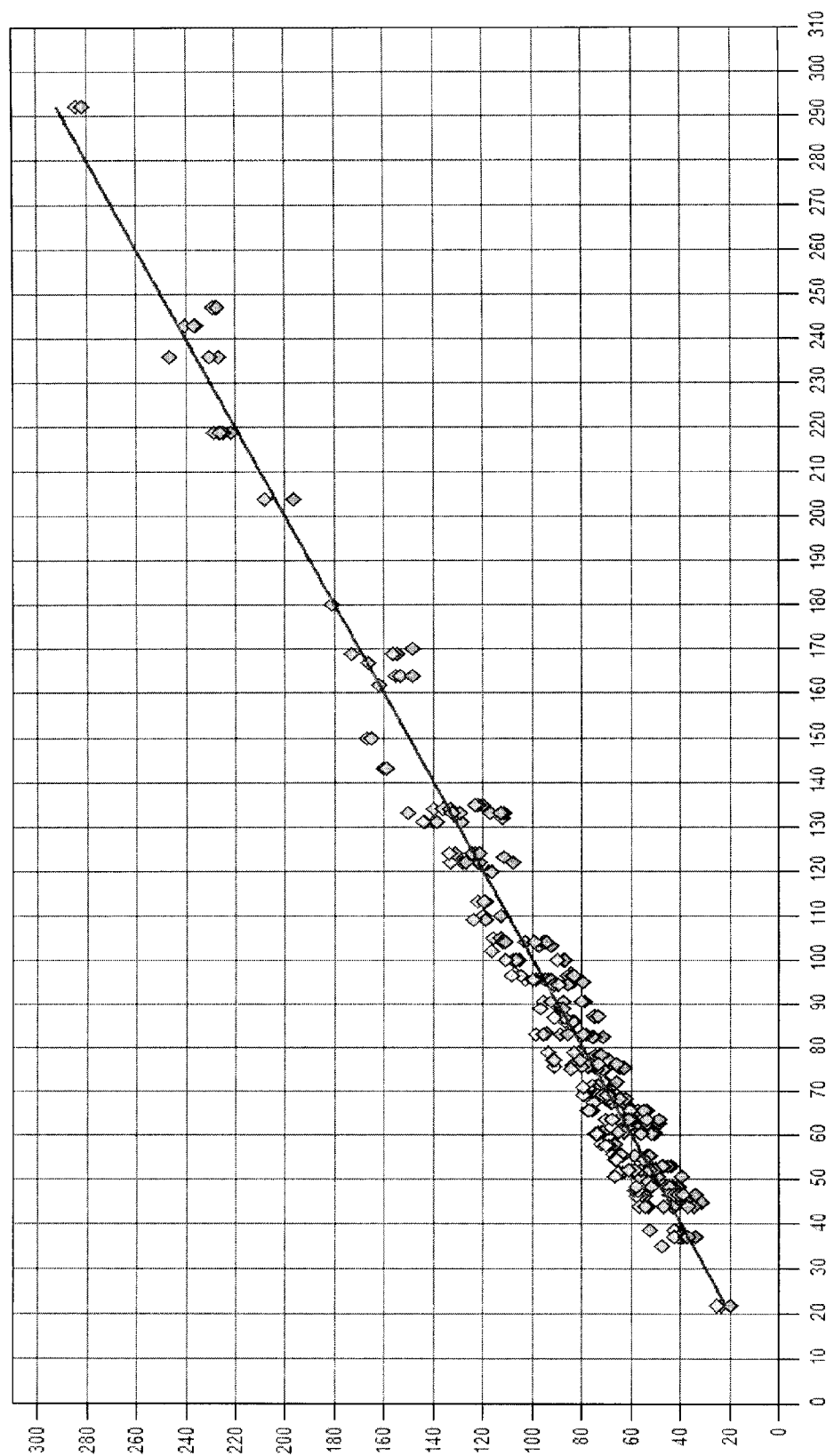
Prediction vs True / H₂O [%] / Cross Validation



Rank: 6 $R^2 = 96.91$ RMSECV = 0.516 Bias: 0.0109 RPD: 5.69
Validation No: 6 + Ore-Albedo-H₂O.q2

Chloride (mg/L) - Fig. 4d

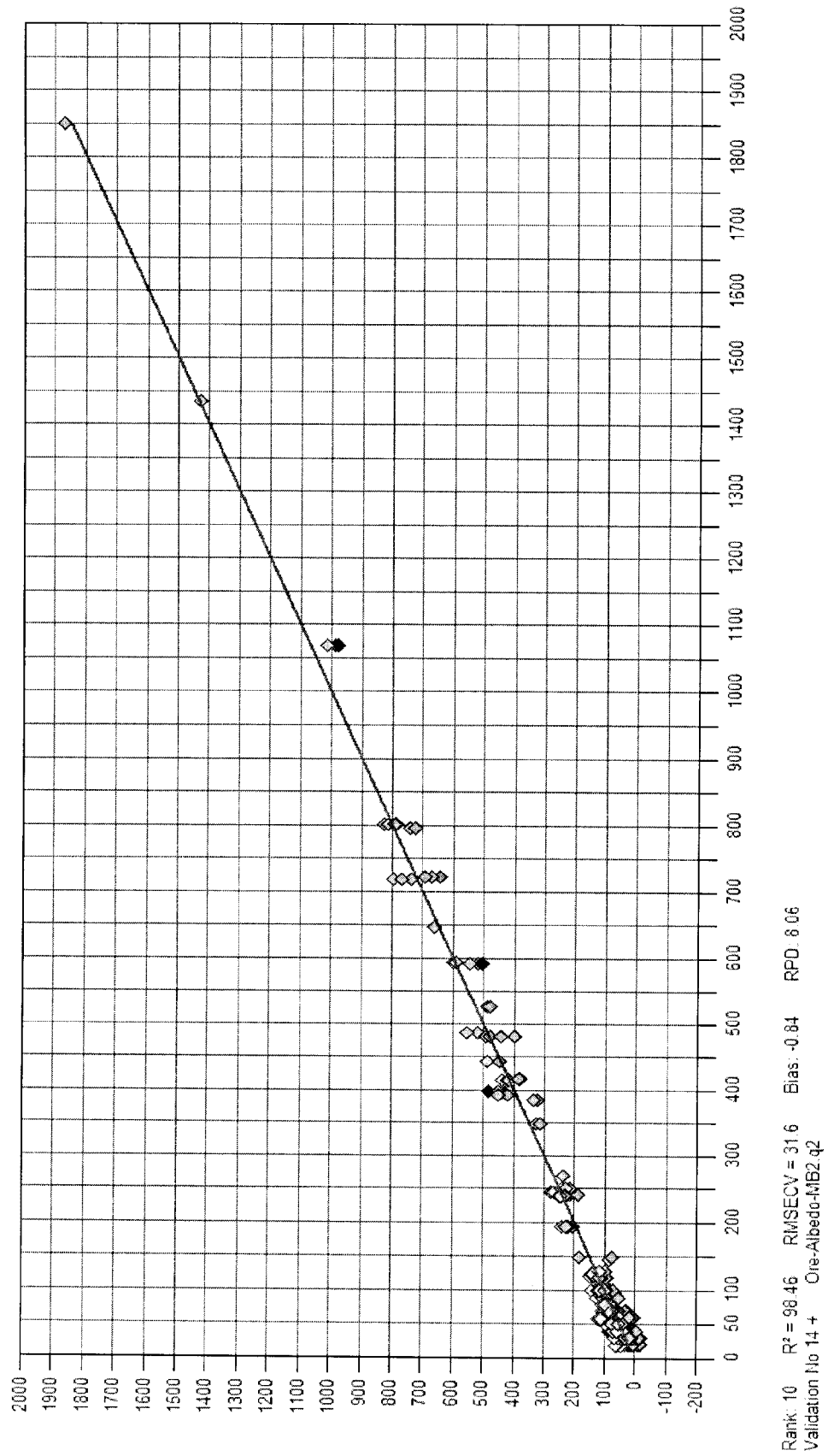
Prediction vs True / CL / Cross Validation



Rank: 10 $R^2 = 96.71$ RMSECV = 8.66 Bias: -0.222 RPD: 5.52
Validation No 9 + Ore-Albedo-CL.q2

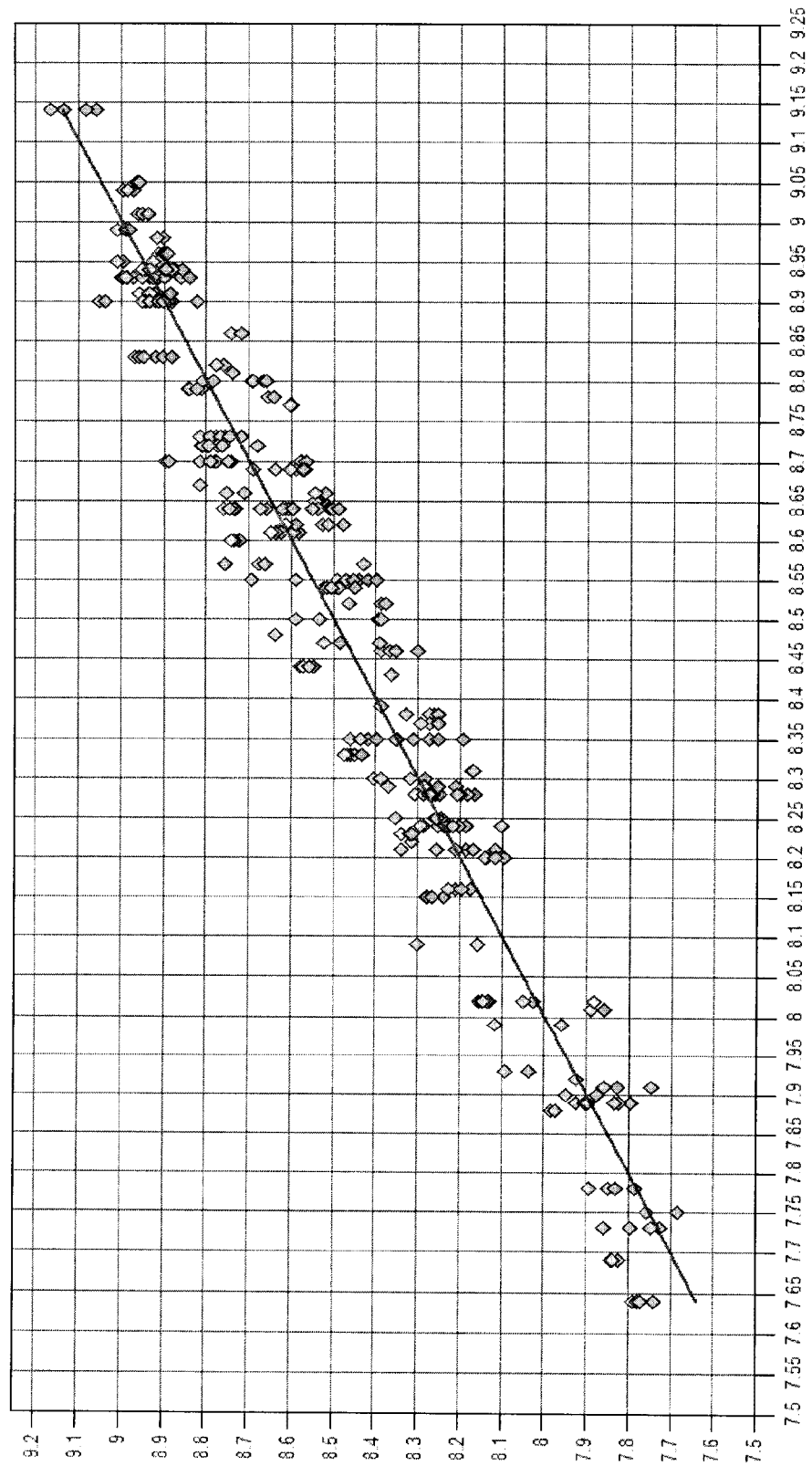
MB (ml/100g) - Fig. 4e

Prediction vs True / MB [ml/100g] / Cross Validation



pH - Fig. 4f

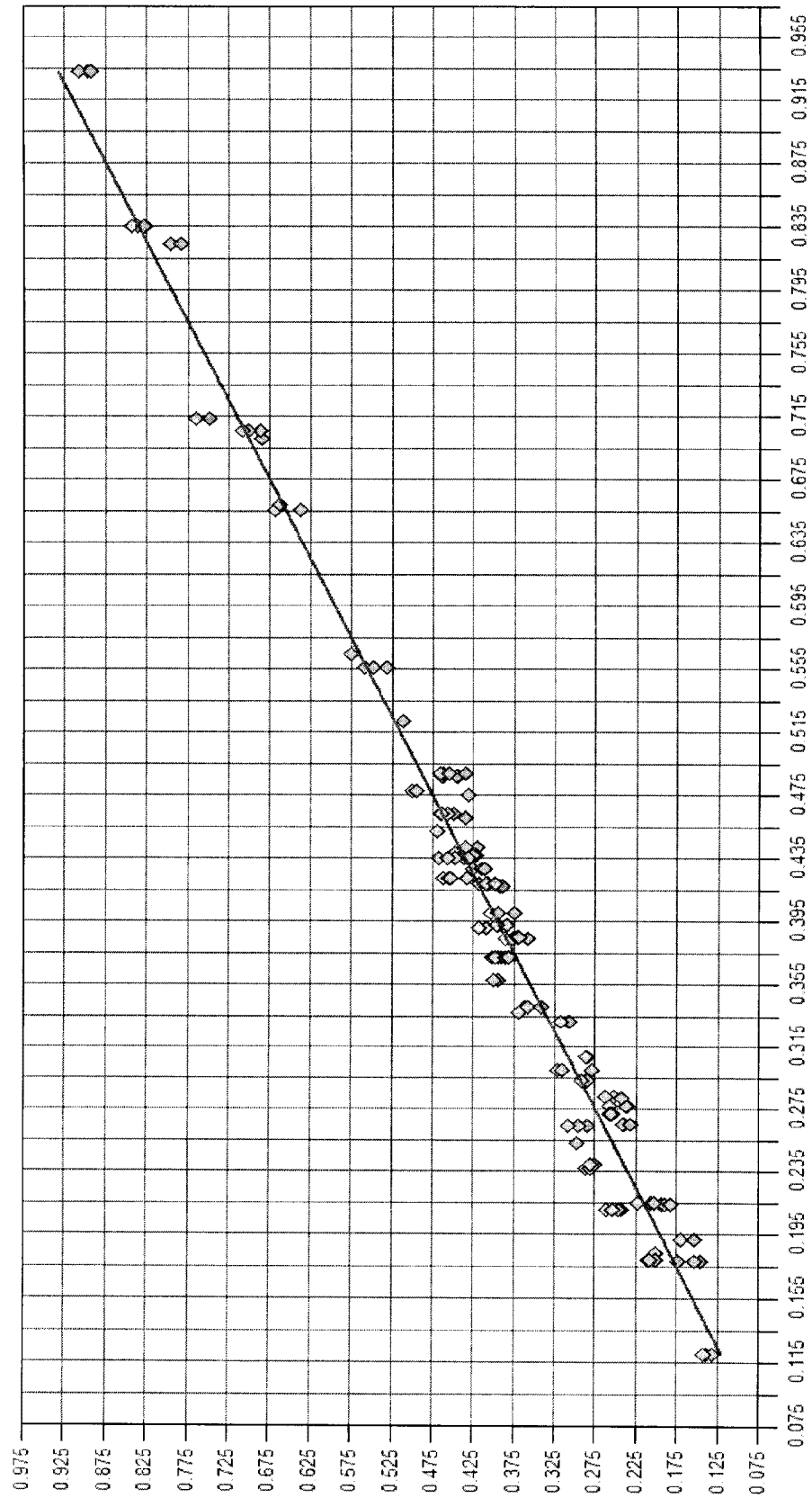
Prediction vs True / pH / Cross Validation



Rank: 10 $R^2 = 94.24$ RMSECV = 0.0875 Bias: -6.66E-005 RPD 4.17
Validation No 9 + Ore-Albedo-pH.q2

Ca++ (mg/L) Fig. 4g

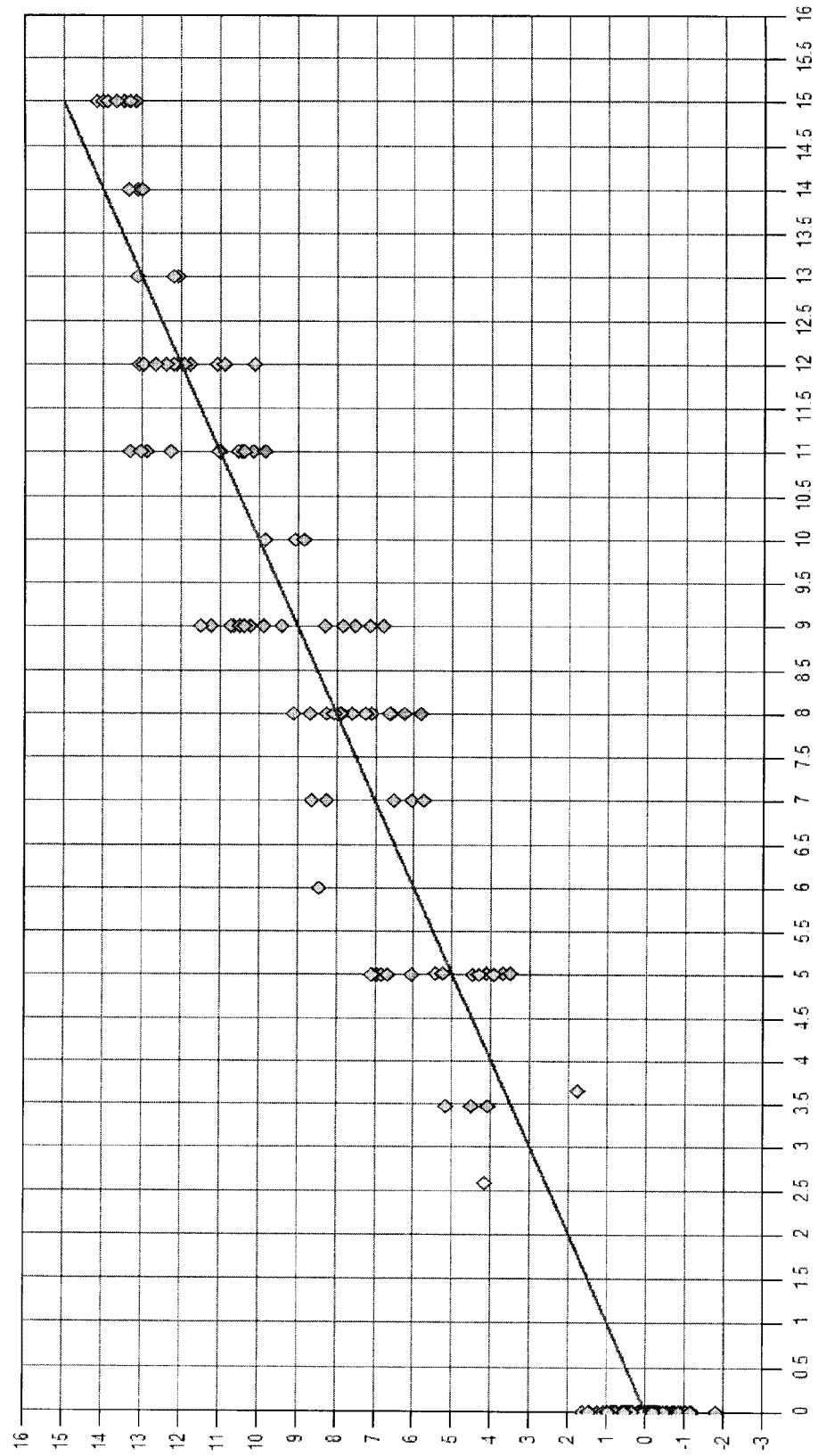
Prediction vs True / Ca / Cross Validation



Rank: 9 $R^2 = 97.96$ RMSECV = 0.0251 Bias: 0.00203 RPD: 7.03
Validation No 14 + Ore-Albedo-Ca q2

CO3-- (mg/L) Fig. 4h

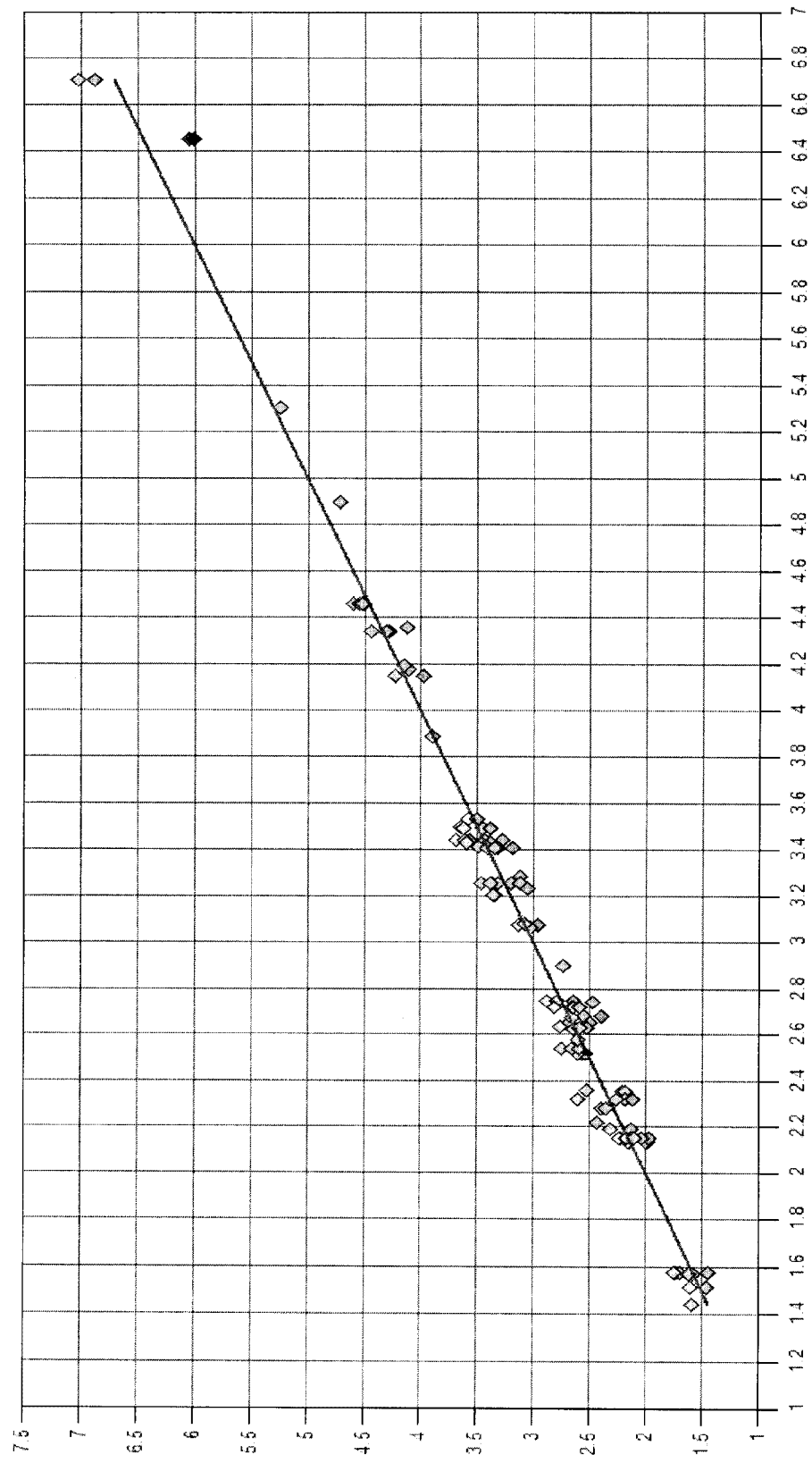
Prediction vs True / CO3 / Cross Validation



Rank: 9 R² = 96.29 RMSECV = 1 Bias: -0.00405 RPD: 5.19
Validation No: 10 + Ore-Albedo-CO3 q2

K⁺, (mg/L) Fig. 4i

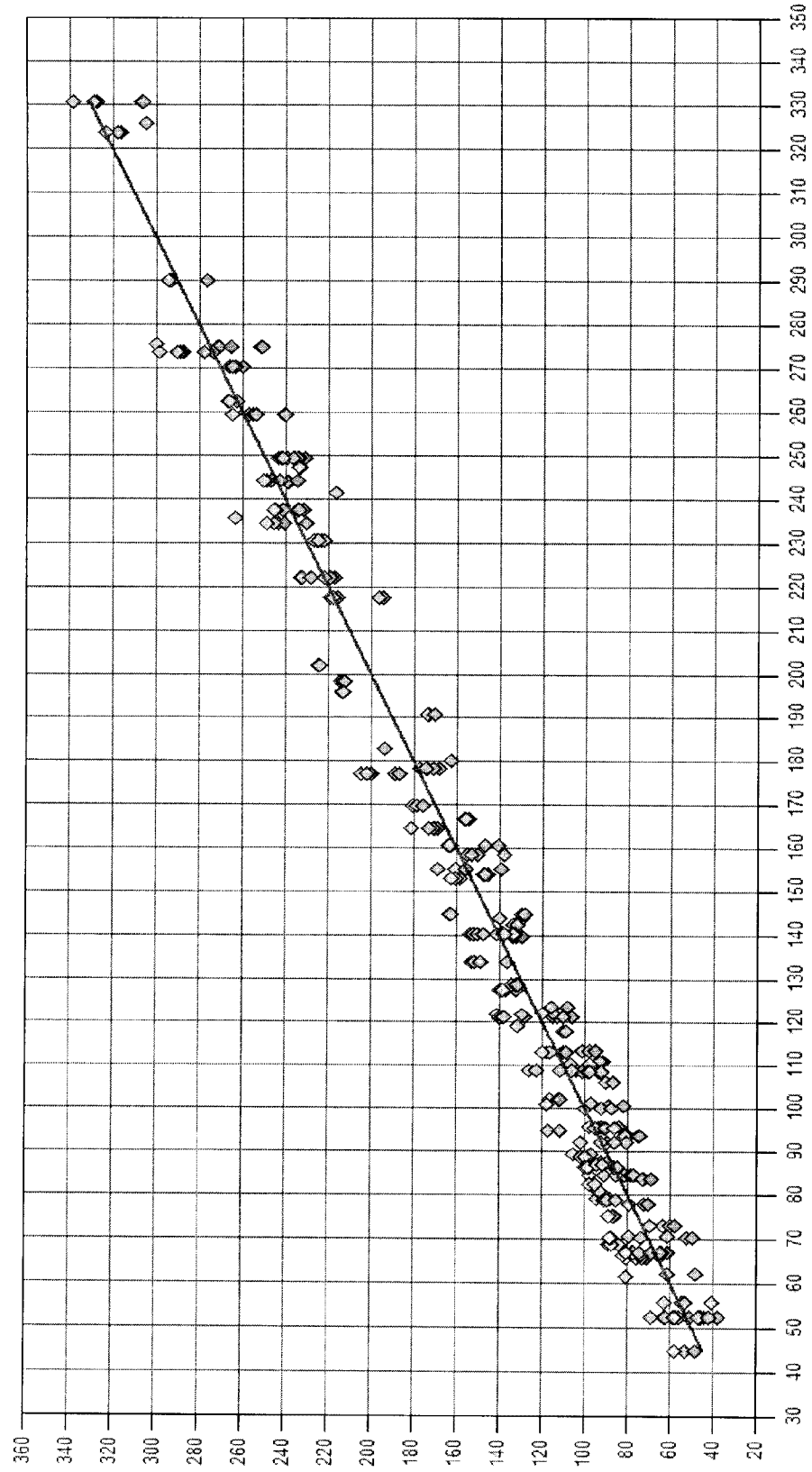
Prediction vs True / K / Cross Validation



Rank: 10 R² = 98.29 RMSECV = 0.138 Bias: -0.000902 RPD: 7.65
Validation No 24 + One-Albedo-K.q2

Na+ (mg/L) Fig. 4j

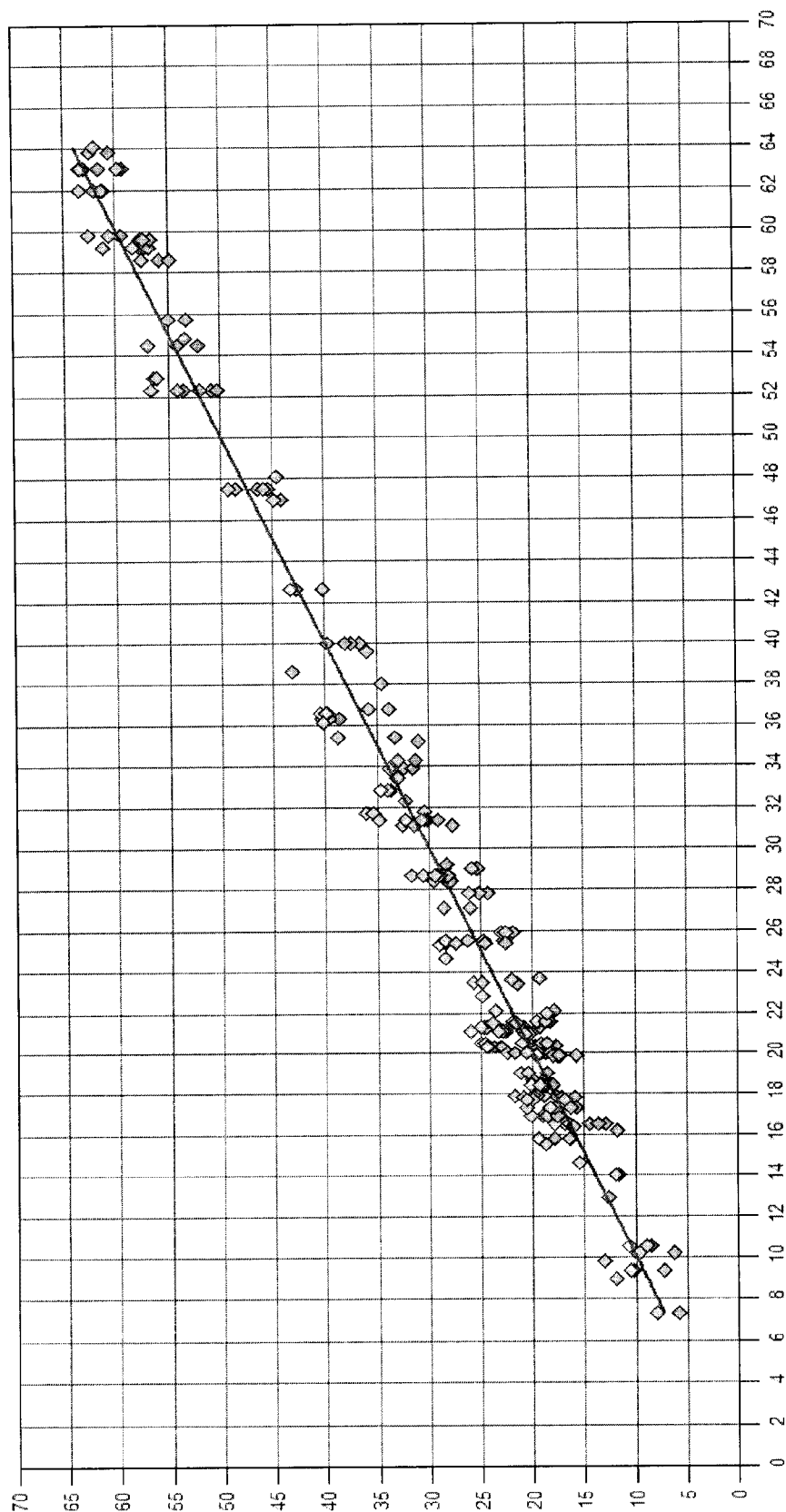
Prediction vs True / Na / Cross Validation



Rank 4 $R^2 = 97.44$ RMSECV = 11.7 Bias: 0.0306 RPD: 6.25
Validation No 12 + Ore-Albedo-Na q2

SO4-- (mg/L) Fig. 4k

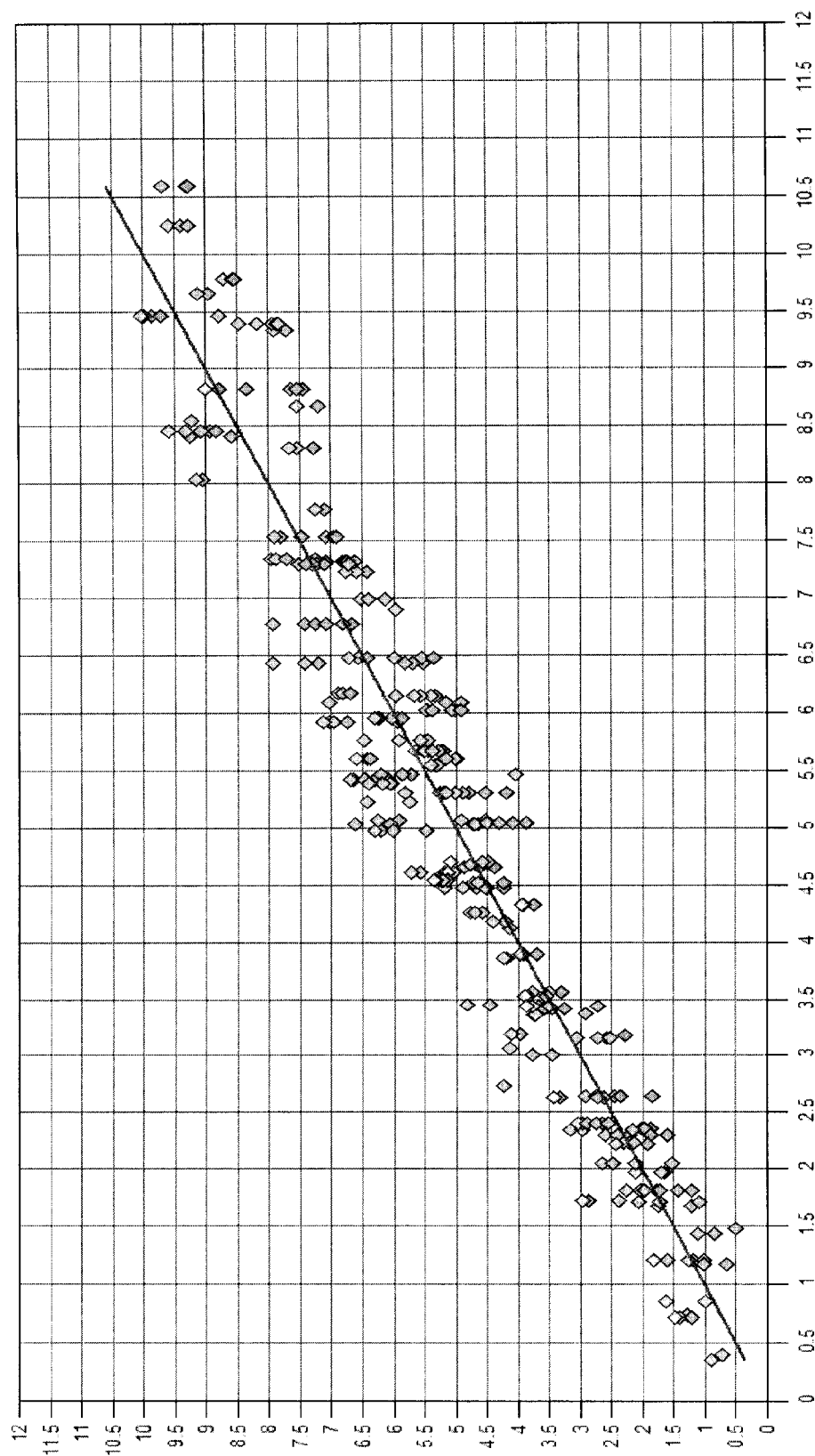
Prediction vs True / SO4 / Cross Validation



Rank: 9 R² = 97.77 RMSECV = 2.28 Bias: 0.0319 RPD: 6.69
Validation No 8 + Ore-Albedo-SO4.q2

PSD<45um, (%) Fig. 4I

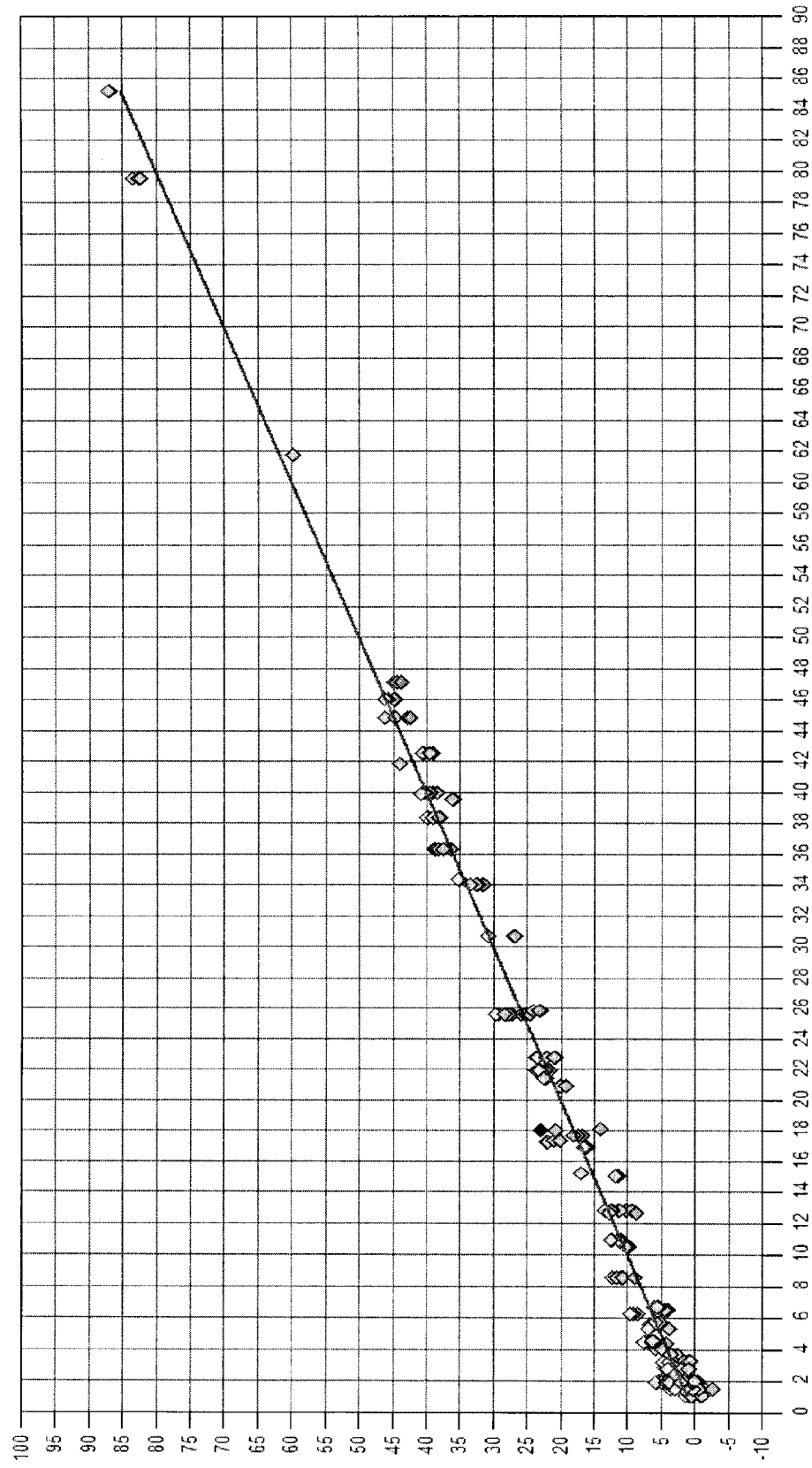
Prediction vs True / 45um [%] / Cross Validation



Rank: 10 $R^2 = 91.99$ RMSECV = 0.671 Bias: -0.0172 RPD: 3.53
Validation No 12 + Ore-Albedo-45um.q2

Clay, (%) Fig. 4m

Prediction vs True / Clay [%] / Cross Validation



Rank: 10 $R^2 = 98.86$ RMSECV = 1.9 Bias: -0.0343 RPD: 9.35
Validation No 12 + Ore-Albedo-Clay.q2

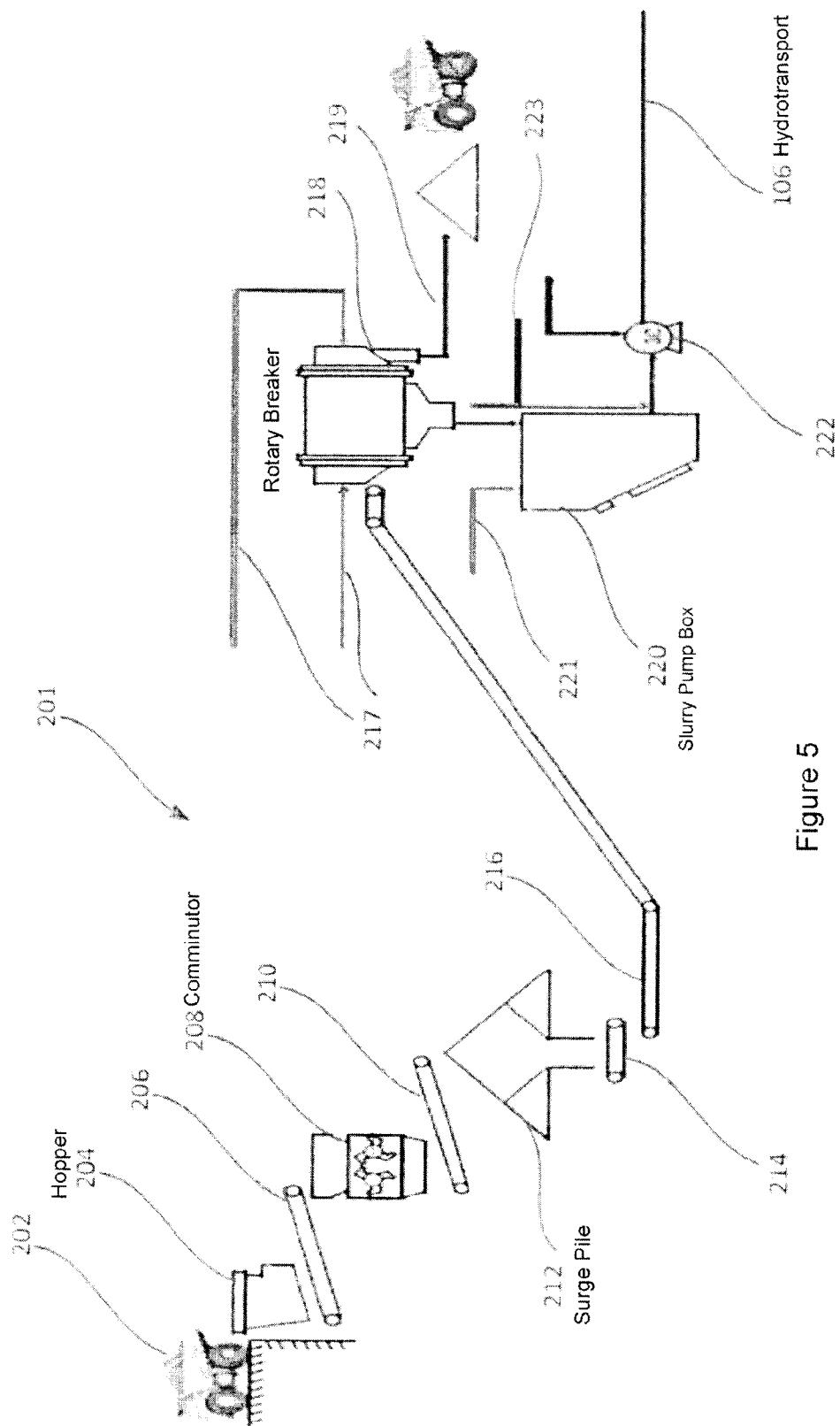


Figure 5

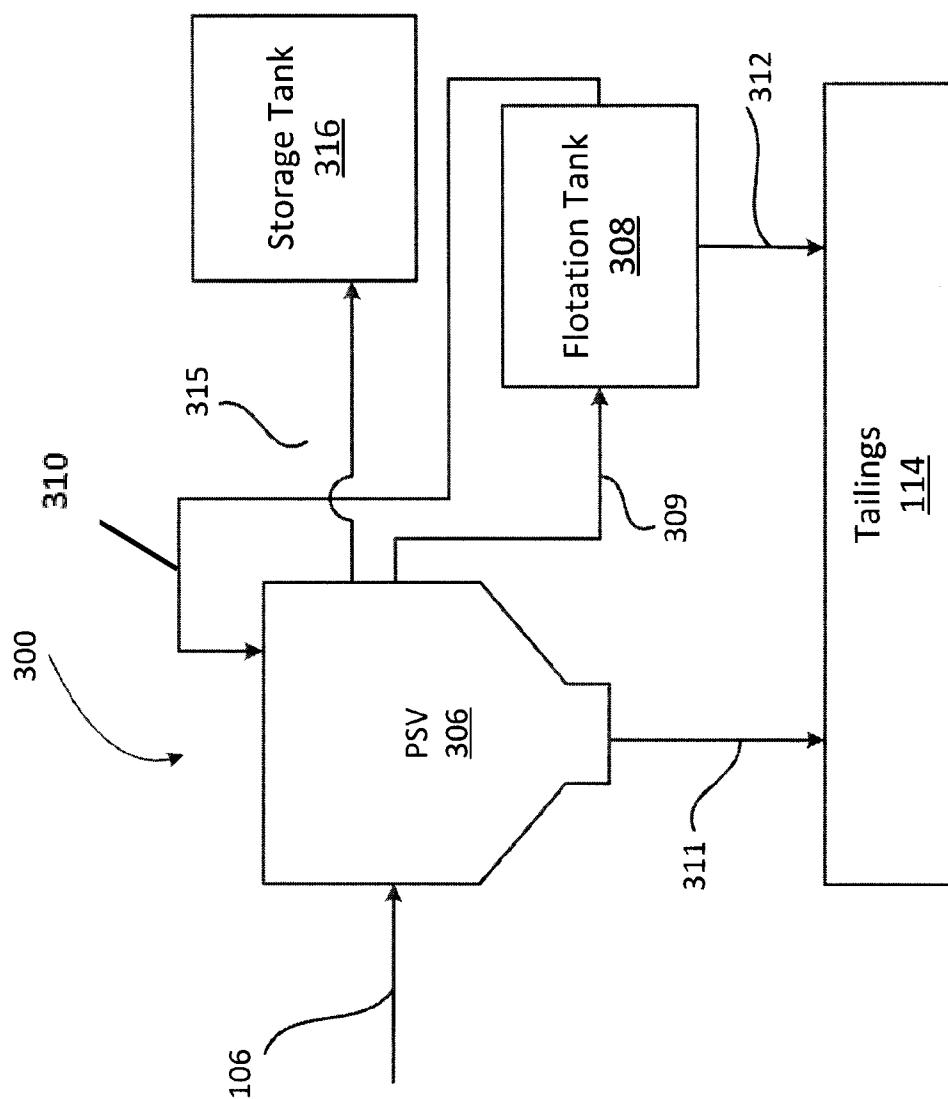


Figure 6

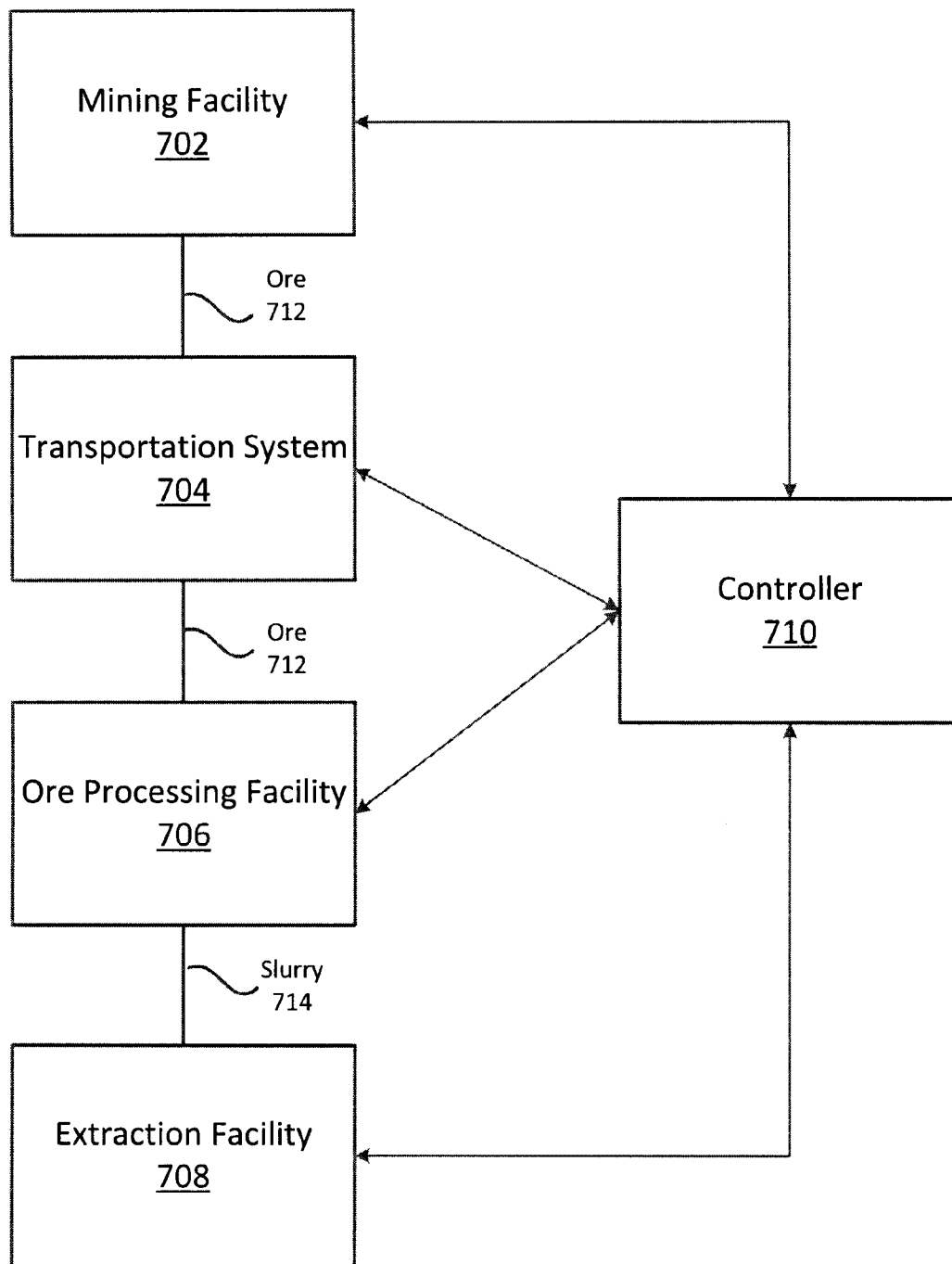


Figure 7

