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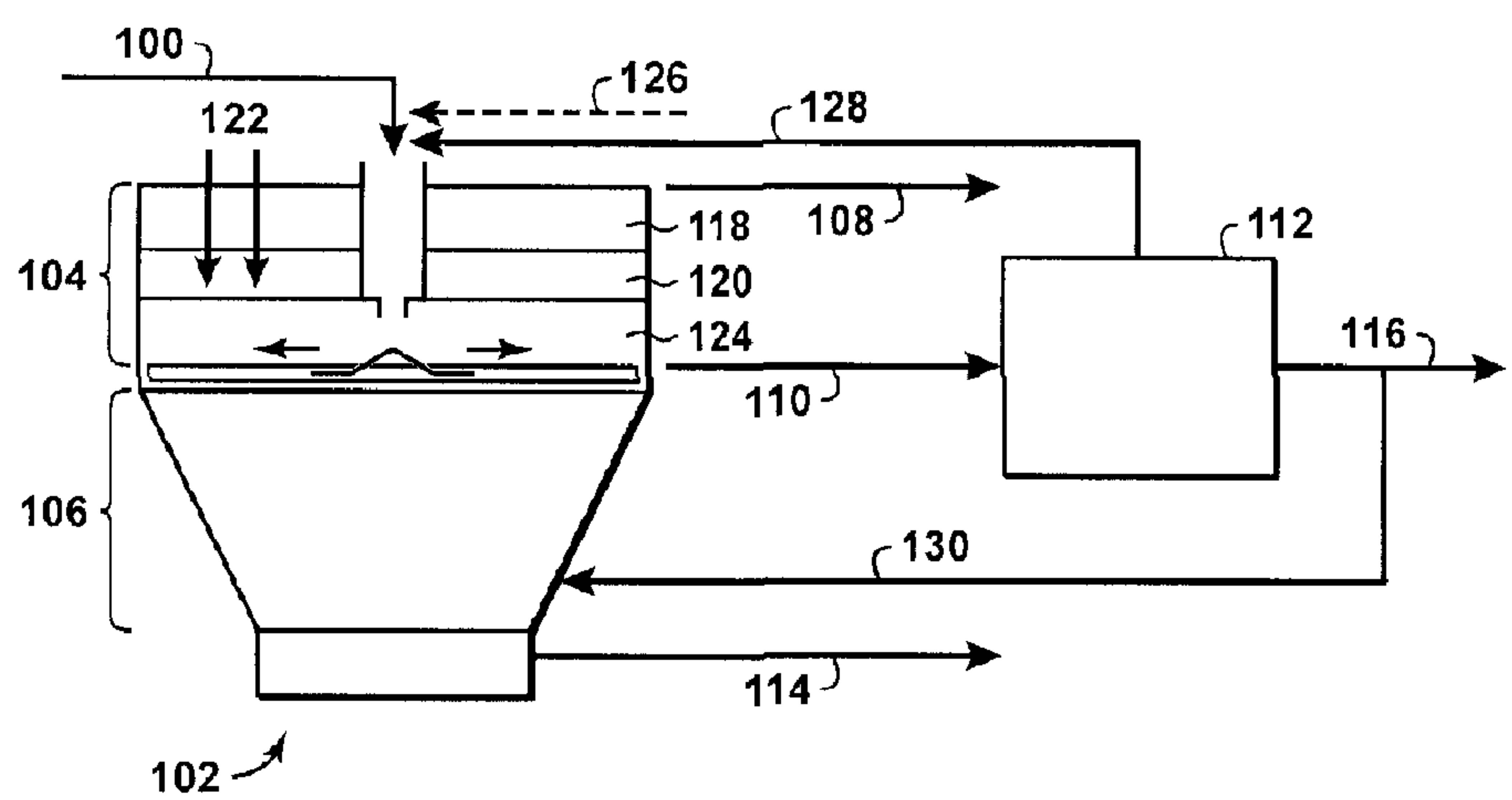
(54) Titre : METHODE DE CONTROLE D'UN PROCEDE D'EXTRACTION DE SABLE BITUMINEUX A BASE D'EAU
(54) Title: METHOD OF CONTROLLING A WATER-BASED OIL SAND EXTRACTION PROCESS



(57) Abrégé/Abstract:
Disclosed is a method of controlling a water-based oil sand extraction process, the method comprising:

a) providing a feed stream comprising oil sand;
b) analyzing the feed stream to obtain a fines parameter indicative of a fines content of the feed stream;
c) introducing the feed stream into a primary separation cell (PSC);
d) withdrawing a bitumen froth from the PSC;
e) withdrawing a middlings from the PSC;
f) withdrawing a coarse sand tailings (CST) from the PSC; and
g) adjusting a density gradient in the PSC based on the obtained fines parameter.

ABSTRACT

Disclosed is a method of controlling a water-based oil sand extraction process, the method comprising:

a) providing a feed stream comprising oil sand;
b) analyzing the feed stream to obtain a fines parameter indicative of a fines content of the feed stream;
c) introducing the feed stream into a primary separation cell (PSC);
d) withdrawing a bitumen froth from the PSC;
e) withdrawing a middlings from the PSC;
f) withdrawing a coarse sand tailings (CST) from the PSC; and
g) adjusting a density gradient in the PSC based on the obtained fines parameter.

METHOD OF CONTROLLING A WATER-BASED OIL SAND EXTRACTION PROCESS

BACKGROUND

Field of Disclosure

[0001] The disclosure relates generally to the field of oil sand processing, and more particularly to water-based extraction.

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] 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.

[0004] 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.

[0005] 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) or as a water-based oil sand extraction process. WBE is a commonly used process to extract bitumen from mined oil sand.

[0006] 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.

[0007] In one WBE process, a water and oil sand slurry is separated into three major streams in the PSC: bitumen froth, middlings, and a PSC underflow (also referred to as coarse sand tailings (CST)).

[0008] 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.

[0009] Solvent is typically recovered from the diluted product bitumen component before the bitumen is delivered to a refining facility for further processing.

[0010] 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, which is incorporated herein by reference.

[0011] From the PSC, the middlings, which may comprise 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).

[0012] It would be desirable to have an alternative or improved method of controlling a WBE process, such as to improve separation efficiency in the PSC, as compared to certain existing processes, so that more bitumen is withdrawn in the bitumen froth and less bitumen is withdrawn in the middlings and/or the CST.

SUMMARY

[0013] It is an object of the present disclosure to provide a method of controlling a WBE process.

[0014] Disclosed is a method of controlling a water-based oil sand extraction process, the method comprising:

a) providing a feed stream comprising oil sand;
b) analyzing the feed stream to obtain a fines parameter indicative of a fines content of the feed stream;
c) introducing the feed stream into a primary separation cell (PSC);
d) withdrawing a bitumen froth from the PSC;
e) withdrawing a middlings from the PSC;
f) withdrawing a coarse sand tailings (CST) from the PSC; and
g) adjusting a density gradient in the PSC based on the obtained fines parameter.

[0015] 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

[0016] 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.

[0017] Fig. 1 is a schematic of a PSC.

[0018] Fig. 2 is a graph of bitumen in CST versus cone density.

[0019] Fig. 3 is a graph of bitumen in flotation tailings versus middlings density.

[0020] Fig. 4 is a graph of fines content of oil sand versus K40 measurements.

[0021] Fig. 5 is a graph of PSC cone and middlings densities versus K40 measurements.

[0022] Fig. 6 is a graph of PSC cone density, K40 measurements, and bitumen content of CST.

[0023] Fig. 7 is a flow diagram of a bitumen extraction system using K40 to control PSC density.

[0024] Fig. 8 is a flow diagram of a process control scheme to adjust PSC density gradient.

[0025] 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

[0026] 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.

[0027] 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.

[0028] Throughout this disclosure, where a range is used, any number between or inclusive of the range is implied.

[0029] 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.

[0030] "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.

[0031] "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.

[0032] "Fine particles" or "fines" are generally defined as those solids having a size of less than 44 microns (μm), as determined by laser diffraction particle size measurement.

[0033] "Coarse particles" are generally defined as those solids having a size of greater than 44 microns (μm).

[0034] The term "solvent" as used in the present disclosure should be understood to mean either a single solvent, or a combination of solvents.

[0035] 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.

[0036] 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.

[0037] 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 C_4 to C_{20} or C_4 to C_6 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.

[0038] The PSC is an important part of WBE as bitumen froth is separated from the majority of water and solids. Fig. 1 depicts an example of a PSC and its operation. With reference to Fig. 1, the feed to the PSC (102) is a feed stream (100) comprising oil sand, which may be an aerated oil sand slurry from a hydrotransport line stemming from mined oil sand ore. The illustrated PSC (102) comprises a cylindrical section (104) at the top where aerated bitumen froth with some solids and water rises upwards and flows to the next process equipment for cleanup in froth treatment, and a conical section (106) below, which creates a densification zone (comprising the majority of solids and water) establishing a vertical density gradient in the PSC, which enables separation of bitumen froth. The cylindrical section (104) may comprise three layers, a froth layer (118), an underwash layer (120) into which an underwash (122) is added, and a middlings layer (124). Dilution water (126) may be added to the feed stream (100). Three streams typically leave the PSC (102), namely, a bitumen froth (108) comprising the majority of the bitumen from the oil sand which is withdrawn near the top of the PSC, a middlings (110) comprising some bitumen which is withdrawn near the bottom of the cylindrical section of the PSC and which are sent to flotation cells (112) for secondary recovery of bitumen, and a coarse sands tailings (CST) (114) which is withdrawn at the bottom of the PSC. The CST (114) may comprise water and the majority of solids from the oil sand slurry. The CST (114) typically contains some bitumen which is one of the primary locations for losses of bitumen in the WBE process. A small amount of bitumen is also lost to the flotation tailings (116), the stream leaving the flotation cells (112) from the secondary recovery process. The flotation cells (112) also produce a recovered bitumen stream (128) which may be passed back into the PSC (102). PSC operation may be controlled in a way to minimize the amount of the bitumen in the CST (114) and flotation tailings (116). It has been observed that cone and middlings densities, or more broadly a density gradient within the PSC, play an important role in effective separation in the PSC and hence bitumen losses in the tailings streams leaving the PSC. Further, PSC cone density is important to establishing the density gradient; therefore, cone density directly affects effective separation of bitumen froth from the majority of solids and water. Generally, a higher cone density helps establish a better density gradient. However, a PSC is generally operated with a cone density within a minimum and maximum to optimize separation efficiency while also maintaining operability of a CST pump. The impact of cone density on the amount of bitumen in the CST is illustrated in Fig. 2 where PSC cone density has been shown to inversely correlate with the bitumen content of the CST. Higher bitumen content of the CST is an indication of poor separation efficiency which directly affects overall bitumen recovery from the oil sand. Figs. 2, 3, 5, and 6 are based on an oil sand plant performance covering approximately 12 hours of operation from the PSC using real-time instruments (continuous lines or grab samples) analyzed in a laboratory for bitumen content. Similarly, Fig. 3 shows the impact of middlings density on the amount of bitumen in the flotation tailings. Unlike the CST, it is observed in Fig. 3 that the amount of bitumen in the flotation tailings increases with the increased density of the middlings layer. Therefore, it can be seen that the densities within the PSC can affect separation efficiency which in turn affects bitumen recovery in the PSC. To maximize separation efficiency in the PSC, plant operators may use multiple controls to maintain a target density gradient, such as withdrawal rate of CST, controlling addition of dilution water, and middlings withdrawal rate. In the present operation, this response, however, has been reactive meaning that an operator adjusts one or more of these controls once higher bitumen losses have already been observed or operating parameters (such as the cone density) have already been observed to be outside a target range. This approach already results in increased bitumen losses which could otherwise be minimized if a pre-determinate indicator enabling feed-forward control was available. Additionally, due to swings that may occur rapidly in feed composition or operations, as well as lag time due in measuring these changes, these "reactive adjustments" made after the change or problem has already occurred, may actually result in incorrect, or at least non-optimum, modifications to the process.

[0039] While density gradient can vary due to many factors, the variation is expected to be lower during steady operation, such as relatively stable PSC feed rates at constant oil sand ore quality, e.g., minor variations in bitumen and fines contents of the ore. This, however, may not be the case when there are sudden changes in the ore feed quality, particularly solids particle size distribution, more commonly known as fines fraction of the solids in the oil sand (particles less than 44 microns in size). Sudden large changes in the fines content of the ore can disturb the density gradient within PSC, resulting in increased bitumen losses. Therefore, there exists a need in the industry for a better feed-forward / proactive control to minimize instances of sub-optimal density gradient that may be attributed to sudden changes in ore fine solids content. Until recently, however, there was no reliable real-time measurement of fines content in the oil sand. More recently, fines analyzer based on gamma decay of potassium element present in the oil sand have been shown to reasonably estimate fines content in the oil sand. Fig. 4 shows the relationship between fines content and K40 measurements. Figure 4 is the outcome of sampling over several months where dry ore samples were collected at regular intervals from the apron feeder and compared with K40 signals over the same period.

[0040] A proactive or feed-forward process control to better maintain PSC density gradient requires an indicator of fines content of the oil sand that can be used to respond when density gradient disturbance is anticipated. Gamma radiation based fines analyzers such as a K40 (potassium 40) analyzer may be utilized to estimate fines content of the mined oil sand in real-time before the bitumen extraction process starts with the addition of hot water. A K40-based gamma radiation fines analyzer typically detects the presence of clays containing a radioactive isotope of potassium, and potentially thorium and uranium, which in turn relates to fines content of the oil sand. Fig. 4 illustrates a proportional relationship of fines content of oil sand versus a K40 fines analyzer measurement. Furthermore, it has been discovered in the testing and data analysis herein that cone density inversely correlates with K40 output with a time lag approximately equal to residence time in hydrotransport. Similarly, middling density correlates positively with the K40 measurement. Fig. 5 illustrates an example of such a relationship where PSC cone and middlings densities are plotted against K40 measurements. This relationship is particularly pronounced when there is sudden change in the K40 output, which generally also corresponds to instances of higher bitumen content in the CST and flotation tailings (higher bitumen losses during primary extraction). The observation that there is time lag in the densities response when there is sudden large change in K40 output can be advantageously used to improve density control and operation of PSC in a feed-forward manner to minimize bitumen losses. Fig. 6 further illustrates this observation along with the amount of bitumen in the CST and flotation tailings. Fig. 6 is a graph of PSC cone density, K40 measurements, and bitumen content of CST. It is evident that K40 can be a useful indicator as the amount of bitumen in both the streams increase as K40 measurement increases, which results in reduced cone and increased middlings densities in the PSC.

[0041] The observations from Figs. 2, 3, 5 and 6 can advantageously be used to develop a feed-forward process control scheme that enables adjusting a PSC density gradient proactively in relation to fines content estimated in real-time. This may result in improved extraction of bitumen from the oil sand by reducing the amount of bitumen lost in the primary extraction, hence, improving overall recovery. An example of controlling the density gradient is to adjust the ratio of middlings to CST withdrawal rates where the middlings withdrawal rate is increased and the CST withdrawal rate is decreased when K40 measurement (an indicated of fines content of the oil sand) increases, or vice versa. Another example of controlling the density gradient is to adjust the PSC dilution water to reduce middlings density when the K40 measurement increases, or vice-versa. An example of a means to affect the CST withdrawal rate is to adjust the pump speed while the middlings withdrawal rates can be affected by valve opening between the PSC and the flotation cells, and/or by varying PSC dilution water.

[0042] Therefore, it has been discovered herein that a fines parameter indicative of a fines content of a feed stream comprising oil sand to a PSC can be valuable information and can be used to adjust a density gradient in the PSC in a feed-forward control system to provide accurate and timely adjustments to the PSC operations in a WBE process. Adjusting a density gradient in the PSC may in turn allow for process improvements, such as improved separation resulting in more bitumen in the bitumen froth and less bitumen in the CST and/or the middlings.

[0043] A method of controlling a WBE process may include the following steps. A feed stream comprising oil sand is provided (a). The "feed stream" (or "oil sand feed stream") is any suitable feed stream comprising oil sand, for instance mined oil sand. Then, the feed stream is (b) analyzed to obtain a fines parameter indicative of a fines content of the feed stream. Next, the feed stream is (c) introduced into a PSC, (d) a bitumen froth is withdrawn from the PSC, (e) a middlings is withdrawn from the PSC, and (f) a CST is withdrawn from the PSC. Additionally, (g) based on the obtained fines parameter, a density gradient in the PSC is adjusted.

[0044] The density gradient may comprise a density gradient in a cone section of the PSC, a density gradient in a middlings section of the PSC, or a combination thereof. In practice, a density gradient may be calculated using density measurements at different vertical levels in the PSC.

[0045] Step g) may comprise adjusting a withdrawal rate of the middlings from the PSC, a withdrawal rate of the CST from the PSC, a dilution water addition rate to the PSC, an addition rate of middlings displacement to the PSC, an addition rate of a cone flush water to the PSC, or a combination thereof. Step g) may comprise increasing the middlings withdrawal rate, decreasing the CST withdrawal rate, increasing the dilution water addition rate, or a combination thereof, when the fines content increases. Step g) may comprise decreasing the middlings withdrawal rate, increasing the CST withdrawal rate, decreasing the dilution water addition rate, or a combination thereof, when the fines content decreases. The method may comprise using step g) to maintain the density gradient in the PSC within a target operating range. As illustrated in Fig. 1, middlings displacement (130) to the PSC is a slipstream of the flotation tailings (116) that is recycled back into the lower PSC area (106). Middlings displacement may be used as a lever to increase or decrease inflows or outflows of the PSC.

[0046] The CST withdrawal rate may be adjusted by adjusting a CST pump speed. The middlings withdrawal rate may be adjusted by adjusting a valve between the PSC and downstream equipment receiving the middlings. The downstream equipment may comprise one or more flotation cells. The dilution water addition rate may be adjusted by adjusting a valve on a dilution water line upstream of the PSC. Steps b) and g) may be repeated at predetermined intervals or may be effected continuously. There may be a predetermined lag time between the analyzing in step b) and the adjusting in step g).

[0047] The fines parameter may be obtained using natural gamma radiation detection. The natural gamma radiation detection comprises measuring gamma radiation emitted during decay of potassium-40, uranium-238, or thorium 232.

[0048] The fines parameter may be expressed as counts per second as a function of either individual potassium-40, uranium-238, or thorium 232, or as a combined count per seconds of potassium-40, uranium-238, and thorium 232.

[0049] The fines parameter may be obtained using PGNAA (Prompt Gamma Neutron Activation Analysis), LIBS (Laser-Induced BreakdownSpectroscopy), reflectance Hyperspectroscopy, XRF (X-Ray Fluorescence), Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES), or Atomic Absorption (AA).

[0050] Step b) may be effected online, inline, offline, or atline. The analysis may be effected online, inline, offline, or atline.

[0051] While a K40 analyzer is used as an example of a fines analyzer, any suitable analyzer may be used. Similarly, while examples of dilution water and CST withdrawal rates are used as examples of cone density control means, any suitable control means may be used. The method may be practiced in both manual and automatic process control configurations.

[0052] Fig. 7 is a flow diagram of a bitumen extraction system using K40 to control PSC density. Oil sand ore (702) from a mine passes through dry ore handling (704), a slurry preparation plant (706), hydrotransport (708), a bitumen extraction plant (710), and further processing (712). A fines analyzer (714) analyzes the oil sand and transmits the result to a controller (716). The controller (716) controls the bitumen extraction plant (710) as described herein.

[0053] Fig. 8 is a flow diagram of a process control scheme to adjust PSC density gradient. The control system includes a cone density controller (802) and a middlings withdrawal controller (804) for controlling the respective flowrates to maintain the PSC density gradient and interface within target ranges. The cone density controller (802) receives a PSC cone density measurement (806). The middlings withdrawal controller (804) receives a PSC middlings density measurement (808). A K40 controller (810) sends a K40 fines analyzer output signal to a ratio controller (812). The ratio controller (812) splits the signal between a cone density sum control block (814) and a middlings withdrawal sum control block (816) based on a predetermined function. The cone density sum control block (814) takes the current density controller setpoint and increases/decreases the CST withdrawal rate (818) based on the fines signal from the K40 controller (810) via the ratio controller (812). On the middlings side of the scheme, depending on current operating conditions, the output of the middlings withdrawal sum control block (816) can be sent to a middlings withdrawal control valve (820) or a dilution water control valve (822) based on predetermined conditions and constraints. As an example, if the current cone density controller (802) is asking for a flow of 7500 m^3/h to maintain the cone density on target, an increase in fines content from the K40 controller (810) would trigger the ratio controller (812) to request a reduction in flow of 500 m^3/h proactively and would adjust the CST flow down to 7000 m^3/h before the fines actually arrive in the PSC. The numbers used in this paragraph are not intended to be limiting in any way.

[0054] 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.

CLAIMS:

1. A method of controlling a water-based oil sand extraction process, the method comprising:
   a) providing a feed stream comprising oil sand;
   b) analyzing the feed stream to obtain a fines parameter indicative of a fines content of the feed stream;
   c) introducing the feed stream into a primary separation cell (PSC);
   d) withdrawing a bitumen froth from the PSC;
   e) withdrawing a middlings from the PSC;
   f) withdrawing a coarse sand tailings (CST) from the PSC; and
   g) adjusting a density gradient in the PSC based on the obtained fines parameter.

2. The method of claim 1, wherein the density gradient comprises a density gradient in a cone section of the PSC, a density gradient in a middlings section of the PSC, or a combination thereof.

3. The method of claim 1 or 2, wherein step g) comprises adjusting a withdrawal rate of the middlings from the PSC, a withdrawal rate of the CST from the PSC, a dilution water addition rate to the PSC, an addition rate of middlings displacement to the PSC, an addition rate of a cone flush water to the PSC, or a combination thereof.

4. The method of claim 3, wherein step g) comprises increasing the middlings withdrawal rate, decreasing the CST withdrawal rate, increasing the dilution water addition rate, or a combination thereof, when the fines content increases.

5. The method of claim 3, wherein step g) comprises decreasing the middlings withdrawal rate, increasing the CST withdrawal rate, decreasing the dilution water addition rate, or a combination thereof, when the fines content decreases.

6. The method of any one of claims 1 to 5, comprising using step g) to maintain the density gradient in the PSC within a target operating range.

7. The method of any one of claims 4 to 6, wherein the CST withdrawal rate is adjusted by adjusting a CST pump speed.

8. The method of any one of claims 4 to 6, wherein the middlings withdrawal rate is adjusted by adjusting a valve between the PSC and downstream equipment receiving the middlings.

9. The method of claim 8, wherein the downstream equipment comprises one or more flotation cells.

10. The method of any one of claims 4 to 6, wherein the dilution water addition rate is adjusted by adjusting a valve on a dilution water line upstream of the PSC.

11. The method of any one of claims 1 to 10, wherein steps b) and g) are repeated at predetermined intervals.

12. The method of any one of claims 1 to 10, wherein steps b) and g) are effected continuously.

13. The method of claim 11 or 12, wherein there is a predetermined lag time between the analyzing in step b) and the adjusting in step g).

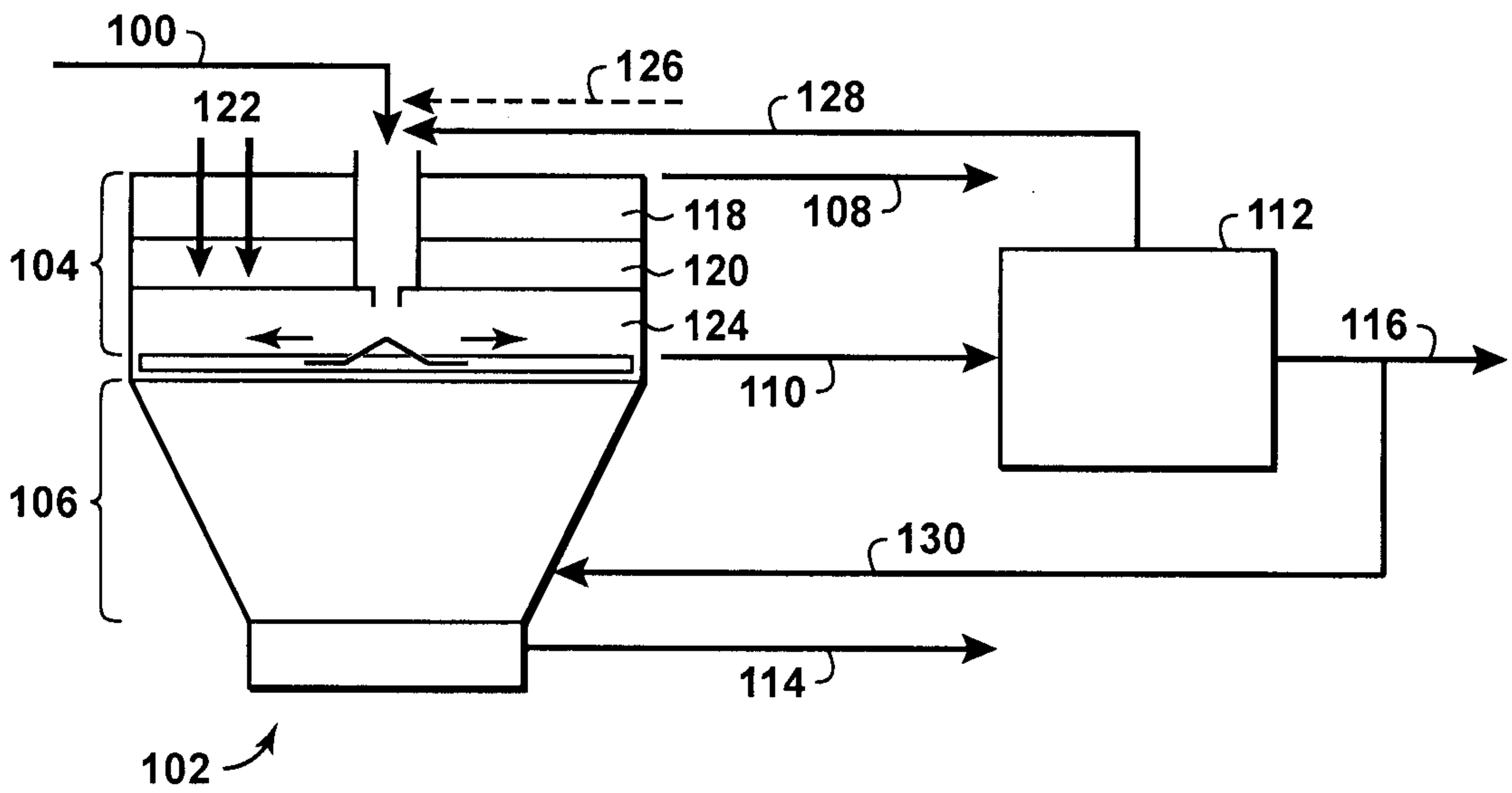
14. The method of any one of claims 1 to 13, wherein the fines parameter is obtained using natural gamma radiation detection.

15. The method of claim 14, wherein the natural gamma radiation detection comprises measuring gamma radiation emitted during decay of potassium-40, uranium-238, or thorium-232.

16. The method of any one of claims 1 to 15, wherein the fines parameter is expressed as counts per second as a function of either individual potassium-40, uranium-238, or thorium-232, or as a combined count per seconds of potassium-40, uranium-238, and thorium-232.

17. The method of any one of claims 1 to 11, wherein the fines parameter is obtained using PGNAA (Prompt Gamma Neutron Activation Analysis), LIBS (Laser-Induced BreakdownSpectroscopy), reflectance Hyperspectroscopy, XRF (X-Ray Fluorescence), Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES), or Atomic Absorption (AA).

18. The method of any one of claims 1 to 17, wherein step b) is effected online, inline, offline, or atline.


100
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102

FIG. 1

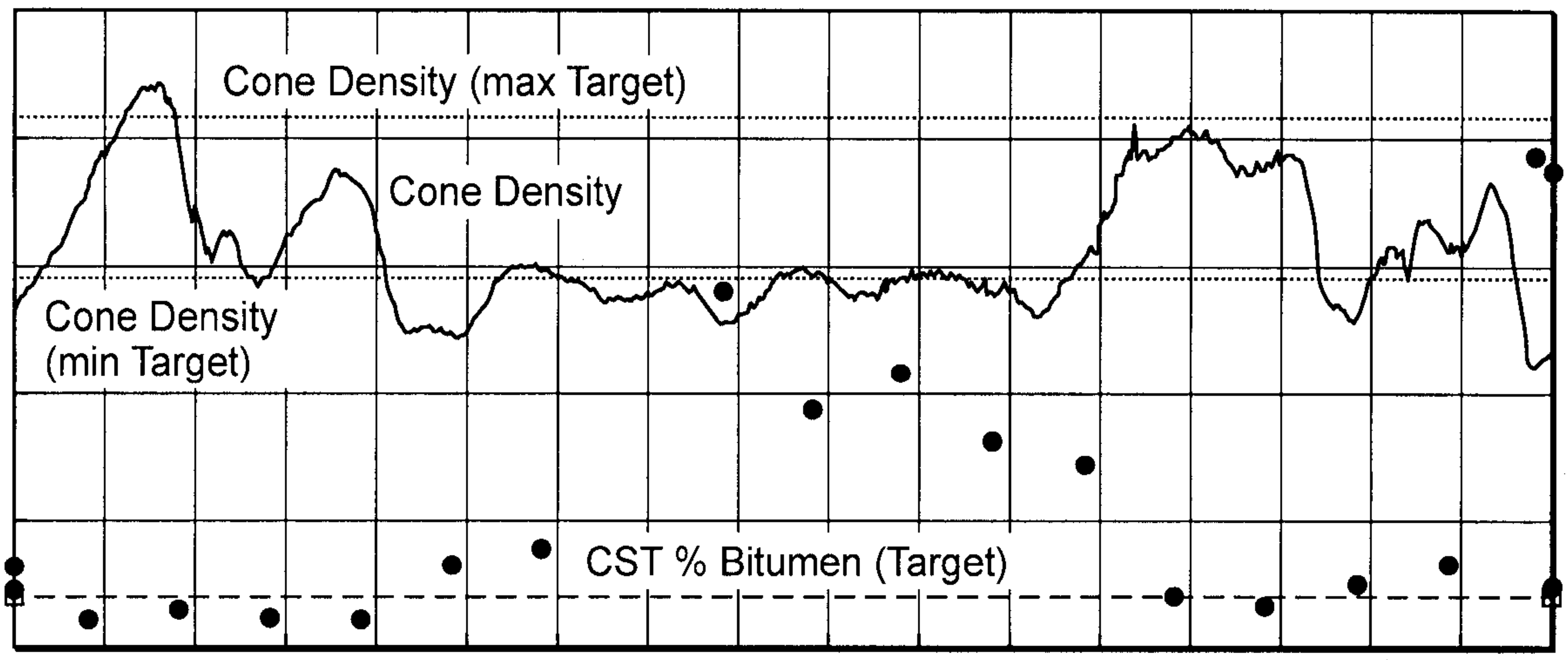
Cone Density (max Target)
Cone Density
Cone Density
(min Target)
CST % Bitumen (Target)

FIG. 2

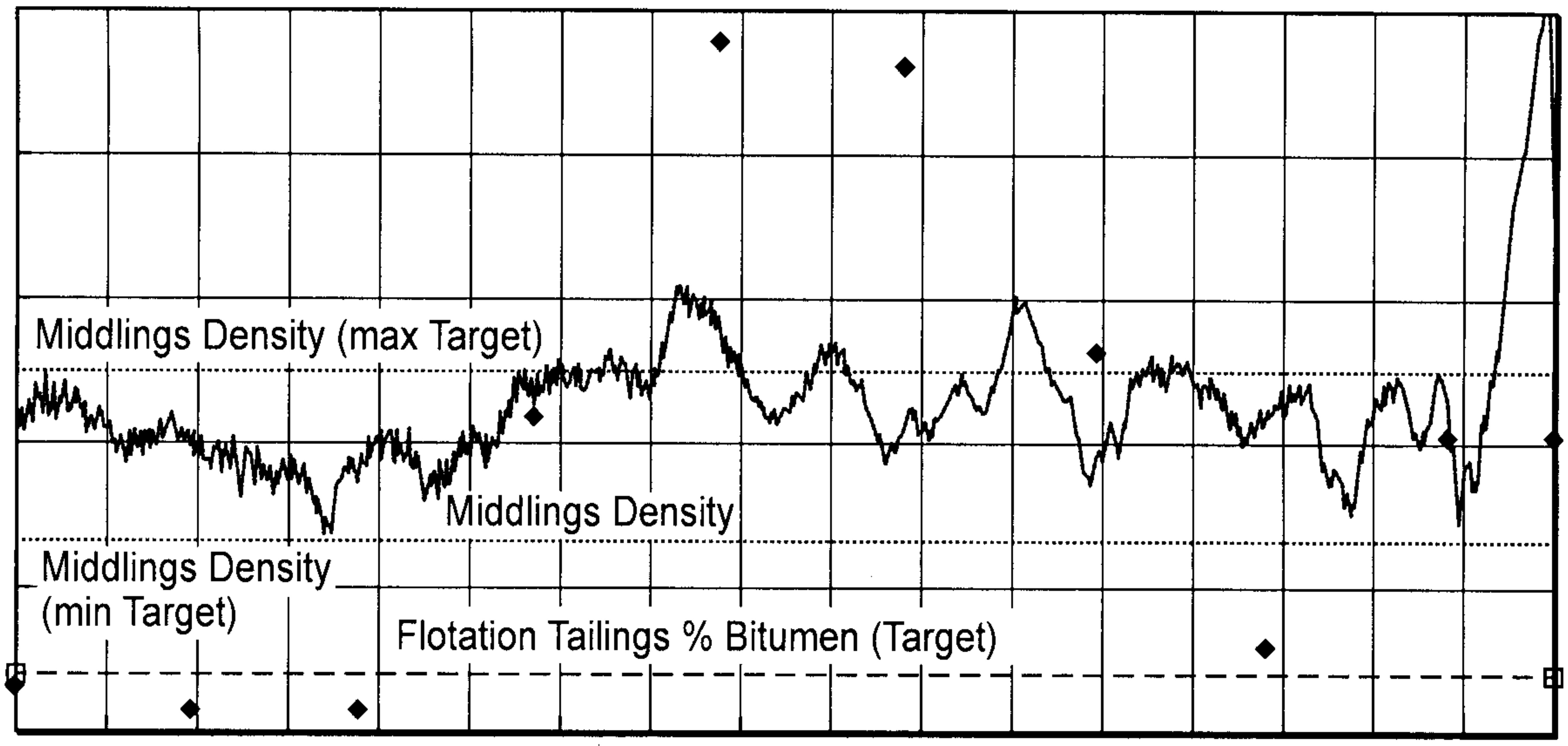
Middlings Density (max Target)
Middlings Density
Middlings Density
(min Target)
Flotation Tailings % Bitumen (Target)

FIG. 3

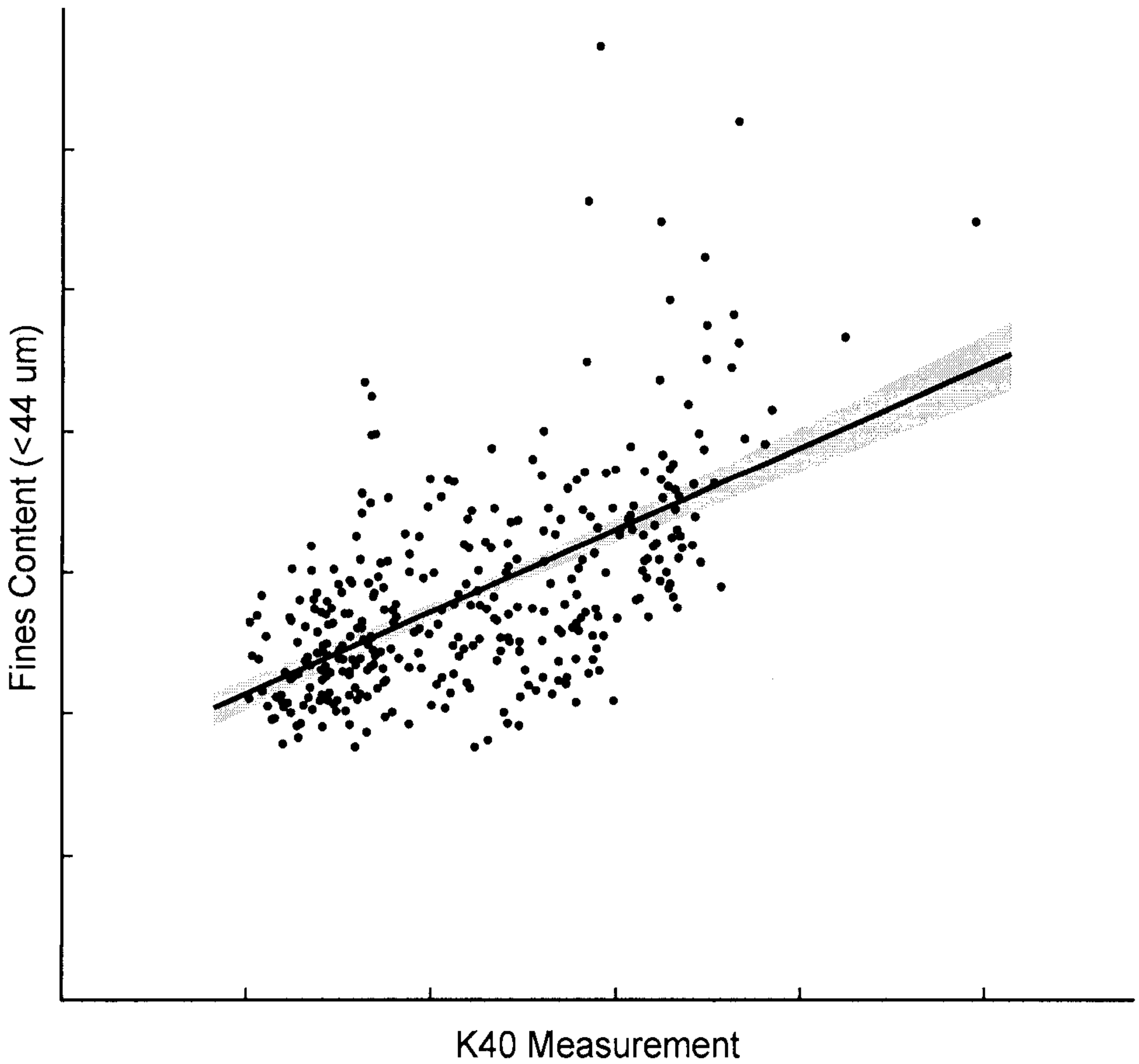
Fines Content (<44 um)
K40 Measurement

FIG. 4

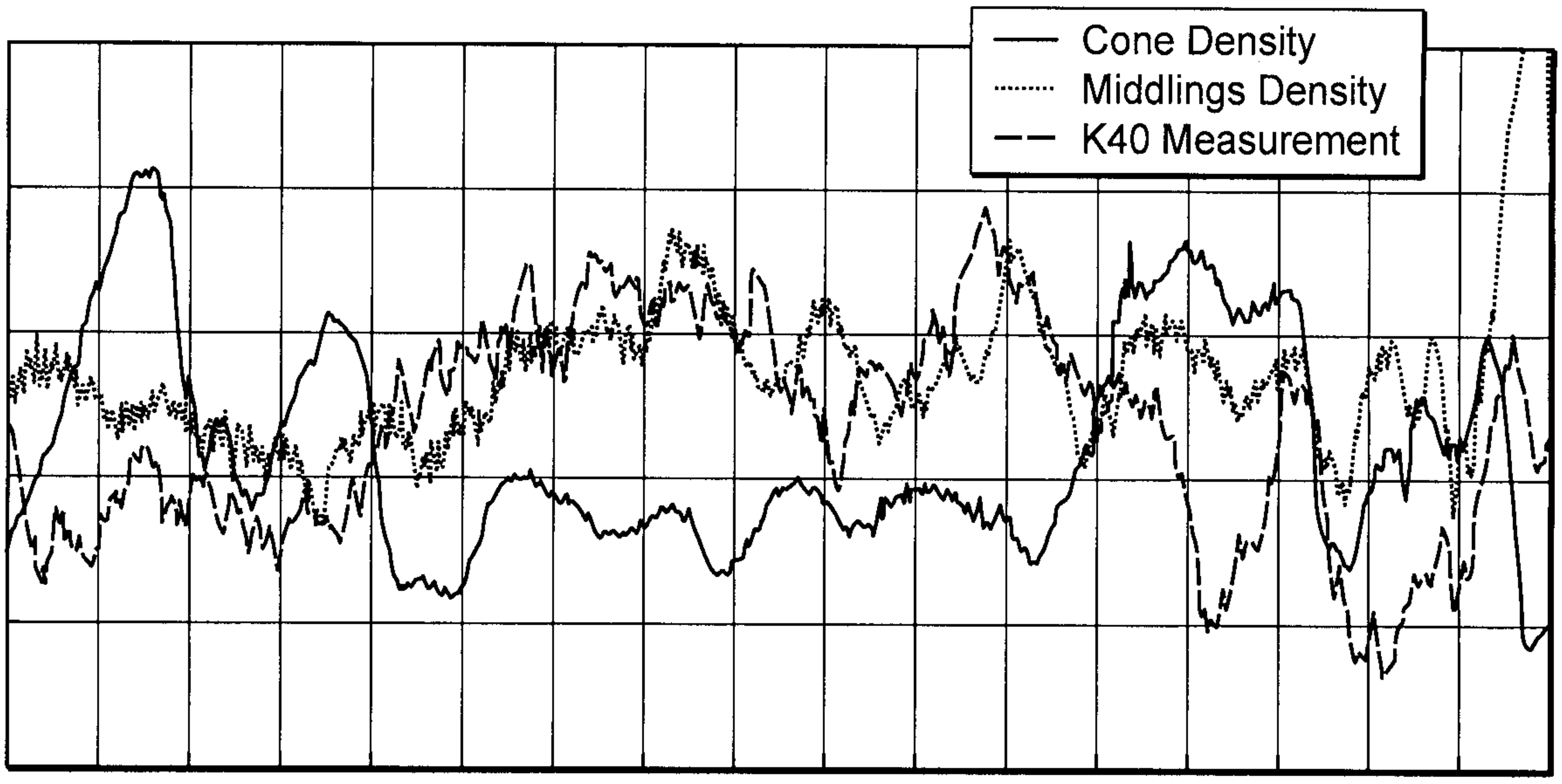
Cone Density
Middlings Density
K40 Measurement

FIG. 5

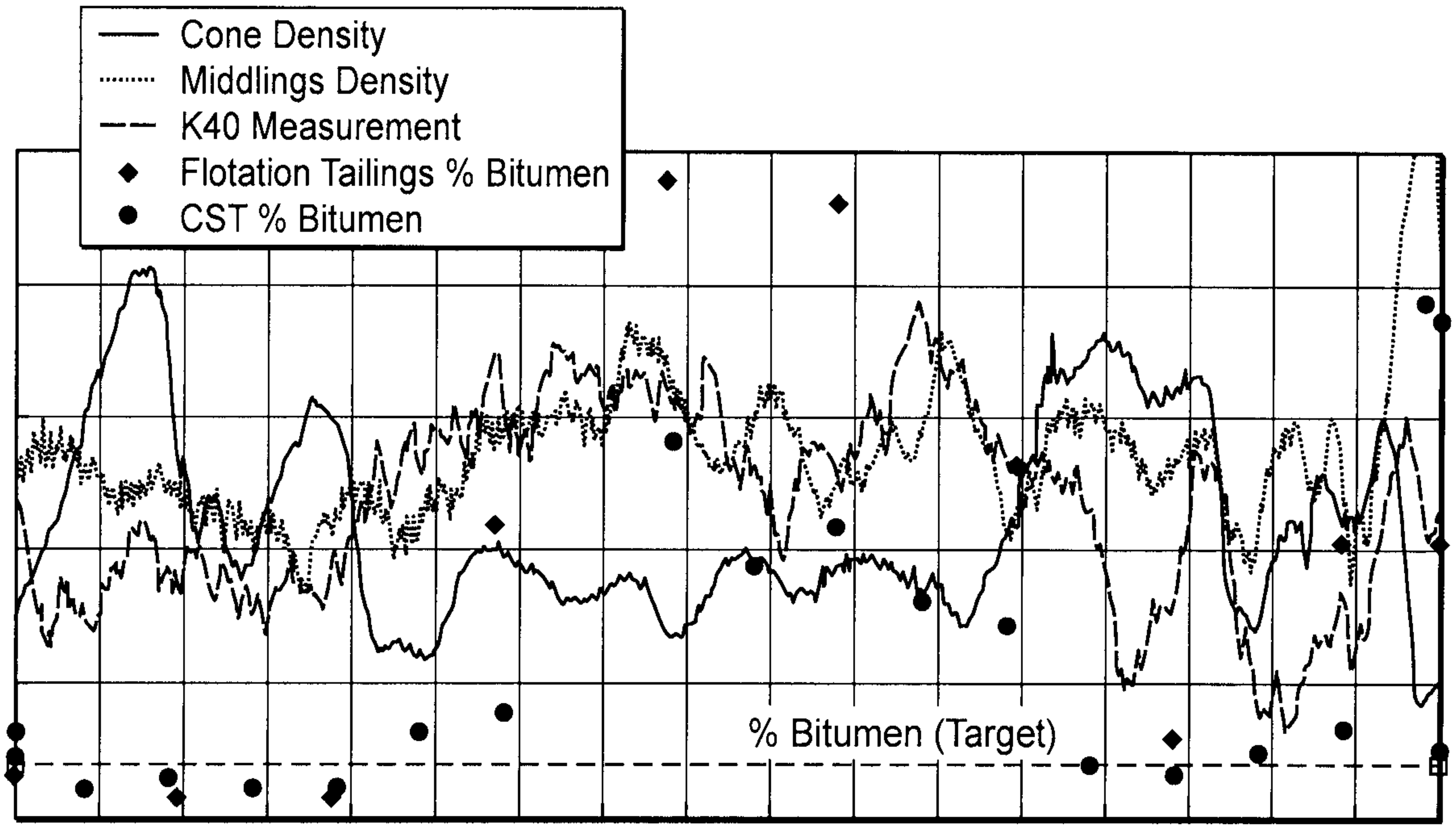
Cone Density
Middlings Density
K40 Measurement
Flotation Tailings % Bitumen
CST % Bitumen
% Bitumen (Target)

FIG. 6

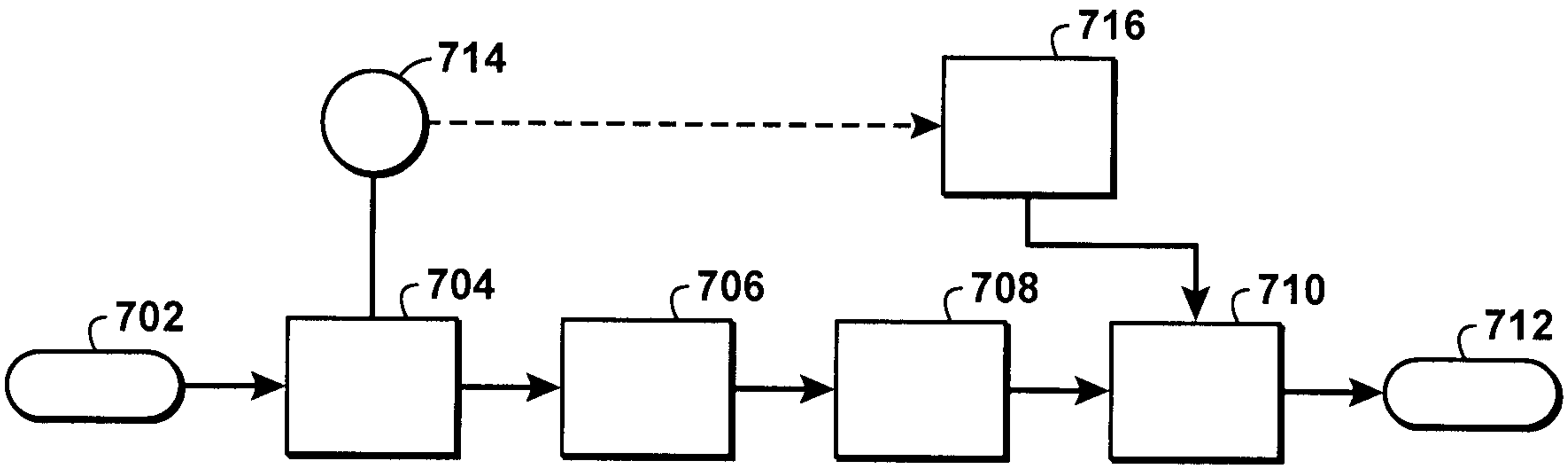
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FIG. 7

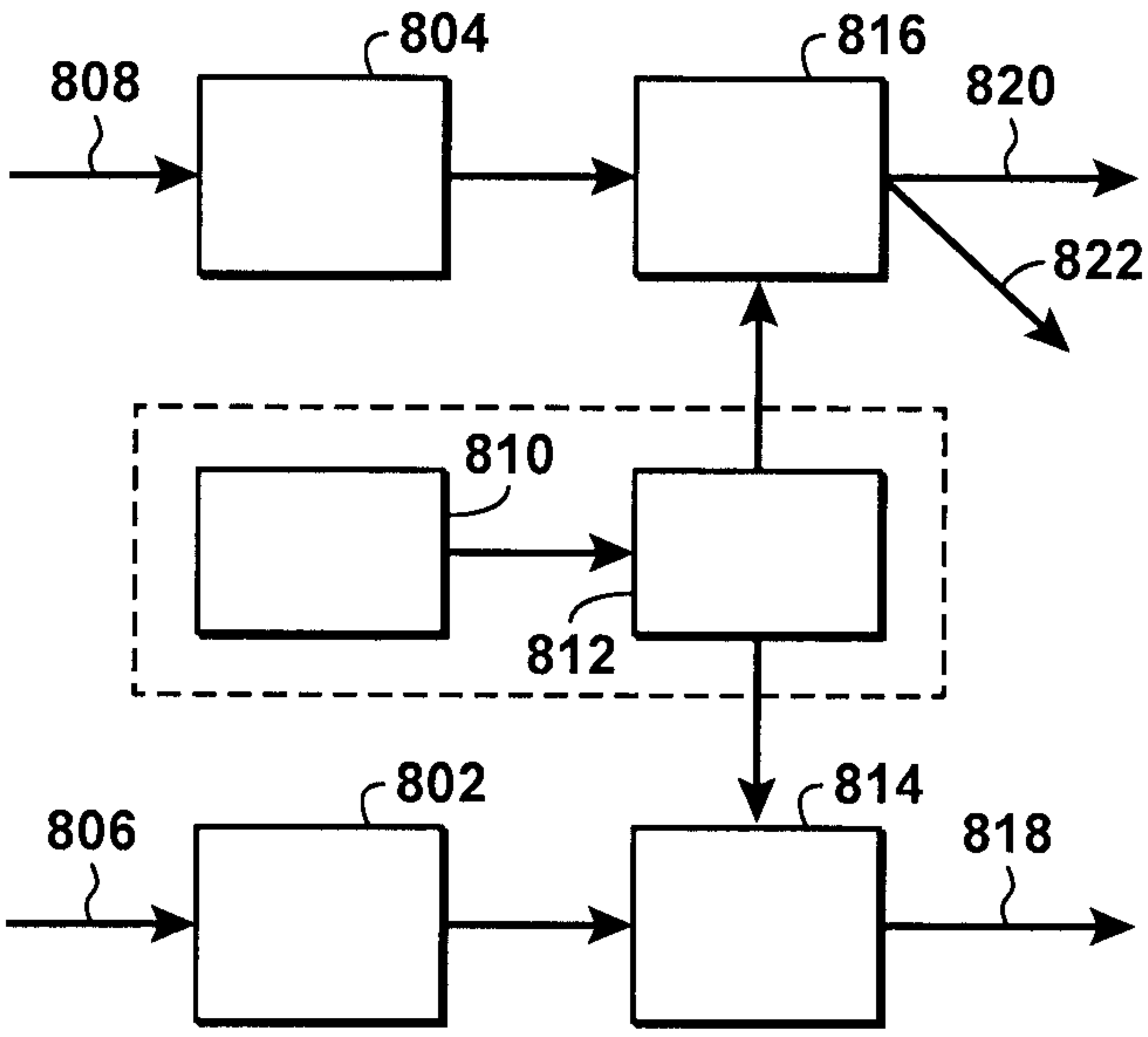
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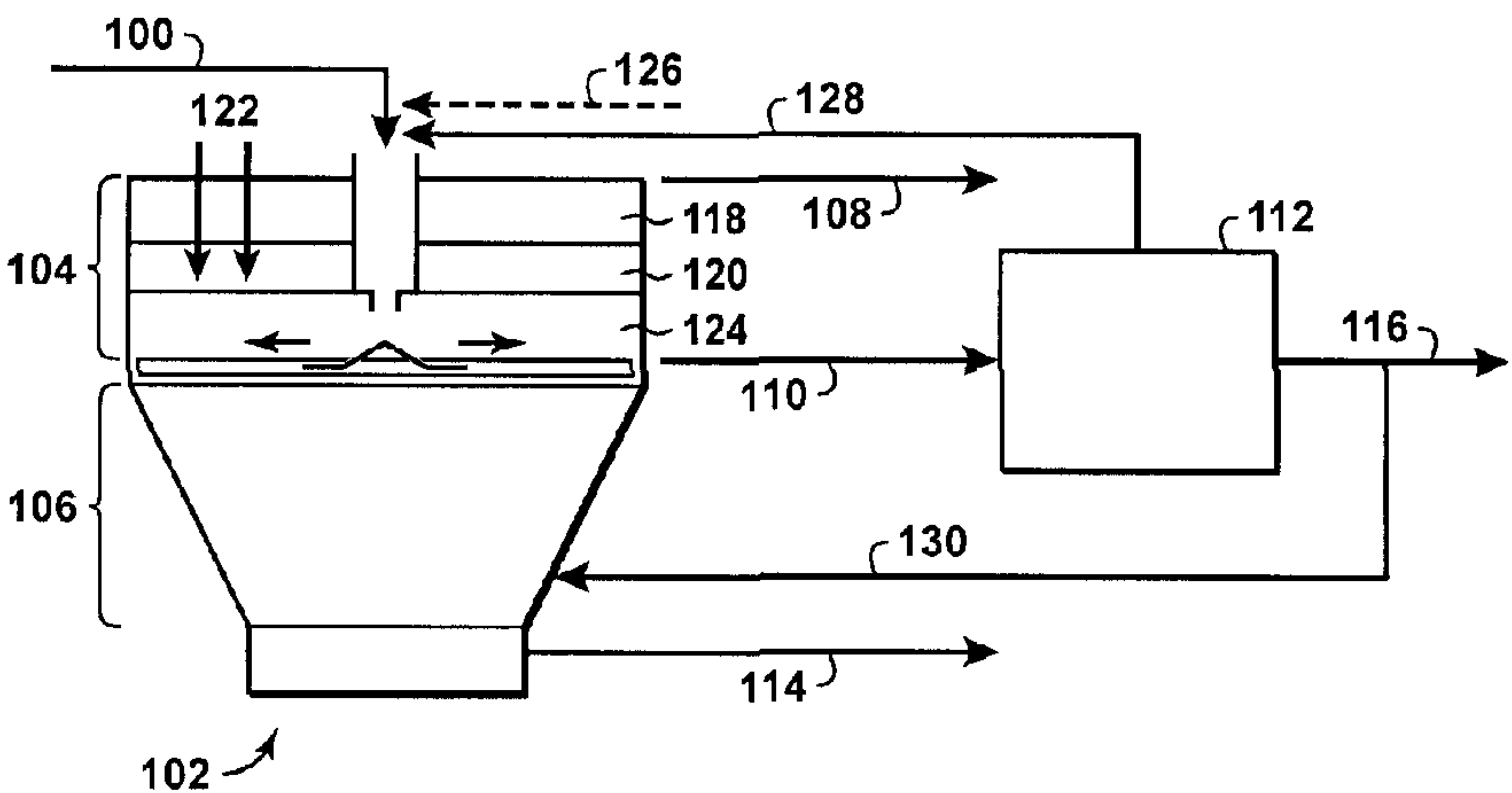
FIG. 8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