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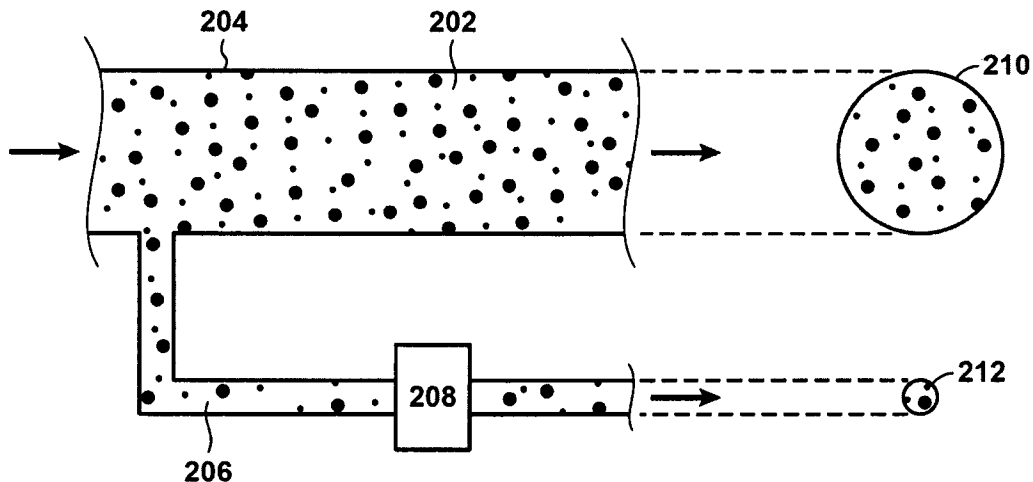
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(54) Titre : PROCÉDE DE MESURE D'UNE BOUE A L'AIDE D'UN ECHANTILLON NON REPRESENTATIF

(54) Title: METHOD OF MEASURING A SLURRY USING A NON-REPRESENTATIVE SAMPLE



(57) Abrégé/Abstract:

Disclosed is a method comprising: (a) providing a slurry comprising a fluid and solids; (b) removing a slip stream from the slurry, wherein the slip stream is a non-representative sample; (c) measuring, directly or indirectly, a fluid flow rate in the slip stream; (d) measuring, directly or indirectly, a fluid flow rate in the slurry; (e) measuring, directly or indirectly, a flow rate of a particle of interest in the slip stream; and (f) converting, using (c), (d) and (e), the flow rate of the particle of interest in the slip stream to a flow rate of a particle of interest in the slurry.

ABSTRACT

Disclosed is a method comprising:

- (a) providing a slurry comprising a fluid and solids;
- (b) removing a slip stream from the slurry, wherein the slip stream is a non-representative sample;
- (c) measuring, directly or indirectly, a fluid flow rate in the slip stream;
- (d) measuring, directly or indirectly, a fluid flow rate in the slurry;
- (e) measuring, directly or indirectly, a flow rate of a particle of interest in the slip stream; and
- (f) converting, using (c), (d) and (e), the flow rate of the particle of interest in the slip stream to a flow rate of a particle of interest in the slurry.

METHOD OF MEASURING A SLURRY USING A NON-REPRESENTATIVE SAMPLE

BACKGROUND

Field of Disclosure

[0001] The disclosure relates generally to the field of measurement of slurries, for instance measurement of oil sand slurries.

Description of Related Art

[0002] This section is intended to introduce various aspects of the art, which may be associated with the present disclosure. This discussion is believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present disclosure. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of prior art.

[0003] Measurement of slurries, such as mining slurries including oil sand slurries is often desired. Additional background on oil sand processes will now be provided.

[0004] Modern society is greatly dependent on the use of hydrocarbon resources for fuels and chemical feedstocks. Hydrocarbons are generally found in subsurface formations that can be termed “reservoirs”. Removing hydrocarbons from the reservoirs depends on numerous physical properties of the subsurface formations, such as the permeability of the rock containing the hydrocarbons, the ability of the hydrocarbons to flow through the subsurface formations, and the proportion of hydrocarbons present, among other things. Easily harvested sources of hydrocarbons are dwindling, leaving less accessible sources to satisfy future energy needs. As the costs of hydrocarbons increase, the less accessible sources become more economically attractive.

[0005] Recently, the harvesting of oil sand to remove heavy oil has become more economical. Hydrocarbon removal from oil sand may be performed by several techniques. For example, a well can be drilled to an oil sand reservoir and steam, hot air, solvents, or a

combination thereof, can be injected to release the hydrocarbons. The released hydrocarbons may be collected by wells and brought to the surface. In another technique, strip or surface mining may be performed to access the oil sand, which can be treated with water, steam or solvents to extract the heavy oil.

[0006] Oil sand extraction processes are used to liberate and separate bitumen from oil sand so that the bitumen can be further processed to produce synthetic crude oil or mixed with diluent to form “dilbit” and be transported to a refinery plant. Numerous oil sand extraction processes have been developed and commercialized, many of which involve the use of water as a processing medium. Where the oil sand is treated with water, the technique may be referred to as water-based extraction (WBE). WBE is a commonly used process to extract bitumen from mined oil sand. Other processes are non-aqueous solvent-based processes. An example of a solvent-based process is described in Canadian Patent Application No. 2,724,806 (Adeyinka *et al*, published June 30, 2011 and entitled “Process and Systems for Solvent Extraction of Bitumen from Oil Sands”). Solvent may be used in both aqueous and non-aqueous processes.

[0007] One WBE process is the Clark hot water extraction process (the “Clark Process”). This process typically requires that mined oil sand be conditioned for extraction by being crushed to a desired lump size and then combined with hot water and perhaps other agents to form a conditioned slurry of water and crushed oil sand. In the Clark Process, an amount of sodium hydroxide (caustic) may be added to the slurry to increase the slurry pH, which enhances the liberation and separation of bitumen from the oil sand. Other WBE processes may use other temperatures and may include other conditioning agents, which are added to the oil sand slurry, or may operate without conditioning agents. This slurry is first processed in a Primary Separation Cell (PSC), also known as a Primary Separation Vessel (PSV), to extract the bitumen from the slurry.

[0008] In one bitumen extraction process, a water and oil sand slurry is separated into three major streams in the PSC: bitumen froth, middlings, and a PSC underflow.

[0009] Regardless of the type of WBE process employed, the process will typically result in the production of a bitumen froth that requires treatment with a solvent. For example, in the Clark Process, a bitumen froth stream comprises bitumen, solids, and water. Certain

processes use naphtha to dilute bitumen froth before separating the product bitumen by centrifugation. These processes are called Naphtha Froth Treatment (NFT) processes. Other processes use a paraffinic solvent, and are called Paraffinic Froth Treatment (PFT) processes, to produce pipelineable bitumen with low levels of solids and water. In the PFT process, a paraffinic solvent (for example, a mixture of iso-pentane and n-pentane) is used to dilute the froth before separating the product, diluted bitumen, by gravity. A portion of the asphaltenes in the bitumen is also rejected by design in the PFT process and this rejection is used to achieve reduced solids and water levels. In both the NFT and the PFT processes, the diluted tailings (comprising water, solids and some hydrocarbon) are separated from the diluted product bitumen.

[0010] Solvent is typically recovered from the diluted product bitumen component before the bitumen is delivered to a refining facility for further processing.

[0011] The PFT process may comprise at least three units: Froth Separation Unit (FSU), Solvent Recovery Unit (SRU) and Tailings Solvent Recovery Unit (TSRU). Mixing of the solvent with the feed bitumen froth may be carried out counter-currently in two stages in separate froth separation units. The bitumen froth comprises bitumen, water, and solids. A typical composition of bitumen froth is about 60 wt. % bitumen, 30 wt. % water, and 10 wt. % solids. The paraffinic solvent is used to dilute the froth before separating the product bitumen by gravity. The foregoing is only an example of a PFT process and the values are provided by way of example only. An example of a PFT process is described in Canadian Patent No. 2,587,166 to Sury.

[0012] From the PSC, the middlings, comprising bitumen and about 10-30 wt. % solids, or about 20-25 wt. % solids, based on the total wt. % of the middlings, is withdrawn and sent to the flotation cells to further recover bitumen. The middlings are processed by bubbling air through the slurry and creating a bitumen froth, which is recycled back to the PSC. Flotation tailings (FT) from the flotation cells, comprising mostly solids and water, are sent for further treatment or disposed in an External Tailings Area (ETA).

[0013] In ETA tailings ponds, a liquid suspension of oil sand fines in water with a solids content greater than 2 wt. %, but less than the solids content corresponding to the Liquid Limit

are called Fluid Fine Tailings (FFT). FFT settle over time to produce Mature Fine Tailings (MFT), having above about 30 wt. % solids.

[0014] As described above, measurement of slurries, such as mining slurries including oil sand slurries is often desired. Such measurements may be used for myriad purposes including process control. For instance, solid-liquid separation of slurries is often desired. Successful solid-liquid separation depends heavily on the slurry feed to the solid-separation process. One or more additives are typically used to achieve physiochemical change in the slurry such as flocculation, agglomeration, or aggregation, to facilitate solid-liquid separation. One factor of interest is the amount of additive(s) that is required to achieve good process performance for a specific slurry feed. Additive dosage is typically determined offline and applied to a consistent slurry feed. However, when slurry feeds change quickly and frequently, such an approach may no longer be effective or practical. Measurement of slurries may also be useful to obtain fines flow distribution in a unit or area of a plant, or to obtain a plant-wide fines balance, for instance to control an oil sand mining operation or tailings deposition management.

SUMMARY

[0015] It is an object of the present disclosure to provide a method of measuring a slurry, for instance an oil sand slurry.

[0016] Disclosed is a method comprising:

- (a) providing a slurry comprising a fluid and solids;
- (b) removing a slip stream from the slurry, wherein the slip stream is a non-representative sample;
- (c) measuring, directly or indirectly, a fluid flow rate in the slip stream;
- (d) measuring, directly or indirectly, a fluid flow rate in the slurry;
- (e) measuring, directly or indirectly, a flow rate of a particle of interest in the slip stream; and
- (f) converting, using (c), (d) and (e), the flow rate of the particle of interest in the slip stream to a flow rate of a particle of interest in the slurry.

[0017] The foregoing has broadly outlined the features of the present disclosure so that the detailed description that follows may be better understood. Additional features will also be described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] These and other features, aspects and advantages of the disclosure will become apparent from the following description, appending claims and the accompanying drawings, which are briefly described below.

[0019] Fig. 1 is a diagram showing particle distribution in a slurry stream with a slipstream having an analyzer, the slipstream being representative of the slurry stream (prior art).

[0020] Fig. 2 is a diagram showing particle distribution in a slurry stream with a slipstream having an analyzer, is the slipstream being non-representative of the slurry stream.

[0021] It should be noted that the figures are merely examples and no limitations on the scope of the present disclosure are intended thereby. Further, the figures are generally not drawn to scale, but are drafted for purposes of convenience and clarity in illustrating various aspects of the disclosure.

DETAILED DESCRIPTION

[0022] For the purpose of promoting an understanding of the principles of the disclosure, reference will now be made to the features illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the disclosure is thereby intended. Any alterations and further modifications, and any further applications of the principles of the disclosure as described herein are contemplated as would normally occur to one skilled in the art to which the disclosure relates. It will be apparent to those skilled in the relevant art that some features that are not relevant to the present disclosure may not be shown in the drawings for the sake of clarity.

[0023] At the outset, for ease of reference, certain terms used in this application and their meaning as used in this context are set forth below. To the extent a term used herein is not defined below, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Further, the present processes are not limited by the usage of the terms shown below, as all equivalents, synonyms, new developments and terms or processes that serve the same or a similar purpose are considered to be within the scope of the present disclosure.

[0024] Throughout this disclosure, where a range is used, any number between or inclusive of the range is implied.

[0025] A "hydrocarbon" is an organic compound that primarily includes the elements of hydrogen and carbon, although nitrogen, sulfur, oxygen, metals, or any number of other elements may be present in small amounts. Hydrocarbons generally refer to components found in heavy oil or in oil sand. However, the techniques described are not limited to heavy oils but may also be used with any number of other reservoirs to improve gravity drainage of liquids. Hydrocarbon compounds may be aliphatic or aromatic, and may be straight chained, branched, or partially or fully cyclic.

[0026] "Bitumen" is a naturally occurring heavy oil material. Generally, it is the hydrocarbon component found in oil sand. Bitumen can vary in composition depending upon the degree of loss of more volatile components. It can vary from a very viscous, tar-like, semi-solid material to solid forms. The hydrocarbon types found in bitumen can include aliphatics, aromatics, resins, and asphaltenes. A typical bitumen might be composed of:

19 weight (wt.) % aliphatics (which can range from 5 wt. % - 30 wt. %, or higher);
19 wt. % asphaltenes (which can range from 5 wt. % - 30 wt. %, or higher);
30 wt. % aromatics (which can range from 15 wt. % - 50 wt. %, or higher);
32 wt. % resins (which can range from 15 wt. % - 50 wt. %, or higher); and
some amount of sulfur (which can range in excess of 7 wt. %), the weight % based upon total weight of the bitumen.

In addition, bitumen can contain some water and nitrogen compounds ranging from less than 0.4 wt. % to in excess of 0.7 wt. %. The percentage of the hydrocarbon found in bitumen can vary.

The term “heavy oil” includes bitumen as well as lighter materials that may be found in a sand or carbonate reservoir.

[0027] “Heavy oil” includes oils which are classified by the American Petroleum Institute (“API”), as heavy oils, extra heavy oils, or bitumens. The term “heavy oil” includes bitumen. Heavy oil may have a viscosity of about 1,000 centipoise (cP) or more, 10,000 cP or more, 100,000 cP or more, or 1,000,000 cP or more. In general, a heavy oil has an API gravity between 22.3° API (density of 920 kilograms per meter cubed (kg/m^3) or 0.920 grams per centimeter cubed (g/cm^3)) and 10.0° API (density of 1,000 kg/m^3 or 1 g/cm^3). An extra heavy oil, in general, has an API gravity of less than 10.0° API (density greater than 1,000 kg/m^3 or 1 g/cm^3). For example, a source of heavy oil includes oil sand or bituminous sand, which is a combination of clay, sand, water and bitumen. The recovery of heavy oils is based on the viscosity decrease of fluids with increasing temperature or solvent concentration. Once the viscosity is reduced, the mobilization of fluid by steam, hot water flooding, or gravity is possible. The reduced viscosity makes the drainage or dissolution quicker and therefore directly contributes to the recovery rate.

[0028] The term “bituminous stream” refers to a stream derived from oil sand that requires downstream processing in order to realize valuable bitumen products or fractions. The bituminous stream is one that comprises bitumen along with undesirable components. Undesirable components may include but are not limited to clay, minerals, coal, debris and water. The bituminous stream may be derived directly from oil sand, and may be, for example, raw oil sand ore. Further, the bituminous stream may be a stream that has already realized some initial processing but nevertheless requires further processing. Also, recycled streams that comprise bitumen in combination with other components for removal as described herein can be included in the bituminous stream. A bituminous stream need not be derived directly from oil sand, but may arise from other processes. For example, a waste product from other extraction processes which comprises bitumen that would otherwise not have been recovered may be used as a bituminous stream.

[0029] The term “solvent” as used in the present disclosure should be understood to mean either a single solvent, or a combination of solvents.

[0030] The terms “approximately,” “about,” “substantially,” and similar terms are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. It should be understood by those of skill in the art who review this disclosure that these terms are intended to allow a description of certain features described and claimed without restricting the scope of these features to the precise numeral ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described and are considered to be within the scope of the disclosure.

[0031] The articles “the”, “a” and “an” are not necessarily limited to mean only one, but rather are inclusive and open ended so as to include, optionally, multiple such elements.

[0032] The term “paraffinic solvent” (also known as aliphatic) as used herein means solvents comprising normal paraffins, isoparaffins or blends thereof in amounts greater than 50 wt. %. Presence of other components such as olefins, aromatics or naphthenes may counteract the function of the paraffinic solvent and hence may be present in an amount of only 1 to 20 wt. % combined, for instance no more than 3 wt. %. The paraffinic solvent may be a C₄ to C₂₀ or C₄ to C₆ paraffinic hydrocarbon solvent or a combination of iso and normal components thereof. The paraffinic solvent may comprise pentane, iso-pentane, or a combination thereof. The paraffinic solvent may comprise about 60 wt. % pentane and about 40 wt. % iso-pentane, with none or less than 20 wt. % of the counteracting components referred above.

[0033] The term “fines” means mineral solids sized less than 44 microns.

[0034] The term “sand” means mineral solids sized greater than or equal to 44 microns.

[0035] The term “fines flow rate” means the flow rate of fines and may be on a volume or mass basis unless otherwise indicated.

[0036] The term “solid flow rate” means the flow rate of solids and may be on a volume or mass basis unless otherwise indicated.

[0037] The term “sand to fines ratio” or “SFR” means the mass ratio of sand to fines unless otherwise indicated.

[0038] The present inventors have found that it is possible to use a non-representative slipstream of the slurry to carry out certain valuable measurements and still obtain accurate an analysis of the slurry. This is accomplished using a using a “dispersed particle in fluid” approach. For the purpose of the analysis, the ratio of particles of interest (e.g. fine particles) to water is taken to be the same in a slipstream as in the slurry. Experimental data supporting this approach is provided below. The experimental results herein have led to the discovery that the fines concentration and fines-to-fluid ratio are relatively consistent over different mixing conditions and subsampling locations. This is true even when the sands content varies in the sample due to non-homogeneity of the sampling process. This makes the fines concentration and fines-to-fluid concentration robust characteristics (i.e., essentially constants) across the mixing conditions and subsampling locations. Accordingly, the present inventors have found that it is possible to use a non-representative slipstream of the slurry to carry out certain valuable measurements and still (with the knowledge of this constant relationship between the water and fines content even when a truly representative sample is not taken) to accurately predict the composition or certain parameters in the slurry stream wherein it was previously thought could only be achieved if the sample stream was an accurate representation of the slurry stream composition.

[0039] The present approach enables flexibility in sampling and analyzing systems and methods by being able to calculate slurry stream compositions without the need for ensuring that the analyzed sample is representative (i.e., has essentially the same composition) as the slurry stream. For example, this approach enables the use of online analyzers with simple, non-representative sampling systems. The sampling points may be at any position around a slurry-carrying pipe that contains slurry, after a pump, or in fully developed flow, and based on any suitable sampler design and line size, provided solids settling and plugging can be controlled, but with this new knowledge of utilizing a “dispersed particle in fluid” approach under the current discovery, full mixing and distribution of the slurry at the point of sampling (to ensure homogeneity of the sample) is not necessary as taught in the prior art. The resultant measurements may be used for myriad process controls, for instance feed-forward process setpoint tuning or feedback process control. Precise measurement of fines, clays and other slurry properties may enable improved control of many key process parameters such as

flocculent dosage, caustic dosage, throughput, etc. Sampling can be significant challenge on slurry streams. Well-designed sampling systems can be expensive and complex, and still may not capture fully representative samples. The present approach may enable accurate online slurry analysis and parameter optimization with relatively rudimentary sampling systems.

[0040] The approach may be used with any suitable slurry stream to measure the concentration of any class of particle which tends to remain well dispersed in the slurry. The approach may also be used with an online analyzer or ‘experiment’ to measure a property or optimum operating parameter that would be expected to follow the water or a dispersed class of particle. For example, the experiment could involve dosing an additive in different concentrations and monitoring the slurry response to determine the optimal dose of the additive for a desired processing outcome.

[0041] Fig. 1 is a diagram showing the particle distribution of a slurry stream (102) in a main pipeline (104) with a “representative” slipstream (106) removed from the main slurry line for analysis representative of the prior art. Here, the representative slipstream (106) is passed through analyzer (108) for analysis. The analyzer may be used to determine a mass flow rate, a particle flow rate, or a solids flow rate. As can be seen in the “representative” slipstream (106) in Fig. 1 in the prior art, in order to get a true analysis of the composition of the slurry stream, or certain key parameters thereof, care must be taken to ensure that the “representative” slipstream (106) has essentially the same composition and particle distribution as the slurry stream (102). This requires ensuring adequate mixing of the slurry stream and positioning of the slipstream sampling system to ensure the slipstream is representative of the slurry stream. Additionally, in the prior art, if the slipstream (106) is not representative of the slurry stream (102), the results will have an inherent error, or skew, leading to improper slurry stream compositional inference. This is further illustrated by comparing the exploded view (110) of the slurry stream (102) and the exploded view (112) of the “representative” slipstream (106), where, in the prior art, the composition/distribution in both slurry stream (102) and the “representative” slipstream (106) must be essentially the same for proper operation.

[0042] Fig. 2 is a diagram showing the particle distribution of a slurry stream (202) in a main pipeline (204) with a “non-representative” slipstream (206) removed from the main

slurry line for analysis representative per the present disclosure. Here, the non-representative slipstream (206) is passed through analyzer (208) for analysis. The analyzer may be used to determine a mass flow rate, a particle flow rate, or a solids flow rate. As can be seen in the “non-representative” slipstream (206) in Fig. 2, in order to get a true analysis of the composition of the slurry stream, or certain key parameters thereof, it is not necessary to ensure that the “non-representative” slipstream (206) has essentially the same composition and particle distribution as the slurry stream (202). Therefore, in the present embodiments, it is no longer necessary to provide adequate mixing of the slurry stream and positioning of the slipstream sampling system to ensure the slipstream is representative of the slurry stream. Additionally, errors in the data obtained from the analyzer (208) may be reduced since the present “dispersed particle in fluid” approach removes some of the uncertainty in the analyzer readings. This concept is further illustrated by comparing the exploded view (210) of the slurry stream (202) and the exploded view (212) of the “non-representative” slipstream (206), where, as can be seen, the present embodiments can utilize a “non-representative” slipstream (206) wherein it is not required that composition/distribution in both slurry stream (202) and the “representative” slipstream (206) be essentially the same for proper operation.

[0043] Optional density meters (not shown) may be used to measure the density of slurry stream (202) and the “non-representative” slipstream (206). While this is not required to obtain all key compositional/parameters values of the slurry stream (202) from the analysis of the “non-representative” slipstream (206), the density measurements may be required to determine some of the key compositional/parameters values of the slurry stream (202) based on the analysis of the “non-representative” slipstream (206).

[0044] Various slurries could be analyzed, for instance hydrotransport slurries; primary separation vessel slurries; middlings; extraction tailings such as coarse sand tailings (CST), flotation tailings (FT), froth treatment tailings; pond tailings such as fluid fine tailings (FFT) and mature fine tailings (MFT); tailings treatment streams such as thickener feeds, thickener overflow (O/F), thickener underflow (U/F), cyclone overflow (O/F), centrifuge inlet and outlet streams, and flocculant mixer inlet and outlet streams.

[0045] Various dispersed particles could be measured, for instance fines less than 44 microns, fines less than 2 microns, clays, and dispersed bitumen.

[0046] Examples of methods of analysis include laser diffraction, ultrasonic, image analysis, turbidity, K40 analysis, laser induced breakdown spectroscopy (LIBS), near infrared (NIR), prompt gamma neutron activation analysis (PGNAA). For analyzing dispersed bitumen, a tailings oil analyzer or NIR may be used.

[0047] Examples of slurry properties or optimum operating parameters may include optimum flocculent dosage, carrier fluid viscosity, optimum caustic or other process additive dosage, and predicted primary separation cell (PSC) separation performance.

[0048] A “representative sample” is a sample where the fluid and solids profile is substantially the same as the fluid and solids profile of the slurry from which the sample is obtained. In conventional methods, a representative sample is obtained and analyzed to provide an analysis of the slurry.

[0049] A “non-representative sample” is a sample where the fluid and solids profile differs substantially from the fluid and solids profile of the slurry from which the sample is obtained. A sample is considered “non-representative” when it would not be deemed as an appropriate representation of the slurry profile for use in conventional methods.

[0050] A method may comprise:

- (a) providing a slurry comprising a fluid and solids;
- (b) removing a slip stream from the slurry, wherein the slip stream is a non-representative sample;
- (c) measuring, directly or indirectly, a fluid flow rate in the slip stream;
- (d) measuring, directly or indirectly, a fluid flow rate in the slurry;
- (e) measuring, directly or indirectly, a flow rate of a particle of interest in the slip stream; and
- (f) converting, using (c), (d) and (e), the flow rate of the particle of interest in the slip stream to a flow rate of a particle of interest in the slurry.

[0051] The slurry is a flowable mixture of fluid and solids. The slurry may be any suitable slurry where a non-representative sample may be used to measure desired properties of the slurry using the approach described herein. The slurry may be an oil sand stream intended as a feed stream to a solid-liquid separation process, tailings treatment process, bitumen extraction process, or bitumen recovery process. The oil sand stream may be an oil sand tailings stream. The oil sand tailings stream may stem from an aqueous based extraction process. The oil sand tailings stream may stem from a solvent-based extraction process. The oil sand tailings stream may comprise coarse tailings, middlings, flotation tailings, froth separation tailings, tailings solvent recovery unit (TSRU) tailings, fluid fine tailings (FFT), mature fine tailings (MFT), thickened tailings, thickener overflow, centrifuged tailings, hydrocycloned tailings, or a combination thereof. The oil sand tailings stream may comprise a feed stream to a thickener, a thickener overflow, or a thickener underflow. The oil sand tailings stream may comprise a feed stream to a centrifuge, filter, or inline mixer. The slurry may comprise a mining slurry, for instance a hydrotransport slurry. The slurry may comprise a thickener underflow. The slurry may comprise a drilling mud or waste stream from a drilling operation.

[0052] An example of a solid-liquid separation process in the oil sands field involves introducing an oil sand tailings stream, which in this example is a feed stream to a thickener (or “thickener feedstream”), into a thickener along with a flocculant and/or a coagulant to facilitate solid-liquid separation and thus water recovery and tailing disposal. Flocculant dosage may be adjusted to improve flocculation for a given thickener feedstream. When the thickener feedstream being introduced into the thickener is highly variable, flocculant dose adjustment in real-time based on changing slurry feed to improve flocculation is important to thickener operation and performance. Floc formation can be affected by multiple factors, such as thickener feedstream composition, water chemistry, flocculant quality, and impurity content. For example, a floc size that is too small may lead to a lower settling rate, higher fines loss, thickener bed expansion, or flooding. A floc size that is too large (and therefore too heavy), may lead to higher bed rheology, poor dewatering, thickener rake operation difficulty, or rat-holing. Sub-optimal or poor additive dosage may lead to sub-optimal or poor thickener performance or a reduction in thickener availability, which may lead to lower fines recovery efficiency, a more challenging deposition operation, or decreased process water availability.

[0053] Another suitable solid-liquid separation process is the re-flocculation of a thickener underflow (i.e. a slurry). In this process, a flocculant is added to the sheared underflow from a thickener such as described in the preceding paragraph. In this way, a second flocculation occurs to repair broken or partial flocs due to shearing before discharging to facilitate solid-liquid separation of the thickener underflow in a deposition area.

[0054] Some processes have lower feed variability, for instance because their tailings are conditioned with hydrocyclones or are processing mature fine tailings (MFT, which have matured to a narrow compositional range in a tailings pond. The additive dosage adjustment described herein may nonetheless be useful in such processes. In particular, despite lower feed variability or narrower fines content variation, the additive dosage also depends on other variability, such as clay mineralogy, water chemistry, feed rheology, etc. Proper and timely dosage adjustment to account for process variability for desired process performances is useful.

[0055] The solid liquid separation may involve re-flocculation of shared thickened tailings, inline flocculation of MFT, or MFT centrifuging. In solvent-based extraction and agglomeration of oil sands, the subject additive may be the bridging liquid used.

[0056] The fluid is the non-solid portion of the slurry. The fluid may be water, or water and bitumen. Water and bitumen have the same density and therefore can be viewed together as a fluid for the purposes of the fluid and solid analysis. The solids may comprise particles of various sizes and may comprise sand and fines. "Flow rate" as used herein may be on a volume or mass basis unless otherwise indicated.

[0057] The "particle of interest" may be, for instance, fines (i.e. mineral solids sized less than 44 microns), clay (i.e. mineral solids sized less than 2 microns), or any other suitable category of solids. The particle of interest should be a particle that is readily suspended in a stirred fluid.

[0058] Step (e) may comprises:

- (e1) measuring, directly or indirectly, a solid flow rate in the slip stream; and
- (e2) measuring, directly or indirectly, a concentration, or a concentration parameter, of the particle of interest on a dry solid basis in the slip stream.

[0059] Step (f) may comprise converting, using (c), (d), (e1), and (e2), the measured concentration, or the measured concentration parameter, of the particle of interest on a dry solid basis in the slip stream to a flow rate of the particle of interest on a dry solid basis in the slurry.

[0060] The method may further comprise measuring, directly or indirectly, a solid flow rate of the slurry stream.

[0061] The method may further comprise calculating a concentration of the particle of interest on dry solid basis using the measured solid flow rate of the slurry stream and the flow rate of the particle of interest in the slurry.

[0062] Where the concentration, the concentration parameter, or the flow rate of the particle of interest on the dry solid basis in the slurry falls outside of an operation window of a solid-liquid separation process, the method may comprise bypassing a solids-liquid separation process and passing the slurry to a designated area as an untreated slurry. The operation window can be violated or exceeded by either SFR or flow rate of the particle of interest. If only the SFR is too large or too small, the fine stream or sandy stream may be cut back or added to bring the SFR back into range. If the flow rate of particle of interest is out of range, then the flow rate of slurry may be cut back.

[0063] Based on the concentration, the concentration parameter, or the flow rate of the particle of interest on the dry solid basis in the slurry, the method may comprise adjusting flocculent mixing in the slurry.

[0064] Based on the concentration, the concentration parameter, or the flow rate of the particle of interest on the dry solid basis in the slurry, the method may comprise adjusting a downstream solid-liquid separation process.

[0065] The method may further comprise

- (h) determining an additive dosage to the slip stream; and
- (i) converting, using (c) and (d), the determined additive dosage to a recommended additive dosage to the slurry.

[0066] The step of determining the recommended additive dosage to the slip stream may comprise measuring at least a portion of the slip stream at a plurality of additive dosage levels to obtain a characteristic indicative of a degree of flocculation, agglomeration, or aggregation for each of a plurality of additive dosage levels and using the following logic rules, wherein the plurality of additive dosage levels are termed (n-y), (n), and (n+z), characteristics are termed signal (n-y), signal (n), and signal (n+z), where y and z are predetermined incremental additive dosage levels, where y and z are the same or different:

[0067] - if signal (n-y) < signal (n) < signal (n+z), then signal for additive dosage (n+z) to the slip stream and increase dosage level in next slip stream dosing;

[0068] - if signal (n-y) < signal (n) = signal (n+z), then signal for additive dosage (n) to the slip stream; and

[0069] - if signal (n-y) = signal (n) = signal (n+z), then signal for additive dosage (n-y) to the slip stream and lower additive dosage level in next slip stream dosing.

[0070] The measurement of the slip stream may be performed by any suitable instrument or technique capable of obtaining the characteristic indicative of a degree of flocculation, agglomeration, or aggregation, with sufficient accuracy. The characteristic indicative of a degree of flocculation, agglomeration, or aggregation (also referred to herein simply as “characteristic”) may include a measure of flocculent, agglomerate, or aggregate size; a measure of flocculent, agglomerate, or aggregate settling rate; a measure of supernatant turbidity; a measure of flocculent, agglomerate, or aggregate compaction density; or a measure of flocculent, agglomerate, or aggregate filtration rate. The “characteristic” may be obtained by measuring particle size, for instance using particle size analyzers, for instance focused beam reflectance measurement (FBRM) probes or particle vision measurement (PVM) probes. Both FBRM and PVM probes may be inserted directly into the slip stream to measure the degree of flocculation, agglomeration, or aggregation. Bench testing has indicated that both FBRM and PVM probes are capable of determining underdose for flotation tailings and mature fine tailings flocculation. However, these probes cannot distinguish between an optimal state and an overdose state. The obtained characteristics may be used to determine a recommended additive dosage level of the slurry, as illustrated below. Additionally, the obtained characteristics may

be used with correlation reference data to determine a compositional parameter of the slurry. Examples of composition parameters are fines content and clay content. Where the determined compositional parameter falls outside of an operation window of the solid-liquid separation process, one may bypass the solids-liquid separation process and pass the slurry to a designated area as an untreated slurry. The method may further comprise, based on the recommended additive dosage to the slurry, adjusting the additive dosage to the slurry. The adjusting of the additive dosage may be performed in real time. The additive may comprise a flocculant, a coagulant, or an agglomerant. Canadian Patent No. 2,925,223 (Liu et al.) provides additional detail on an iterative approach to adjusting additive dosage.

[0071] Step (c) may comprises measuring a flow rate in the slip stream, measuring a density of the slip stream, and calculating the fluid flow rate in the slip stream from the measured density and known or estimated densities of the fluid and the solids. Theoretically, if such an analyzer were available, solid content could be measured directly as well. Therefore, if the mass flow rate measured from step (e) is known instead of the volumetric flow rate, solid content measurement from step (c), then a density measurement is not needed.

[0072] Step (d) may comprise measuring a flow rate in the slurry, measuring a density of the slurry, and calculating the fluid flow rate in the slurry from the measured density and known or estimated densities of the fluid and the solids.

[0073] The measurements of steps (c) and (d) may be performed by one or more online analyzers. The measurements of steps (c) and (d) are by volumetric flow meter or mass flow meter.

[0074] The method may further comprise floating off bitumen in the slip stream to reduce bitumen interference in slip stream measurement.

[0075] Density meter(s) may be used to measure density of the slurry or slip stream. Flow meter(s) may be used to measure and/or regulate the flow rate(s) of the slip stream(s) or portions thereof.

[0076] Various process adjustment may be made based on measured or calculated parameters. For instance, for solid-liquid separation processes, the following may be adjusted:

additive dosage level, flocculant dosage level, coagulant dosage level, agglomerant dosage level, or flocculant mixing. The adjustment may include combining the slurry with another stream in a proportion to satisfy operational specifications of the solid-liquid separation process. The adjustment may be of an operating parameter of a thickener in the solid-liquid separation process. For instance, the operating parameter of the thickener may include a bed height of the thickener, a feed rate to the thickener, an underflow rate from the thickener, a residence time in the thickener, a rake torque, or dilution water addition control to achieve a desired fines-in-fluid concentration range for a thickener operation. The adjustment may include adjusting an operating parameter downstream of a thickener in the solid-liquid separation process. For instance, the operating parameter downstream of the thickener may include dilution of a thickener underflow or additional additive addition to the thickener underflow.

[0077] Adjustments may be performed in real-time. “Real-time” as used herein may include some delays such as processing delays but is distinct from, for example, off line measurement, analysis, and adjustment.

[0078] Adjustment may also include:

- adjusting the rate at which one or more flocculant(s) are added to a thickener feed stream
- adjusting the rate at which one or more flocculant(s) are added to a thickener underflow stream during re-flocculation
- adjusting the rate at which other additives (e.g. coagulants) are added to a tailings treatment process
 - adjusting whether a tailings stream from an extraction plant (e.g. flotation tailings (FT) or froth treatment tailings (FTT) (e.g. TSRU tailings)) are fed to a tailings treatment process or are by-passed to a designated area
 - adjusting the rate at which Fluid Fine Tailings (FFT) are fed to a mixbox for mixing the slurry

- adjusting the rate at which an additional tailings stream, such as coarse sand tailings (CST), are fed to a mixbox for mixing the slurry
- adjusting the operating parameters of flocculant mixing equipment during re-flocculation (e.g. dynamic mixer rotations per minute (rpm))
- adjusting operating parameters of a thickener (e.g. underflow and overflow rates, rake speed, and shear thinning loop speed) to control the residence time and bed height in the thickener.

[0079] The measured and calculated parameters may provide guidance on upstream or downstream operation, such as changing a tailing stream(s) blending ratio, recycling FFT, or changing bed residence time. For example, a slurry compositional range may be compared to an acceptable operating window of a tailings treatment process to determine whether the slurry should be fed to the treatment unit or diverted to a designated area, e.g. a tailings pond.

[0080] The composition and solid mass flow rates and/or blending rate of a slurry to a thickener may be adjusted by varying the feed rates of FFT or another stream (e.g. CST) to achieve a target dosage level, thus regulating an overall feed composition range to a solid-liquid separation unit to maintain its steady and desired performance and managing additive supply. Additionally, feed composition range adjustment is important to achieve downstream deposit properties in a deposition area.

[0081] Operation parameters of a solid-liquid separation unit, e.g. bed height of a thickener, may be adjusted to match the compositional range of the slurry to achieve a desired product specification.

[0082] The inferred compositional range variation along with feed rate and density as a function of stream time may be integrated to inform compositional range of thickener underflow, that may then be used together with additional information for further process decisions of downstream operations, for instance dilution, dosage level of flocculation, agglomeration or aggregation steps, mixing control, use of additional additives, or diversion of a stream.

[0083] The approach described herein may be used in hydrotransport slurry lines feeding PSCs (primary separation cells) where fines flow and fines concentration information is useful. Various PSC operational adjustments may be made based on measured or calculated parameters using the approach described herein.

[0084] Table 1 provides examples of slurries, particles of interest, and process control which may be used with the approach described herein.

[0085] Table 1. Examples of slurries, particles of interest, and process control.

Slurry	Particle class or particle property	Process control
Thickener feed (FT & FFT combined)	Fines or clay content Optimal flocculant dose (see Canadian Patent No. 2,925,223, Liu et al.)	Flocculant dose setpoint, throughput, dilution rate, bed level
Flotation tailings	Fines or clay content	Flocculant dose, blending ratio with FFT
Coarse tailings	Fines or clay content	Tailings beaching operation for fines capture
Fluid fine tailings	Fines or clay content	Flocculant dose, blending ratio with FT
Hydrotransport	Fines or clay content	Caustic, dilution water, temperature
Middlings	Dispersed bitumen content, fines	Flotation cell rate, mixing speed, dilution water addition, air injection rate

[0086] In Table 1, the coarse tailing operation is related to beaching and fines capture on the beach. For example, knowing SFR of coarse tailings could help determine the discharge rate, discharge location, the need to bring in FFT over for mixing, duration of beaching, etc.

[0087] For the hydrotransport line, knowing fines flow or fines concentrations, could be used to determine ore fine level, which may guide caustic dosage to the PSC, the need for adding a secondary additive, adjusting PSC dilution water or operation temperature. Such adjustment is described, for instance, in Canadian Patent No. 2,967,868 (Castellanos et al).

[0088] A method for online determination of a concentration of a class of particles of interest in a slurry stream may comprise:

- flowing a slurry through a primary pipe or in a vessel, the slurry comprising a carrier fluid and particles of different classes;
- taking a slipstream off the primary pipe or vessel using a sampling line or other flow splitting device;
- measuring a density of the slipstream;
- computing a solids content and a carrier fluid content in the slipstream from the measured density and known or estimated densities of the carrier fluid and solid particles;
- feeding the slipstream into an analyzer to measure a concentration of the particle class of interest;
- computing a ratio of the particle class of interest to carrier liquid in the slipstream;
- measuring a density of the primary slurry stream;
- computing a solids content and a carrier fluid content in the primary slurry stream from the measured density and known or estimated densities of the carrier fluid and solid particles;
- computing a flow rate of the particle class of interest in the primary stream by assigning the same ratio of particle class of interest to carrier fluid as was measured in the slipstream; and

- computing a concentration of the particle class of interest in the primary stream on a dry solid basis by dividing the flow rate of the particle of interest to the flow rate of the solids in the primary slurry stream.

[0089] Experiment

[0090] A high SFR slurry (15 wt. % solids content, "SC") with a density of 1.10 kg/L was mixed in a bucket at different mixing conditions and then subsampled from different locations while mixing.

[0091] Table 2. Subsamples Analysis

Mixing	Sampling Location	Sample SC wt. %	Sample SFR	Sample Fines-to-Fluid Ratio	Bucket SFR
Mid RPM Mixing	Top	5	0.9	0.031	4.7
Mid RPM Mixing	Bottom	19	6.8	0.029	5.0
Hand Mixing	Top	4	0.2	0.030	4.9
Hand Mixing	Bottom	22	8.8	0.029	5.1

[0092] These results demonstrate that the mixing is not sufficient to fully suspend all solids to obtain a representative sample. These results also demonstrate that the fines concentration and the fines-to-fluid ratio are relatively consistent over different mixing conditions and subsampling locations. This makes the fines concentration and fines-to-fluid concentration (i.e., a "constant" value in the sampling process, regardless of the true representativeness of the sample, that was never before realized) more robust characteristics of the sample across the mixing conditions and subsampling locations. Accordingly, the present inventors have found that it is actually possible to use a "non-representative" slipstream of the slurry to carry out certain valuable measurements. It should be understood that numerous changes, modifications, and alternatives to the preceding disclosure can be made without

departing from the scope of the disclosure. The preceding description, therefore, is not meant to limit the scope of the disclosure. Rather, the scope of the disclosure is to be determined only by the appended claims and their equivalents. It is also contemplated that structures and features in the present examples can be altered, rearranged, substituted, deleted, duplicated, combined, or added to each other.

[0093] The scope of the claims should not be limited by particular embodiments set forth herein, but should be construed in a manner consistent with the specification as a whole.

CLAIMS:

1. A method comprising:
 - (a) providing a slurry comprising a fluid and solids;
 - (b) removing a slip stream from the slurry, wherein the slip stream is a non-representative sample;
 - (c) measuring, directly or indirectly, a fluid flow rate in the slip stream;
 - (d) measuring, directly or indirectly, a fluid flow rate in the slurry;
 - (e) measuring, directly or indirectly, a flow rate of a particle of interest in the slip stream; and
 - (f) converting, using (c), (d) and (e), the flow rate of the particle of interest in the slip stream to a flow rate of a particle of interest in the slurry.
2. The method of claim 1, wherein step (e) comprises:
 - (e1) measuring, directly or indirectly, a solid flow rate in the slip stream; and
 - (e2) measuring, directly or indirectly, a concentration, or a concentration parameter, of the particle of interest on a dry solid basis in the slip stream.
3. The method of claim 2, wherein step (f) comprises converting, using (c), (d), (e1), and (e2) the measured concentration, or the measured concentration parameter, of the particle of interest on a dry solid basis in the slip stream to a flow rate of the particle of interest on a dry solid basis in the slurry.
4. The method of any one of claims 1 to 3, further comprising measuring, directly or indirectly, a solid flow rate of the slurry stream.
5. The method of claim 1 or 4, further comprising calculating a concentration of the particle of interest on dry solid basis using the measured solid flow rate of the slurry stream and the flow rate of the particle of interest in the slurry.

6. The method of claim 3, further comprising, where the concentration, the concentration parameter, or the flow rate of the particle of interest on the dry solid basis in the slurry falls outside of an operation window of a solid-liquid separation process, bypassing a solids-liquid separation process and passing the slurry to a designated area as an untreated slurry.

7. The method of claim 3, further comprising, based on the concentration, the concentration parameter, or the flow rate of the particle of interest on the dry solid basis in the slurry, adjusting flocculent mixing in the slurry.

8. The method of claim 3, further comprising, based on the concentration, the concentration parameter, or the flow rate of the particle of interest on the dry solid basis in the slurry, adjusting a downstream solid-liquid separation process.

9. The method of any one of claims 1 to 8, further comprising:

- (g) determining an additive dosage to the slip stream; and
- (h) converting, using (c) and (d), the determined additive dosage to a recommended additive dosage to the slurry.

10. The method of claim 9, wherein the step of determining the recommended additive dosage to the slip stream comprises measuring at least a portion of the slip stream at a plurality of additive dosage levels to obtain a characteristic indicative of a degree of flocculation, agglomeration, or aggregation for each of a plurality of additive dosage levels and using the following logic rules, wherein the plurality of additive dosage levels are termed (n-y), (n), and (n+z), characteristics are termed signal (n-y), signal (n), and signal (n+z), where y and z are predetermined incremental additive dosage levels, where y and z are the same or different:

- if $\text{signal (n-y)} < \text{signal (n)} < \text{signal (n+z)}$, then signal for additive dosage (n+z) to the slip stream and increase dosage level in next slip stream dosing;
- if $\text{signal (n-y)} < \text{signal (n)} = \text{signal (n+z)}$, then signal for additive dosage (n) to the slip stream; and

- if signal (n-y) = signal (n) = signal (n+z), then signal for additive dosage (n-y) to the slip stream and lower additive dosage level in next slip stream dosing.

11. The method of claim 9 or 10, further comprising, based on the recommended additive dosage to the slurry, adjusting the additive dosage to the slurry.

12. The method of claim 11, wherein the adjusting of the additive dosage is performed in real-time.

13. The method of any one of claims 9 to 12, wherein the additive comprises a flocculant, a coagulant, or an agglomerant.

14. The method of any one of claims 1 to 13, wherein step (c) comprises measuring a flow rate in the slip stream, measuring a density of the slip stream, and calculating the fluid flow rate in the slip stream from the measured density and known or estimated densities of the fluid and the solids.

15. The method of any one of claims 1 to 14, wherein step (d) comprises measuring a flow rate in the slurry, measuring a density of the slurry, and calculating the fluid flow rate in the slurry from the measured density and known or estimated densities of the fluid and the solids.

16. The method of any one of claims 1 to 15, wherein the slurry is an oil sand stream intended as a feed stream to a solid-liquid separation process, tailings treatment process, bitumen extraction process, or bitumen recovery process.

17. The method of claim 16, wherein the oil sand stream is an oil sand tailings stream.

18. The method of claim 17, wherein the oil sand tailings stream stems from an aqueous based extraction process.

19. The method of claim 17, wherein the oil sand tailings stream stems from a solvent-based extraction process.
20. The method of claim 17, wherein the oil sand tailings stream comprises coarse tailings, middlings, flotation tailings, froth separation tailings, tailings solvent recovery unit (TSRU) tailings, fluid fine tailings (FFT), mature fine tailings (MFT), thickened tailings, thickener overflow, centrifuged tailings, hydrocycloned tailings, or a combination thereof.
21. The method of claim 17, wherein the oil sand tailings stream comprises a feed stream to a thickener, a thickener overflow, or a thickener underflow.
22. The method of claim 17, wherein the oil sand tailings stream comprises a feed stream to a centrifuge, filter, or inline mixer.
23. The method of any one of claims 1 to 15, wherein the slurry comprises a mining slurry.
24. The method of any one of claims 1 to 15, wherein the slurry comprises a thickener underflow.
25. The method of any one of claims 1 to 15, wherein the slurry comprises a drilling mud or waste stream from a drilling operation.
26. The method of any one of claims 1 to 25, wherein the measurements of steps (c) and (d) are performed by one or more online analyzers.
27. The method of any one of claims 1 to 26, wherein the measurements of steps (c) and (d) are by volumetric flow meter or mass flow meter.
28. The method of any one of claims 1 to 27, further comprising floating off bitumen in the slip stream to reduce bitumen interference in slip stream measurement.

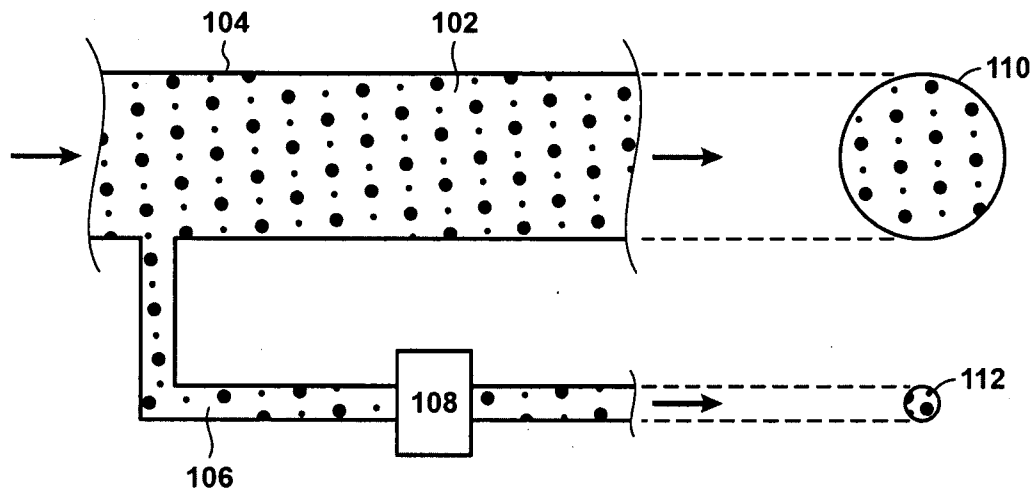


FIG. 1
(Prior Art)

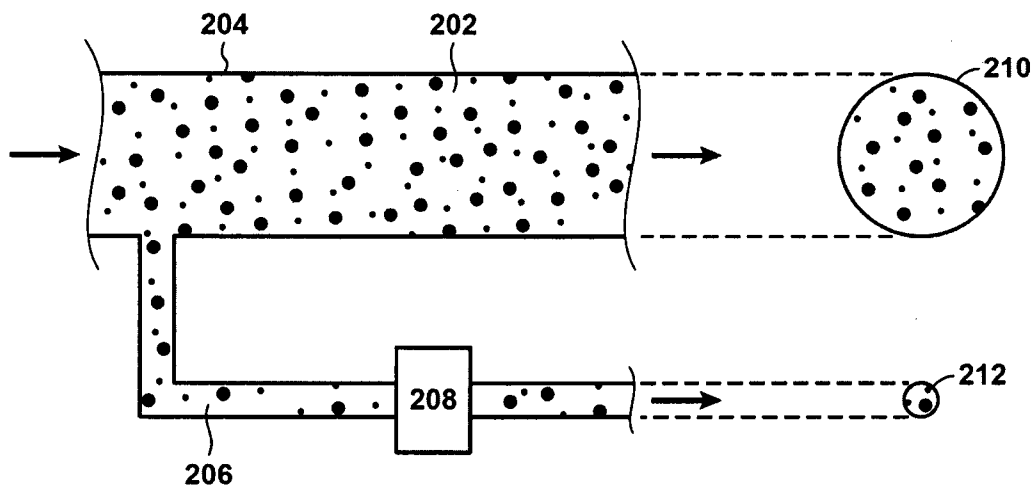


FIG. 2

