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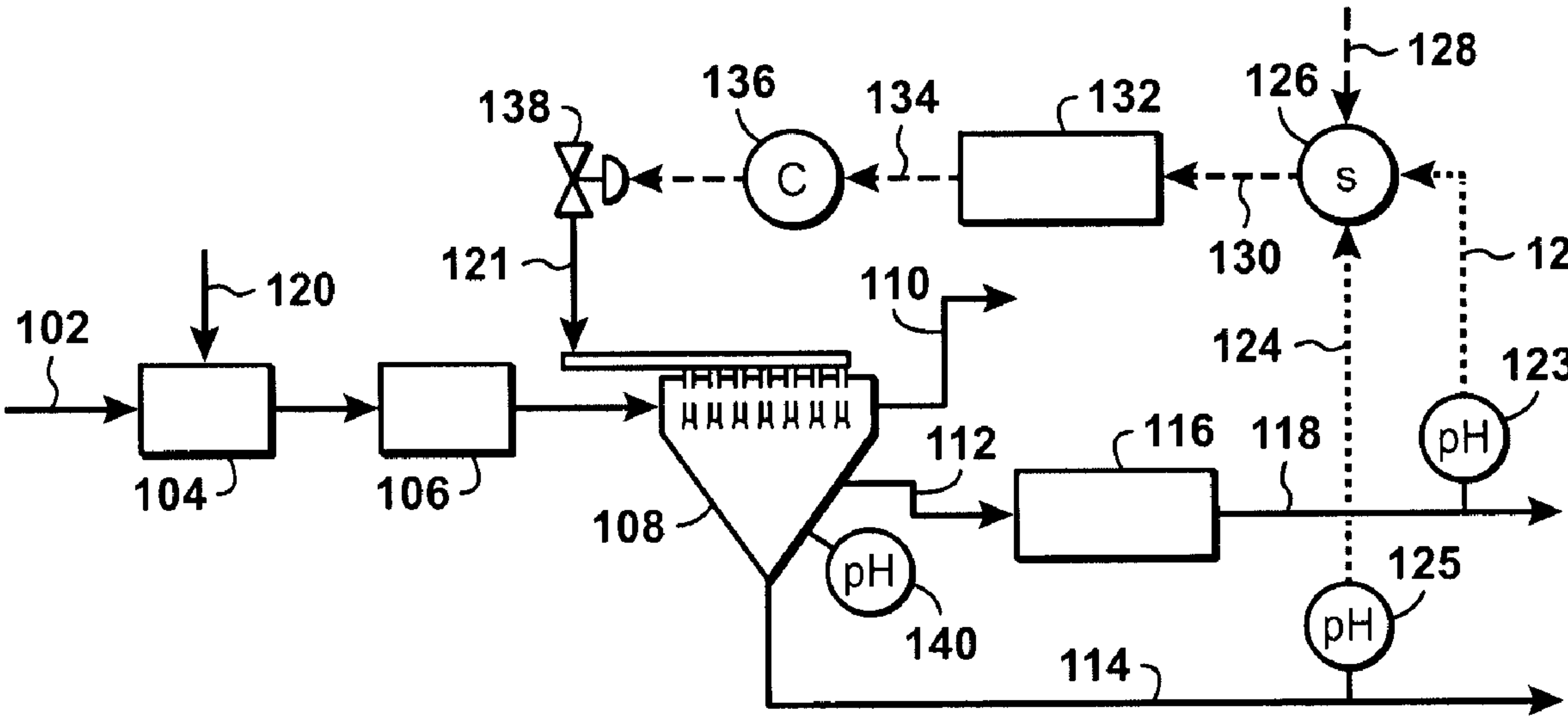
(54) **Titre : EXTRACTION DU BITUME EMPLOYANT UNE AIDE DE PROCEDE**
(54) **Title: BITUMEN EXTRACTION USING A PROCESS AID**



(57) **Abrégé/Abstract:**
Disclosed is a method comprising providing an oil sand slurry stream stemming from an oil sand ore; processing the oil sand slurry stream into bitumen froth, middlings, and coarse sand tailings (CST), including using a primary separation cell (PSC); and adding an acidic process aid beneath a froth layer in the PSC or to the middlings, for reducing a pH level beneath the froth layer in the PSC or of the middlings, for assisting bitumen and air attachment and for reducing solids in the bitumen froth or a froth recycle stream.

ABSTRACT

Disclosed is a method comprising providing an oil sand slurry stream stemming from an oil sand ore; processing the oil sand slurry stream into bitumen froth, middlings, and coarse sand tailings (CST), including using a primary separation cell (PSC); and adding an acidic process aid beneath a froth layer in the PSC or to the middlings, for reducing a pH level beneath the froth layer in the PSC or of the middlings, for assisting bitumen and air attachment and for reducing solids in the bitumen froth or a froth recycle stream.

BITUMEN EXTRACTION USING A PROCESS AID

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

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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, 20-30 wt. % water, and 10-20 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.

[0011] From the PSC, the middlings, which may comprise bitumen and about 10-40 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. Fine 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 water-based oil sand extraction.

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SUMMARY

[0013] It is an object of the present disclosure to provide an alternative method of water-based oil sand extraction.

[0014] Disclosed is a method comprising providing an oil sand slurry stream stemming from an oil sand ore; processing the oil sand slurry stream into bitumen froth, middlings, and coarse sand tailings (CST), including using a primary separation cell (PSC); and adding an acidic process aid beneath a froth layer in the PSC or to the middlings, for reducing a pH level beneath the froth layer in the PSC or of the middlings, for assisting bitumen and air attachment and for reducing solids in the bitumen froth or a froth recycle stream.

[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 method including adding a process aid beneath a froth layer in the PSC.

[0018] Fig. 2 is a schematic of a method including adding a process aid to the middlings.

[0019] Fig. 3 is a graph of middlings pH as a function of caustic dosage, from different ores.

[0020] Fig. 4 is a graph of froth quality as a function of middlings pH, from different ores.

[0021] Fig. 5A is a graph of froth solids as a function of acid injection.

[0022] Fig. 5B is a graph of bitumen recovery as a function of acid injection.

[0023] Fig. 6A is a graph of middlings solids wt. % as a function of post-conditioning acid injection after insufficient bitumen liberation (inadequate caustic addition).

[0024] Fig. 6B is a graph of approximated bitumen recovery as a function of post-conditioning acid injection after insufficient bitumen liberation (inadequate caustic addition).

[0025] Fig. 7A is a graph of middlings solids wt. % as a function of post-conditioning acid injection after sufficient bitumen liberation (adequate caustic addition).

[0026] Fig. 7B is a graph of middlings fines wt. % (stream basis) as a function of post-conditioning acid injection after sufficient bitumen liberation (adequate caustic addition).

[0027] Fig. 7C is a graph of approximated bitumen recovery as a function of post-conditioning acid injection after sufficient bitumen liberation (adequate caustic addition).

[0028] Fig. 7D is a graph of middlings SFR (sand to fines ratio) as a function of post-conditioning acid injection after sufficient bitumen liberation (adequate caustic addition).

[0029] Fig. 8 is a graph of flocculent dosage requirements for middlings samples generated using different acidification level (post-conditioning).

[0030] Figs. 9A-9D are graphs of froth solids recovery versus primary bitumen recovery for different ore grades.

[0031] Figs. 10A and 10B are graphs of froth solids wt. % versus primary bitumen recovery for different ore grades.

[0032] 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

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drawn to scale, but are drafted for purposes of convenience and clarity in illustrating various aspects of the disclosure.

DETAILED DESCRIPTION

[0033] 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.

[0034] 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.

[0035] Throughout this disclosure, where a range is used, any number between or inclusive of the range is implied.

[0036] 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

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liquids. Hydrocarbon compounds may be aliphatic or aromatic, and may be straight chained, branched, or partially or fully cyclic.

[0037] "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.

[0038] "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.

[0039] "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.

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[0040] "Coarse particles" are generally defined as those solids having a size of greater than 44 microns (μm).

[0041] The term "solvent" as used in the present disclosure should be understood to mean either a single solvent, or a combination of solvents.

[0042] 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.

[0043] 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.

[0044] 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.

[0045] In a PSC, bitumen froth is separated from the majority of water and solids. A feed to the PSC comprises bitumen, solids, and water, which may be an aerated oil sand slurry from a hydrotransport line stemming from mined oil sand ore. A PSC may comprise a cylindrical section 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 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 may comprise a froth layer, an underwash layer into which an underwash is added, and a middlings layer. The "middling layer" inside the PSC means the phase in the PSC beneath the bitumen froth and above the CST. Three streams typically leave the PSC, namely, a bitumen froth comprising the majority of the bitumen from the oil sand which is withdrawn near the top of the PSC, middlings comprising some bitumen which is withdrawn near the bottom of the cylindrical section of the PSC and which are sent to flotation cells for secondary recovery of bitumen, and a coarse sands tailings (CST) which are withdrawn at the bottom of the PSC. The CST may comprise water and the majority of solids from the oil sand slurry.

[0046] The main objective in the PSC is to achieve maximum separation between product (bitumen froth) and waste components (water and solids). Good solids separation from the froth and good distribution of solids in the PSC outlet streams are advantageous for several reasons. Solids carried over with the bitumen froth reduces froth quality leading to potential inefficiencies in downstream equipment (e.g. high frequency of filters flushing or cleaning, and limited tank capacity) or downtime issues (e.g. pipeline or equipment erosion issues and reduced equipment reliability). Unpredictable middlings solids wt. % or unexpected sand-to-fines (SFR) variations in the flotation tailings stream may lead to potential instabilities in the thickener and inadequate floculent dosification. Therefore, it is advantageous to be able to tune the PSC solids distribution to assist the stability of downstream operations.

[0047] One method may comprise:

a. providing an oil sand slurry stream stemming from an oil sand ore;
b. processing the oil sand slurry stream into bitumen froth, middlings, and coarse sand tailings (CST), including using a primary separation cell (PSC); and

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c. adding an acidic process aid beneath a froth layer in the PSC or to the middlings, for reducing a pH level beneath the froth layer in the PSC or of the middlings, for assisting bitumen and air attachment and for reducing solids in the bitumen froth or a froth recycle stream.

[0048] The oil sand slurry stream may be any suitable oil sand slurry stream and may stem from mined oil sand. The oil sand slurry stream may be a feed stream to a PSC. The oil sand slurry stream may comprise 5 to 10 wt. % bitumen, 30 to 60 wt. % water, and 40 to 60 wt. % solids. The middlings may comprise 0.5 to 3 wt. % bitumen, 60 to 85 wt. % water, and 10 to 40 wt. % solids.

[0049] A sufficient amount of the acidic process aid may be added to reduce the pH level beneath the froth layer in the PSC or of the middlings to below 8.4. The acidic process aid may be added both beneath the froth layer in the PSC and to the middlings. The acidic process aid may also be added to a middlings withdrawal stream for reducing solids in a froth recycle stream. The addition of the acidic process aid in the PSC is below the froth layer to preserve bitumen recovery in the froth layer.

[0050] The method may further comprise providing the oil sand ore and adding a caustic process aid to the oil sand ore to form the oil sand slurry stream having a pH above 8.0, or above 8.2, or above 8.4, for assisting bitumen liberation from sand from the oil sand ore. An additional acidic process aid may be added to the CST.

[0051] The acidic process aid may comprise HCl, SO_x, NO_x, HF, H_2SO_4, HNO_3, H_3PO_4, boric acid, formic acid, acetic acid, propionic acid, butyric acid, valeric acid, phosphonic acid, polyphosphonocarboxylic acid, Poly-Phosphino Carboxyllic Acid, diethylenetriamine penta methylene-phosphonic acid, diethylenetriamine penta(methylene phosphonic acid), an acrylic acid polymer, a maleic acid polymer, NaH_2PO_4, $NaHCO_3$, or a combination thereof. The acidic process aid may comprise HCl. The acidic process aid may be introduced with dilution water, with underwash water, at an end of a hydrotransport line

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delivering the oil sand slurry stream, at a froth recycle stream pipe leading to the PSC, or at an inlet of the PSC.

[0052] The method may further comprise measuring at least one property of the oil sand ore and, based on this measurement, adjusting a dosage of the acidic process aid. The method may further comprise measuring a solids content or solids content and particle size distribution (PSD) of the bitumen froth and, based on this measurement, adjusting a dosage of the acidic process aid. The method may further comprise measuring a particle size distribution (PSD) of fine tailings (FT) downstream of the middlings and, based on this measurement, adjusting a dosage of the acidic process aid. The method may further comprise measuring a pH level beneath a froth layer in the PSC and, based on this measurement, adjusting a dosage of the acidic process aid. The method may further comprise measuring a pH level of fine tailings (FT) downstream of the middlings and, based on this measurement, adjusting a dosage of the acidic process aid. The method may further comprise measuring a pH level of the CST and, based on this measurement, adjusting a dosage of the acidic process aid. The measurement may be sent to a setpoint hub, wherein the set point hub additionally receives a desired setpoint. The setpoint hub may compare the measurement to the desired setpoint, and send a signal to a controller. The controller may send a signal to a dosage controller which controls the dosage of the acidic process aid. The measurement and dosage adjustment may be effected automatically. The measurement may be effected online, inline, offline, or atline.

[0053] In one method, froth quality and PSC solids distribution may be improved by an acidification step during bitumen flotation. The acidification step may be accomplished by injecting a first process aid during conditioning to increase a pH to above 8.0, or above 8.2, or above 8.4 to induce maximum bitumen liberation from the oil sand, and by injecting a second process aid to the PSC to acidify middlings water (i.e., reduce pH below 8.4) to facilitate bitumen-air attachment and to modify solids distribution. The second process aid may be HCl or another pH regulator. The second process aid injection may be accomplished using dilution water, underwash water, middlings stream, or alternative PSC injection streams below the froth layer. The second process aid may be injected in the middlings withdrawal stream to improve secondary froth quality. The first process aid may be controlled depending on ore properties. The second process aid may be controlled by feedback control from froth solids wt%, froth solids PSD, FT solids PSD, pH measurements in the PSC (including a water layer immediately below an underwash injection level and/or FT and/or CST streams). The second process aid may also be injected directly into a CST stream.

[0054] Fig. 1 is a schematic of a method including adding a process aid beneath a froth layer in the PSC. An oil sand slurry stream (102) comprising mined bituminous ore is mixed with water in an ore preparation plant (OPP) (104). The oil sand slurry stream (102) is passed through hydro-transport (HT) (106) and is introduced into a primary separation cell (PSC) (108). The PSC produces bitumen froth (110), middlings (112), and coarse sand tailings (CST) (114). The middlings are introduced into flotation cells (116) producing fine tailings (FT) (118). A process aid (120) (e.g., caustic) is added to the oil sand slurry stream (102). An acidic process aid (121) may be added beneath a froth layer in the PSC, for reducing a pH level beneath the froth layer in the PSC, for assisting bitumen and air attachment (i.e. by increasing bitumen hydrophobicity) and for reducing solids in the bitumen froth. The pH measurements (123,125, and 140) may be taken of at least one of the FT (118), the CST (114), and a middling layer inside the PSC (108). For simplicity in the Fig. 1, the water chemistry parameter measurements at two locations, the FT (118) and the CST (114) are shown feeding back (122 and 124) from separate pH analyzers (123 and 125) to a set point hub (126). Desired set point data (128) is fed into the set point hub (126). Based on the pH measurement(s) (122 and 124) and the desired set point data (126), a set point offset signal (130) may be fed to a feedback controller (132). A control signal (134) may be sent from the feedback controller (132) to a controller (136). The controller (136) may send a signal to an acidic process aid dosage controller (138) for dosing acidic process aid (121) addition. It should be noted that while, for simplicity, the description of Fig. 1 only illustrates the feedback signal from the pH analyzers (123 and 125) located on the FT (118) and CST (114) of the water-based oil extraction process, similarly, a pH analyzer (140) shown in the PSC (108) may be utilized in a similar manner. Additionally, the pH analyzers may be used either individually or in any combination.

[0055] Fig. 2 is a schematic of a method including adding a process aid to the middlings. An oil sand slurry stream (202) comprising mined bituminous ore is mixed with water in an ore preparation plant (OPP) (204). The oil sand slurry stream (202) is passed through hydro-transport (HT) (206) and is introduced into a primary separation cell (PSC) (208). The PSC produces bitumen froth (210), middlings (212), and coarse sand tailings (CST) (214). The middlings are introduced into flotation cells (216) producing fine tailings (FT) (218) and a froth recycle stream (217). A process aid (220) (e.g., caustic) is added to the oil sand slurry stream (202). An acidic process aid (221) may be added to the middlings (212), for reducing a pH level of the middlings (212), for assisting bitumen and air attachment and for reducing solids in the froth recycle stream (217). The froth recycle stream (217) may be recycled back to the inlet of the PSC (208) (not shown). Fig. 2 illustrates a pH analyzer (215) located on the FT stream (218). The pH measurement (222) is shown feeding back from the pH analyzer (215) to a set point hub (226). Desired set point data (228) is fed into the set point hub (226). Based on the pH measurement (222) and the desired set point data (228), a set point offset signal (230) may be fed to a controller (236). The controller (236) may send a signal to an acidic process aid dosage controller (238) for dosing acidic process aid (221) addition.

[0056] Fig. 3 is a graph of lab generated middlings pH as a function of caustic dosage, from different ores. The different ores are HF (high fines ore with more than 20 wt. % fines); BC (base case with about 11-18 wt. % fines); and LF (low fines ore with less than 11 wt. % fines). This demonstrates that middlings pH is significantly affected by caustic dosage.

[0057] Fig. 4 is a graph of lab generated froth quality (as indicated by bitumen to solids ratio (B/S)) as a function of middlings pH, from different ores. The different ores are HF (high fines ore with more than 20 wt. % fines); BC (base case with about 11-18 wt. % fines); and LF (low fines ore with less than 11 wt. % fines). This demonstrates that high middlings pH leads to poor froth quality. Low froth quality (i.e. bitumen/solids ratio of less than 4) is more commonly observed with low fines ore (i.e. less 11 wt. % fines) or caustic over-dosage (Region II, pH above 8.6).

[0058] Fig. 5A is a graph of froth solids as a function of acid injection. Fig. 5B is a graph of bitumen recovery as a function of acid injection. In respect of Fig. 5A and 5B, caustic was added in a conditioning step in the lab scale experiments. Acid injection in the PSC inlet stream could counterbalance negative effects of high middlings pH. Acid injection post-conditioning reduces froth solids (Fig 5A) without significant effects on bitumen recovery (Fig 5B). The benefits of froth solids reduction are more pronounced in low fines ores.

[0059] Acid addition in the middlings withdrawal stream can potentially improve secondary froth quality (froth from flotation circuit). If secondary froth quality is high enough, it could be mixed with the primary froth product, instead of being recycled back to the PSC inlet. In this particular scenario, the amount of froth recycle could be replaced by hydrotransport slurry, increasing PSC throughput.

[0060] Acid injection may facilitate preferential removal of coarse particles (above 44 μm). Coarse particles are expected to be more detrimental for erosion issues in the froth pipelines.

[0061] Low pH in the PSC is typically banned given that it is expected to increase middlings viscosity and thus reduce bitumen recovery. Lab scale testing confirmed two different scenarios, A and B:

[0062] A - Acid injection (post-conditioning) after insufficient bitumen liberation

[0063] Experiments conducted with low/inadequate caustic addition during conditioning, followed by systematic acid addition during a flotation step (via dilution water). Fig. 6A is a graph of middlings solids wt. % as a function of post-conditioning acid injection after insufficient bitumen liberation (inadequate caustic addition). Fig. 6B is a graph of approximated bitumen recovery as a function of post-conditioning acid injection after insufficient bitumen liberation (inadequate caustic addition). In respect of Figs. 6A and 6B, caustic was added during a conditioning step, and an acid was added during a flotation step in these lab scale experiments. In these cases (Figs. 6A and 6B), middlings characteristics (solids wt. % and SFR) remained similar. However, bitumen recovery was significantly reduced as acid volume injected increased. This scenario is not recommended.

[0064] B- Acid injection (post-conditioning) after sufficient bitumen liberation

[0065] Experiments conducted with high enough caustic addition (to maximize bitumen liberation) during conditioning, followed by systematic acid addition during a flotation step (via dilution water). Fig. 7A is a graph of middlings solids wt. % as a function of post-conditioning acid injection after sufficient bitumen liberation (adequate caustic addition). Fig. 7B is a graph of middlings fines wt. % (stream basis) as a function of post-conditioning acid injection after sufficient bitumen liberation (adequate caustic addition). Fig. 7C is a graph of approximated bitumen recovery as a function of post-conditioning acid injection after sufficient bitumen liberation (adequate caustic addition). Fig. 7D is a graph of middlings SFR (sand to fines ratio) as a function of post-conditioning acid injection after sufficient bitumen liberation (adequate caustic addition). In respect of Figs. 7A-7D, caustic was added during a conditioning step, and an acid was added during a flotation step in these lab scale experiments. In these cases (Figs. 7A-D), pH adjustment of middlings allowed tuning of middlings sand-to-fines ratio (SFR) by controlling solids distribution. Middlings characteristics were tuned without detrimental effects on recovery (Figs. 7A-D).

[0066] A lab experiment was conducted comparing middlings conditioning using caustic and flotation without using an acid addition versus middlings conditioning using caustic using an acid addition. After seven days, qualitative observations of the middlings samples suggested a relative improvement of middlings behavior due to relatively faster solids settling. The characteristics of the middlings sample without acid addition were: 1) high turbidity of the carried fluid in the middlings samples, indicating a high amount of suspended solids; and 2) an unclear interface between the coarse solids and the carried fluid. The characteristics of the middlings sample with acid addition were: carried fluid in middlings samples looks more translucent, indicating a lower amount of suspended solids; and 2) a clear interface distinction between the settled coarse solids and the carried fluid.

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[0067] Fig. 8 is a graph of flocculent dosage requirements for middlings samples generated using different acidification level (post-conditioning). The conditioning used 150 ppm of NaOH (middlings samples generated from lab batch extraction tests) with acid addition post-conditioning (HCl: 0.1M).

[0068] Caustic addition during oil sand conditioning may be at a dosage high enough to maximize bitumen liberation (e.g. pH 8.0 - 8.4). Acid injection (e.g. HCl) in the PSC inlet (or the middlings withdrawal stream) may be at a dosage high enough to increase bitumen hydrophobicity which facilitates bitumen-air attachment and enhances water and solids rejection from the froth phase without affecting bitumen recovery. The acidic process aid may be added in a dosage of 5 and 100 ppmw.

[0069] Figs. 9A-9D are graphs of froth solids recovery versus primary bitumen recovery for different ore types (Lab batch extraction tests results). Bitumen recovery is defined as grams of bitumen in the froth divided by grams of bitumen in ore. Solids recovery is defined as grams of solids in the froth divided by grams of solids in ore. Fig. 9A- High fines ore, Fig. 9B - Medium fines ore, Fig. 9C - Low fines and high grade ore, Fig. 9D - Summary plot for different ore types. Bitumen recovery increases as caustic dosage increases. However, there is a threshold beyond which further increase in caustic dosage results in minimal increase in bitumen recovery while it does substantially increase froth solids recovery. Adding the acidic process aid in the PSC/flotation stage (*after* recovery has been maximized) reduces froth solids recovery.

[0070] Figs. 10A and 10B. are graphs illustrating the relationship between froth solids wt% versus primary bitumen recovery for different ore types (based on lab batch extraction tests results). Bitumen recovery typically increases with caustic addition. Depending on ore type and process water characteristics, process aid (i.e., caustic) can be as low as 0 ppm. For example high grade ore in operations using recycled water. In general, low fines/high grade ores are more prone to have high bitumen recoveries as well as high froth solids. Adding the acidic process aid in the PSC/flotation stage (*after* recovery has been maximized) effectively reduces froth solids wt% (as shown in Fig 10B).

[0071] 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 an oil sand slurry stream stemming from an oil sand ore;
   b) processing the oil sand slurry stream into bitumen froth, middlings, and coarse sand tailings (CST), including using a primary separation cell (PSC); and
   c) adding an acidic process aid beneath a froth layer in the PSC or to the middlings, for reducing a pH level beneath the froth layer in the PSC or of the middlings, for assisting bitumen and air attachment and for reducing solids in the bitumen froth or a froth recycle stream.

2. The method of claim 1, wherein a sufficient amount of the acidic process aid is added to reduce the pH level beneath the froth layer in the PSC or of the middlings to below 8.4.

3. The method of claim 1 or 2, wherein the acidic process aid is added both beneath the froth layer in the PSC and to the middlings.

4. The method of claim 3, further comprising adding the acidic process aid to a middlings withdrawal stream for reducing solids in the froth recycle stream.

5. The method of any one of claim 1 to 4, further comprising providing the oil sand ore and adding a caustic process aid to the oil sand ore to form the oil sand slurry stream having a pH above 8.0, for assisting bitumen liberation from sand from the oil sand ore.

6. The method of any one of claims 1 to 5, wherein an additional acidic process aid is added to the CST.

7. The method of any one of claims 1 to 6, wherein the acidic process aid comprises HCl, SO_x, NOx, HF, H_2SO_4, HNO_3, H_3PO_4, boric acid, formic acid, acetic acid, propionic acid, butyric acid, valeric acid, phosphonic acid, polyphosphonocarboxylic acid, Poly-Phosphino

Carboxyllic Acid, diethylenetriamine penta methylene-phosphonic acid, diethylenetriamine penta(methylene phosphonic acid), an acrylic acid polymer, a maleic acid polymer, NaH_2PO_4, $NaHCO_3$, or a combination thereof.

8. The method of any one of claims 1 to 6, wherein the acidic process aid comprises HCl.

9. The method of any one of claims 1 to 8, wherein the acidic process aid is introduced with dilution water, with underwash water, at an end of a hydrotransport line delivering the oil sand slurry stream, at a froth recycle stream pipe leading to the PSC, or at an inlet of the PSC.

10. The method of any one of claims 1 to 9, further comprising measuring at least one property of the oil sand ore and, based on this measurement, adjusting a dosage of the acidic process aid.

11. The method of any one of claims 1 to 9, further comprising measuring solids particle size distribution (PSD) of the bitumen froth and, based on this measurement, adjusting a dosage of the acidic process aid.

12. The method of any one of claims 1 to 9, further comprising measuring a particle size distribution (PSD) of fine tailings (FT) downstream of the middlings and, based on this measurement, adjusting a dosage of the acidic process aid.

13. The method of any one of claims 1 to 9, further comprising measuring a pH level beneath a froth layer in the PSC and, based on this measurement, adjusting a dosage of the acidic process aid.

14. The method of any one of claims 1 to 9, further comprising measuring a pH level of fine tailings (FT) downstream of the middlings and, based on this measurement, adjusting a dosage of the acidic process aid.

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15. The method of any one of claims 1 to 9, further comprising measuring a pH level of the CST and, based on this measurement, adjusting a dosage of the acidic process aid.

16. The method of any one of claims 10 to 15, wherein the measurement is sent to a setpoint hub, wherein the set point hub additionally receives a desired setpoint.

17. The method of claim 16, wherein the setpoint hub compares the measurement to the desired setpoint, and sends a signal to a controller.

18. The method of claim 17, wherein the controller sends a signal to a dosage controller which controls the dosage of the acidic process aid.

19. The method of any one of claims 1 to 18, wherein the oil sand slurry stream comprises 5 to 10 wt. % bitumen, 30 to 60 wt. % water, and 40 to 60 wt. % solids.

20. The method of any one of claims 1 to 19, wherein the middlings comprise 0.5 to 3 wt. % bitumen, 60 to 85 wt. % water, and 10 to 40 wt. % solids.

21. The method of any one of claims 10 to 18, wherein the measurement and dosage adjustment are effected automatically.

22. The method of any one of claims 10 to 18, wherein the measurement is effected online, inline, offline, or atline.

23. The method of any one of claims 1 to 22, wherein the acidic process aid is added in an amount of 5 to 100 ppmw.

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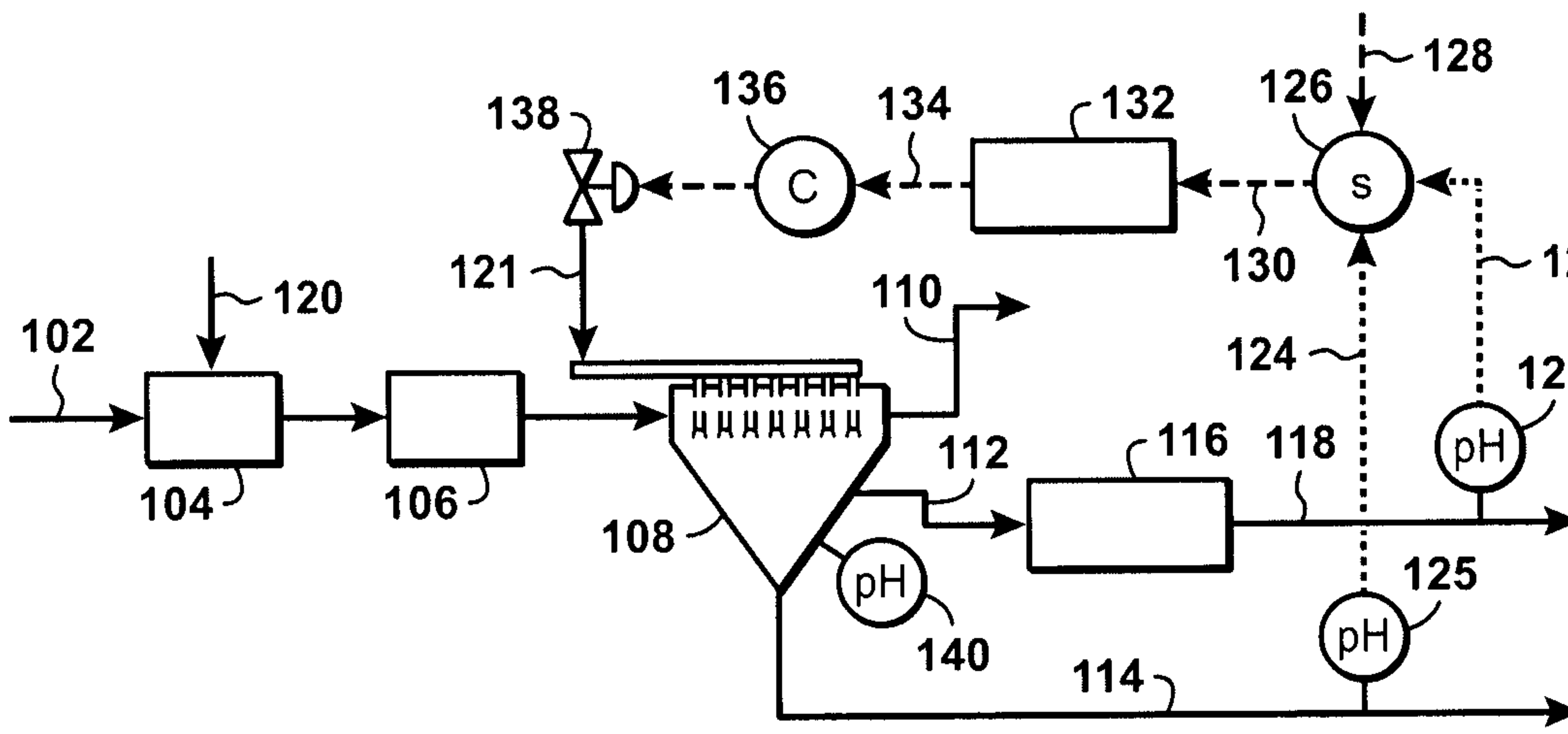
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136
C
134
132
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s
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124
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123
pH
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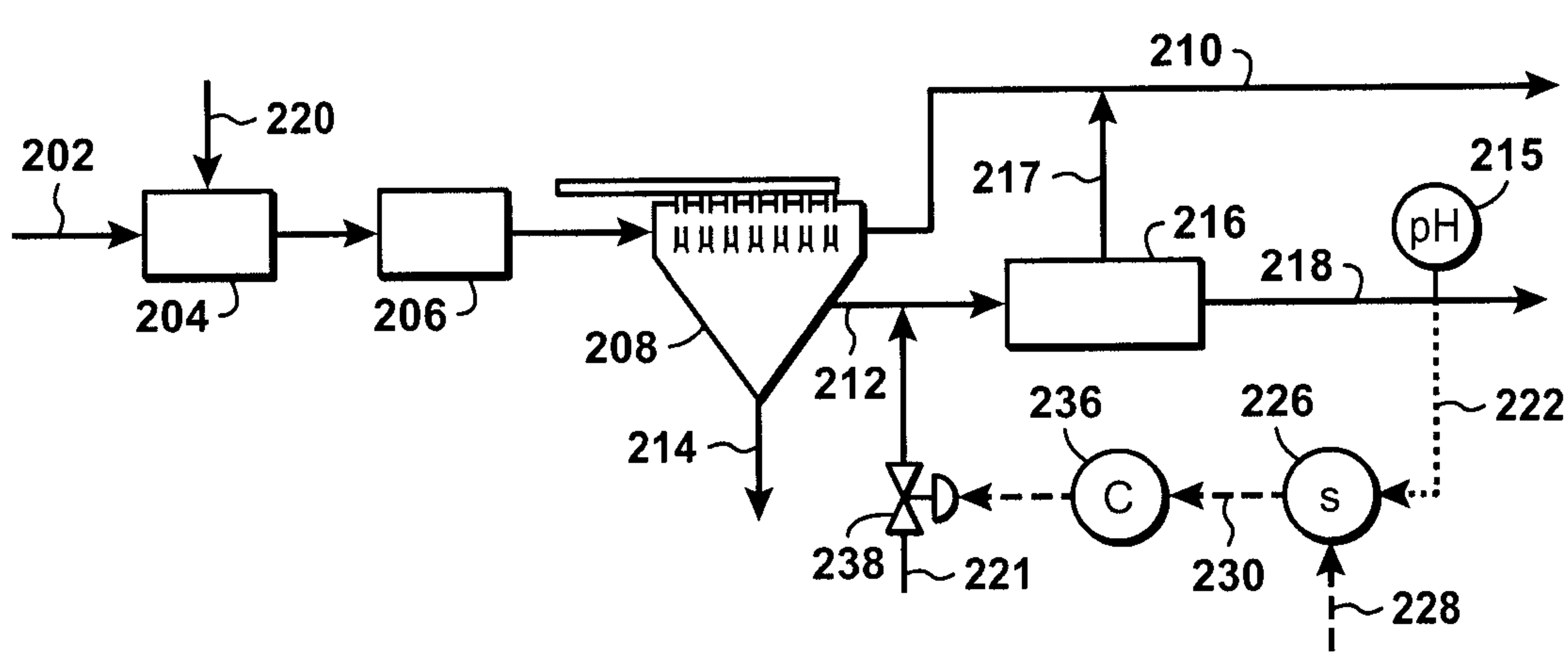
140
125
pH
114

FIG. 1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214
236
C
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s
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230
228

FIG. 2

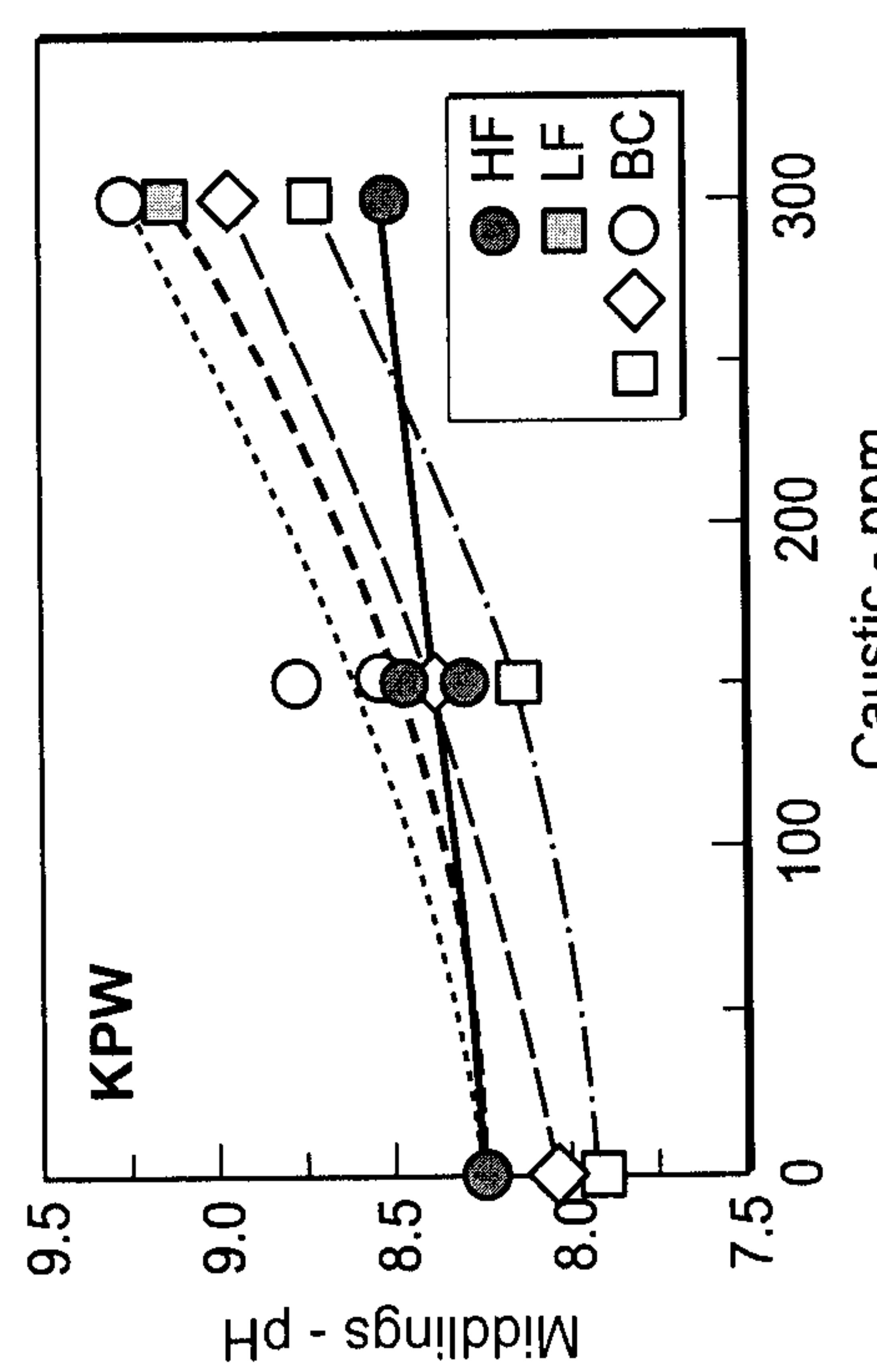

FIG. 3

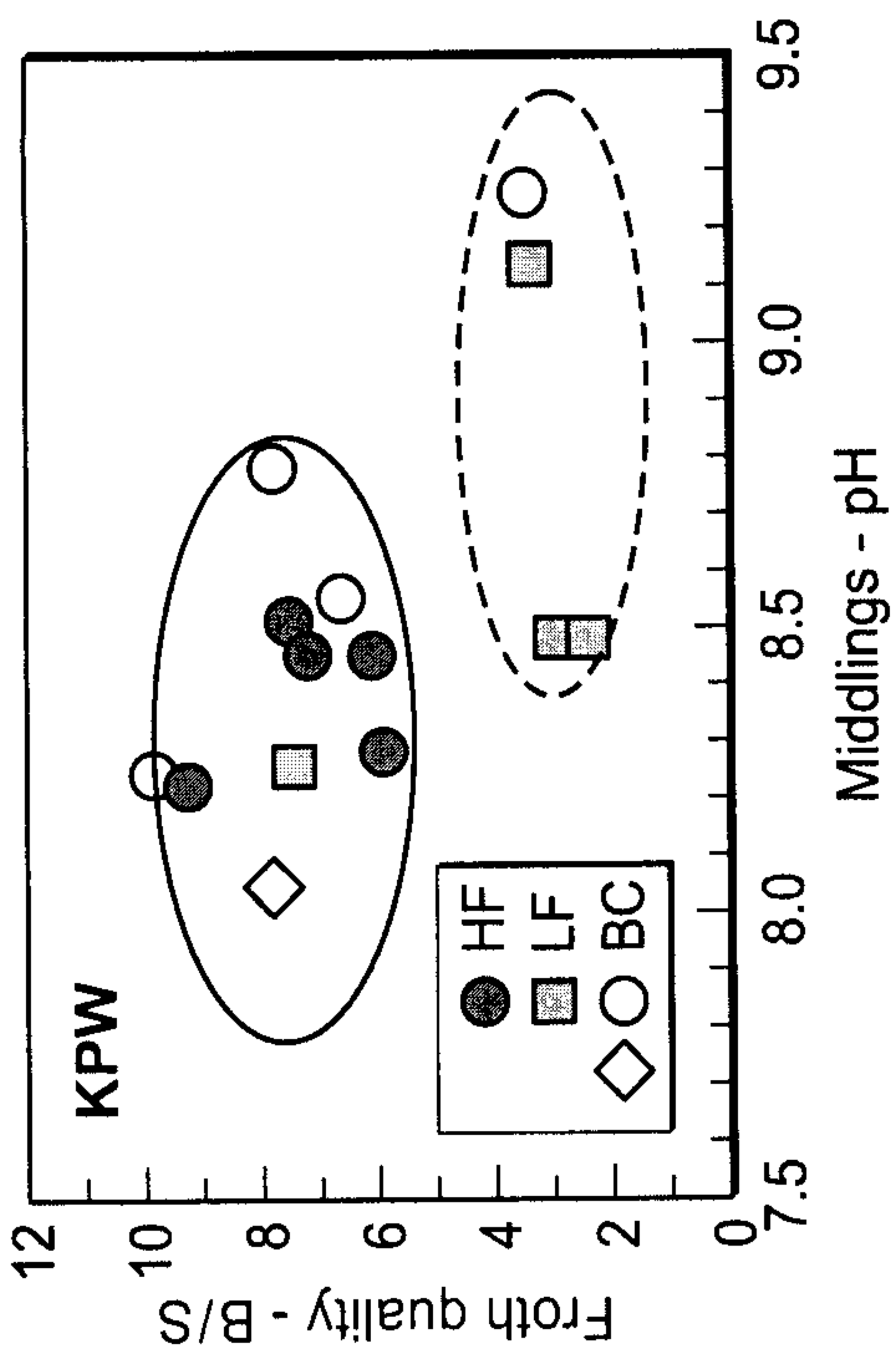

FIG. 4

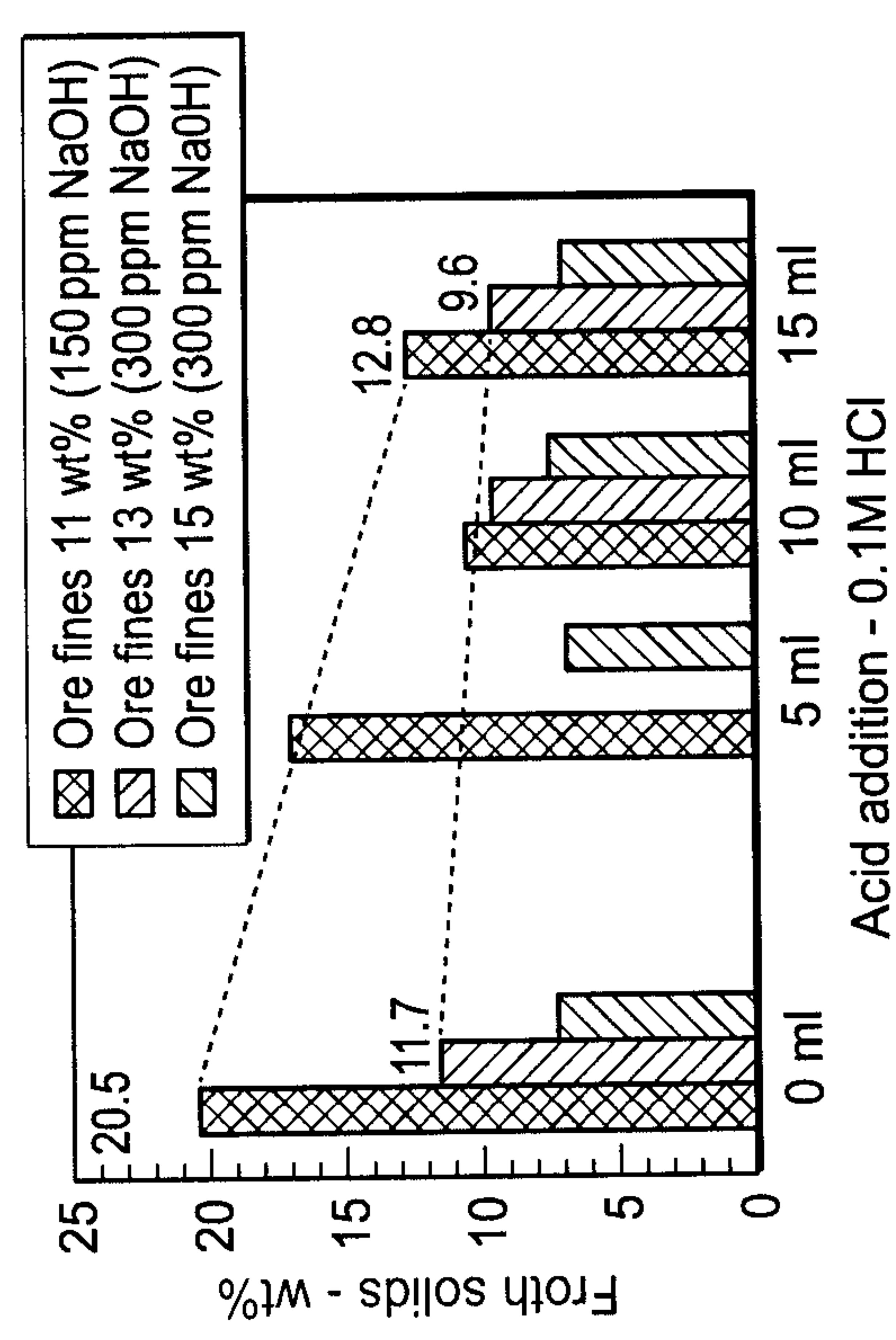

FIG. 5A

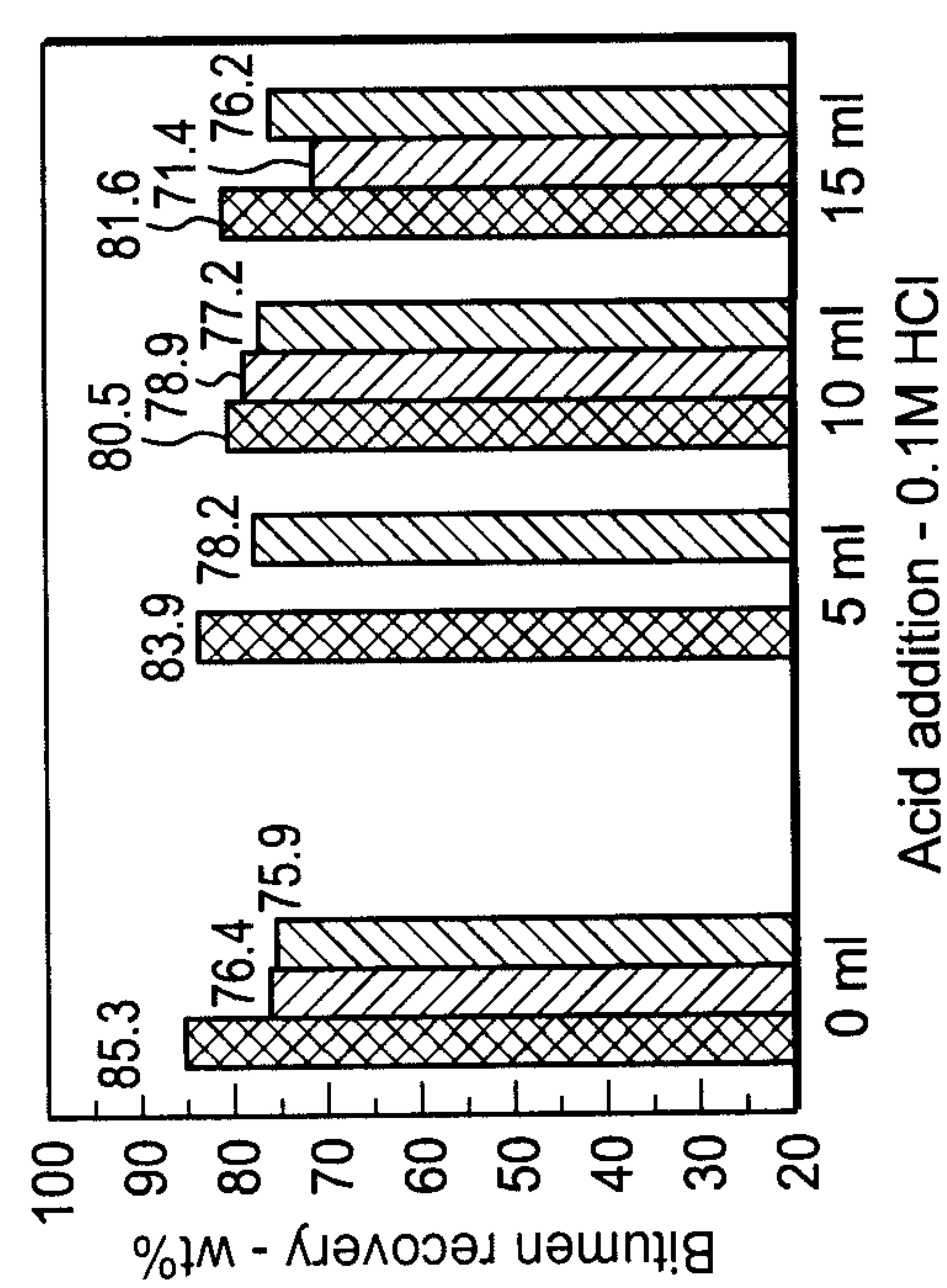

FIG. 5B

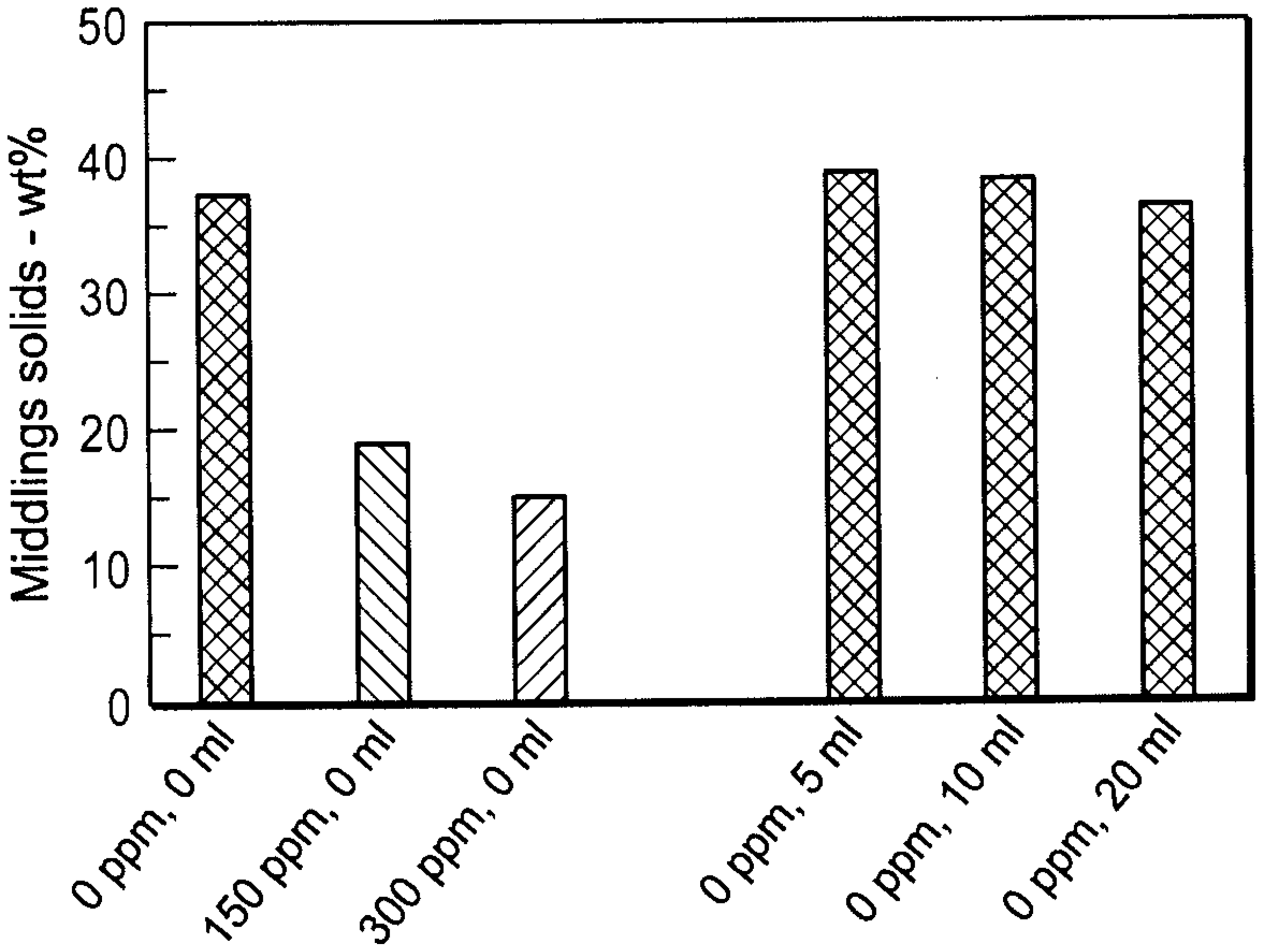
50
40
30
20
10
0
Middlings solids - wt%
0 ppm, 0 ml
150 ppm, 0 ml
300 ppm, 0 ml
0 ppm, 5 ml
0 ppm, 10 ml
0 ppm, 20 ml

FIG. 6A

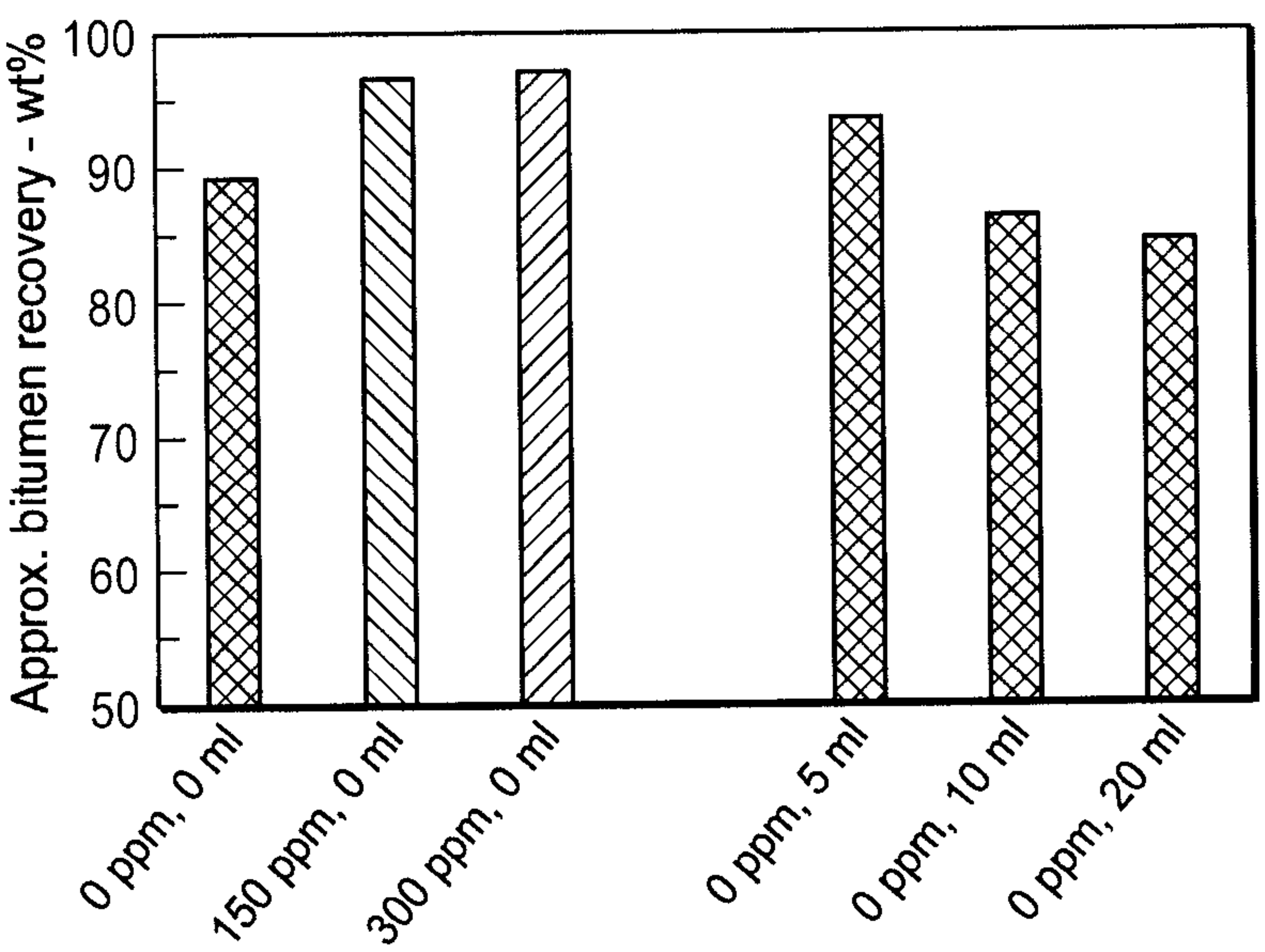
100
90
80
70
60
50
Approx. bitumen recovery - wt%
0 ppm, 0 ml
150 ppm, 0 ml
300 ppm, 0 ml
0 ppm, 5 ml
0 ppm, 10 ml
0 ppm, 20 ml

FIG. 6B

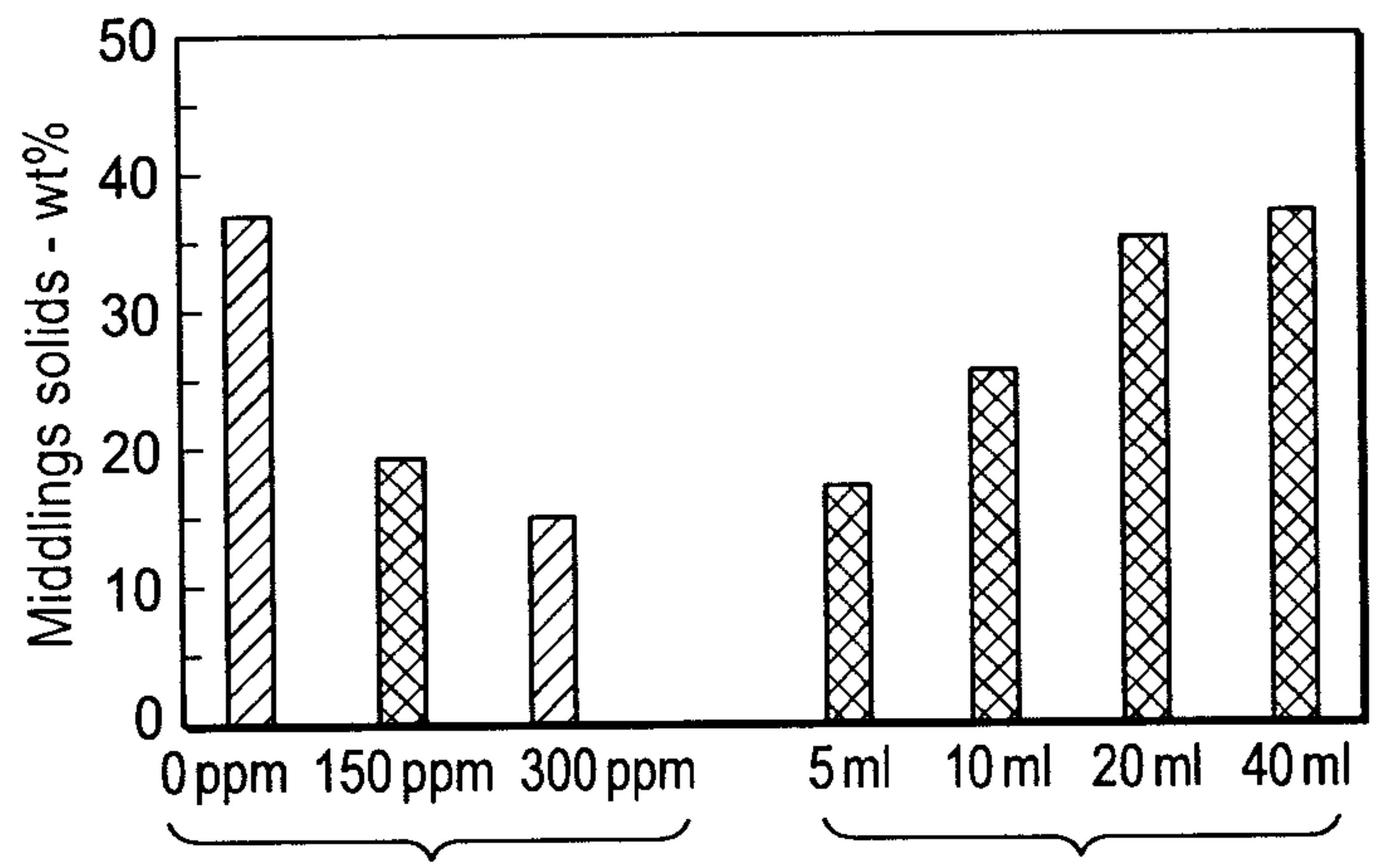

FIG. 7A

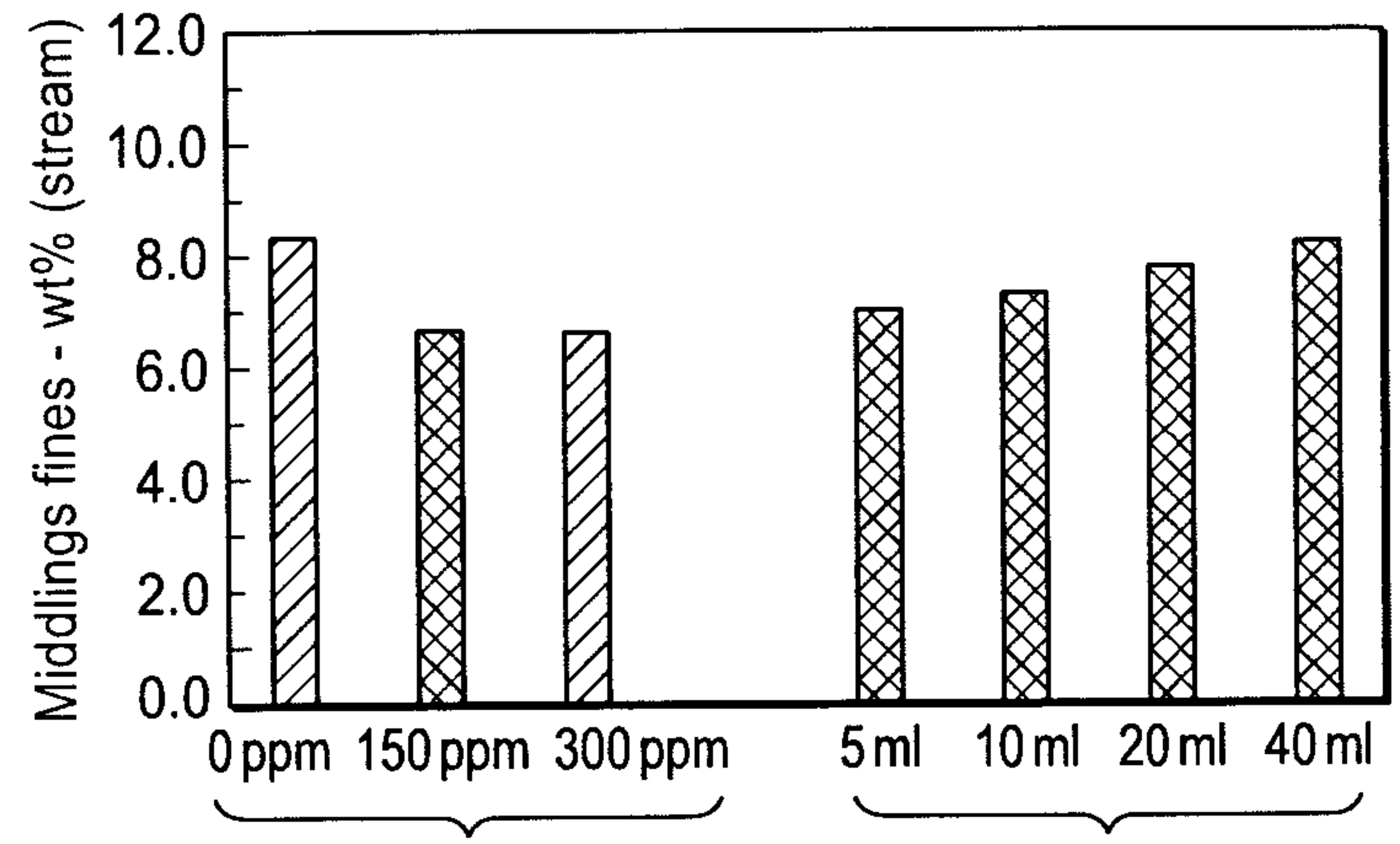

FIG. 7B

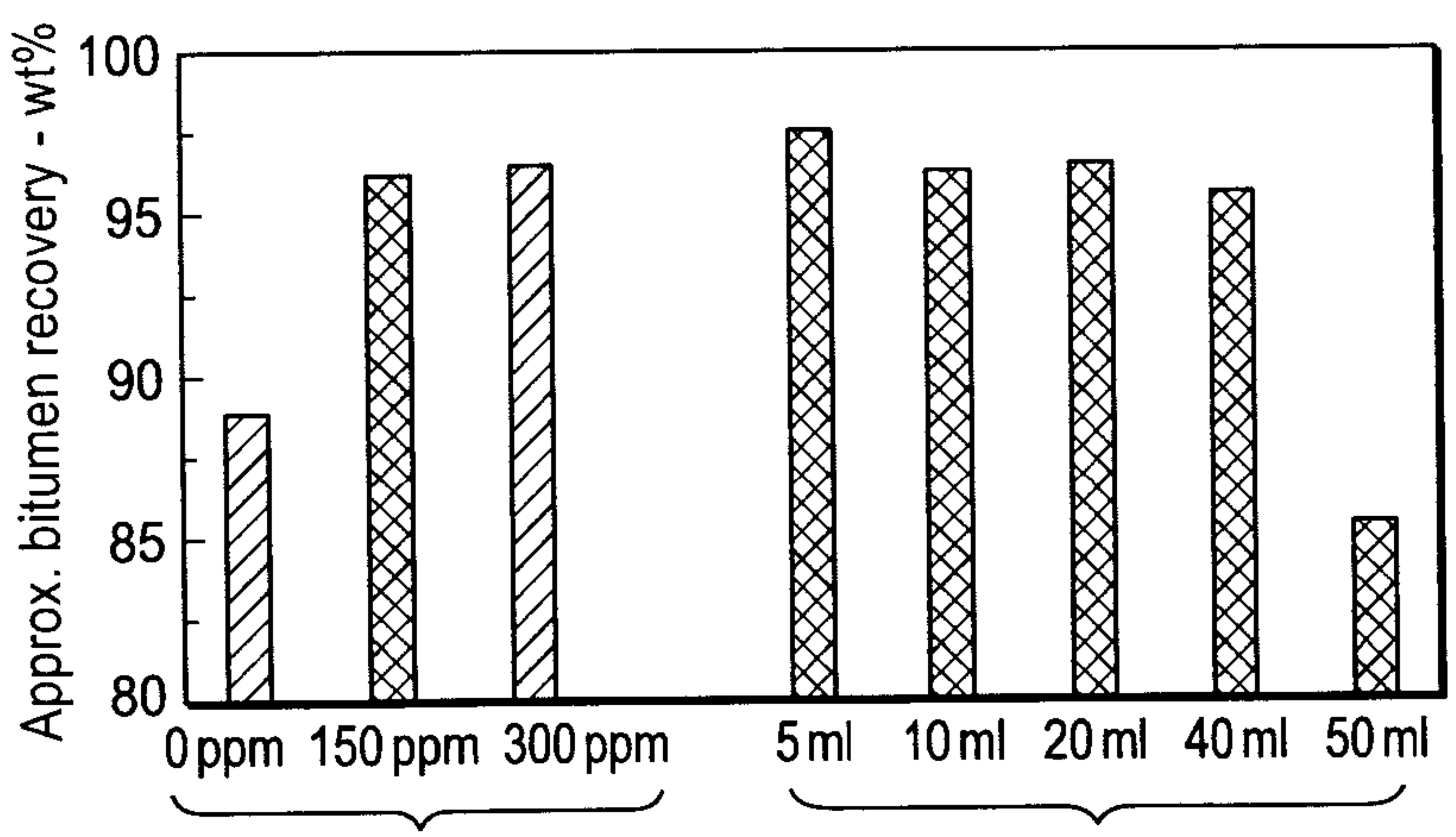

FIG. 7C

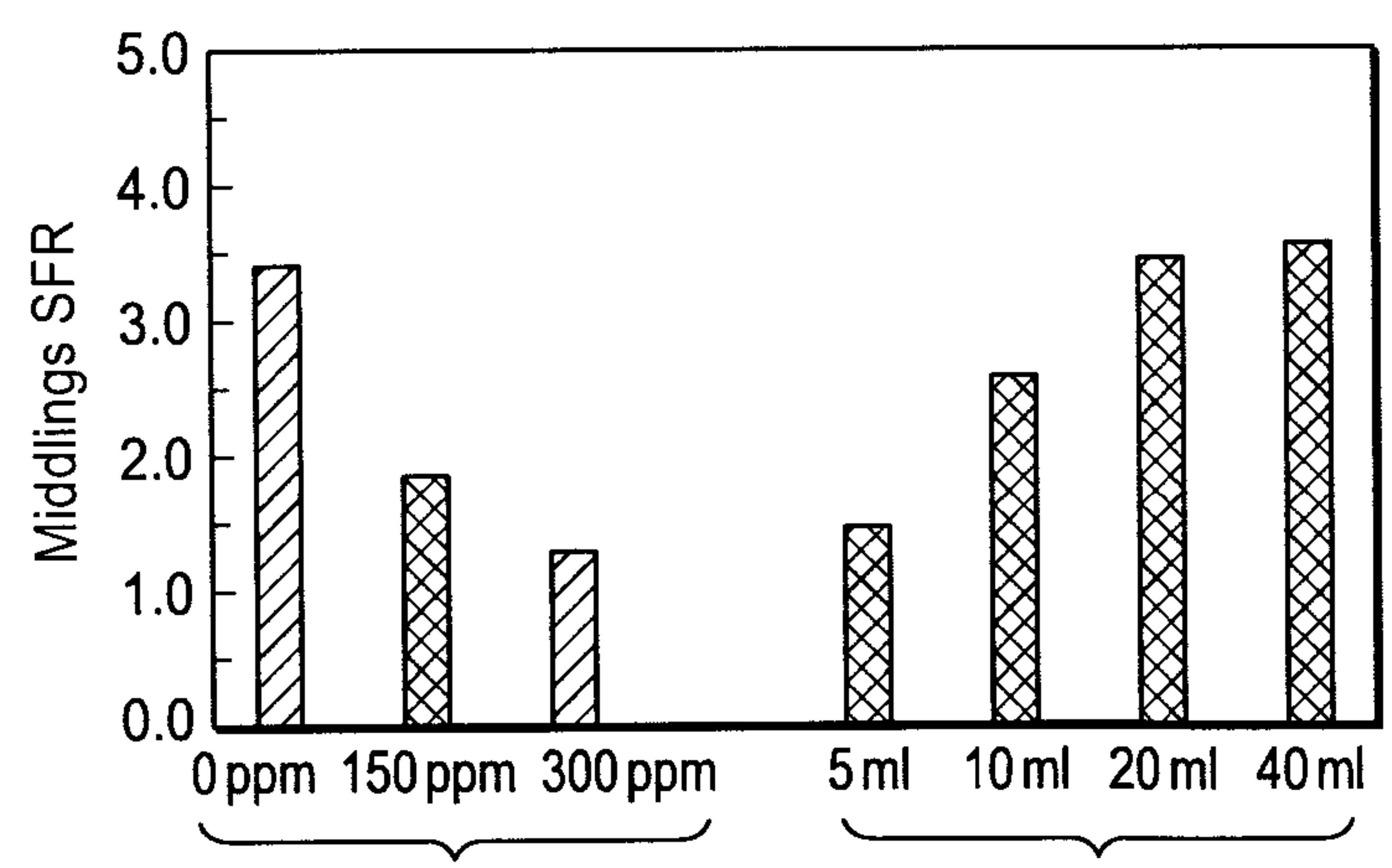

FIG. 7D

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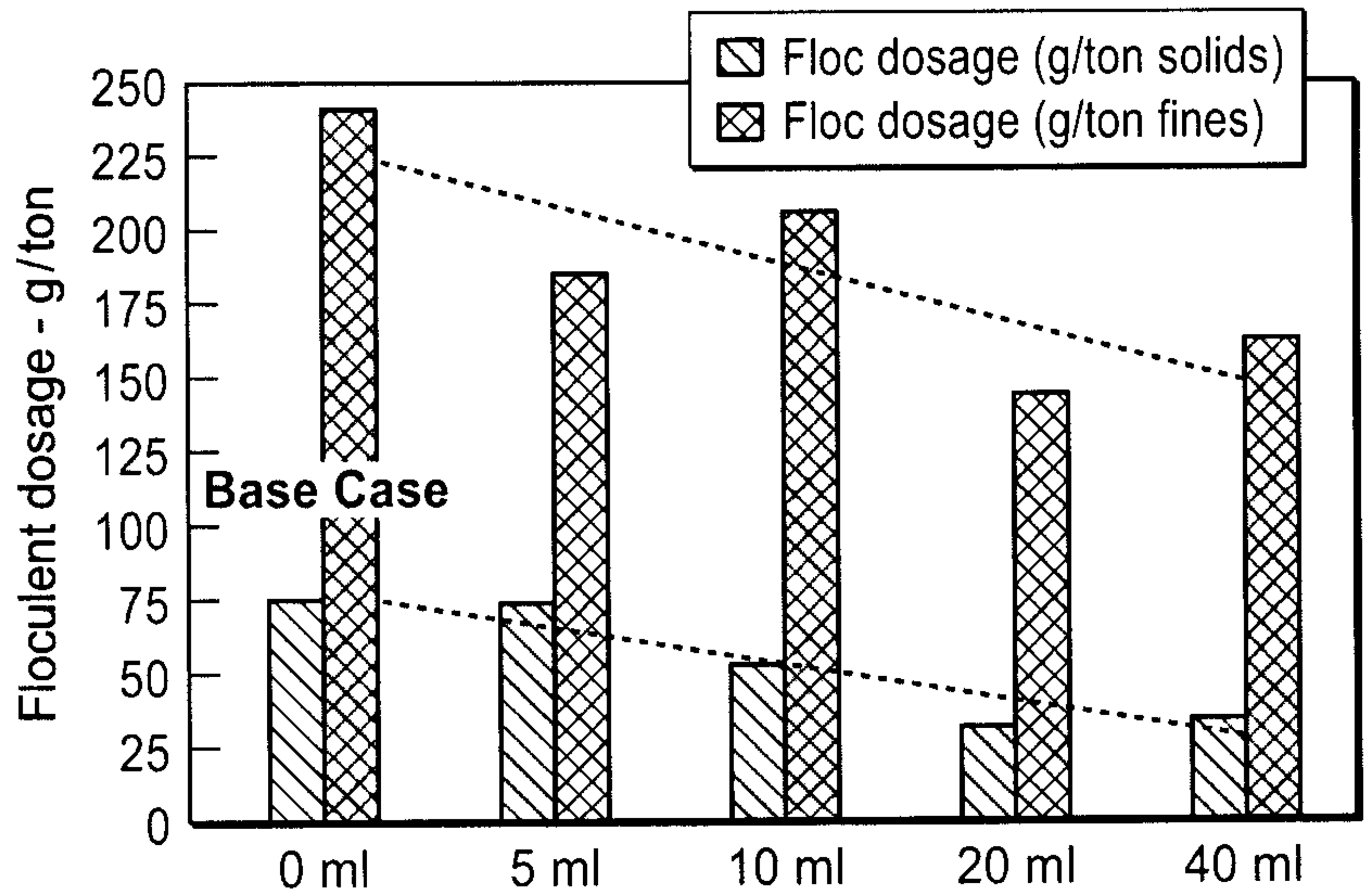
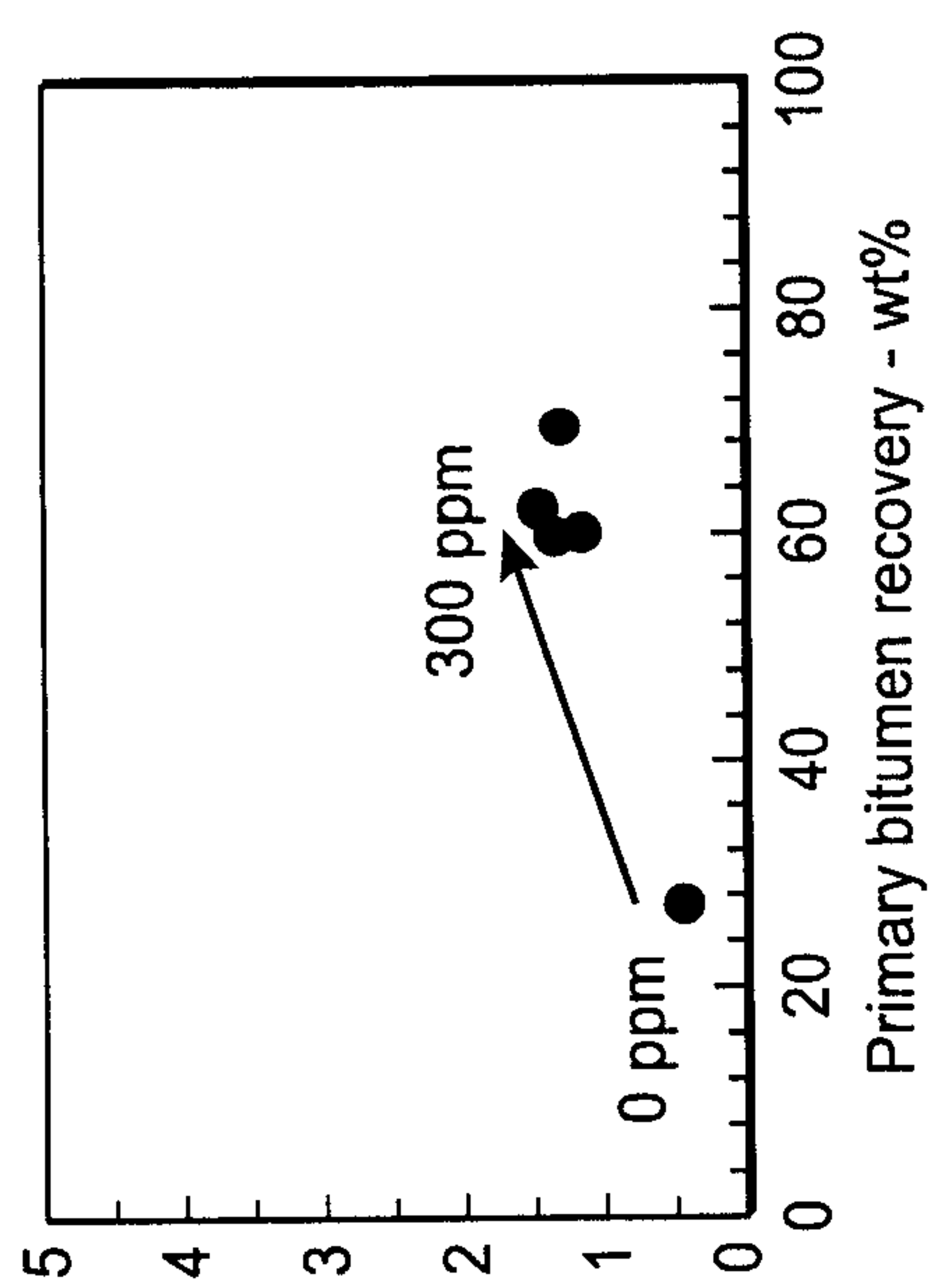
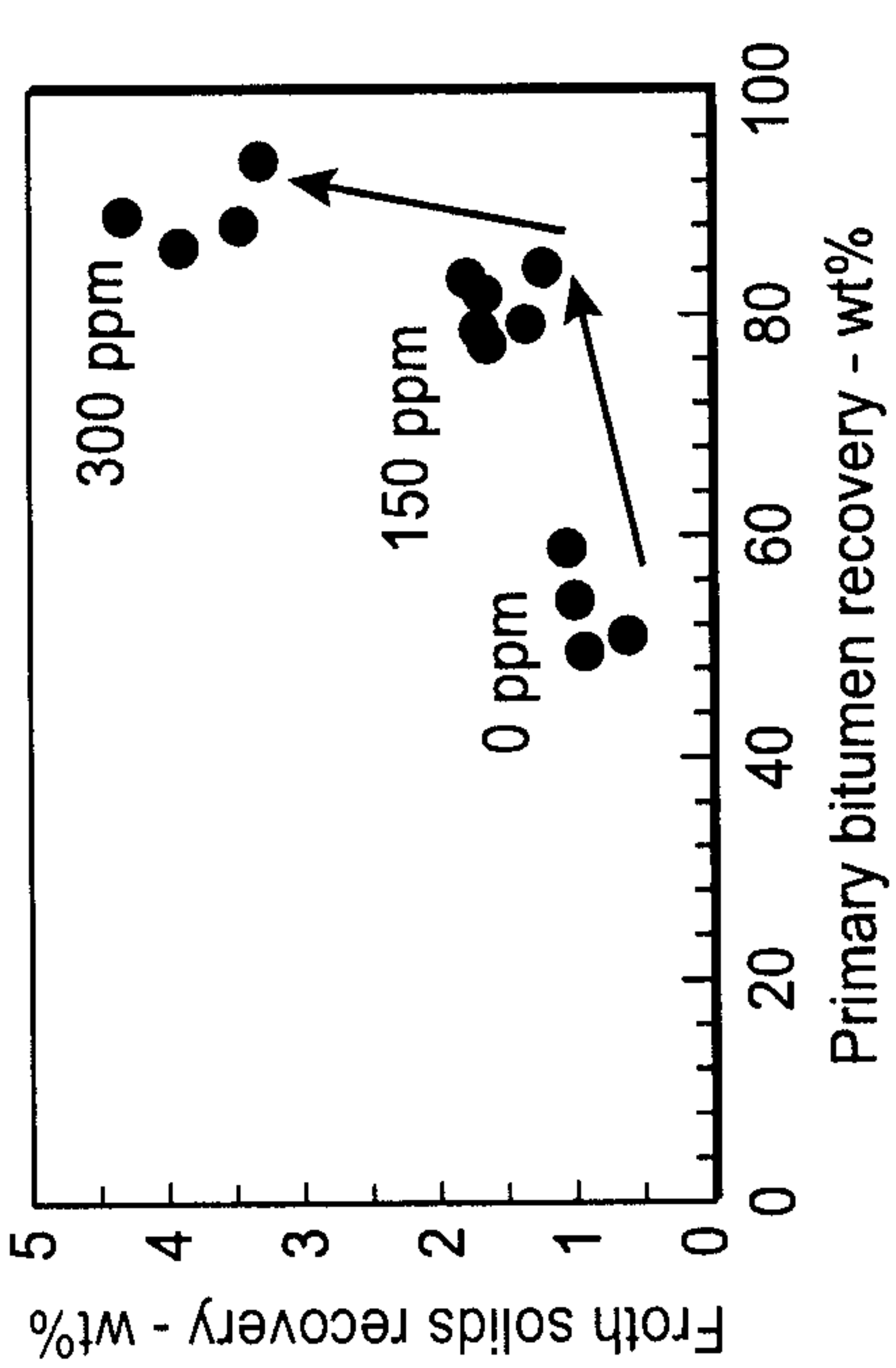

Floc dosage (g/ton solids)
Floc dosage (g/ton fines)
Floculent dosage - g/ton
250
225
200
175
150
125
100
75
50
25
0
Base Case
0 ml
5 ml
10 ml
20 ml
40 ml

FIG. 8



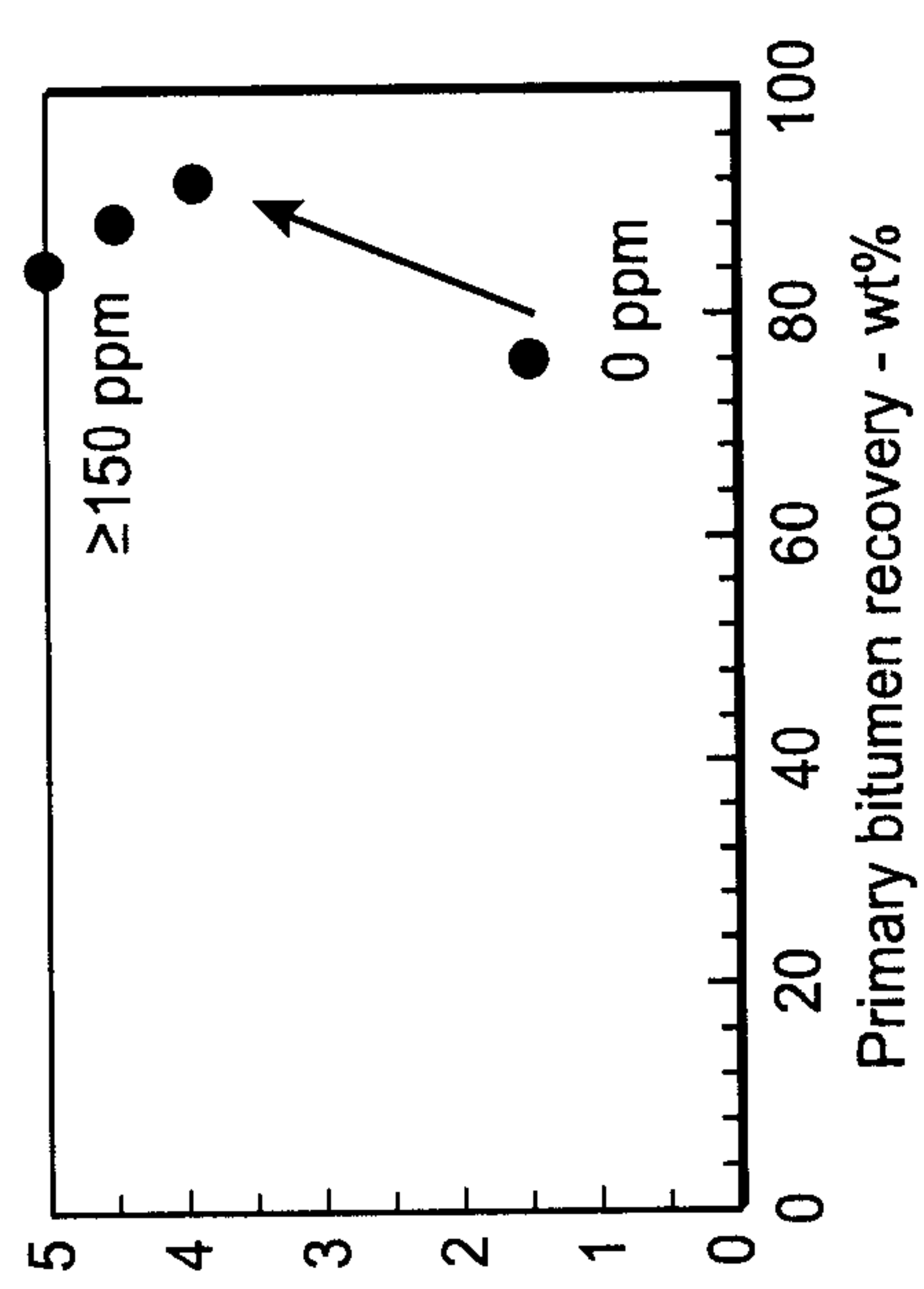
High Fines Ore (e.g. ≥20 wt% fines)

FIG. 9A



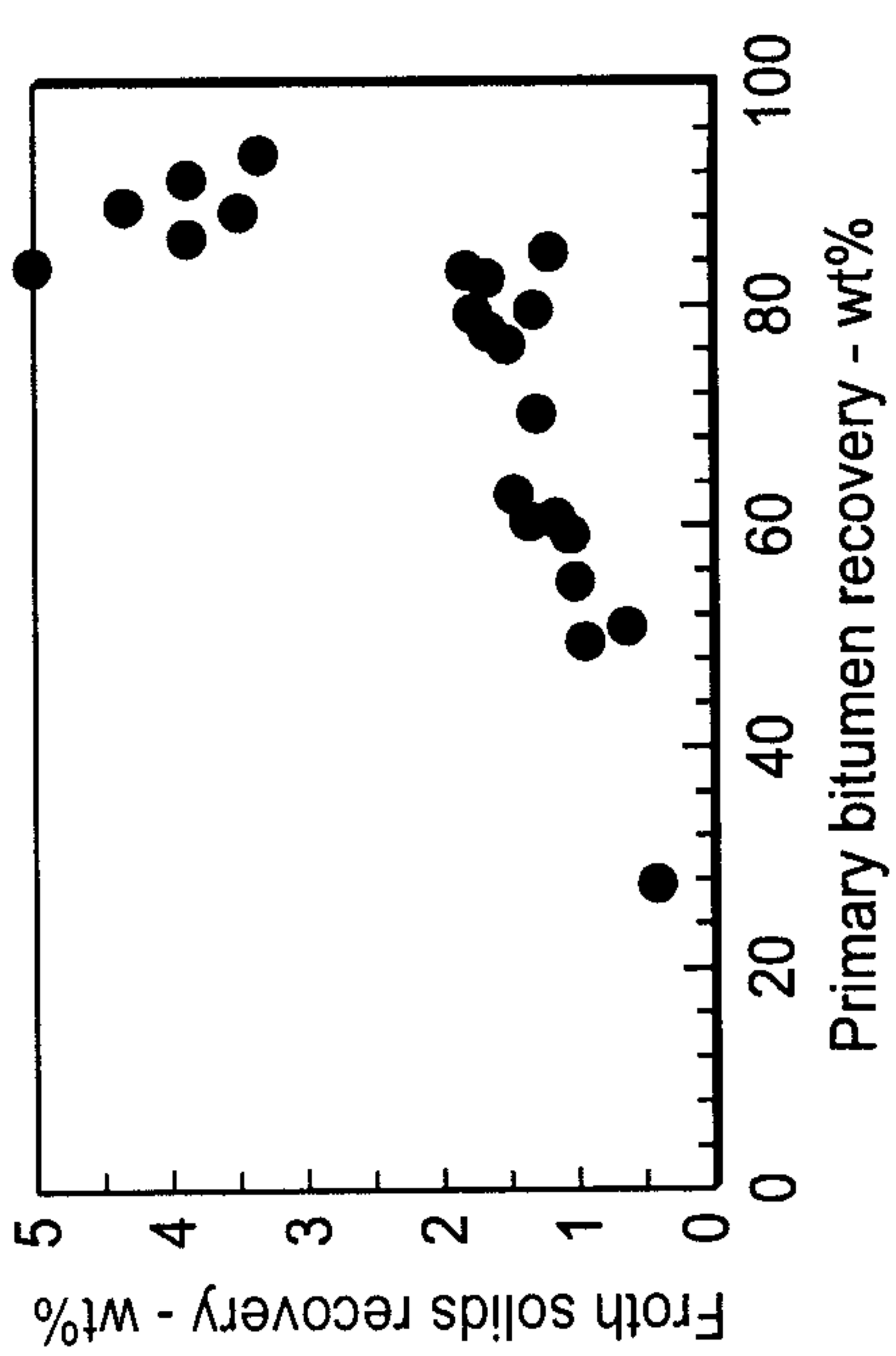
Medium Fines Ore (e.g. [11-18] wt% fines)

FIG. 9B



Low Fines Ore (e.g. ≤11 wt% fines)

FIG. 9C



Summary Plot of All Ores

FIG. 9D

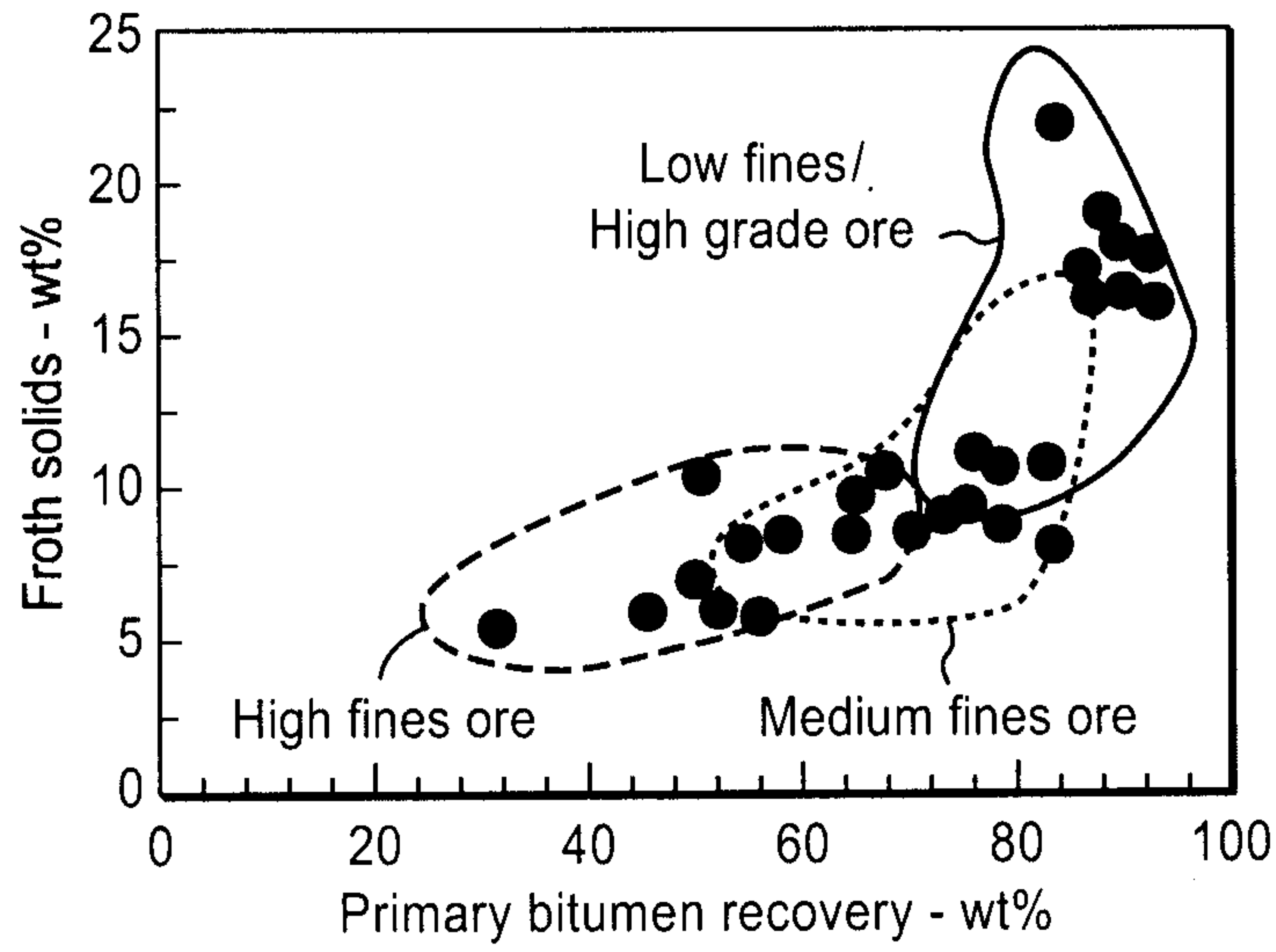


FIG. 10A

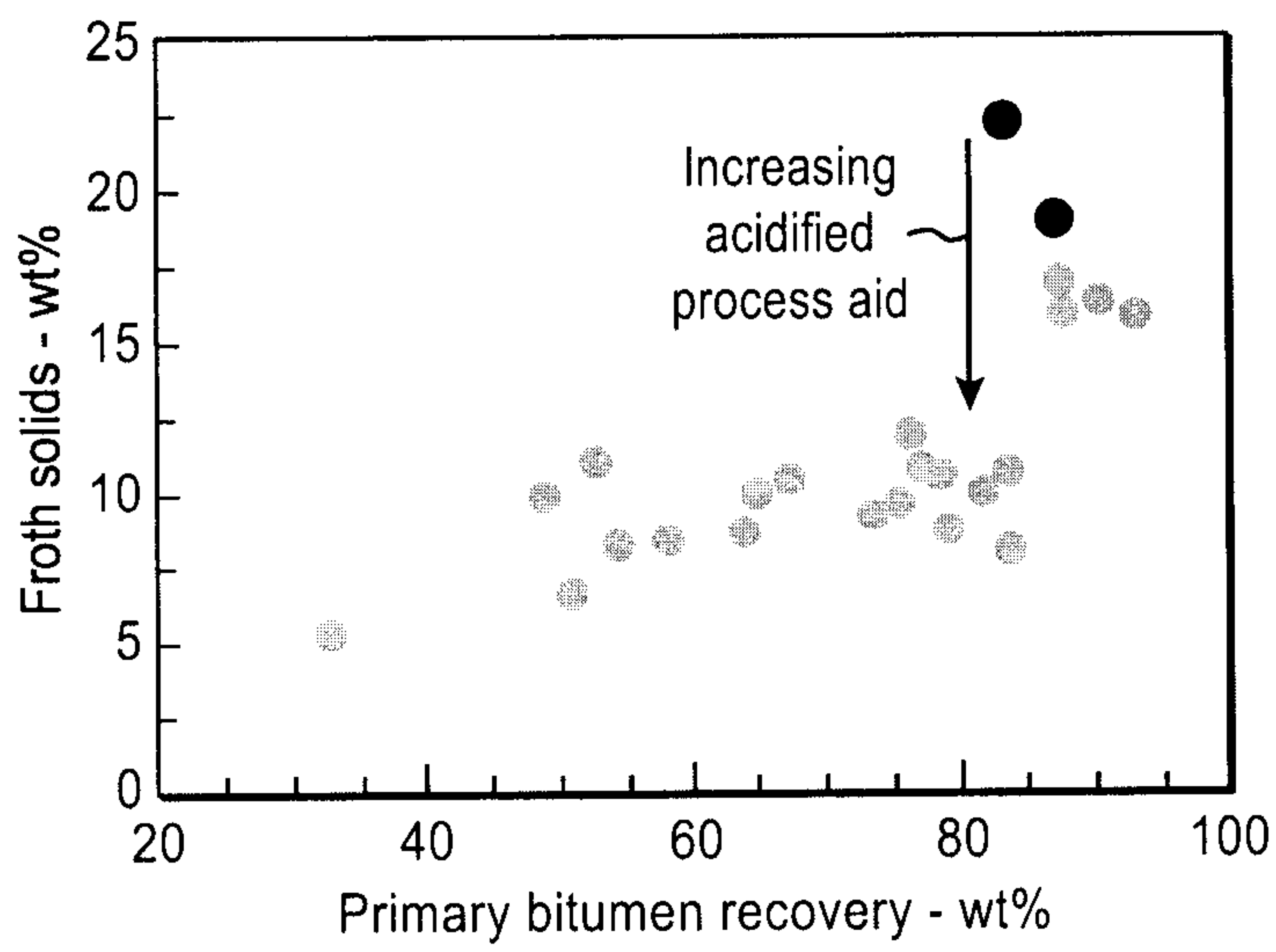
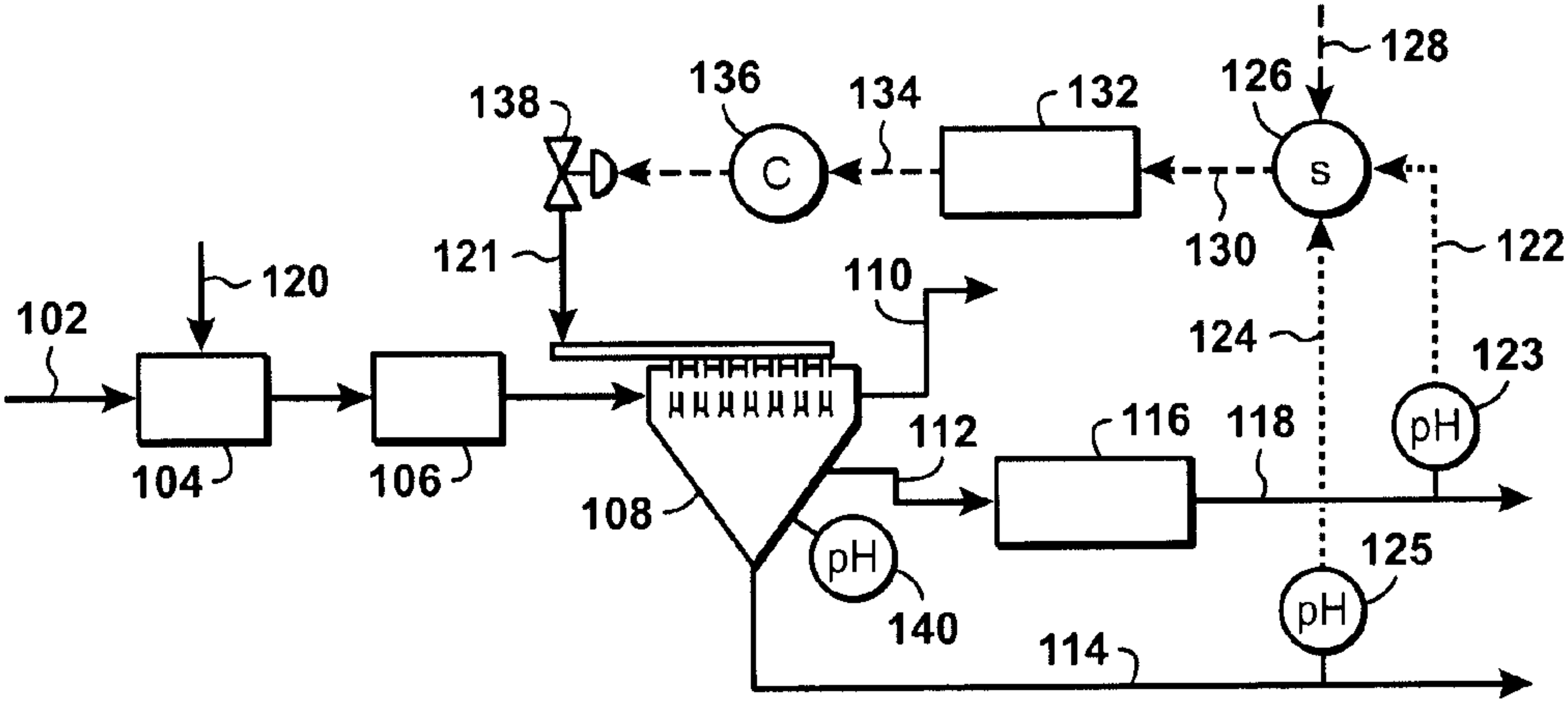


FIG. 10B


128
126
136
134
132
138
C
s
130
122
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120
110
102
124
123
pH
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104
106
108
pH
125
pH
140
114