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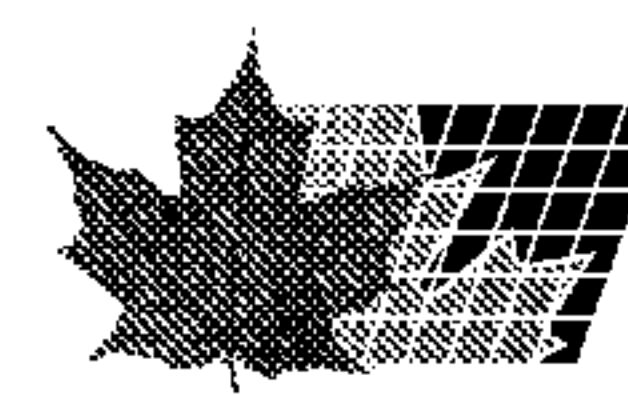
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(54) Titre : PROCÉDE D'AGGLOMERATION DE BOUES DE SABLES BITUMINEUX A BASE DE SOLVANT

(54) Title: AGGLOMERATION PROCESS FOR SOLVENT-BASED OIL SAND SLURRY

(57) **Abrégé/Abstract:**

Disclosed is a method of processing a bituminous feed including: a) contacting the bituminous feed with a solvent to form a slurry; b) adding a bridging liquid to the slurry and flowing the slurry to agitate solids within the slurry to form an agglomerated slurry comprising agglomerates and a low solids bitumen extract; c) measuring a characteristic of the slurry at one or more points along the slurry flow; d) adjusting the bridging liquid addition to the slurry based on the characteristic; and e) separating the agglomerates from the low solids bitumen extract.



**ABSTRACT**

Disclosed is a method of processing a bituminous feed including: a) contacting the bituminous feed with a solvent to form a slurry; b) adding a bridging liquid to the slurry and flowing the slurry to agitate solids within the slurry to form an agglomerated slurry comprising agglomerates and a low solids bitumen extract; c) measuring a characteristic of the slurry at one or more points along the slurry flow; d) adjusting the bridging liquid addition to the slurry based on the characteristic; and e) separating the agglomerates from the low solids bitumen extract.

## AGGLOMERATION PROCESS FOR SOLVENT-BASED OIL SAND SLURRY

### BACKGROUND

#### 5 Field of Disclosure

[0001] The disclosure relates generally to the field of oil sand processing. More particularly, the disclosure relates to agglomeration of solvent-based oil sand slurries.

#### Description of Related Art

10 [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.

15 [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  
20 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  
25 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  
30 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). WBE is a commonly used process to extract bitumen from mined oil sand.

[0006] Alternatively, Solvent-Based Extraction (SBE) may be used to extract bitumen from mined oil sand. In general, SBE involves mixing oil sand with a hydrocarbon solvent to form an oil sand slurry, adding a bridging liquid to the oil sand slurry, agitating the mixture in a slow and controlled manner to nucleate particles, and continuing such agitation to permit these nucleated particles to form larger multi-particle spherical agglomerates for removal. The bridging liquid is preferably water or an aqueous solution since the solids of oil sand are mostly hydrophilic and water is immiscible with hydrocarbon solvents.

[0007] An example of SBE is described in Canadian Patent No. 2,724,806 (Adeyinka *et al*). In the process of Canadian Patent No. 2,724,806, a solvent is combined with a bituminous feed derived from oil sand to form an initial slurry. The initial slurry is separated into a fine solids stream and coarse solids stream followed by agglomeration of solids from the fine solids stream to form an agglomerated slurry. The agglomerated slurry is then separated into agglomerates and a low solids bitumen extract.

[0008] Another example of SBE is described in Canadian Patent No. 2,740,670 (Adeyinka *et al*). Canadian Patent No. 2,740,670 describes the use of a pipeline to provide the agitation necessary for agglomeration. A bituminous feed is contacted with an extraction liquor (comprising a solvent) to form a slurry. The slurry is then flowed through a pipeline and a bridging liquid is added to the slurry and agitation is provided to assist agglomeration. The result is an agglomerated slurry comprising agglomerates and a low solids bitumen extract. The agglomerated slurry is then separated into agglomerates and a low solids bitumen extract.

[0009] It would be desirable to have an alternative or improved agglomeration process.

### SUMMARY

5 [0010] It is an object of the present disclosure to provide an alternative or improved agglomeration process.

[0011] Disclosed is a method of processing a bituminous feed, the method comprising:

- a) contacting the bituminous feed with a solvent to form a slurry;
- 10 b) adding a bridging liquid to the slurry and flowing the slurry to agitate solids within the slurry to form an agglomerated slurry comprising agglomerates and a low solids bitumen extract;
- c) measuring a characteristic of the slurry at one or more points along the slurry flow;
- 15 d) adjusting the bridging liquid addition to the slurry based on the characteristic; and
- e) separating the agglomerates from the low solids bitumen extract.

[0012] 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  
20 also be described herein.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0013] These and other features, aspects and advantages of the disclosure will become apparent from the following description, appending claims and the accompanying drawings,  
25 which are briefly described below.

[0014] Fig. 1 is a flow chart of a method of processing a bituminous feed.

[0015] Fig. 2 is a flow diagram of a method of processing a bituminous feed.

[0016] Fig. 3 is a schematic of pipeline agglomeration of an oil sand slurry.

[0017] Fig. 4 is a schematic of pipeline agglomeration of an oil sand slurry.

[0018] Fig. 5 is a graph of slurry pipeline pressure differential versus solids content of the slurry.

[0019] Fig. 6 is a graph of slurry permeability versus slurry water content.

[0020] Fig. 7 is a graph of pump pressure and permeability versus residence time.

5 [0021] Fig. 8 is a graph of Fast Fourier Transforms of pressure differential versus slurry water content.

[0022] Fig. 9a is a graph of modeled predictions of pressure gradient as a function of particle size in a 4 inch diameter pipe.

10 [0023] Fig. 9b is a graph of modeled predictions of pressure gradient as a function of particle size in a 6 inch diameter pipe.

[0024] Fig. 9c is a graph of modeled predictions of pressure gradient as a function of particle size in a 10 inch diameter pipe.

[0025] Fig. 10 is a graph of gamma ray scans plotting slurry height in the pipeline against slurry density.

15 [0026] Fig. 11 is a graph of Focused Beam Reflectance Measurement (FBRM) plotting percentage of counts per second against chord length.

[0027] 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  
20 aspects of the disclosure.

### **DETAILED DESCRIPTION**

[0028] 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  
25 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.

**[0029]** 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.

**[0030]** Throughout this disclosure, where a range is used, any number between or inclusive of the range is implied.

**[0031]** 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.

**[0032]** “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.

5 [0033] “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  
10 between 22.3° API (density of 920 kilograms per meter cubed ( $\text{kg/m}^3$ ) or 0.920 grams per  
centimeter cubed ( $\text{g/cm}^3$ )) and 10.0° API (density of 1,000  $\text{kg/m}^3$  or 1  $\text{g/cm}^3$ ). An extra heavy  
oil, in general, has an API gravity of less than 10.0° API (density greater than 1,000  $\text{kg/m}^3$  or  
1  $\text{g/cm}^3$ ). 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  
15 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.

[0034] The term “bituminous feed” refers to a stream derived from oil sand that  
requires downstream processing in order to realize valuable bitumen products or fractions.  
20 The bituminous feed 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 feed may be derived directly from oil sand, and may be, for example,  
raw oil sand ore. Further, the bituminous feed may be a feed that has already realized some  
initial processing but nevertheless requires further processing. Also, recycled streams that  
25 comprise bitumen in combination with other components for removal as described herein can  
be included in the bituminous feed. A bituminous feed 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 feed.

[0035] “Fine particles” or “fines” are generally defined as those solids having a size of less than 44 microns ( $\mu\text{m}$ ), as determined by laser diffraction particle size measurement.

[0036] “Coarse particles” are generally defined as those solids having a size of greater than 44 microns ( $\mu\text{m}$ ).

5 [0037] The term “solvent” as used in the present disclosure should be understood to mean either a single solvent, or a combination of solvents.

[0038] 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  
10 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.

15 [0039] 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.

[0040] The term “paraffinic solvent” 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  
20 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  $\text{C}_4$  to  $\text{C}_{20}$  or  $\text{C}_4$  to  $\text{C}_6$  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  
25 none or less than 20 wt. % of the counteracting components referred above.

[0041] The term “agglomerate” refers to conditions that produce a cluster, aggregate, collection or mass, such as nucleation, coalescence, layering, sticking, clumping, fusing and sintering, as examples.

[0042] A goal of agglomeration in SBE processes is to capture fines. Insufficient fines  
30 capture can be a detriment to downstream operations, potentially causing a low filtration rate

or even plugging of a downstream unit. Large particles in the agglomeration operation may result in excessive bitumen occlusion and hence affect the recovery.

**[0043]** As outlined in the summary section, and now with reference to Figure 1, the present disclosure relates to a method of processing a bituminous feed, the method  
5 comprising:

a) contacting (102) the bituminous feed with a solvent to form a slurry;

b) adding (104) a bridging liquid to the slurry and flowing the slurry to agitate solids within the slurry to form an agglomerated slurry comprising agglomerates and a low solids bitumen extract;

10 c) measuring (106) a characteristic of the slurry at one or more points along the slurry flow;

d) adjusting (108) the bridging liquid addition to the slurry based on the characteristic; and

e) separating (110) the agglomerates from the low solids bitumen extract.

15 **[0044]** As shown in Figure 2, an extraction liquor (202) comprising solvent is mixed with a bituminous feed (204) from oil sands in a slurry system (206) to form a slurry (208). The slurry is fed into a pipeline (210). Extraction may begin when the solvent is contacted with the bituminous feed (204) and a portion of the extraction may occur in the pipeline (210). The slurry (208) is flowed in the pipeline (210), and at one or more points along the pipeline  
20 (210), a bridging liquid (212) is added to the pipeline to assist agglomeration of the slurry. Alternatively or additionally, bridging liquid may be added to the slurry prior to the pipeline. Some form of agitation is also used to assist agglomeration, as described below. Agitation may be provided by turbulent flow in the pipeline.

**[0045]** The agglomerated slurry (214), comprising agglomerates and a low solids  
25 bitumen extract, is sent to a solid-liquid separator (216) to produce a low solids bitumen extract (218) and agglomerates (220).

**[0046]** The low solids bitumen extract is sent to a solvent recovery unit (222) to recover solvent (224) leaving a bitumen product (226). The agglomerates (220) are sent to a tailings solvent recovery unit (228) to recover solvent (230) leaving dry tailings (232).  
30 Generally, dry tailings do not have a substantial amount of free draining liquid.

[0047] The bituminous feed may be oil sand, which is contacted with solvent that is free of bridging liquid in a slurry system to produce a pumpable slurry. The slurry may be well mixed in order to dissolve the bitumen. The bitumen may be first extracted from the bituminous feed prior to agglomeration in order to prevent (or limit) the agglomeration process from hampering the dissolution of bitumen into the solvent. A portion of the bridging liquid may be directly mixed with the bituminous feed before or at the same time as the solvent so that bitumen extraction and agglomeration occur simultaneously. The bridging liquid may be added before or at the same time as the solvent in order to minimize the dispersion of fines, which may reduce the solids content of the bitumen extract after the agglomeration process.

[0048] The formed agglomerates may be sized on the order of 0.1-1.0 mm, or on the order of 0.1-0.3 mm. At least 80 wt. % of the formed agglomerates may be 0.1-1.0 mm or 0.1-0.3 mm in size. The rate of agglomeration may be controlled by a balance between velocity within the pipeline (i.e. flow turbulence), fines content of the slurry, bridging liquid addition, and residence time within the pipeline.

[0049] Figure 3 illustrates an exemplary pipeline that is segmented into three zones. The slurry (308), comprising the bituminous feed and the solvent, is fed into the pipeline (310). In the extraction zone (350), bitumen extraction, which began prior to delivering the slurry (308) to the pipeline (310), continues. The extraction zone (350) is designed to provide enough residence time and agitation to dissolve the bitumen. In the extraction zone (350), agglomeration generally does not occur, or is limited, because bridging liquid is preferably not injected into the pipeline in the extraction zone of the pipeline. However, where the process detects that the bituminous feed includes a large amount of connate water and that agglomerated particles already exist, little to no bridging liquid may be added and agglomeration will indeed occur in the extraction zone.

[0050] At some point, bridging liquid (312a) is added to the pipeline (310). Adding a sufficient amount of bridging liquid (312a) assists agglomerate nucleation in the nucleation zone (352). The amount of bridging liquid added within the nucleation zone may be less than or equal to or much less than the total amount of bridging liquid needed for desired agglomeration. The amount of bridging liquid added within the nucleation zone may be 5 to

100% of the total amount of bridging liquid added within the pipeline. The amount of bridging liquid added within the nucleation zone may be 20 to 85% of the total amount of bridging liquid added within the pipeline.

5 [0051] At a later point, additional bridging liquid (312b) may be added to the pipeline (310) to assist agglomerate growth, in the agglomerate growth zone (354), to a desired size for subsequent solid-liquid separation. The bridging liquid (312b) may be added to the agglomerate growth zone (354) at several points to assist uniform mixing of the bridging liquid with the slurry.

10 [0052] The three zones are not necessarily discrete zones. For instance, extraction may continue after the extraction zone, and nucleation may continue after the nucleation zone.

[0053] The agglomerate growth zone (354) may be followed by a comminution zone. The mixing energy within the comminution zone is increased significantly in order to comminute the undesirably large agglomerates that form in the agglomerate growth zone. Methods for increasing the mixing energy include, but are not limited to, increasing the slurry velocity within the comminution zone and/or having internal structures within the comminution zone of the pipeline.

[0054] Like Figure 3, Figure 4 illustrates a pipeline (410) in more detail divided into three zones, the extraction zone (450), the nucleation zone (452), and the agglomerate growth zone (454). The slurry (408), and bridging liquids (412a and 412b) are also shown. Measurement (456) of one or more characteristic of the slurry at one or more points along the pipeline (410) can be used to control (458) the operation upstream or downstream of the measurement location(s). The measurement (456) may be made at one or more points along the pipeline in any or all of the zones. The control (458) may be control of bridging liquid addition.

25 [0055] The characteristic may be a pressure differential measured in the slurry flow, density of the slurry, or particle size distribution of the slurry. Each of these characteristics will now be described individually although two or more of characteristics may be used together. The characteristic may be a solids characteristic, that is, a characteristic of the solids profile of the slurry or an analog therefor.

[0056]        **Pressure Differential.** Slurry pipeline pressure differential is a function of particle size, particle distribution, concentration and flow velocity as seen in Figure 5, from Kaushal *et al.*, *International Journal of Multiphase Flow* 31 (2005) 809–823.

[0057]        Among these variables, the particle size itself is a function of the bridging liquid content of the solids in the slurry. The permeability measured downstream via a filtration unit operation is also a function of the particle size and sensitive to the bridging liquid content as seen in Figure 6, which depicts variation in permeability as a function of bridging liquid content added for agglomeration based on data from one liter stirred tank experiments. The term permeability in this context refers to the ability of fluids to flow through a partially permeable structure, such as a bed of particles (such as sand, charcoal, or beads), a filter, a membrane, which typically preferentially restricts solid particles in a solid/liquid fluid that are larger than a certain size from passing through the permeable structure. The measured permeability is an indication of the size of particles as well as the particle size distribution of the particles forming the bed.

[0058]        Experiments were performed in which 350 grams (g) of solids was mixed with solvent to create a slurry in a stirred tank. The impeller in the stirred tank was rotated at 1500 rotations per minute (rpm). The amount of fines in the solids was varied in a range of 10 wt. %-25 wt. % of the total mass (i.e. 350g). The overall solids concentration of the slurry was 30 wt %-60 wt % in different tests. A known amount of water (as bridging liquid) was added for the agglomeration step and provided a residence time in the tank, varying in the range of 15 seconds-2 minutes. The amount of water added was also a variable, as depicted in Figure 6. The slurry was then transferred to a filtration unit, where a vacuum was drawn and subsequently, the permeability was measured. This experiment was repeated multiple times with increasing amount of bridging liquid addition in each case. The trends from the experimentation are shown in Figure 6, depicting increase in permeability as a function of bridging liquid content added in the agglomeration step in each experiment.

[0059]        In a pipeline, measured pressure differential can be used as a characteristic and is a non-intrusive/in-situ property that can be measured across a pump or straight pipe section. The pressure differential can be used as an indication of the bridging liquid content in the

solid particles that are present in the slurry. The pressure differential may be measured across multiple points in a pipe section.

5 [0060] There are at least two approaches for implementation of this concept. The first, relatively simplistic approach, is to use the pressure differential data directly. It has been observed in experimental work in 6 inch and 4 inch pipelines that the pipeline pressure differential varies depending on bridging liquid content of the slurry, as seen in Figure 7. In these experiments, solids and solvent were mixed in a tank and then passed through a pipeline with a diameter of 6 inches. The solids content of the slurry in these cases varied in the range of 30 wt. %-60 wt. %. The flow was maintained above a pre-calculated minimum settling  
10 velocity in this pipeline (at least above 2.8m/s in these cases) and a known amount of bridging liquid was added. A similar protocol was followed in experiments corresponding to a 4 inch pipeline. In particular, Figure 7 shows variation in pump pressure rise and straight section pressure differential as a function of bridging liquid content (and residence time). Also, permeability follows a similar trend, which is favorable to the present concept.

15 [0061] The second approach, which requires data processing, is based on Fast Fourier Transforms (FFTs) of pressure differential data, for instance from agglomeration in a pipeline of a given diameter. A distinct sensitivity to bridging liquid content was observed, as shown in Figure 8. As an example, Fast Fourier Transforms (FFTs) were performed on the pressure differential data collected on slurries with different bridging liquid content and hence,  
20 different particle sizes. Figure 8 depicts the shift in the processed curves depending on the bridging liquid content. This sensitivity can be leveraged to understand the bridging liquid content or particle size distribution in the slurry. In particular, Figure 8 shows results of FFT on pressure measurements depicting shift in peaks based on bridging liquid content with a 6 inch pipeline and 60 wt. % solids content of the slurry.

25 [0062] Figures 9a, 9b, and 9c illustrate theoretical predictions from a model depicting pressure differential as a function of particle size for various pipe dimensions and fines concentration. Solid lines are 25 wt. % fines and dotted lines are 10 wt. % fines. Black lines are 30 wt. % slurry and grey lines are 50 wt. % slurry. Figures 9a, 9b, and 9c show the sensitivity of pressure differential to particle size distribution, and slurry density is shown in  
30 the theoretical calculations made using the model.

[0063] For implementation, one needs to decouple the sensitivity to bridging liquid content from that of slurry density. One way is to generate a set of preliminary data that can be used to create a baseline. Once this is generated, an algorithm can be programmed and that can predict the required bridging liquid to be added in the system to optimize the process. The residence time for agglomeration is typically short (on the order of about 1-5 minutes) and hence programing this may be the easiest and most timely manner to respond to the conditions in the pipeline.

[0064] Therefore, the method may further comprise data processing the characteristic of the slurry prior to adjusting the bridging liquid addition. The data processing may be performed on measured pressure differential information, measured density, or measured particle size distribution.

[0065] **Slurry Density.** The density may be a local density, or a density profile. Solids and solvent were mixed in a tank and then passed through a pipeline with a diameter of 6 inches. The flow was maintained above a pre-calculated settling velocity in this pipeline (equal to or above 2.8 m/s) and a known amount of bridging liquid was added. The solids concentration was varied in the range of 30-45% by weight. A similar protocol was followed in experiments corresponding to a 4 inch pipeline. In these experiments in 6 inch and 4 inch pipelines, Gamma-Ray scan measurements were made on a slurry before and after water addition. Figure 10 shows Gamma-Ray scans measured in a 6 inch pipeline experiment. The x-axis is the slurry density and y-axis depicts the height in pipeline, with a  $y/D$  (height/diameter) of 1 being the top of the pipeline and 0 being bottom of the pipeline (radial location) at common superficial liquid or slurry velocity. In this data, a clear shift in recording was observed as a function of a) change in solids content of the slurry and b) water addition (i.e. particle size distribution in the slurry). When there is a larger amount of solids in the system, the overall slurry density changes. Also, when the bridging liquid is added to the system, the particles combine, and as observed in Figure 10, there is a highly visible change in the local density across the diameter of pipe due to settling of the larger particles. Based on observation of the 60 wt. %, 8% water injected data of Figure 10, the system could also be operated at a higher velocity to prevent or limit bed formation in the system.

[0066] A traversing Gamma-Ray densitometer provides a measurement of the in-situ density of the slurry in the loop. The densitometer provides a measurement of the change in density (solids concentration) with vertical position in the pipe and by averaging this density profile it also provides a measure of the density of the material over the cross-section through a slice of the pipe which is equivalent to the in-situ density of the slurry in the loop. Alternately multiple fixed position densitometers could provide an equivalent density profile. The traversing Gamma-Ray densitometer consists of a source, a housing for the source, shutter and a collimator to provide a narrow slit of gamma radiation to a scintillation radiation detector. Radiation measurements were collected on a data acquisition system. The entire system was mounted to a solid steel frame attached to a hydraulic jack which was used to raise and lower the traversing unit. The vertical position of the unit can be measured to within 0.01 mm with digital calipers. Measurements were performed at y/D intervals of 0.05. The solids concentration of the slurry in the loop at specific heights can be calculated from the measured radiation intensity based on the Beer-Lambert law. The absorption coefficients for fluid and the solids were taken from a database and measured prior to the tests for the solvents used in the study. All concentration measurements were corrected for background radiation. The following equation below shows the Beer-Lambert law for a two phase mixture in pipe flow.

$$\frac{N}{N_0} = \exp[-(\mu_w X_w + \mu_f X(1-C) - \mu_s X C)]$$

20 N = measured intensity (Hz or counts/s)

$N_0$  = unattenuated intensity (Hz or counts/s)

$\mu$  = radiation absorption coefficients for pipe wall (w), fluid (f) and solids (s)

$X_w$  = length of beam through the pipe wall (cm)

X = path length of beam through the pipe interior (cm)

25 C = volumetric chord averaged, solids concentration (volume %)

[0067] **Particle size measurement.** The characteristic may comprise a particle size distribution of the slurry. Information about the particle size in the slurry can be gathered via non-intrusive instrumentation that can be mounted on the pipeline. These can be directly looking at the pipeline itself or at a slip stream withdrawn from the pipeline for

characterization. The particle size distribution of the slurry may be measured by an optical method or by a laser method. A few examples include a Focused Beam Reflectance Measurement (FBRM), Particle View Microscopy (PVM), and CYCLONEtrac™. Figure 11 shows FBRM data from a 6 inch pipeline depicting shift in chord length depending on particle size distribution. In this case, the FBRM was mounted on the pipeline at a 45 degree angle. It is positioned such that the laser is looking at the slurry in the direction of flow. The device is connected to a data acquisition system and measurements were recorded in the software installed on the computer. Prior to installation in the pipeline, a calibration was performed with the FBRM device on samples to ensure the device performs as expected. The particle size distribution may be measured across multiple points in a pipe or in one or multiple withdrawn slip streams. The characteristic may also be a particle size analog.

**[0068] Adjustment of Bridging Liquid Addition.** Based on the measured characteristic, the bridging liquid addition may be adjusted. The adjustment of the bridging liquid addition may comprise adjusting an amount of bridging liquid addition, a flow rate of bridging liquid, a location of bridging liquid addition, a method of bridging liquid addition, a composition of the bridging liquid, or a combination thereof. This adjustment may be through feed-forward or feedback control. This adjustment may be particularly useful in upset conditions such as lower slurry density or ore variability due to weather or mine location. The adjustment of bridging liquid addition may be effected automatically based on step c). The bridging liquid may be added to the slurry at two or more points along the slurry flow. The bridging liquid addition may be dissolution in the slurry.

**[0069] Agglomerate Size.** Macro-agglomerates or micro-agglomerates may be formed from the solids of the bituminous feed. Macro-agglomerates are agglomerates that are predominantly greater than 2 mm in diameter. These agglomerates comprise both the fine particles (less than 44 µm) and sand grains of the oil sands. Micro-agglomerates are agglomerates that are predominately less than 1 mm in diameter and they principally comprise fine particles of the oil sands. It has been found that for the SBE process with agglomeration described above, the formation of micro-agglomerates are more suitable for maximizing bitumen recovery for a range of oil sands grades.

[0070] **Pipeline Zones.** Nominally, the pipeline may comprise two zones, an extraction zone and an agglomeration zone. As depicted in Figures 3 and 4, the agglomeration zone may comprise a nucleation zone and an agglomeration growth zone. The function of the extraction zone is to dissolve the bitumen from the oil sands into the solvent.

5 Where the solvent is first exposed to the bituminous feed within the process, bitumen may be extracted from the oil sands prior to the agglomeration step in order to prevent (or limit) the agglomeration process from hampering the dissolution of bitumen into the solvent. Thus, it is desirable to prevent or limit the agglomeration of particles within the extraction zone. Dissolution or extraction may be partially or fully complete before entering the agglomeration  
10 in the pipeline. The process need not be performed in a pipeline.

[0071] The function of the agglomeration zone is to agglomerate the solids to the amount commensurate with achieving economically viable solid-liquid separation. Micro-agglomerates may be generally preferred because they allow for good solid-liquid separation without entrapping a significant amount of the bitumen extract within the  
15 agglomerates. The extraction of the bitumen prior to the agglomeration process may have the effect of reducing the required residence time in the agglomeration zone, when compared to certain other proposed processes which require extraction of bitumen and agglomeration to occur simultaneously. The reduced residence time of the agglomeration zone allows for agglomerates of smaller particle size distribution to form.

20 [0072] The agglomeration zone may comprise a bridging liquid dispersion/nucleation zone, an agglomerate growth zone, and a comminution zone. The agglomeration process is initiated within the nucleation zone. The amount of bridging liquid added within the nucleation zone may be less or much less than the total amount of bridging liquid needed for desired agglomeration. The amount of bridging liquid added within the nucleation zone may  
25 be 5 to 100% of the total amount of bridging liquid added within the agglomeration zone. The amount of bridging liquid added within the nucleation zone may be 20 to 85% of the total amount of bridging liquid added within the agglomeration zone. Following the nucleation zone, additional bridging liquid is added within the agglomeration growth zone in order to grow the agglomerates to the desired size and reduce the amount of fine solids dispersed  
30 within the bitumen extract. The bridging liquid may be added to the agglomerate growth zone

at several points to assist uniform mixing of the bridging liquid within the slurry. A  
 comminution zone may follow the agglomerate growth zone in order to comminute the  
 undesirably large agglomerates that may form in the agglomerate growth zone. The  
 comminution may be effected by, for example, increasing the velocity within the  
 5 comminution zone or having internal structures within the comminution zone.

[0073] **Velocity within Pipeline.** The nature of slurry flow within a horizontal  
 pipeline depends on the ratio of the average flow velocity of the slurry within the pipeline to  
 the limiting settling velocity of the slurry. When the average flow velocity is sufficiently  
 greater than the limiting settling velocity, the slurry flow within the pipeline is homogenous  
 10 with no average concentration changes across the pipe. At any velocity below the limiting  
 settling velocity, the slurry flow becomes heterogeneous with the concentration of the solids  
 increasing towards the bottom of the pipe. For an average flow velocity that is heterogeneous  
 but where the slurry velocity remains greater than about 40% of the limiting settling velocity,  
 the solids that are deposited at the bottom of the pipe can flow by bouncing and rolling along  
 15 the pipe. This type of flow is called saltation flow. The average flow velocity that is below  
 that which is needed for saltation flow is usually avoided since pipeline plugging will occur as  
 solids are continuously injected into the pipeline.

[0074] The limiting settling velocity for a slurry is best determined by conducting  
 tests with the slurry flowing within a pipeline test rig. In the absence of such tests, the  
 20 limiting settling velocity  $V_L$  can be estimated using the following equation proposed by R  
 Durand:

$$V_L = F_L \sqrt{2gD \frac{\rho_s - \rho_l}{\rho_l}}$$

where,  $g$  is the acceleration due to gravity,  $D$  is the diameter of the pipeline,  $\rho_s$  is the  
 density of the solids within the slurry, and  $\rho_l$  is the density of the liquid of the slurry.  $F_L$  is  
 25 a parameter that is dependent upon the particle size distribution and the solids volume  
 concentration within the slurry. For a slurry with mixed particle size, such as that expected  
 for oil sands slurries as described herein,  $F_L$  has been measured to have values within the  
 range of 0.5 to 1.5.

[0075] In the extraction zone, the average flow velocity within the pipeline can be that needed for saltation flow or greater. It is preferable that the slurry flow be homogenous or mildly heterogeneous. However, this not necessary since the solvent will digest the oil sands lumps even under low agitation conditions. The average flow velocity within the extraction zone may be 1 to 6 m/sec. The average flow velocity within the extraction zone may be 2 to 4 m/sec.

[0076] In the agglomeration zone, it is desired that the slurry remains in the turbulent flow regime of slurry such that the solids are exposed to the high shear forces. The average flow velocity within the agglomeration zone may be greater than 2 m/sec. The average flow velocity within the agglomeration zone may be 2.5 to 6 m/sec. Practical considerations such as erosion of the pipeline, equipment capacity and excessive pressure change will limit the average flow velocity within all zones making up the agglomeration zone.

[0077] **Residence Time.** By using pipeline agglomeration, one has the flexibility to have a long residence time for the extraction and agglomeration processes since the length of the pipeline can be readily increased to achieve the desired residence time. Increasing the residence time of the extraction process may result in an increase in both the bitumen recovery and the rate of solid-liquid separation. The residence time of the extraction zone may be less than 5 minutes or greater than 5 minutes, or may be greater than 10 minutes, or may be greater than 15 minutes, or may greater than 30 minutes. The residence time of the agglomeration zone may be in the range of 30 seconds to 10 minutes. The residence time of the agglomeration zone may be in the range of 1 to 5 minutes. The residence time of the bridging liquid dispersion/nucleation zone within the agglomeration zone may be less than 30 seconds. Where the agglomeration zone comprises a comminution zone, the residence time within the agglomeration zone may be extended beyond 5 minutes to provide the required residence time for the comminution zone.

[0078] **Geometry of Pipeline.** The pipeline diameter of the extraction zone may be constant and as large as possible commensurate with keeping the slurry flow above the saltation velocity. Exemplary pipeline diameters are in the range of 0.1 to 1.5 m. These pipeline diameters are similar in size to those of the hydrotransport pipelines used in the water-based extraction process. Since the total pipeline length may comprise mostly the

extraction zone, attempts should be made to minimize erosion within this portion of the pipeline.

[0079] For the agglomeration zone of the pipeline, it is desirable to have homogenous or close to homogenous type flow in order to ensure or promote uniform agglomerate formation and growth. The homogenous slurry flow can be accomplished by reducing the pipeline diameter of the agglomeration zone in order to increase the average flow velocity of the slurry and reduce the limiting settling velocity. The pipeline diameter in the agglomeration zone may be 0.1 to 1.5 m. The homogenous slurry flow may also be accomplished by incorporating a recycle loop with the agglomeration zone. The recycle loop may act to increase the average flow velocity within the agglomeration zone. The pipeline of the agglomeration zone may be configured at angles to the horizontal. The configuration of the pipeline at angles will have the effect of reducing the limiting settling velocity of the slurry. By way of example, the pipeline may be angled 5° to 45° to horizontal. In an alternate configuration, the pipeline may be positioned vertically. A vertical positioning has the benefit of mitigating vertical segregation of particles in the pipeline.

[0080] The above described methods of promoting homogenous or near homogenous slurry flow may be employed separately or in combination in order to maximize effectiveness. Additionally, the pipeline of the agglomeration zone may comprise internal structures to promote homogenous slurry flow. Exemplary structures include intermittently spaced static mixers. It may be preferable that static mixers, or the like, be included in the pipeline in such a way that they can be readily replaced since such devices may be subject to high rates of erosion. Other potential internal structures will be readily known by those skilled in the art.

[0081] **Solvent.** The solvent is used to extract bitumen from the bituminous feed. The term “solvent” as used herein should be understood to mean either a single solvent, or a combination of solvents.

[0082] The solvent may form part of an extraction liquor. The extraction liquor may be a solution of a hydrocarbon solvent(s) and bitumen, where the bitumen content of the extraction liquor may range between 10 to 50 wt. %. It may be desirable to have dissolved bitumen within the extraction liquor in order to increase the volume of the extraction liquor without an increase in the required inventory of hydrocarbon solvent(s). In cases where

non-aromatic hydrocarbon solvents are used, the dissolved bitumen within the extraction liquor also increases the solubility of the extraction liquor towards dissolving additional bitumen.

[0083] The solvent used in the process may include low boiling point solvents such as low boiling point cycloalkanes, or a mixture of such cycloalkanes, which substantially dissolve asphaltenes. The solvent may comprise a paraffinic solvent in which the solvent to bitumen ratio is maintained at a level to avoid or limit precipitation of asphaltenes.

[0084] It may be desirable to use hydrocarbon solvents that preferentially precipitate asphaltenes from the bitumen. The precipitated asphaltenes may agglomerate with the oleophilic solids within the slurry which can help to produce a bitumen extract with less entrained fine particles.

[0085] While it is not necessary to use a low boiling point solvent, when it is used, there is the extra advantage that solvent recovery through an evaporative process proceeds at lower temperatures, and requires a lower energy consumption. When a low boiling point solvent is selected, it may be one having a boiling point of less than 100°C.

[0086] The solvent may comprise an organic solvent or a mixture of organic solvents. For example, the solvent may comprise a paraffinic solvent, an open chain aliphatic hydrocarbon, a cyclic aliphatic hydrocarbon, or a mixture thereof. Should a paraffinic solvent be utilized, it may comprise an alkane, a natural gas condensate, a distillate from a fractionation unit (or diluent cut), or a combination of these comprising more than 40% small chain paraffins of 5 to 10 carbon atoms; therefore considered primarily a small chain (or short chain) paraffin mixture. Should an alkane be selected as the solvent, the alkane may comprise a normal alkane, an iso-alkane, or a combination thereof. The alkane may specifically comprise heptane, iso-heptane, hexane, iso-hexane, pentane, iso-pentane, or a combination thereof. Should a cyclic aliphatic hydrocarbon be selected as the solvent, it may comprise a cycloalkane of 4 to 9 carbon atoms. A mixture of C<sub>4</sub>-C<sub>9</sub> cyclic and/or open chain aliphatic solvents would be appropriate.

[0087] Exemplary cycloalkanes include cyclohexane, cyclopentane, or a mixture thereof.

[0088] If the solvent is selected as the distillate from a fractionation unit, it may for example be one having a final boiling point of less than 180°C. An exemplary upper limit of the final boiling point of the distillate may be less than 100°C.

[0089] A mixture of C<sub>4</sub>-C<sub>10</sub> cyclic and/or open chain aliphatic solvents would also be appropriate. For example, it can be a mixture of C<sub>4</sub>-C<sub>9</sub> cyclic aliphatic hydrocarbons and paraffinic solvents where the percentage of the cyclic aliphatic hydrocarbon in the mixture is greater than 50%.

[0090] Solvent may be recycled from a downstream step. For instance, as described below, solvent recovered in a solvent recovery unit, may be used to wash agglomerates, and the resulting stream may be used as solvent. As a result, the solvent may comprise residual bitumen and residual solid fines.

[0091] The solvent may also include additives. These additives may or may not be considered a solvent per se. Possible additives may be components such as de-emulsifying agents or solids aggregating agents. Having an agglomerating agent additive present in the bridging liquid and dispersed in the first solvent may be helpful in the subsequent agglomeration step. Exemplary agglomerating agent additives include cements, fly ash, gypsum, lime, brine, water softening wastes (e.g. magnesium oxide and calcium carbonate), solids conditioning and anti-erosion aids such as polyvinyl acetate emulsion, commercial fertilizer, humic substances (e.g. fulvic acid), polyacrylamide based flocculants and others. Additives may also be added prior to gravity separation with the second solvent to enhance removal of suspended solids and prevent emulsification of the two solvents. Exemplary additives include methanoic acid, ethylcellulose and polyoxyalkylate block polymers.

[0092] **Bridging Liquid.** A bridging liquid is a liquid with affinity for the solids particles in the bituminous feed, and which is immiscible in the solvent. Exemplary aqueous liquids may be recycled water from other aspects or steps of oil sands processing. The aqueous liquid need not be pure water, and may indeed be water containing one or more salts, a waste product from conventional aqueous oil sand extraction processes which may include additives, aqueous solution with a range of pH, emulsions, or any other acceptable aqueous solution capable of adhering to solid particles within the pipeline in such a way that permits fines to adhere to each other. An exemplary bridging liquid is water.

[0093] The bridging liquid may be added to the slurry in a concentration of less than 20 wt. % of the slurry. The bridging liquid may be added to the slurry in a concentration of less than 10 wt. % of the slurry. The bridging liquid may be added in a concentration of between 1 wt. % and 20 wt. % or between 1 wt. % and 10 wt. %. The bridging liquid may  
5 comprise fine particles (for instance less than 44  $\mu\text{m}$ ) suspended therein. These fine particles may serve as seed particles for the agglomeration process. The bridging liquid may comprise less than 40 wt. % solid fines. The agglomerated slurry may have a solids content of 20 to 70 wt. %. The bridging liquid may be in the form of an emulsion, for instance as described in Canadian Patent No. 2,738,194.

10 [0094] **Ratio of Solvent to Bitumen for Agglomeration.** The process may be adjusted to render the ratio of the solvent to bitumen in the pipeline at a level that avoids or limits precipitation of asphaltenes during agglomeration. It may be that some amount of asphaltene precipitation is unavoidable, but by adjusting the amount of solvent flowing into the system, with respect to the expected amount of bitumen in the bituminous feed, when  
15 taken together with the amount of bitumen that may be entrained in the solvent used, can permit the control of a ratio of solvent to bitumen in the agglomerator. When the solvent is assessed for an optimal ratio of solvent to bitumen during agglomeration, the precipitation of asphaltenes can be minimized or avoided beyond an unavoidable amount. Another advantage of selecting an optimal solvent to bitumen ratio is that when the ratio of solvent to bitumen is  
20 too high, costs of the process may be increased due to increased solvent requirements.

[0095] An exemplary ratio of solvent to bitumen to be selected as a target ratio during agglomeration may be around 2:1. A ratio of 5:1 to 1.5:1 or 3:1 to 1.5:1 or 2:1 to 1.5:1, may also be desired target ratios for agglomeration. For clarity, ratios may be expressed herein using a colon between two values, such as "2:1", or may equally be expressed as a single  
25 number, such as "2", which carries the assumption that the denominator of the ratio is 1 and is expressed on a weight to weight basis.

[0096] Where precipitation in the pipeline is preferred, the solvent to bitumen ratio must be increased past the point of incipient precipitation.

[0097] **Slurry System.** The slurry system may optionally be a mix box, a pump, a  
30 hopper-jet pump assembly (for instance as described in Canadian Patent Application

No. 2,900,391), or a combination of these. By slurring the solvent together with the bituminous feed, and optionally with additional additives, the bitumen entrained within the feed is given an opportunity to become extracted into the solvent phase prior to agglomeration within the pipeline. The resulting slurry from the slurry system may have a solid content in the range of 10 to 65 wt. %. The slurry may have a solid content in the range of 30 to 50 wt. %. The temperature of the slurry may be in the range of 20-70°C. An elevated slurry temperature is desired in order to increase the bitumen dissolution rate and reduce the viscosity of the slurry to promote more effective sand digestion and agglomerate formation. Temperatures above 70°C are feasible, and temperatures approaching the boiling point of the solvent may be used, but are generally avoided due to the complications resulting from high vapor pressures.

**[0098] Solid-Liquid Separator.** As described above, the agglomerated slurry may be separated into a low solids bitumen extract and agglomerates in a solid-liquid separator. The solid-liquid separator may comprise any suitable unit capable of separating solids from liquids, so as to remove agglomerates. Exemplary types of units include a gravity separator, a clarifier, a cyclone, a screen, a pan filter, a belt filter or a combination thereof.

**[0099]** The system may comprise a solid-liquid separator but may alternatively contain more than one. When more than one solid-liquid separation step is employed at this stage of the process, it may be said that both steps are conducted within one solid-liquid separator, or if such steps are dissimilar, or not proximal to each other, it may be said that a primary solid-liquid separator is employed together with a secondary solid-liquid separator. When a primary and secondary unit are both employed, generally, the primary unit separates agglomerates, while the secondary unit involves washing agglomerates.

**[00100]** Non-limiting methods of solid-liquid separation of an agglomerated slurry are described in Canadian Patent No. 2,724,806 (Adeyinka *et al.*), issued February 24, 2015.

**[00101] Recycle and Recovery of Solvent.** The process may involve removal and recovery of solvent used in the process.

**[00102]** In this way, solvent is used and re-used, even when a good deal of bitumen is entrained therein. Because an exemplary solvent:bitumen ratio in the pipeline may be 2:1 or lower, it is acceptable to use recycled solvent containing bitumen to achieve this ratio. The

amount of make-up solvent required for the process may depend solely on solvent losses, as there is no requirement to store and/or not re-use solvent that has been used in a previous extraction step. When solvent is said to be “removed”, or “recovered”, this does not require removal or recovery of all solvent, as it is understood that some solvent may be retained with  
5 the bitumen even when the majority of the solvent is removed.

**[00103]** The system may contain a single solvent recovery unit for recovering the solvent(s) arising from the separator. The system may alternatively contain more than one solvent recovery unit. Part of the solvent recovery may happen in a compartment within the filter.

10 **[00104]** Solvent may be recovered by conventional means. For example, typical solvent recovery units may comprise a fractionation tower or a distillation unit.

**[00105]** The solvent recovered in the process may comprise entrained bitumen therein, and can thus be re-used for combining with the bituminous feed.

15 **[00106]** 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.

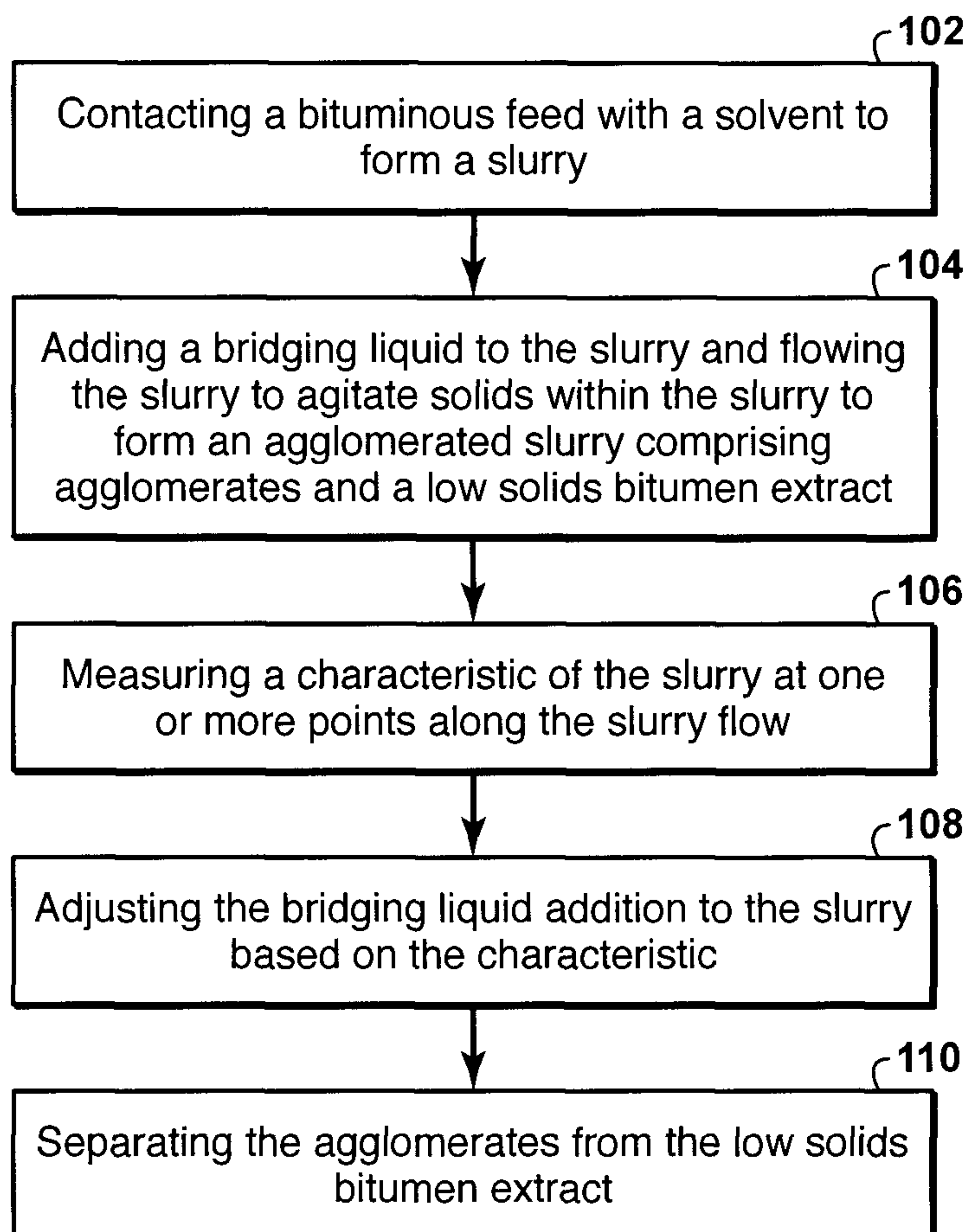
**[00107]** The scope of the claims should not be limited by particular embodiments set forth herein, but should be construed in a manner consistent with the specification as a whole.

**CLAIMS:**

1. A method of processing a bituminous feed, the method comprising:
  - a) contacting the bituminous feed with a solvent to form a slurry;
  - b) adding a bridging liquid to the slurry and flowing the slurry to agitate solids within the slurry to form an agglomerated slurry comprising agglomerates and a low solids bitumen extract;
  - c) measuring a solids characteristic of the slurry at one or more points along the slurry flow, wherein the solids characteristic is a characteristic of a solids profile of the slurry or an analog therefor, and wherein the solids characteristic comprises a pressure differential in the slurry, density of the slurry, or a particle size distribution of the slurry;
  - d) adjusting the bridging liquid addition to the slurry based on the characteristic;and
  - e) separating the agglomerates from the low solids bitumen extract.
2. The method of claim 1, wherein the solids characteristic comprises the pressure differential in the slurry.
3. The method of claim 2, wherein the pressure differential is measured across a pump or across multiple points in a pipe section.
4. The method of claim 1, wherein the solids characteristic comprises the density of the slurry.
5. The method of claim 4, wherein the density comprises a bulk density, a local density, or a density profile.
6. The method of claim 4 or 5, wherein the density of the slurry is measured by a gamma ray densitometer.

7. The method of claim 4 or 5, wherein the density is measured in a pipe.
8. The method of claim 1, wherein the solids characteristic comprises the particle size distribution of the slurry.
9. The method of claim 8, wherein the particle size distribution of the slurry is measured by an optical method.
10. The method of claim 8, wherein the particle size distribution of the slurry is measured by a laser method.
11. The method of any one of claims 8 to 10, wherein the particle size distribution is measured across multiple points in a pipe or in one or multiple withdrawn slip streams.
12. The method of any one of claims 1 to 11, wherein adjusting the bridging liquid addition comprises adjusting an amount of bridging liquid addition, a flow rate of bridging liquid, a method of bridging liquid addition, location of bridging liquid addition, composition of the bridging fluid, or a combination thereof.
13. The method of claim 12, wherein step d) is effected automatically based on step c).
14. The method of any one of claims 1 to 13, wherein the adjusting the bridging liquid addition is upstream of a measuring location.
15. The method of any one of claims 1 to 13, wherein the adjusting the bridging liquid addition is downstream of a measuring location.

16. The method of any one of claims 1 to 15, wherein the bridging liquid is added to the slurry at two or more points along the slurry flow.
17. The method of any one of claims 1 to 16, wherein the slurry flow is in a pipe.
18. The method of any one of claims 1 to 17, wherein the bridging liquid addition is after bitumen dissolution in the slurry.
19. The method of claim 1, further comprising data processing the solids characteristic of the slurry prior to d).
20. The method of any one of claims 1 to 19, comprising effecting step c) prior to any bridging liquid addition.
21. The method of claim 20, wherein step d) comprises adjusting the bridging liquid addition to zero.

**1/9****FIG. 1**

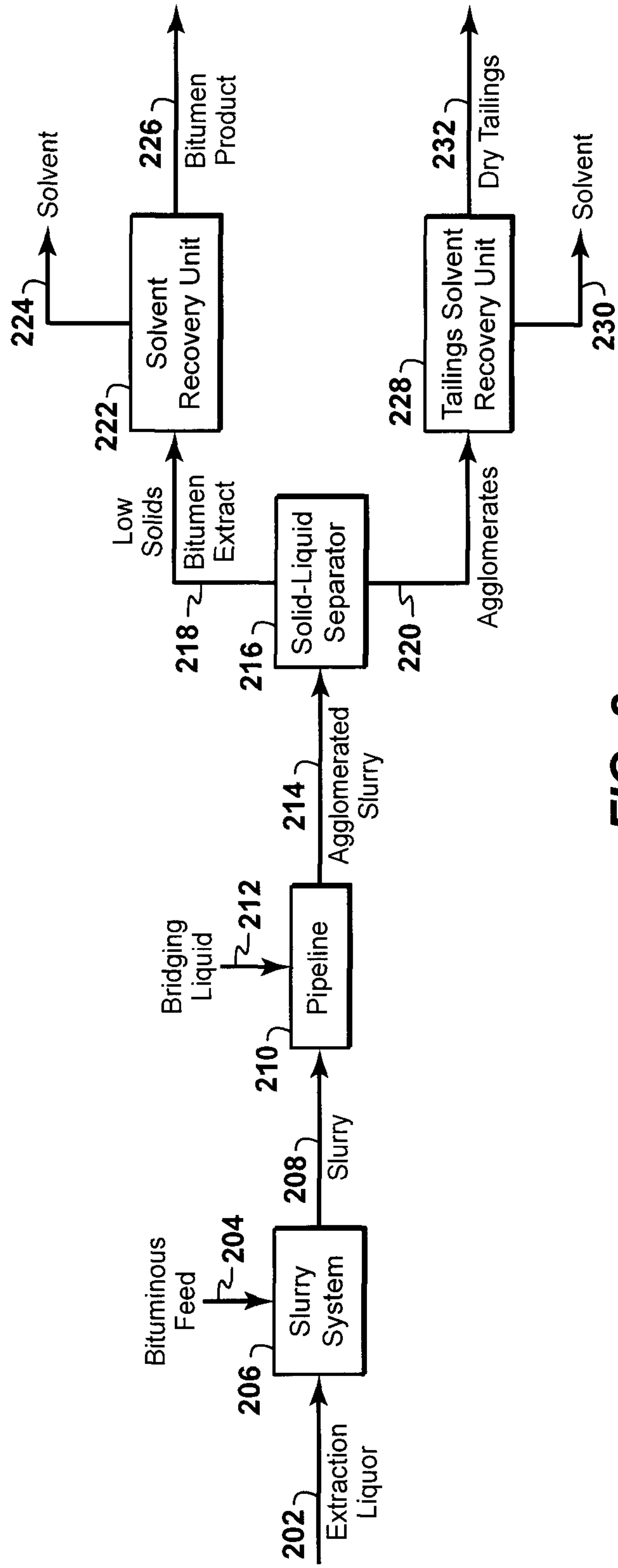


FIG. 2

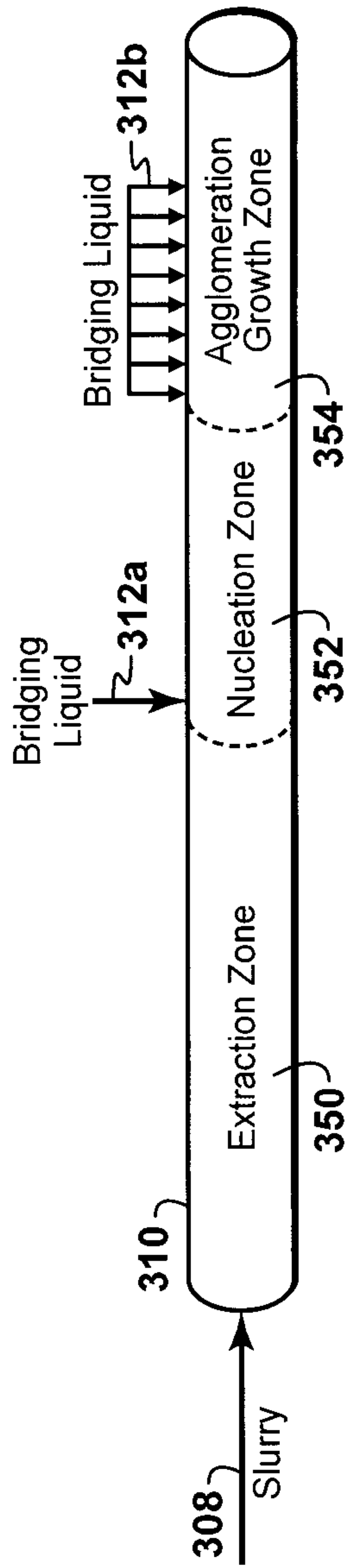


FIG. 3

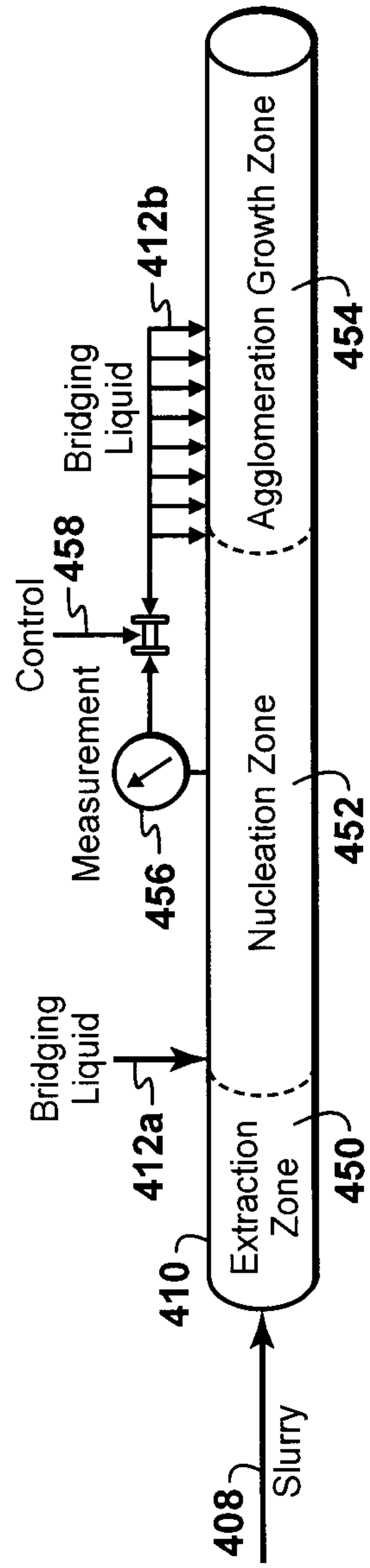


FIG. 4

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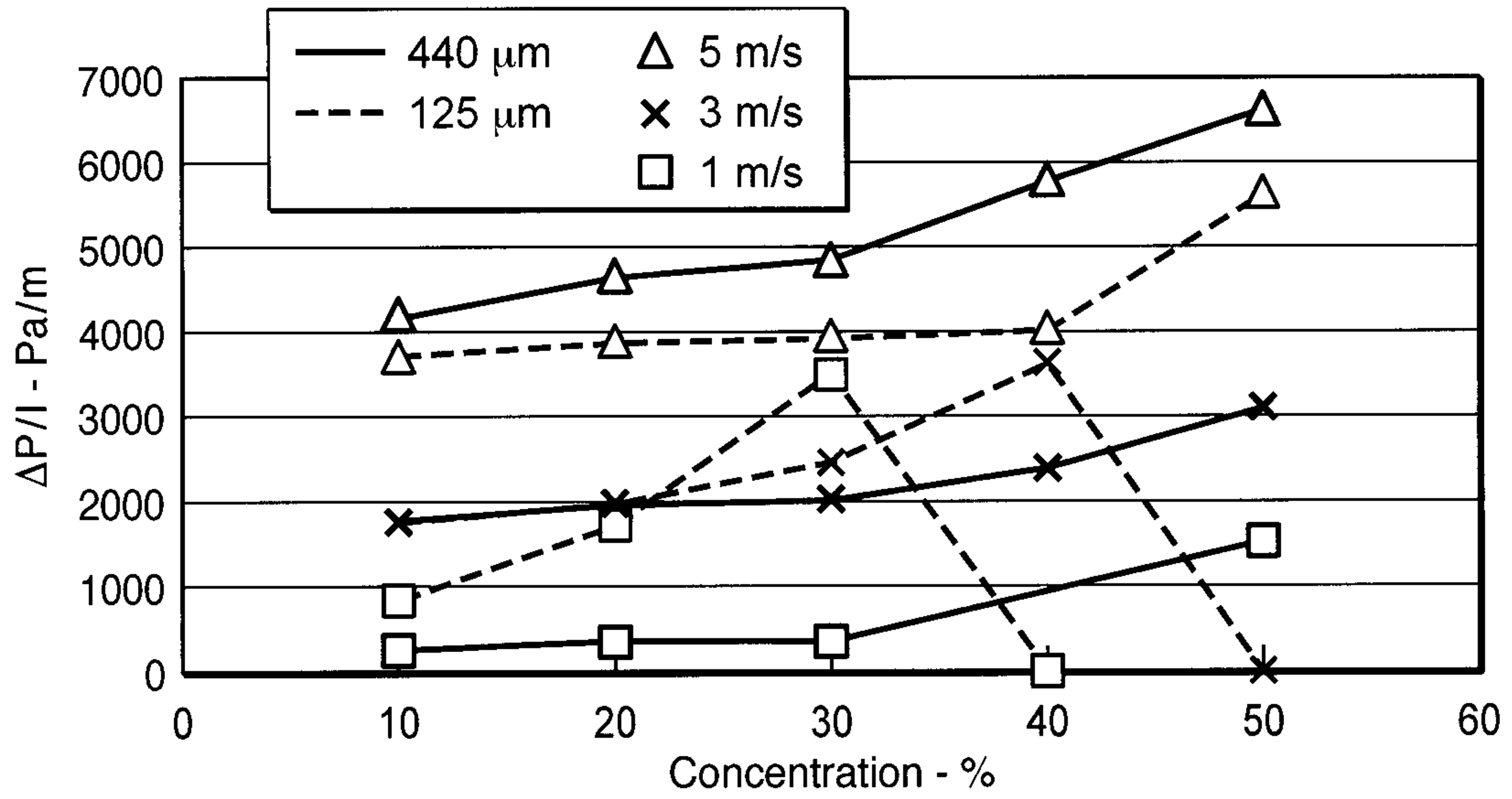


FIG. 5

50wt% slurry, 25% fines, 2 min residence time  
Parr vessel (1L)

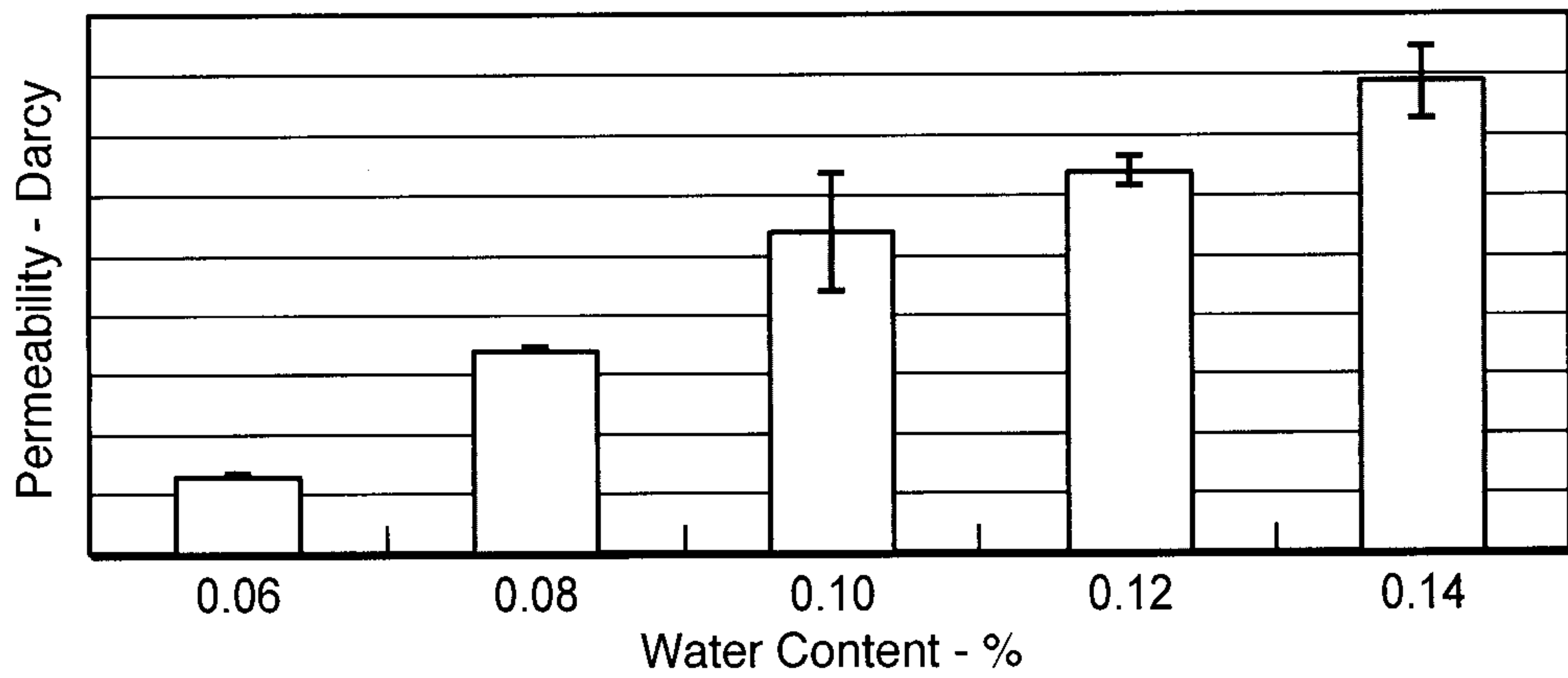


FIG. 6

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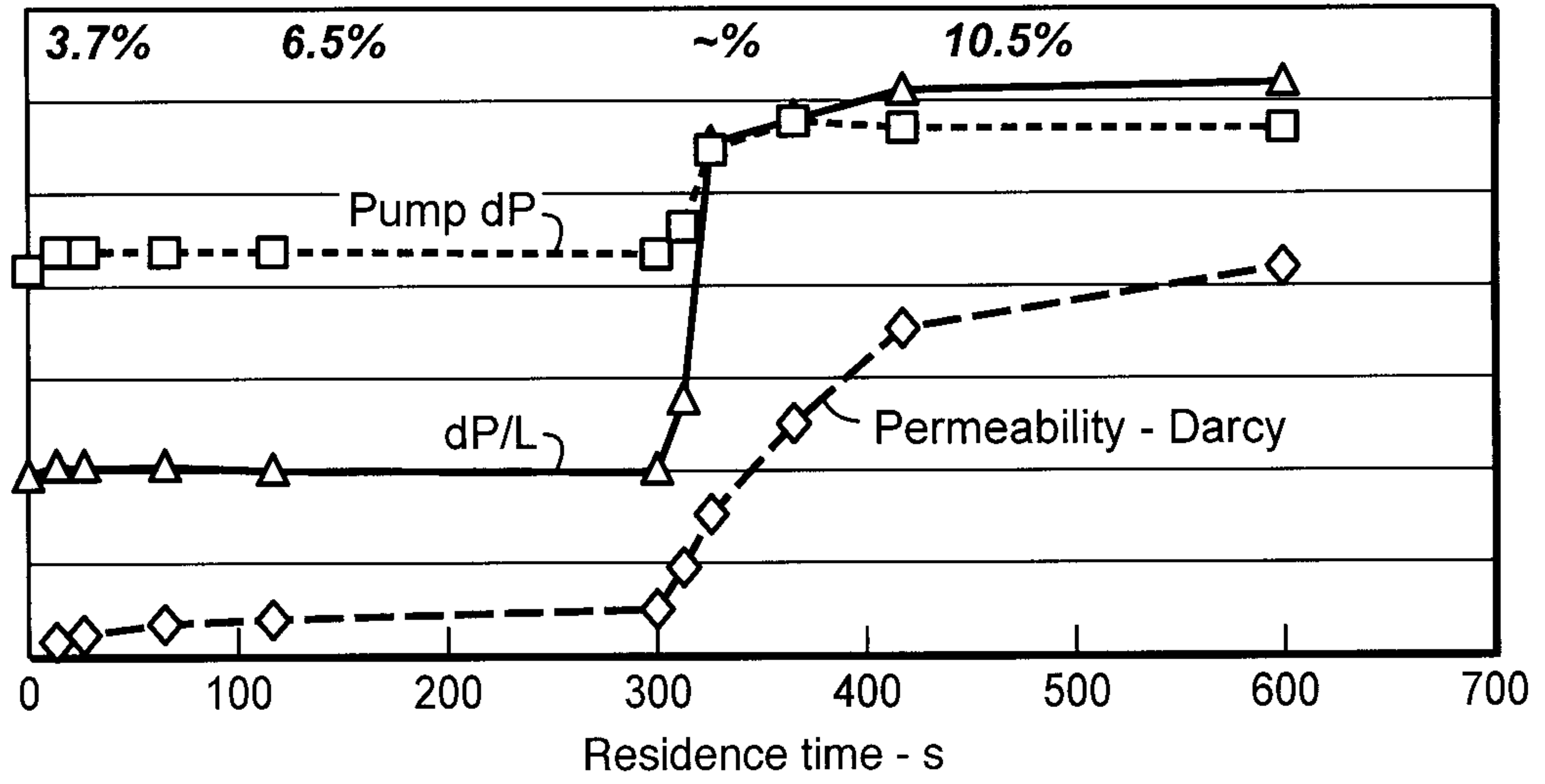


FIG. 7

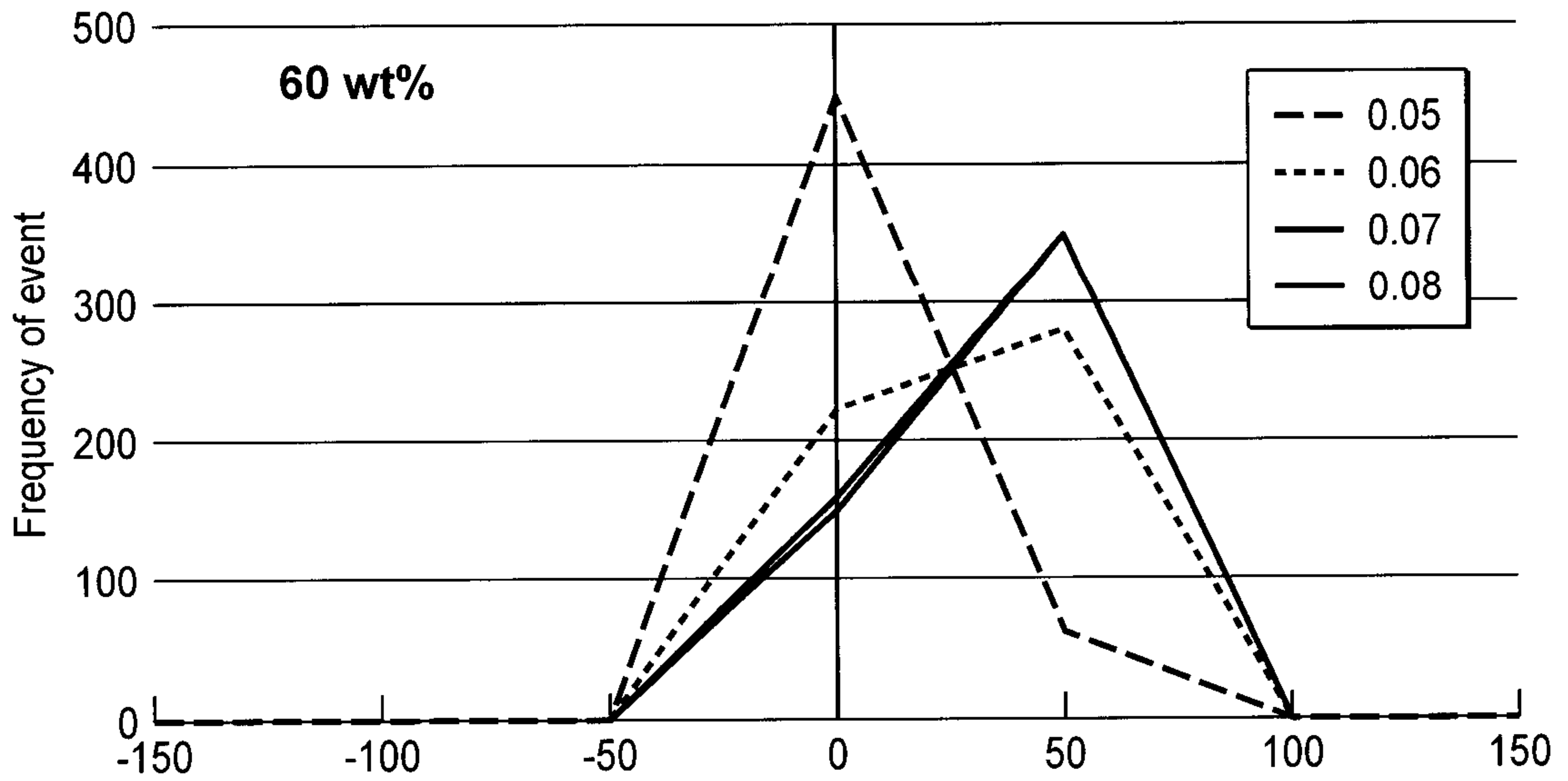
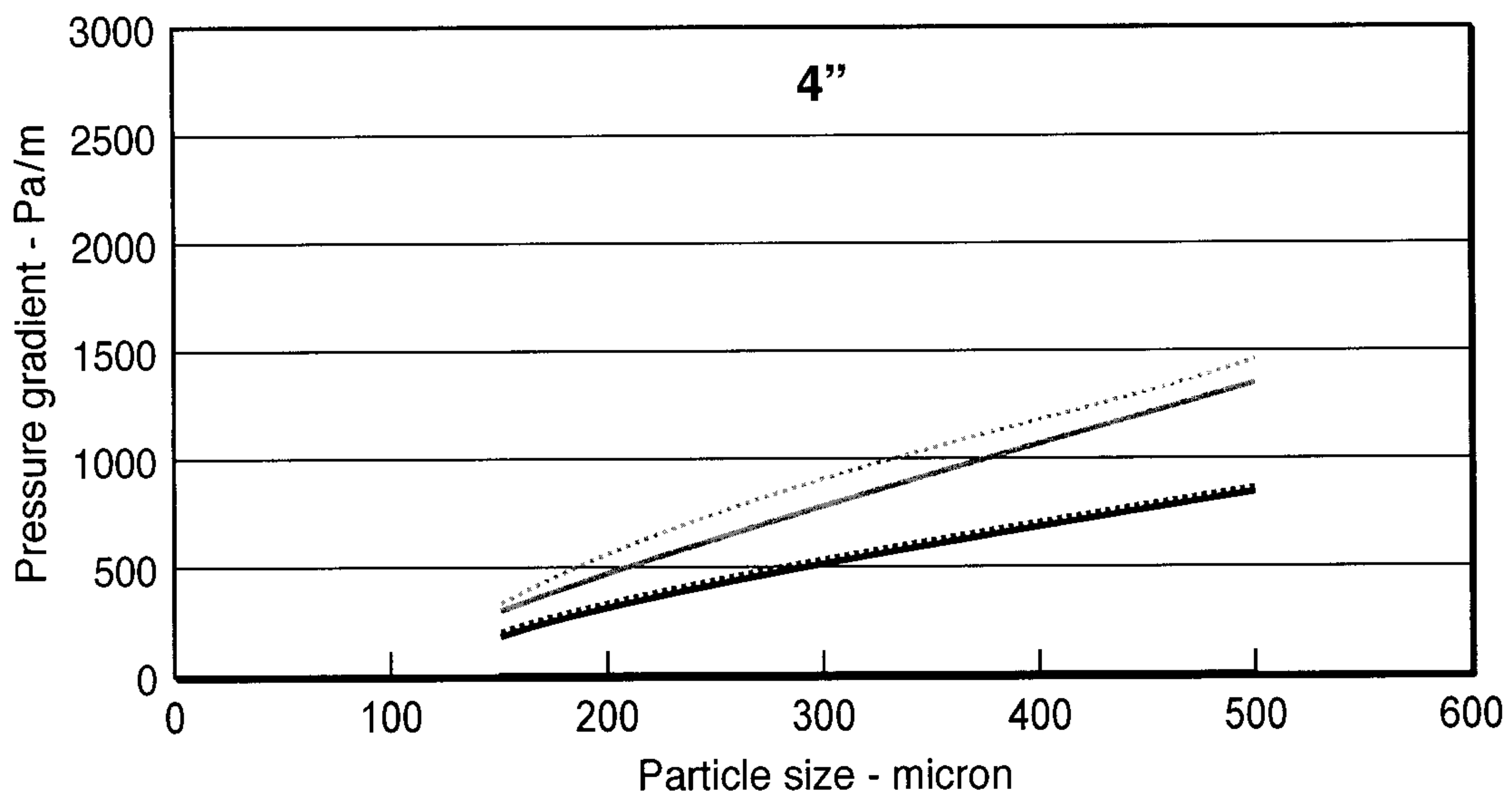
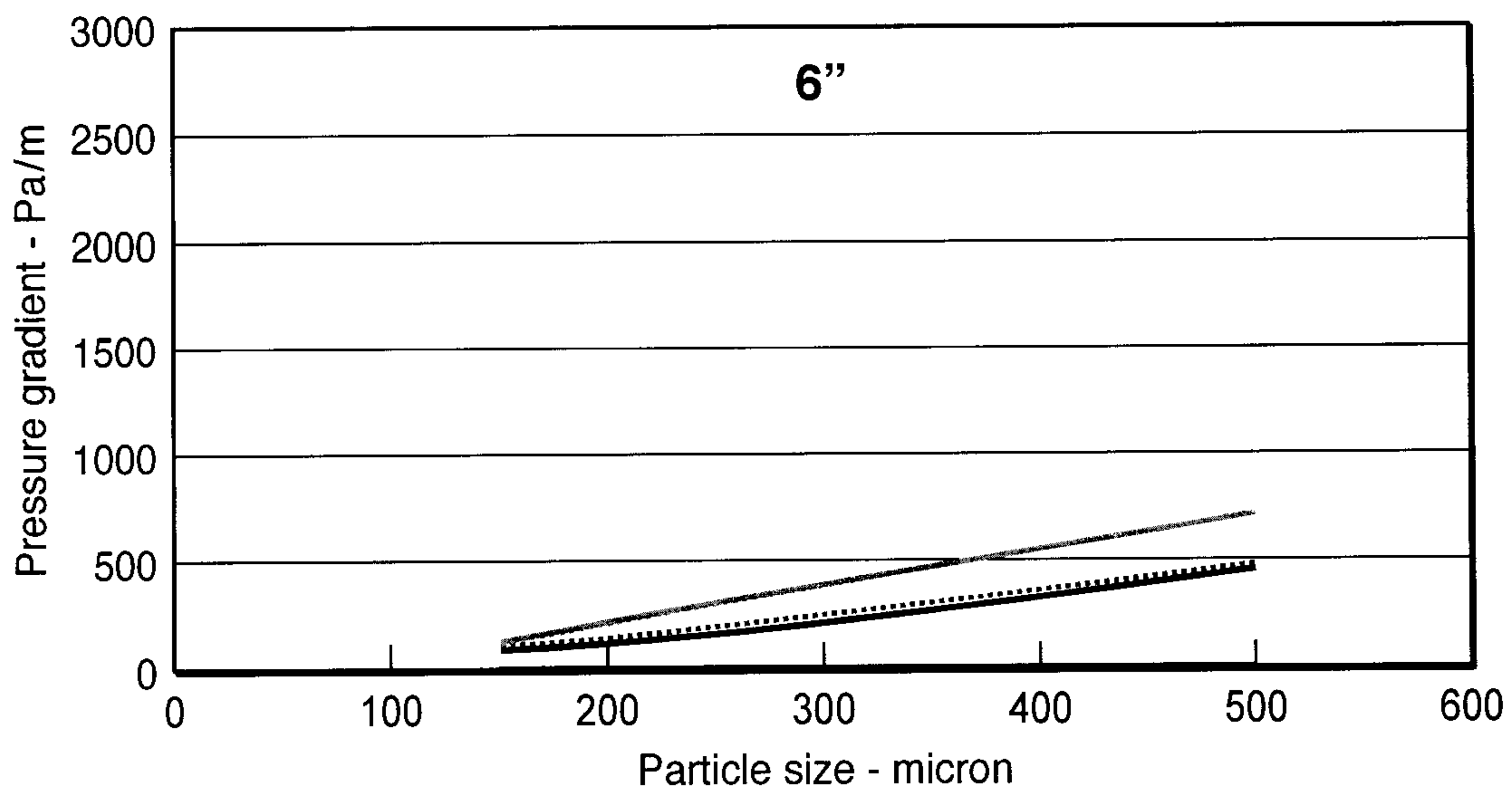


FIG. 8

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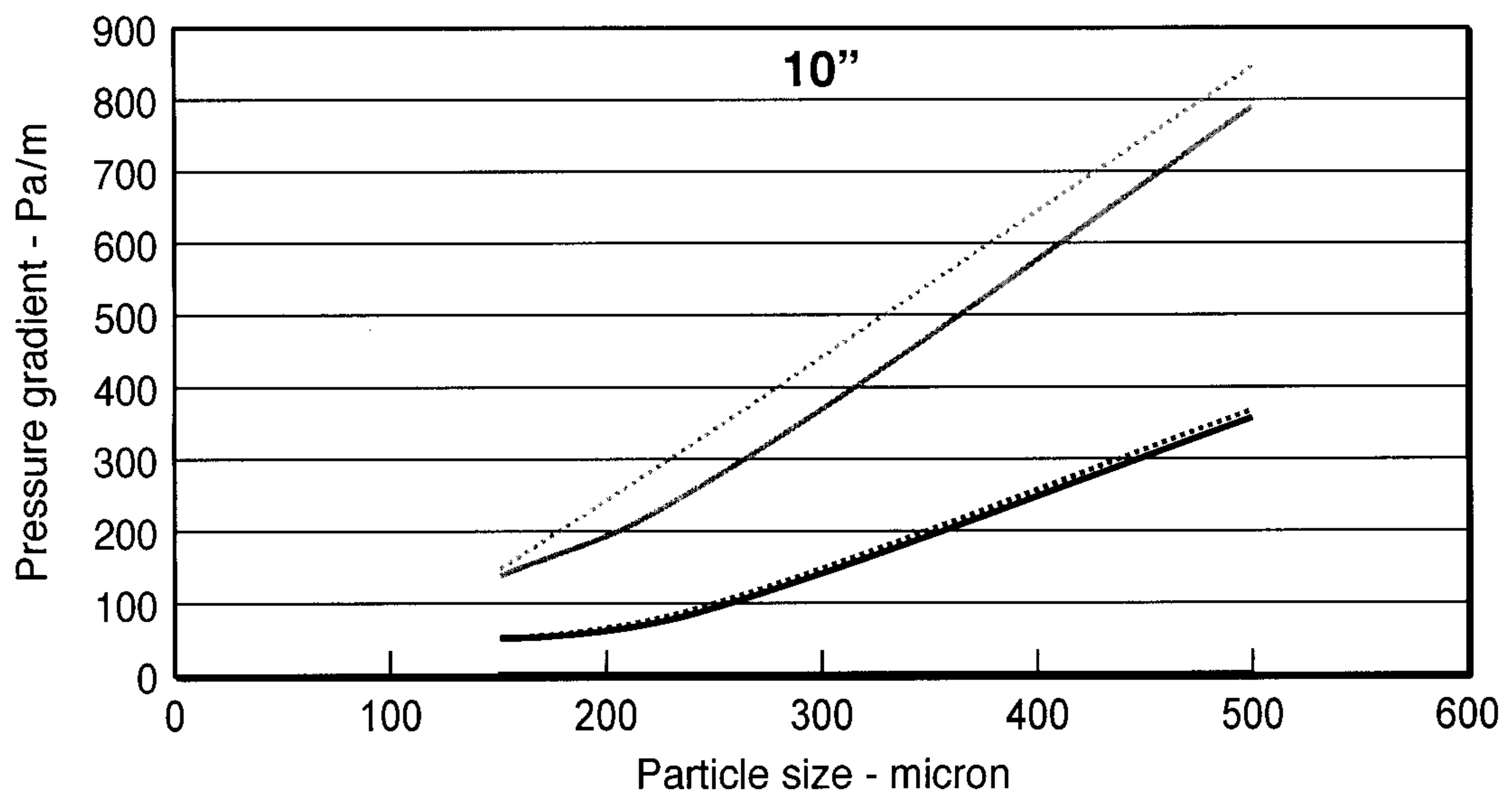


**FIG. 9A**



**FIG. 9B**

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**FIG. 9C**

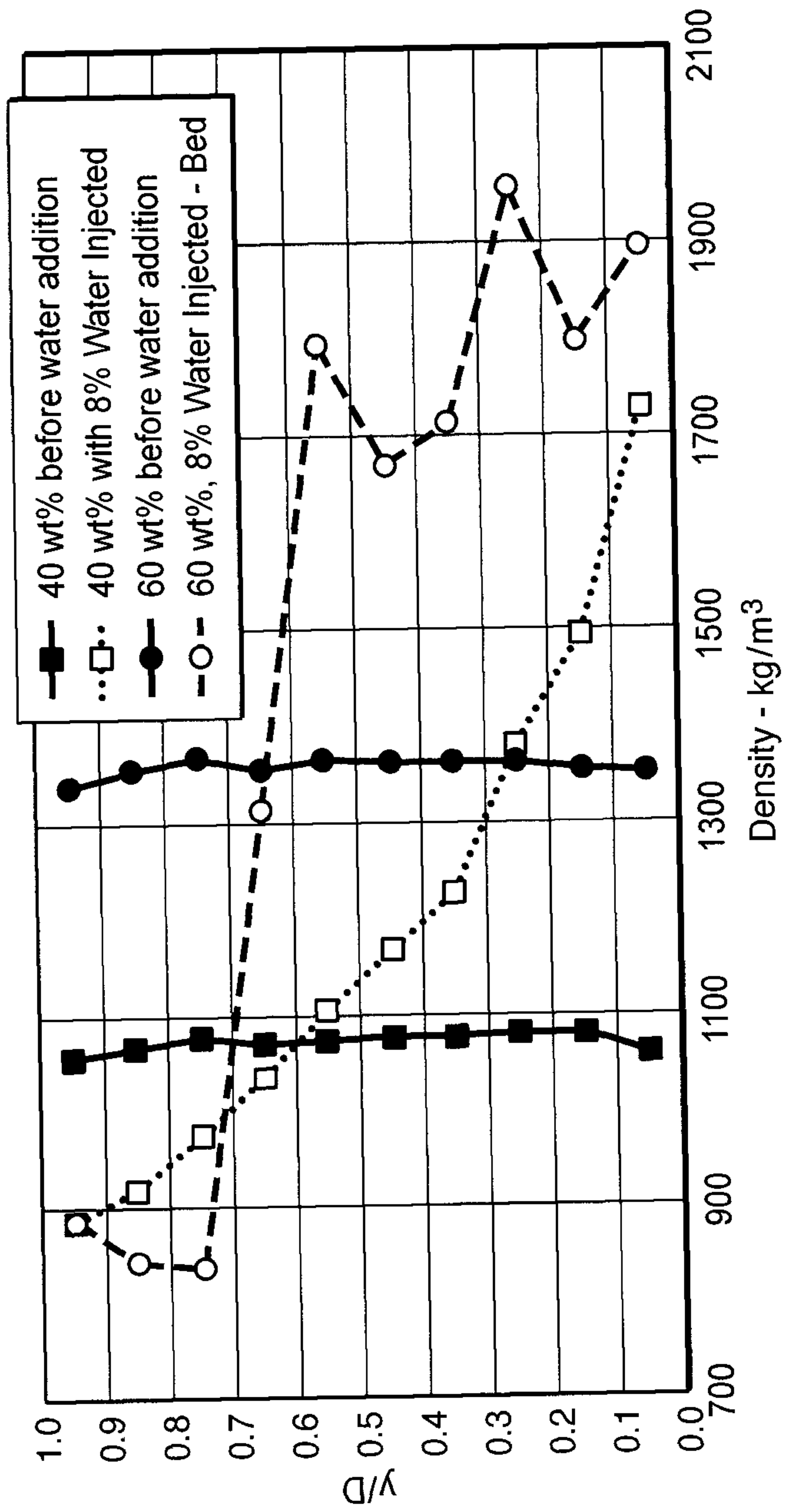
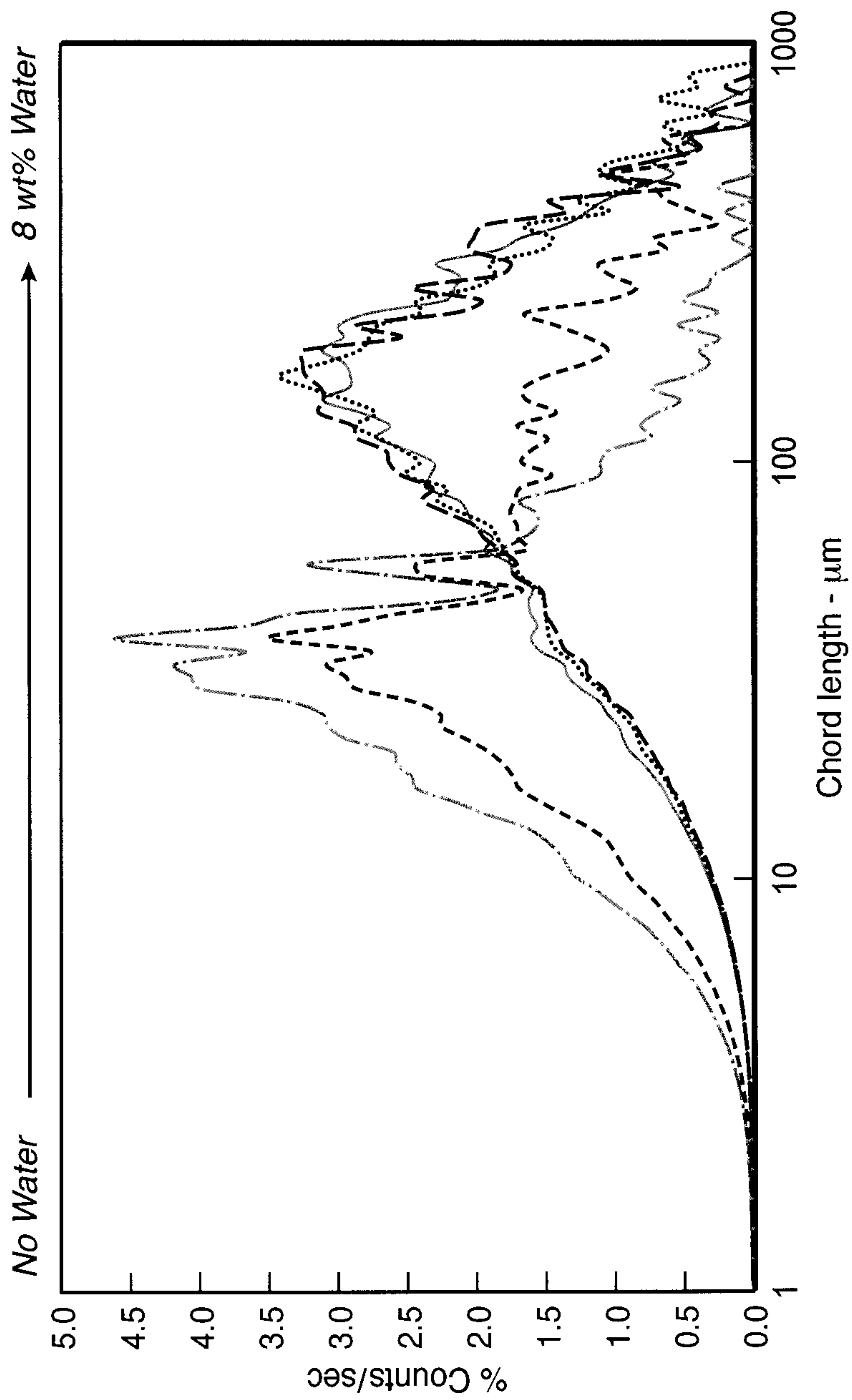


FIG. 10



**FIG. 11**