



(12) **DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION**

(13) **A1**

(22) Date de dépôt/Filing Date: 2018/08/10

(41) Mise à la disp. pub./Open to Public Insp.: 2020/02/02

(30) Priorité/Priority: 2018/08/02 (US62/713672)

(51) Cl.Int./Int.Cl. *C10G 1/04* (2006.01),
C02F 1/463 (2006.01), *C02F 1/50* (2006.01),
C02F 1/52 (2006.01), *C02F 1/56* (2006.01),
C02F 9/06 (2006.01)

(71) Demandeur/Applicant:
KEMIRA OYJ, FI

(72) Inventeurs/Inventors:
FENDERSON, THOMAS, CA;
PELAEZ, MIGUEL, US

(74) Agent: BERESKIN & PARR LLP/S.E.N.C.R.L.,S.R.L.

(54) Titre : SYSTEMES ET PROCEDES DE TRAITEMENT DE PRODUITS DE QUEUE

(54) Title: SYSTEMS AND METHODS FOR TREATING TAILINGS

(57) **Abrégé/Abstract:**

Methods and apparatus or systems useful in the treatment of tailings are provided, e.g., oil sands tailings, and mature fine tailings. These methods and apparatus or system used therein comprise the combined use of electrocoagulation and chemical flocculation effected using one or more flocculants. The combined use of electrocoagulation and chemical flocculation in these methods and using these apparatus or system results in improvements such as improved removal of fine, slow settling clay particles, persistent contaminants, and/or residual bitumen; lower solids content, lower turbidity, and lower carbon oxygen demand ("COD").

ABSTRACT

Methods and apparatus or systems useful in the treatment of tailings are provided, e.g., oil sands tailings, and mature fine tailings. These methods and apparatus or system used therein comprise the combined use of electrocoagulation and chemical flocculation effected using one or more flocculants. The combined use of electrocoagulation and chemical flocculation in these methods and using these apparatus or system results in improvements such as improved removal of fine, slow settling clay particles, persistent contaminants, and/or residual bitumen; lower solids content, lower turbidity, and lower carbon oxygen demand ("COD").

SYSTEMS AND METHODS FOR TREATING TAILINGS

FIELD OF THE ART

[001] The present disclosure generally relates to systems and methods for treating tailings, e.g., oil sands tailings.

BACKGROUND

[002] Bituminous sands, also referred to as oil sands, are a type of petroleum deposit. Oil sands typically contain naturally occurring mixtures of sand, clay, water, and a dense, extremely viscous form of petroleum technically referred to as bitumen (or colloquially "tar" due to their similar appearance, odor, and color). Oil sands may be found in large quantities in many countries throughout the world, most abundantly so in Canada and Venezuela. Oil sand deposits in northern Alberta in Canada (Athabasca oil sands) are thought to contain approximately 1.6 trillion barrels of bitumen, and production from oil sands mining operations is expected to reach 1.5 million barrels of bitumen per day by 2020.

[003] Oil sands reserves are an important part of the world's oil reserves, particularly as higher oil prices and new technology enable oil sands reserves to be profitably extracted and upgraded to usable products. Oil sands are often referred to as unconventional oil or crude bitumen, in order to distinguish the bitumen extracted from oil sands from the free-flowing hydrocarbon mixtures known as crude oil traditionally produced from oil wells.

[004] Conventional crude oil may be extracted from the ground by drilling oil wells into a petroleum reservoir and allowing oil to flow into them under natural reservoir pressure, although artificial lift and techniques such as water flooding and gas injection may be required to maintain production as reservoir pressure drops toward the end of a field's life. Since extra-heavy oil and bitumen flow very slowly, if at all, towards producing wells under normal reservoir conditions, the sands may be extracted by strip mining or the oil made to flow into wells by *in situ* techniques that reduce the viscosity, such as by injecting steam, solvents, and/or hot air into the sands. These processes may use more water and may require larger amounts of energy than conventional oil extraction, although many conventional oil fields also typically require large amounts of water and energy to achieve good rates of production.

BRIEF SUMMARY

[005] The present embodiments generally relate to methods of treating tailings comprising adding at least one flocculant to the tailings substrate, and subjecting the tailings substrate to at least one electrocoagulation procedure. In some embodiments, such treatment methods may provide for enhanced results including any or all of the following: reduction in the solids content of the treated tailings, reduced turbidity and chemical oxygen demand, the ability to use lower dosages of flocculant, improved removal of flocs and reduced energy demand. In some embodiments methods of treating fluid fine tailings, mature fine tailings, or a combination thereof, are provided which may comprise adding at least one flocculant to the tailings substrate, and subjecting the tailings substrate to at least one electrocoagulation procedure. In some embodiments methods of treating undiluted tailings or diluted tailings are provided which may comprise adding at least one flocculant to the tailings substrate, and subjecting the tailings substrate to at least one electrocoagulation procedure. Furthermore, the present embodiments generally encompass methods of treating tailings such as, for example, oil sands tailings and/or mature fine tailings and/or fluid fine tailings, which methods may comprise adding at least one flocculant to the tailings substrate, and subjecting the tailings substrate to at least one electrocoagulation procedure. In some embodiments, the combined use of electrocoagulation and chemical flocculation may provide for one or more of the following: (i) reduction in solids content in tailings, (ii) reduction of turbidity in tailings, (iii) reduced chemical oxygen demand, (iv) improved flocculation and/or improved flocculation at lower flocculant dosages, and (v) reduced solids content in treated tailings and changed composition of the treated tailings. In some embodiments, said tailings may comprise diluted tailings or undiluted tailings. In some embodiments, said tailings may comprise fluid fine tailings, mature fine tailings, or a combination thereof.

[006] In some embodiments, a flocculant is added to the tailings substrate after an electrocoagulation procedure. In some embodiments, a flocculant is added to the tailings substrate prior to and/or during an electrocoagulation procedure. In some embodiments, the at least one flocculant may comprise an acrylamide (“AMD”) flocculant. In some embodiments, the at least one flocculant may comprise one or more high molecular weight flocculants. Said high

molecular weight flocculants may have a molecular weight of greater than about 500,000; about 5,000,000; about 10,000,000; about 15,000,000; about 20,000,000; or about 25,000,000 Daltons. In some embodiments, one or more polymer flocculants may have a molecular weight in the range of about 500,000 to about 30,000,000 Daltons. In some embodiments, the at least one flocculant may comprise one or more charged flocculant compounds e.g., one or more cationic or anionic polyacrylamide flocculants. In some embodiments, the at least one flocculant may comprise one or more anionic charged flocculants. In some embodiments, the at least one flocculant may comprise an anionic flocculant which comprises from greater than 0% or more to about 100 mol% of a charged monomer or from about 20 mol% to about 95 mol% of a charged monomer, or from about 50% or more to about 95% or more mol% of a charged monomer. In some embodiments, the at least one flocculant may comprise an acrylamide flocculant that comprises from greater than 0 mol% or more to about 100 mol% of a charged monomer, such as an anionic monomer, or from about 50% or more to about 95% or more mol% of a charged monomer, such as an anionic monomer or comprises 20-45 mol% or 50 mol% or more of a charged monomer such as an anionic monomer.

[007] Furthermore, in some embodiments of the methods described herein, said method may comprise the addition of one or more polysaccharides to the tailings substrate. In some embodiments, said one or more polysaccharides comprise xylan units. In some embodiments, said addition of said one or more polysaccharides may result in synergistic effects. Said synergistic effects may include one or more of reduced turbidity values, reduced supernatant solids content or greater fines capture, reduced formation of non-segregated tailings, reduced carbon oxygen demand, increased water release, a desirable degree of floc formation; or a combination of any of the foregoing. In some embodiments, said synergistic effects may include greater fines capture resulting in better overflow clarity. Moreover, in some embodiments the use of electrocoagulation may improve flocculation of said tailings, as compared to a method comprising the addition of the at least one flocculant without electrocoagulation. In some embodiments of the methods described herein, said methods may result in improved removal of fine, slow settling clay particles, persistent contaminants, and/or residual bitumen as compared to electrocoagulation alone or flocculation alone. In some embodiments, practicing the methods described herein may result in a treated tailings composition comprising a lower solids content as compared to tailings treated with electrocoagulation alone or flocculation alone. In some

embodiments of the methods described herein, said methods may result in a treated tailings composition comprising a lower carbon oxygen demand (“COD”) as compared to tailings treated with electrocoagulation alone or flocculation alone. Furthermore, in some embodiments of the methods described herein, practicing said methods described herein may result in a treated tailings composition comprising a lower solids content as compared to tailings treated with inorganic coagulant, wherein said tailings were optionally also treated by electrocoagulation. Moreover, in some embodiments, increasing the dosage of said one or more flocculants may result in a corresponding decrease in solids content of a treated tailings composition.

[008] In some embodiments of the methods described herein, the use of electrocoagulation and one or more flocculants may result in synergistic effects, e.g., said synergistic effects may include one or more of reduced turbidity values, reduced supernatant solids content or greater fines capture, reduced formation of non-segregated tailings, reduced carbon-oxygen demand, increased water release, a desirable degree of floc formation; or a combination of any of the foregoing. In some embodiments, said synergistic effects may include greater fines capture resulting in better overflow clarity. In some embodiments, at least one electrocoagulation procedure may be effected using an iron-based electrode. In some embodiments, said iron-based electrodes may comprise an anode and a cathode of a cell in which electrocoagulation occurs. In some embodiments, electrocoagulation may comprise the application of 5 V or less, 5 V or more, 10 V or more, 12 V or more, or 15 V or more to effect said electrocoagulation.

[009] Furthermore, in some embodiments, the dosage of said one or more flocculants may be from about 50 g/ton or more to about 5000 g/ton or more. In some embodiments, said electrocoagulation may utilize a small amount of iron ions to perform coagulation. In some embodiments, said one or more flocculants comprised therein include one or more low molecular weight, medium molecular weight, and/or high molecular weight flocculants. In some embodiments of the methods described herein, said one or more flocculants comprised therein may include one or more anionic, nonionic, and/or cationic flocculants. In some embodiments, said one or more flocculants comprised therein may include AMD and acrylic acid. In some embodiments, use of electrocoagulation may result in a thick layer of solids formed on an anode of a cell used for said electrocoagulation. In some embodiments, said thick layer of solids may be removed by use of a mechanical scraper. In some embodiments, said thick layer of solids may settle to the bottom of the cell by gravity following mechanical scraping and may then be

removed after said settling. In some embodiments, switching of a current used for electrocoagulation may remove said layer of solids. In some embodiments, said thick layer of solids may settle to the bottom of the cell by gravity following said switching of said current and is then removed after said settling.

[0010] In some embodiments of the methods described herein, said method may include an electrocoagulation procedure which results in the formation of hydrogen gas and/or hydrogen gas bubbles on a cathode of a cell used for said electrocoagulation procedure. In some embodiments, formation of said hydrogen gas and/or hydrogen gas bubbles may float flocculated particles to the surface of the tailings solution, thereby providing better separation of contaminants as compared to flocculation alone. In some embodiments, said one or more flocculants may comprise one or more high molecular weight flocculants as compared to other flocculants generally used to treat tailings. In some embodiments, use of said high molecular weight flocculants may result in more gas trapped from the electrocoagulation process occurring in the cathode and further raises more flocculated particles to surface of the tailings solution, thereby providing better separation of contaminants as compared to flocculation alone. In some embodiments, an increase in voltage used to effect electrocoagulation may result in a corresponding increase in the formation of hydrogen gas and/or hydrogen bubbles. In some embodiments, said hydrogen gas and/or hydrogen bubbles may interact with the coagulated particles being formed during electrocoagulation to promote floatation of flocs formed as a result of said method. In some embodiments of the methods described herein, current applied during electrocoagulation may be reversed one or more times. In some embodiments, said reversal of current one or more times may result in a continuous electrocoagulation process. In some embodiments of the methods described herein, said methods may result in formation of a trafficable deposit.

[0011] The present disclosure additionally generally relates to an apparatus or system for use in the treatment of tailings, wherein said apparatus or system comprises a cell for effecting electrocoagulation and chemical flocculation, wherein said cell comprises one or more anodes and one or more cathodes, and further comprises tailings to be treated and one or more flocculants. In some embodiments, said anode and/or said cathode may comprise iron-based electrodes. In some embodiments, said apparatus or system for use in treating tailings further comprises a power supply and/or a means to effect mixing, e.g., a magnetic stirrer. In some

embodiments, using said apparatus to effect both electrocoagulation and chemical flocculation may provide for enhanced flocculant performance. In some embodiments, use of said apparatus to effect both electrocoagulation and chemical flocculation may provide for one or more of the following: (i) reduction in solids content in tailings, (ii) reduction of turbidity in tailings, (iii) reduced chemical oxygen demand, (iv) improved flocculation at lower flocculant dosages, and (v) reduced solids content in treated tailings and changed tailings composition. In some embodiments, said tailings may comprise oil sands tailings, mature fine tailings, undiluted tailings, and/or diluted tailings. In some embodiments, an electrocoagulation procedure may be effected prior to a subsequent chemical flocculation procedure when using said apparatus to treat said tailings. In some embodiments, at least one chemical flocculation step may be effected prior to and/or during an electrocoagulation procedure when using said apparatus to treat said tailings. In some embodiments, chemical flocculation may be effected by the use of one or more flocculants when using said apparatus to treat said tailings. In some embodiments, chemical flocculation may comprise the addition of an acrylamide flocculant ("AMD"). In some embodiments, chemical flocculation may comprise the addition of one or more high molecular weight flocculants. In some embodiments, said one or more high molecular weight flocculants comprise a molecular weight greater than about 500,000; about 5,000,000; about 10,000,000; about 15,000,000; about 20,000,000; or about 25,000,000 Daltons, preferably in the range of from about 500,000 to about 30,000,000 Daltons. In some embodiments, chemical flocculation may comprise the addition of one or more charged flocculant compounds. In some embodiments, chemical flocculation may comprise the addition of one or more anionic charged flocculant compounds. In some embodiments, chemical flocculation may comprise the addition of one or more high molecular weight, charged flocculant compounds. In some embodiments, said one or more flocculants comprise one or more anionic flocculants. In some embodiments, the at least one flocculant may comprise an anionic flocculant which comprises from greater than 0% or more to about 100 mol% of a charged monomer or from about 20 mol% to about 95 mol% of a charged monomer, or from about 50% or more to about 95% or more mol% of a charged monomer. In some embodiments, the at least one flocculant may comprise an acrylamide flocculant that comprises from greater than 0 mol% or more to about 100 mol% of a charged monomer, such as an anionic monomer, or from about 50% or more to about 95% or more mol%

of a charged monomer, such as an anionic monomer or comprises 20-45 mol% or 50 mol% or more of a charged monomer such as an anionic monomer.

[0012] Furthermore, in some embodiments, one or more polysaccharides may be added to said cell of said apparatus. In some embodiments, said one or more polysaccharides may comprise xylan units. In some embodiments, addition of said one or more polysaccharides when using said apparatus may result in synergistic effects. Said synergistic effects may include one or more of reduced turbidity values, reduced supernatant solids content or greater fines capture, reduced formation of non-segregated tailings, reduced carbon-oxygen demand, increased water release, a desirable degree of floc formation; or a combination of any of the foregoing. In some embodiments, said synergistic effects may include greater fines capture resulting in better overflow clarity. In some embodiments, the use of said apparatus or system to effect electrocoagulation to treat said tailings may improve flocculation of said tailings effected by said apparatus. In some embodiments, use of said apparatus or system to treat said tailings may result in improved removal of fine, slow settling clay particles, persistent contaminants, and/or residual bitumen, in particular as compared to electrocoagulation alone or flocculation alone. In some embodiments, use of said apparatus or system to treat said tailings may result in a treated tailings composition comprising a lower solids content as compared to tailings treated with electrocoagulation alone or flocculation alone. In some embodiments, use of said apparatus or system to treat said tailings may result in a treated tailings composition comprising a lower turbidity as compared to tailings treated with electrocoagulation alone or flocculation alone. Furthermore, in some embodiments, use of said apparatus or system to treat said tailings may result in a treated tailings composition comprising a lower carbon oxygen demand (“COD”) as compared to tailings treated with electrocoagulation alone or flocculation alone. In some embodiments, use of said apparatus or system to treat said tailings may result in a treated tailings composition comprising a lower solids content as compared to tailings treated with inorganic coagulant, wherein said tailings were optionally further treated by electrocoagulation.

[0013] In some embodiments, increasing the dosage of said one or more flocculants present in said apparatus or system may result in a corresponding decrease in solids content of the treated tailings composition when said apparatus or system is used to treat said tailings. In some embodiments, use of said apparatus or system may comprise use of said apparatus or system to effect an electrocoagulation procedure and a chemical flocculation procedure results in

synergistic effects. In some embodiments, wherein said synergistic effects may include one or more of reduced turbidity values, reduced supernatant solids content or greater fines capture, reduced formation of non-segregated tailings, reduced carbon-oxygen demand, increased water release, a desirable degree of floc formation; or a combination of any of the foregoing. In some embodiments, said synergistic effects may include greater fines capture resulting in better overflow clarity.

[0014] In some embodiments, said apparatus or system may deliver a voltage selected from 5 V or less, 5 V or more, 10 V or more, 12 V or more, or 15 V or more to effect said electrocoagulation. In some embodiments, the dosage of said one or more flocculants is from about 50 g/ton or more to about 5000 g/ton or more. In some embodiments, the apparatus or system may be capable of effecting electrocoagulation utilizing a small amount of iron ions. In some embodiments, said one or more flocculants comprised therein may include one or more low molecular weight, medium molecular weight, and/or high molecular weight flocculants. In some embodiments, said one or more flocculants comprised therein may include one or more anionic, nonionic, and/or cationic flocculants. In some embodiments, said one or more flocculants comprised therein may include AMD and acrylic acid. In some embodiments, the use of said apparatus or system to treat said tailings may result in a thick layer of solids formed on said one or more anodes of said cell. In some embodiments, said apparatus or system may be used in association with a mechanical scraper. In some embodiments, the use of said apparatus or system to treat said tailings may result in a thick layer of solids which settles to the bottom of the cell by gravity following mechanical scraping and is then removed after said settling. In some embodiments, said apparatus or system may provide for the switching of current during electrocoagulation which facilitates the removal of a layer of solids which is produced by electrocoagulation. Moreover, in some embodiments, the use of said apparatus or system to treat said tailings may result in a thick layer of solids settles to the bottom of the cell by gravity following said switching of said current and is then removed after said settling. In some embodiments, use of said apparatus or system to effect an electrocoagulation procedure may result in the formation of hydrogen gas and/or hydrogen gas bubbles on said one or more cathodes of said cell. In some embodiments, formation of said hydrogen gas and/or hydrogen gas bubbles may float flocculated particles to water surface of the tailings solution, thereby providing better separation of contaminants as compared to flocculation alone. In some embodiments, said

one or more flocculants may comprise one or more high molecular weight flocculants. In some embodiments, use of said high molecular weight flocculants may result in more gas trapped from the electrocoagulation process occurring in the cathode and further raises more flocculated particles to surface of the tailings solution, thereby providing better separation of contaminants as compared to flocculation alone. In some embodiments, said apparatus or system may provide for an increase in voltage to effect electrocoagulation which may result in a corresponding increase in the formation of hydrogen gas and/or hydrogen bubbles. In some embodiments, said hydrogen gas and/or hydrogen bubbles may interact with the coagulated particles being formed during electrocoagulation to promote floatation of flocs formed as a result of said method. In some embodiments, the apparatus or system may provide for current to be applied and reversed one or more times during an electrocoagulation procedure. In some embodiments, said reversal of current one or more times may result in a continuous electrocoagulation process. In some embodiments, use of said apparatus or system to treat said tailings may result in a trafficable deposit.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0015] In the Examples and below the various Figures are referred to either as “**Figure X**” or “**FIG. X**”.

[0016] **Figure 1** shows an image of an electrocoagulation apparatus in accordance with the Examples discussed herein.

[0017] **Figure 2A-Figure 2F** shows visible solid-liquid separation of Mature Fine Tailings (MFT) samples treated with flocculation alone (**FIG. 2A** and **FIG. 2D**), electrocoagulation alone (**FIG. 2B** and **FIG. 2E**), and a combination of electrocoagulation and flocculation (**FIG. 2C** and **FIG. 2F**), in accordance with Example 1.

[0018] **Figure 3A-Figure 3E** shows visible solid-liquid separation of MFT samples treated with inorganic coagulant and electrocoagulation (**FIG. 3A**), electrocoagulation alone (**FIG. 3B**), and electrocoagulation in combination with flocculation using increasing concentrations of a flocculant (**FIG. 3C-FIG. 3E**), in accordance with Example 1.

[0019] **Figure 4A-Figure 4C** shows visible solid-liquid separation of MFT samples treated with a combination of electrocoagulation and flocculation, wherein the voltage used for

electrocoagulation was 5 V (**FIG. 4A**), 10 V (**FIG. 4B**), or 15 V (**FIG. 4C**), in accordance with Example 2.

[0020] **Figure 5** shows treatment of undiluted MFT in accordance with Example 3.

[0021] **Figure 6** shows visible solid-liquid separation of four undiluted MFT samples (numbered 1-4 in **Figure 6**) that were treated in accordance with Example 3.

[0022] **Figure 7** shows a schematic representation of an apparatus for use in the treatment of tailings, in accordance with Example 4.

DETAILED DESCRIPTION

[0023] Disclosed herein are methods for treating tailings, such as, for example, oil sands tailings and/or mature fine tailings. Some embodiments comprise methods for treating tailings comprising adding at least one flocculant to the tailings substrate, and effecting at least one electrocoagulation procedure, which may improve the removal of solids from said tailings and which may improve the dewatering of said tailings. The methods generally may be used for treating oil sands tailings in need of solid-liquid separation, e.g., in order to efficiently recycle water and to reduce the volume of solid tailings which are further handled, such as by transferring them to a dedicated disposal area and/or a tailings pond. By using the methods, a more complete separation of the solids from the water may be achieved, improving process efficiency relative to conventional processes for treating tailings streams. The methods described herein may be used to enhance settling of solids, especially fine and ultrafine solids and/or MFT, in tailings and particularly in oils sands and/or oil sands ore tailings streams. The methods may be readily incorporated into existing processes and may provide economic and environmental benefits. The present disclosure further generally relates to an apparatus or system for use in the treatment of tailings, wherein said apparatus or system may be used to treat said tailings.

DEFINITIONS

[0024] As used herein the singular forms "a", "and", and "the" include plural referents unless the context clearly dictates otherwise. All technical and scientific terms used herein have the same

meaning as commonly understood to one of ordinary skill in the art to which this invention belongs unless clearly indicated otherwise.

[0025] As used herein, the terms "tailings" and "tailings stream" generally refer to the discarded materials that may be generated in the course of extracting a valuable material from an ore. Generally, any mining or mineral processing operation that uses water to convey or wash materials will typically generate a tailings stream. Exemplary tailings include, but are not limited to, tailings from coal mining, copper mining, gold mining, and mineral processing, such as, for example, processing of phosphate, diamond, gold, mineral sands, zinc, lead, copper, silver, uranium, nickel, iron ore, coal, oil sands, and/or red mud. Exemplary tailings also include tailings from the processing of oil sands. While many of the embodiments are described with reference to oil sands tailings, it is understood that the exemplary compositions, processes, and methods are not limited to applications in oil sands tailings, but also can be applied to various other tailings. The term tailings is meant to be inclusive of but not limited to any of the types of tailings discussed herein, for example, process oil sand tailings, in-process tailings, oil sands tailings, and the like.

[0026] The terms "process oil sand tailings", "oil sands tailings stream", "oil sands process tailings", or "oil sands tailings", generally refer to tailings that may be directly generated as bitumen is extracted from oil sands. In tar sand processing, tailings may comprise the whole tar sand ore and any net additions of process water less the recovered bitumen.

[0027] Any tailings fraction obtained from the process, such as tailings from primary separation cell, primary flotation and secondary flotation, process tailings, froth treatment tailings, and mature fine tailings or combination thereof, may be treated by the processes described herein. The tailings may comprise a colloidal sludge suspension comprising clay minerals and/or metal oxides/hydroxides. In some embodiments, the tailings stream may comprise water and solids.

[0028] Tailings generally comprise mineral solids having a variety of particle sizes. Mineral fractions with a particle diameter greater than 44 microns may be referred to as "coarse" particles, or "sand." Mineral fractions with a particle diameter less than 44 microns may be referred to as "fines" and may essentially be comprised of silica and silicates and clays that may be easily suspended in the water. Ultrafine solids ($< 2 \mu\text{m}$) may also be present in the tailings stream and may be primarily composed of clays. The tailings may include but are not limited to including one or more of the coarse particles, fine tailings, MFT, FFT, or ultrafine solids.

[0029] The oil sands tailings may additionally include but are not limited to including one or more of any of the tailings streams that may be produced in a process to extract bitumen from an oil sands ore. In some embodiments, the tailings may comprise paraffinic or naphthenic tailings, for example paraffinic froth tailings. The tailings may be combined into a single tailings stream for dewatering or each tailings stream may be dewatered individually.

[0030] In some embodiments, the tailings stream may be produced from an oil sands ore and may comprise water and solids, for example sand and fines. In some embodiments, the tailings stream, for example, oil sands tailings stream, may comprise at least one of the coarse tailings, fluid fine tailings, MFT, fine tailings, and ultrafine tailings. In some embodiments, the processes may be used to treat ultrafine solids. In some embodiments, the tailings stream, for example, oil sands tailings stream, may comprise a fine (particle size $< 44\ \mu\text{m}$) content of about 10 to about 100 wt%, about 20 to about 100 wt%, about 30 to about 100 wt%, or about 40 to about 90 wt% of the dry tailings. In some embodiments, the tailings stream may comprise about 0.01 to about 5 wt% of bitumen. In some embodiments, the oil sands ore tailings stream may comprise process tailings.

[0031] Any of the above terms referencing “tailings” additionally generally comprises fluid fine tailings (“FFT”) such as mature fine tailings (“MFT”) from tailings ponds and fine tailings from ongoing extraction operations (for example, froth treatment tailings or thickener underflow) which may bypass a tailings pond.

[0032] As used herein, “fines” generally may refer to mineral fractions that may comprise a particle diameter less than 44 microns.

[0033] As used herein, “fluid fine tailings” or “FFT” may comprise a liquid suspension of oil sand fines in water with a solids content greater than 2%.

[0034] The term “mature fine tailings” (“MFT”) generally may refer to fine tailings that may comprise a solids content of about 30-35%, and that generally may comprise almost entirely solids < 44 microns. MFT generally may behave as a fluid-like colloidal material. MFT may comprise FFT with a low sand to fines ratio (“SFR”), i.e., generally less than about 0.3, and a solids content that may be generally greater than about 30%.

[0035] As used herein, “sand” generally may refer to mineral fractions that may comprise a particle diameter greater than 44 microns.

[0036] As used herein, the term “iron” generally refers to any form of iron, for example, iron of any isotopic state, iron of any oxidation state, any form of an iron compound, such as, for example, iron (III) chloride, iron (II) chloride (also known as ferrous chloride), iron (III) chloride hexahydrate, iron (II) sulfate, and iron (III) sulfate. For example, iron chloride as used herein may generally refer to both ferrous chloride and ferric chloride, and iron sulfate generally refers to ferrous sulfate and ferric sulfate, so long as use of either form in any of the methods described herein attains a desired result.

[0037] As used herein, the term “coagulant” generally may refer to an agent that may typically destabilize colloidal suspensions. Coagulants may comprise iron-based coagulants, such as ferrous chloride and/or iron chloride. Examples of other iron-based coagulants may include, but are not limited to including ferric chloride, ferrous chloride, ferric sulfate, ferric chloride sulfate, polyferric sulfate, and ferrous sulfate. Other coagulants may comprise but are not limited to comprising inorganic coagulants such as aluminium sulfate (“ALS”) and other metal sulfates and gypsum, organic coagulants such as polyamines and polyDADMACs, and other inorganic and organic coagulants known in the art. In some embodiments, a coagulant to be used with the compositions, methods, and processes described herein may comprise ALS. In some embodiments, a coagulant to be used with the compositions, methods, and processes described herein may provide synergistic benefits when used in conjunction with flocculants and oxidants as described herein.

[0038] In some embodiments, the coagulant may comprise a poly(diallyldimethyl ammonium chloride) (“polyDADMAC”) compound; an epi-polyamine compound; a polymer that may comprise one or more quaternized ammonium groups, such as acryloyloxyethyltrimethylammonium chloride, methacryloyloxyethyltrimethylammonium chloride, methacrylamidopropyltrimethylammonium chloride, acrylamidopropyltrimethylammonium chloride; or a mixture thereof. In some embodiments, one or more inorganic coagulants may be added to the tailings stream. An inorganic coagulant may, for example, reduce, neutralize or invert electrical repulsions between particles. Inorganic coagulants may comprise but are not limited to inorganic salts such as aluminum chloride, aluminum sulfate, aluminum chlorohydrate, polyaluminum chloride, polyaluminum silica sulfate, ferric chloride, ferrous chloride, ferric sulfate, ferric chloride sulfate, polyferric sulfate, ferrous sulfate, lime, calcium chloride, calcium sulfate, magnesium chloride, sodium aluminate,

various commercially available iron or aluminum salts coagulants, or combinations thereof. In some embodiments, the coagulant may comprise a combination or mixture of one or more organic coagulants with one or more inorganic coagulants. In some embodiments, the coagulant may comprise a combination or mixture of any of the above coagulants.

[0039] As used herein the term “nonionic monomer” generally refers to a monomer that possesses a neutral charge. Exemplary nonionic monomers may comprise but are not limited to comprising monomers selected from the group consisting of acrylamide (“AMD”), methacrylamido, vinyl, allyl, ethyl, and the like. Some exemplary nonionic monomers may be substituted with a side chain selected from, for example, an alkyl, arylalkyl, dialkyl, ethoxyl, and/or hydrophobic group. In some embodiments, a nonionic monomer may comprise AMD.

[0040] As used herein, the term “anionic monomers” may refer to either anionic monomers that are substantially anionic in whole or (in equilibrium) in part, at a pH in the range of about 6.0 to about 8.0. The “anionic monomers” may be neutral at low pH (from a pH of about 2 to about 6), or to anionic monomers that are anionic at low pH.

[0041] Additional examples of anionic monomers may comprise but are not limited to comprising acrylic, methacrylic, maleic monomers and the like, additional examples include but not limited to any monomer substituted with a carboxylic acid group or salt thereof. In some embodiments, anionic monomers which may be substituted with a carboxylic acid group include, for example, acrylic acid, and methacrylic acid. In some embodiments, an anionic monomer may be a (meth)acrylamide monomer wherein the amide group has been hydrolyzed to a carboxyl group. Said monomer may be a derivative or salt of a monomer according to the embodiments. Additional examples of anionic monomers comprise but are not limited to comprising sulfonic acids or a sulfonic acid group, or both. In some embodiments, the anionic monomers may comprise a sulfonic function that may comprise, for example, 2-acrylamido-2-methylpropanesulfonic acid (“ATBS”).

[0042] As used herein, the term “cationic monomer” generally refers to a monomer that possesses a positive charge. Examples of cationic monomers may comprise but are not limited to comprising acryloyloxy ethyl trimethyl ammonium chloride (“AETAC”), methacryloyloxyethyltrimethylammonium chloride (“MAETAC”), methacrylamidopropyltrimethylammonium chloride (“MAPTAC”), dimethylaminoethyl methacrylate (“DMAEMA”), acrylamidopropyltrimethylammonium chloride (“APTAC”).

[0043] Examples of cationic monomers may also comprise but are not limited to comprising dialkylaminoalkyl acrylates and methacrylates, e.g., dimethylaminoethyl methacrylate (“DMAEMA”), and their quaternary or acid salts, including, but not limited to, dimethylaminoethyl acrylate methyl chloride quaternary salt, dimethylaminoethyl acrylate methyl sulfate quaternary salt, dimethylaminoethyl acrylate benzyl chloride quaternary salt, dimethylaminoethyl acrylate sulfuric acid salt, dimethylaminoethyl acrylate hydrochloric acid salt, diethylaminoethyl acrylate, methyl chloride quaternary salt, dimethylaminoethyl methacrylate methyl chloride quaternary salt, dimethylaminoethyl methacrylate methyl sulfate quaternary salt, dimethylaminoethyl methacrylate benzyl chloride quaternary salt, dimethylaminoethyl methacrylate sulfuric acid salt, dimethylaminoethyl methacrylate hydrochloric acid salt, dimethylaminoethyl methacryloyl hydrochloric acid salt, dialkylaminoalkylacrylamides or methacrylamides and their quaternary or acid salts such as dimethylaminopropyl acrylamide methyl sulfate quaternary salt, dimethylaminopropyl acrylamide sulfuric acid salt, dimethylaminopropyl acrylamide hydrochloric acid salt, dimethylaminopropyl methacrylamide methyl sulfate quaternary salt, dimethylaminopropyl methacrylamide sulfuric acid salt, dimethylaminopropyl methacrylamide hydrochloric acid salt, diethylaminoethylacrylate, diethylaminoethylmethacrylate and diallyldialkylammonium halides such as diallyldiethylammonium chloride and diallyldimethyl ammonium chloride (“DADMAC”). Alkyl groups may generally be C₁₋₈ alkyl.

[0044] As used herein, the terms "polymer," "polymers," "polymeric," and similar terms are used in their ordinary sense as understood by one skilled in the art, and thus may be used herein to refer to or describe a large molecule (or group of such molecules) that may comprise recurring units. Polymers may be formed in various ways, including by polymerizing monomers and/or by chemically modifying one or more recurring units of a precursor polymer. Unless otherwise specified, a polymer may comprise a "homopolymer" that may comprise substantially identical recurring units that may be formed by, for example, polymerizing, a particular monomer. Unless otherwise specified, a polymer may also comprise a "copolymer" that may comprise two or more different recurring units that may be formed by, for example, copolymerizing, two or more different monomers, and/or by chemically modifying one or more recurring units of a precursor polymer. Unless otherwise specified, a polymer or copolymer may also comprise a "terpolymer" which generally refers to a polymer that comprises three or more different recurring units. Any

one of the one or more polymers discussed herein may be used in any applicable process, for example, as a flocculant.

[0045] As used herein, the term "flocculant" may generally refer to a reagent that may bridge neutralized or coagulated particles into larger agglomerates, typically resulting in more efficient settling. In some embodiments, the flocculant may comprise any one or more of the polymers discussed herein, for example, one or more polymers comprising one or more anionic, one or more cationic, and/or one or more nonionic monomers. In some embodiments, the flocculant may comprise AMD. In some embodiments, one or more flocculants may comprise a low molecular weight, a medium molecular weight, and/or a high molecular weight. In some embodiments, one or more flocculants may comprise a charged flocculant that may comprise a low charge, a medium charge, and/or a high charge. In some embodiments, one or more flocculants may comprise a high molecular weight, charged flocculant. In some embodiments, one or more flocculants may comprise one or more polysaccharides. In some embodiments, one or more polysaccharides may comprise one or more types of pentosan units and said one or more polysaccharides may be added to the tailings stream. Pentosan units may be monosaccharides having five carbon atoms, including, for example, xylose, ribose, arabinose, and lyxose. In some embodiments, the pentosan unit may be an aldopentose, which has an aldehyde functional group at position 1, such as, for example, the D- or L- forms of arabinose, ribose, xylose and lyxose. Polysaccharides include, but are not limited to including, for example, xylan, hemicellulose, and gum arabic. Hemicellulose may be derived from biomass, for example grasses and wood, such as hardwood. In some embodiments, the hemicellulose may comprise mixtures of xylose, arabinose, mannose and galactose. Gum arabic may comprise arabinose and ribose. In some embodiments, the one or more types of pentosan units comprise xylan units and one or more of hemicellulose and aldopentoses. In some embodiments, one or more polysaccharides may be derived from plant cell walls, for example sugar-cane- or corn-plant cell walls, or algae. In some embodiments, one or more polysaccharides may be derived from sugar cane, or corn. In some embodiments, one or more polysaccharides may be derived from sugar cane bagasse. In some embodiments, one or more polysaccharides may be derived from corn fiber. In some embodiments, one or more polysaccharides comprising one or more types of pentosan units may be a blend or a mixture of polysaccharides comprising one or more types of pentosan units. In some embodiments, one or more polysaccharides comprising one or more types of pentosan units

may consist essentially of polysaccharides comprising one type of pentosan unit, for example xylan. In some embodiments, the one or more types of pentosan units comprise xylan. In some embodiments, one or more polysaccharides comprising one or more types of pentosan units may include one or more of polysaccharides comprising xylan units

[0046] As used herein, the term “produced water” generally refers to any aqueous fluids produced during any type of industrial process, for example, an oil or gas extraction or recovery process, or any portion thereof. Typically the produced water may be obtained during an industrial process involving the use of water, generally copious amounts of water, wherein the end product of such industrial process may be an aqueous material or “produced water” which may be of an undesirable purity. Produced water may be generated during processes or portions thereof which involve oil sands.

[0047] As used herein, the terms “polyacrylamide” or “PAM” generally refer to polymers and co-polymers comprising acrylamide moieties, and the terms encompass any polymers or copolymers comprising acrylamide moieties, e.g., one or more acrylamide (co)polymers. Furthermore, PAMs may comprise any of the polymers or copolymers discussed herein. Additionally, the PAMs described herein, e.g., one or more acrylamide (co)polymers, may be provided in one of various forms, including, for example, dry (powder) form (e.g., DPAM), water-in-oil emulsion (inverse emulsion), suspension, dispersion, or partly hydrolyzed (e.g., HPAM, in which some of the acrylamide units have been hydrolyzed to acrylic acid). In some embodiments, flocculants comprising one or more PAMS may be used in any tailings treatment technique.

[0048] As used herein, the term “trafficable deposit” generally refers to a solid or semi-solid material that has been deposited on or over a surface. A trafficable deposit preferably has a minimum undrained shear strength of 5 kPa one year after deposition, and a minimum undrained shear strength of 10 kPa five years after deposition. A trafficable deposit may be produced according to any of the methods described herein.

[0049] As used herein, the terms “electrocoagulation” and “electrocoagulation procedure” and the like generally refer to a water treatment method comprising destabilizing suspended, emulsified, and/or dissolved contaminants by introducing an electrical current into the medium. Electrocoagulation may lead to the formation of hydrophobic entities which may then be easily removed from solution, such as, for example, by settling or by flotation. Generally, electrical

current may be introduced via parallel metal electrodes, wherein said electrodes may comprise metals such as but not limited to iron and/or aluminum. During electrocoagulation, metal ions may split off or may be sacrificed into the liquid medium, thereby potentially forming a nucleus that may attract contaminants present in the solution to be treated into a precipitate.

Electrocoagulation may be used alone for the treatment of solutions in need of solid-liquid separation, or in combination with other treatment methods. In the present invention electrocoagulation is used in the treatment of tailings and/or oil sands tailings and/or mature fine tailings, e.g., in combination with and/or followed by flocculation.

[0050] As used herein, the term “high molecular weight flocculant” generally refers to a flocculant with a molecular weight from greater than about 500,000; about 5,000,000; about 10,000,000; about 15,000,000; about 20,000,000; about 25,000,000 Daltons; or about 30,000,000 Daltons. In some embodiments, said flocculant may have a molecular weight in the range of about 500,000 to about 30,000,000 Daltons, preferably from about 1,000,000 to about 15,000,000 Daltons. In some embodiments, one or more high molecular weight flocculants may comprise one or more acrylamide flocculants, e.g., an anionic polyacrylamide flocculant, and/or may comprise one or more charged flocculants.

[0051] As used herein, a “charged flocculant” generally refers to a flocculant that is charged, positively or negatively, such as, for example, cationic or anionic polymers. In some embodiments, a charged flocculant may comprise a charged acrylamide flocculant, e.g., an anionic polyacrylamide flocculant. In some embodiments, a charged flocculant may comprise any percent or amount of anionic or cationic charge, i.e., any positive or negative charge wherein the overall charge of said flocculant is greater than 0. For example, in some embodiments, a charged flocculant may comprise from greater than 0% or more to about 100 mol% of a charged monomer. In some embodiments, a charged flocculant may comprise from about 20 mol% to about 95 mol% of a charged monomer, or from about 50% or more to about 95% or more mol% of a charged monomer. In some embodiments, a charged flocculant may comprise an acrylamide flocculant that comprises from greater than 0 mol% or more to about 100 mol% of a charged monomer, e.g., an anionic monomer, preferably from about 50% or more to about 95% or more mol% of a charged monomer, e.g., an anionic monomer. In other embodiments the charged flocculant may comprise 20-45 mol% of a charged monomer, e.g., an anionic monomer. Furthermore said flocculant may be used with any of the methods described herein. In some

embodiments, a charged flocculant may comprise an anionic polyacrylamide flocculant. Said anionic polyacrylamide flocculant may comprise from greater than 0 mol% to about 100 mol% of an anionic monomer. Furthermore, in some embodiments, said anionic polyacrylamide flocculant may comprise from about 20 mol% or more to about 95 mol% or more of an anionic monomer, or from about 50 mol% or more to about 95 mol% or more of anionic monomer. In some embodiments, a charged flocculant may comprise a polyacrylamide-based flocculant that comprises from about 20 mol% or more to about 95 mol% or more, or from about 50 mol% or more to about 95 mol% or more of anionic monomer, and furthermore said flocculant may be used with any of the methods described herein.

[0052] As used herein, in addition to its conventional meaning in the art, the terms “mol%” and/or “mole%”, and the like, generally encompass both theoretical mol% as well as mol% as determined by an analytic technique, for example, ^{13}C NMR.

METHODS AND APPARATUSES

[0053] Disclosed herein are improved methods for treating tailings such as oil sands tailings. The various embodiments comprise methods for treating tailings comprising adding to the tailings substrate at least one flocculant and subjecting the tailings substrate to at least one electrocoagulation procedure which may improve the removal of solids from said tailings and improve the dewatering of said tailings. Additionally, some embodiments generally pertain to a method of treating mature fine tailings by a treatment process which includes at least one electrocoagulation procedure. The methods generally may be used for treating oil sands tailings in need of solid-liquid separation, e.g., in order to efficiently recycle water and to reduce the volume of solid tailings to be further handled, such as by transferring to a dedicated disposal area and/or a tailings pond. By using the methods, a more complete separation of the solids from the water may be achieved, improving process efficiency relative to conventional processes for treating tailings streams. The methods described herein may be used to enhance settling of solids, especially fine and ultrafine solids and/or MFT, in tailings and particularly in oils sands and/or oil sands ore tailings streams. The methods may be readily incorporated into existing processing facilities and may provide economic and environmental benefits. The present disclosure further generally relates to an apparatus for use in the treatment of tailings, wherein said treatment

comprises a combination of electrocoagulation and flocculation. Practicing the methods described herein may result in improved removal of fine, slow settling clay particles, persistent contaminants, and/or residual bitumen, in particular as compared to electrocoagulation alone or flocculation alone. In some embodiments of the methods described herein, electrocoagulation may be effected prior to flocculation of said tailings.

[0054] The present disclosure generally relates to methods of treating tailings, wherein said methods may comprise adding at least one flocculant to the tailings substrate and subjecting the tailings substrate to at least one electrocoagulation procedure. In some embodiments, combined use of electrocoagulation and chemical flocculation may provide for enhanced flocculation of the tailings. Practicing embodiments of the methods disclosed herein may provide for one or more of the following: (i) reduction in solids content in tailings, (ii) reduction of turbidity in tailings, (iii) reduced chemical oxygen demand, (iv) improved flocculation at lower flocculant dosages, and (v) reduced solids content in treated tailings and changed tailings composition. In some embodiments, said tailings may comprise oil sands tailings and/or mature fine tailings.

[0055] In some embodiments, chemical flocculation may comprise the addition of one or more flocculants and/or one or more acrylamide (“AMD”) flocculants. Furthermore, chemical flocculation may comprise the addition of one or more high molecular weight flocculants, and may also comprise the addition of one or more low molecular weight, medium molecular weight, and/or high molecular weight flocculants. Said high molecular weight flocculants may comprise a molecular weight ranging from greater than about 500,000; about 5,000,000; about 10,000,000; about 15,000,000; about 20,000,000; about 25,000,000 Daltons; or about 30,000,000 Daltons. In some embodiments, said flocculant may have a molecular weight in the range of about 500,000 to about 30,000,000 Daltons, preferably from about 1,000,000 to about 15,000,000 Daltons. Moreover, chemical flocculation may comprise the addition of one or more charged flocculants in some embodiments. Said chemical flocculation may also comprise the addition of one or more anionic, nonionic, and/or cationic flocculants. In some embodiments, one or more flocculants may comprise one or more anionic flocculants. In some embodiments, chemical flocculation may comprise the addition of one or more charged acrylamide flocculants, e.g., one or more anionic polyacrylamide flocculants, and/or the addition of one or more high molecular weight, charged flocculant compounds, e.g., one or more high molecular weight anionic polyacrylamide flocculants. In some embodiments, one or more flocculants may comprise AMD and acrylic acid,

i.e., an anionic polyacrylamide flocculant. Said one or more flocculants may comprise from greater than 0 mol% to about 100 mol% of an anionic monomer, e.g., acrylic acid. Furthermore, in some embodiments, said one or more flocculants may comprise from about 20 mol% or more to about 95 mol% or more of one or more anionic monomers, or from about 50 mol% or more to about 95 mol% or more of one or more anionic monomers. In some embodiments, one or more charged flocculants may comprise one or more polyacrylamide-based flocculants that comprise from about 20 mol% to about 95 mol%, or from about 50 mol% or more to about 95 mol% or more of one or more anionic monomers, and furthermore said one or more flocculants may be used with any of the methods described herein, e.g., said one or more flocculants may be used in combination with one or more electrocoagulation procedures. Furthermore, in some embodiments, one or more flocculants may comprise one or more high molecular weight, charged acrylamide flocculants, e.g., one or more high molecular weight anionic polyacrylamide flocculants, and said one or more flocculants may be used in combination with one or more electrocoagulation procedures and/or with any of the methods and/or apparatuses described herein. In some embodiments, the dosage of one or more flocculants that may be used in accordance with the methods may be any dosage of flocculant that achieves a desired result. In some embodiments, the dosage of said one or more flocculants may be from about 50 to about 5000 g/ton. In some embodiments, said dosage may be from about 50 to about 300 g/ton, optionally if said tailings comprise more dilute process tailings. In some embodiments, said dosage may be from about 700 to about 2000 g/t, optionally if said tailings comprise undiluted MFT. In some embodiments, increasing the dosage of said one or more flocculants while using the methods described herein may result in a corresponding decrease in solids content of the treated tailings. In some embodiments, an electrocoagulation procedure may be effected prior to a subsequent chemical flocculation procedure. In some embodiments, at least one chemical flocculation step may be effected prior to and/or during an electrocoagulation procedure.

[0056] When practicing embodiments of the methods described herein, said methods may result in a treated tailings composition comprising a lower solids content as compared to tailings treated with electrocoagulation alone and/or flocculation alone in some embodiments. Furthermore, practicing embodiments of the methods described herein may result in a treated tailings composition comprising a lower turbidity as compared to tailings treated with electrocoagulation alone and/or flocculation alone, and/or may result in a treated tailings

composition comprising a lower carbon oxygen demand (“COD”) as compared to tailings treated with electrocoagulation alone and/or flocculation alone. In some embodiments, use of the methods described herein may result in a treated tailings composition comprising a lower solids content as compared to tailings treated with inorganic coagulant which were optionally further treated with electrocoagulation.

[0057] In some embodiments, the methods described herein may comprise the addition of one or more polysaccharides to a tailings stream. In some embodiments, one or more polysaccharides may comprise one or more types of pentosan units and said one or more polysaccharides may be added to the tailings stream. Pentosan units may be monosaccharides having five carbon atoms, including, for example, xylose, ribose, arabinose, and lyxose. In some embodiments, the pentosan unit may be an aldopentose, which has an aldehyde functional group at position 1, such as, for example, the D- or L- forms of arabinose, ribose, xylose and lyxose. Polysaccharides include, but are not limited to including, for example, xylan, hemicellulose, and gum arabic. Hemicellulose may be derived from biomass, for example grasses and wood, such as hardwood. In some embodiments, the hemicellulose may comprise mixtures of xylose, arabinose, mannose and galactose. Gum arabic may comprise arabinose and ribose. In some embodiments, the one or more types of pentosan units comprise xylan units and one or more of hemicellulose and aldopentoses. In some embodiments, one or more polysaccharides may be derived from plant cell walls, for example sugar-cane- or corn-plant cell walls, or algae. In some embodiments, one or more polysaccharides may be derived from sugar cane, or corn. In some embodiments, one or more polysaccharides may be derived from sugar cane bagasse. In some embodiments, one or more polysaccharides may be derived from corn fiber. In some embodiments, one or more polysaccharides comprising one or more types of pentosan units may be a blend or a mixture of polysaccharides comprising one or more types of pentosan units. In some embodiments, one or more polysaccharides comprising one or more types of pentosan units may consist essentially of polysaccharides comprising one type of pentosan unit, for example xylan. In some embodiments, the one or more types of pentosan units comprise xylan. In some embodiments, one or more polysaccharides comprising one or more types of pentosan units may include one or more of polysaccharides comprising xylan units.

[0058] Embodiments of the methods described herein may further comprise addition of one or more polysaccharides, e.g., one or more polysaccharides comprising xylan units, and synergistic

effects may occur as a result of addition of said one or more polysaccharides, optionally when the tailings to be treated comprise undiluted tailings or when the tailings to be treated comprise diluted tailings. In some embodiments, methods may comprise addition of one or more high molecular weight and/or charged flocculants and addition of one or more polysaccharides. In said embodiments, addition of said one or more polysaccharides and said one or more flocculants during treatment of said tailings may result in synergistic effects. In some embodiments, synergistic effects may include one or more of reduced turbidity values, reduced supernatant solids content or greater fines capture, reduced formation of non-segregated tailings, reduced carbon-oxygen demand, increased water release, a desirable degree of floc formation; or a combination of any of the foregoing. In some embodiments, said synergistic effects may include greater fines capture resulting in better overflow clarity. In some embodiments, the one or more polysaccharides and that may improve the performance of flocculation as some excess iron from electrocoagulation may be present in the tailings to be treated. In some embodiments, the methods described herein may be used to treat undiluted tailings. In some embodiments, a thick layer of solids may be formed on the anodes of an electrocoagulation cell used to effect said methods.

[0059] Some embodiments of the methods described herein may comprise synergistic effects that result from the use of a combination of electrocoagulation and one or more flocculants, e.g., one or more high molecular weight and/or charged flocculants, to treat tailings. Said synergistic effects may include one or more of reduced turbidity values, reduced supernatant solids content or greater fines capture, reduced formation of non-segregated tailings, reduced carbon-oxygen demand, increased water release, a desirable degree of floc formation; or a combination of any of the foregoing. In some embodiments, said synergistic effects may include greater fines capture resulting in better overflow clarity.

[0060] In some embodiments of the methods described herein, the use of electrocoagulation may improve flocculation of tailings. In some embodiments of the methods described herein, at least one electrocoagulation procedure may be effected by using one or more iron-based electrodes, that is, iron-based electrodes may comprise an anode and/or a cathode of a cell in which an electrocoagulation procedure may occur. In some embodiments, electrocoagulation may comprise the application of 5 V or less, 5 V or more, 10 V or more, 12 V or more, or 15 V or more to effect said electrocoagulation while practicing embodiments of the methods described

herein. In some embodiments, electrocoagulation may utilize a small amount of iron ions to perform coagulation.

[0061] In some embodiments of the methods described herein, use of electrocoagulation results in a thick layer of solids formed on an anode of a cell used for said electrocoagulation when said methods are used to treat undiluted tailings or to treat diluted tailings. Said thick layer of solids may be removed by use of a mechanical scraper, and subsequently said thick layer of solids may settle to the bottom of the cell by gravity following mechanical scraping and may then be removed after said settling. In some embodiments, switching of a current used for electrocoagulation in the methods described herein may remove said layer of solids. Said thick layer of solids may then settle to the bottom of the cell by gravity following reversal of said current one or more times and it may then be removed after said settling. In some embodiments, use of an electrocoagulation procedure in the methods described herein may result in formation of hydrogen gas on a cathode of a cell used for said electrocoagulation. The formation of said hydrogen gas may generate hydrogen gas bubbles, and said gas bubbles generated at the cathode by water reduction reaction may float the flocculated particles to the water surface, thereby providing better separation of contaminants compared to flocculation alone. Additionally, use of high molecular weight flocculants may result in more gas trapped from the electrocoagulation process occurring in the cathode and will further raise more flocculated particles to the water surface, thereby providing better separation of contaminants compared to flocculation alone. In some embodiments, use of an increased voltage to effect electrocoagulation may result in a corresponding higher generation of hydrogen in the cathode, and the hydrogen bubbles that may be formed may interact with the coagulated particles being formed during electrocoagulation to promote floatation of the flocs formed. In some embodiments of the methods described herein, current applied during electrocoagulation may be reversed one or more times, and this may result in a continuous electrocoagulation process. In some embodiments, use of the methods described herein may result in formation of a trafficable deposit.

[0062] The present disclosure also generally encompasses an apparatus or system for use in the treatment of tailings, wherein said apparatus or system comprises a cell for effecting electrocoagulation and chemical flocculation, wherein said cell comprises one or more anodes and/or one or more cathodes, and further wherein said cell comprises tailings to be treated and one or more flocculants. In some embodiments, said anode and said cathode may comprise iron-

based electrodes. Said apparatus or system may be used to practice and/or to effect any of the methods described herein. Furthermore, use of said apparatus or system to effect and/or practice any of the methods described herein may achieve any of the desired results discussed with regard to said methods. In some embodiments, said apparatus or system may comprise a power supply and/or a means to effect mixing. Said means to effect mixing may comprise a magnetic stirrer and/or any means known in the art to effect mixing.

[0063] The following examples are presented for illustrative purposes only and are not intended to be limiting.

EXAMPLES

[0064] *Example 1: Treatment of Tailings with Electrocoagulation and/or Flocculation*

[0065] In this example, electrocoagulation alone, flocculation alone, and a combination of electrocoagulation with flocculation were used to treat diluted MFT samples. The MFT was acquired from an active oil sands mining site in Canada, and it had a total solid content of 43.8%. Processed water was acquired from an active oil sands mining site in Canada, and it was used to prepare 10-fold diluted MFT samples for the experiments of the present example.

[0066] An image of the experimental setup used to treat the diluted MFT samples is presented in **Figure 1**. In the instances when electrocoagulation was implemented, the power supply was 1A (12V), and an iron electrode was used as cathode and anode. For the experiments where electrocoagulation was used, the electrocoagulation reaction time in the cell was 15 min, the mixing speed of the magnetic stirrer was set to 8, the volume of the reaction was 250 ml. When both flocculation and electrocoagulation were used, a low molecular weight flocculant (Polymer A) was added as single injection (100 g/ton) after 15 min. of electrocoagulation, and the current was turned off. The flocculant-containing solution was then mixed for 1 min., and the solution was subsequently transferred to a graduated cylinder. For reference, an inorganic coagulant alone (ferrous sulfate) at 3 ppm was used to treat diluted MFT samples, and as a further reference, flocculant alone was used to treat diluted MFT samples. When inorganic coagulant alone and flocculant alone were used to treat diluted MFT samples, each was added as single injection and then the solution was mixed for 1 min.

[0067] **Figure 1** presents results of the experiments evaluating the settling of diluted MFT samples after 1 hour and after 24 hours, wherein the samples were treated with flocculant only (see **Figure 2A** and **Figure 2C**), electrocoagulation only (see **Figure 2B** and **Figure 2E**), and a combination of electrocoagulation and flocculation (see **Figure 2C** and **Figure 2F**), as described above. The flocculated particles appeared at the top of the graduated cylinder (see **Figure 2A-Figure 2C**) after the solutions were transferred to the graduated cylinders. Furthermore, the solid content, turbidity, and COD in the supernatant were measured after 24 hours (see **Table 1**). Referring to **Figure 2A-Figure 2F** and **Table 1**, a significant reduction was observed when using electrocoagulation alone or electrocoagulation in combination with flocculation, as compared to flocculation alone.

TABLE 1

Sample	Average solids content (%)	Turbidity (NTU)	COD (mg/L)
Flocculation only	0.7	476	239
Electrocoagulation only	0.4	112	205
Electrocoagulation + flocculation	0.28	47	196

[0068] Additionally, the effects of different dosages of flocculant to treat diluted MFT were tested (see **Figure 3C-Figure 3E**) and compared to the treatment of diluted MFT using an inorganic coagulant alone (see **Figure 3A**) or electrocoagulation alone (see **Figure 3B**). The solutions were prepared as described above, with flocculant being added at 100 g/ton (see **Figure 3C**), 200 g/ton (see **Figure 3D**), or 300 g/ton (see **Figure 3E**). It should be noted that the supernatant with the inorganic coagulant showed residual iron, thereby indicating that electrocoagulation utilized a small amount of iron ions to perform coagulation.

[0069] ***Example 2: Treatment of Tailings with Electrocoagulation and Flocculation***

[0070] In this example, electrocoagulation at varying voltages in combination with flocculation was used to treat diluted MFT samples. The MFT was acquired from an active oil sands mining site in Canada, and it had a total solid content of 43.8%. Processed water was acquired from an active oil sands mining site in Canada, and it was used to prepare 10-fold diluted MFT samples for the experiments of the present example.

[0071] An image of the experimental setup used to treat the diluted MFT samples is presented in **Figure 1**. In the instances when electrocoagulation was implemented, the power applied was 5V (see **Figure 4A**), 10V (see **Figure 4B**), or 15 V (see **Figure 4C**), and an iron electrode was used as cathode and anode. The electrocoagulation reaction time in the cell was 15 min, the mixing speed of the magnetic stirrer was set to 8, the volume of the reaction was 250 ml. A low molecular weight flocculant (Polymer A) was added as single injection (100 g/ton) to each of the three samples after 15 min. of electrocoagulation, and the current was turned off. The flocculant-containing solutions were then mixed for 1 min., and the solutions were subsequently transferred to graduated cylinders.

[0072] The results of treatment of diluted MFT samples with electrocoagulation at three different voltages in combination with flocculation are presented in **Figure 4A-Figure 4C** and **Table 2**. Referring to **Table 2**, desirable settling rates were achieved with all three voltages tested. Notably, the lowest voltage applied (5V, see **Figure 4A** and **Table 2**) was capable of generating coagulated particles and settling at a desirable rate. The supernatant became clearer as voltage was increased, and more coagulated particles were also observed as the voltage was increased (see **Figure 4A-Figure 4C**). This result demonstrated that higher generation of hydrogen in the cathode resulting from application of increased voltage results in hydrogen bubbles that interacted with the coagulated particles being formed during electrocoagulation and promoted floatation of the flocs formed.

TABLE 2

Voltage (V)	Settling rate (cm/min)
5	0.50
10	0.49
15	0.41

[0073] ***Example 3: Tailings Treatment using Electrocoagulation and/or Flocculation***

[0074] In this example, electrocoagulation was used to treat an undiluted MFT sample, and, subsequently, the treated MFT sample was subjected to flocculation. The MFT was acquired from an active oil sands mining site in Canada, and it had a total solid content of 43.8%.

[0075] When applying electrocoagulation to undiluted MFT, a thick layer was formed in the anodes after 10 minutes when applying ~12 V (see **Figure 5**). The film was removed from the electrode array after every 10 mins. of supplying 12 V of power. After 1 hr of electrocoagulation reaction time, the total volume of the treated tailings was reduced and the average solid content decreased by almost 10% (see **Figure 5**). Notably, the average solids content of the thick solid layers that were formed on the anodes was almost twice that of the original MFT solution (see **Figure 5**).

[0076] Following treatment with electrocoagulation alone, the treated MFT samples were further treated with a flocculant, and the results were compared to an undiluted MFT samples treated with flocculant alone (see **Figure 6**). Referring to **Figure 5**, Sample 1 was treated with a high molecular weight flocculant alone, Sample 2 was treated with Polysaccharide 1 and a high molecular weight flocculant (Polymer B), Sample 3 was treated with electrocoagulation as well as said high molecular weight flocculant (Polymer B), and Sample 4 was treated with electrocoagulation, Polysaccharide 1, and said high molecular weight flocculant (Polymer B).. Referring to **Figure 5**, it was found that polymer flocculants effectively formed flocs for the MFT samples that were treated with electrocoagulation as compared to those that were not treated with electrocoagulation (see **Figure 6**: Samples 1 and 2 compared to Samples 3 and 4). Further, the dosage necessary to obtain flocs from the electrocoagulated MFT was lower than previously observed with MFT not treated with electrocoagulation. Moreover, a synergistic effect was observed when combining Polysaccharide 1 with a high molecular weight polymer flocculant such as Polymer B, (see **Figure 6**: Sample 4, which demonstrated a high degree of water release as well as a desirable degree of floc formation).

[0077] ***Example 4: Treatment Apparatus and Process***

[0078] In the present example, an apparatus and a process that can be applied for the electrocoagulation-based treatment of tailings is described. The schematic, as presented in **Figure 7**, includes the formation of a thick layer of solids in the anode as well as the formation of hydrogen gas in the cathode after application of a desired voltage level (see **Figure 7**). After a certain thickness is achieved, a mechanical scrapper can be used to remove the film, and the removed film can subsequently settle to the bottom by gravity and then can be removed. Alternatively, switching the current from the electrodes can also remove the solid film.

[0079] After the film is formed on the anode, the current can be reversed, and the anode then acts as a cathode. The reversal of the current can lead to generation of hydrogen gas, which promotes the detachment of the thick layer such that it can settle by gravity. As a result of the current switch, the cathode acts as an anode, and a thick layer is formed on the anode. By using a back and forth switching of the voltage, electrocoagulation can become a continuous process. Flocculation can be further added to the treatment process once the electrocoagulation process has achieved a desired result.

[0080] In the preceding procedures, various steps have been described. It will, however, be evident that various modifications and changes may be made thereto, and additional procedures may be implemented, without departing from the broader scope of the procedures as set forth in the claims that follow.

CLAIMS

1. A method of treating tailings, comprising adding at least one flocculant to the tailings substrate, and subjecting the tailings substrate to at least one electrocoagulation procedure.
2. The method of claim 1 wherein the combined use of electrocoagulation and chemical flocculation provides for one or more of the following: (i) reduction in solids content in tailings, (ii) reduction of turbidity in tailings, (iii) reduced chemical oxygen demand, (iv) improved flocculation at lower flocculant dosages, and (v) reduced solids content in treated tailings and changed tailings composition.
3. The method of any one of the foregoing claims, wherein said tailings comprise fluid fine tailings, mature fine tailings, or a combination thereof.
4. The method of any one of the foregoing claims, wherein said tailings comprise undiluted tailings.
5. The method of any one of the foregoing claims, wherein said tailings comprise diluted tailings.
6. The method of any one of the foregoing claims, wherein a flocculant is added to the tailing substrate after an electrocoagulation.
7. The method any one of the foregoing claims wherein a flocculant is added to the tailings substrate prior to and/or during an electrocoagulation procedure.
8. The method of any one of the foregoing claims, wherein the at least one flocculant comprises an acrylamide ("AMD") flocculant.
9. The method of any one of the foregoing claims, wherein the at least one flocculant comprises one or more high molecular weight flocculants.
10. The method of claim 9, wherein said one or more high molecular weight flocculants have a molecular weight of greater than about 500,000; about 5,000,000; about 10,000,000; about 15,000,000; about 20,000,000; or about 25,000,000 Daltons, preferably in the range of from about 500,000 to about 30,000,000 Daltons.
11. The method of any one of the foregoing claims, wherein the at least one flocculant comprises one or more anionic charged flocculants.
12. The method of any one of the foregoing claims, wherein the at least one flocculant comprises an anionic flocculant which comprises from greater than 0% or more to about

100 mol% of a charged monomer or from about 20 mol% to about 95 mol% of a charged monomer, or from about 50% or more to about 95% or more mol% of a charged monomer.

13. The method of any one of the foregoing claims, wherein the at least one flocculant comprises an acrylamide flocculant that comprises from greater than 0 mol% or more to about 100 mol% of a charged monomer, such as an anionic monomer, or from about 50% or more to about 95% or more mol% of a charged monomer, such as an anionic monomer or comprises 20-45 mol% or 50 mol% or more of a charged monomer such as an anionic monomer.
14. The method of any of the foregoing claims which comprises the addition of one or more polysaccharides to the tailings substrate.
15. The method of claim 14, wherein said one or more polysaccharides comprise xylan units.
16. The method of claim 14 or 15, wherein the addition of the one or more polysaccharides results in reduced turbidity values, reduced supernatant solids content or greater fines capture, reduced formation of non-segregated tailings, reduced carbon-oxygen demand, increased water release, a desirable degree of floc formation; or a combination of any of the foregoing.
17. The method of any one of the foregoing claims, wherein the use of electrocoagulation improves flocculation of said tailings, as compared to a method comprising the addition of the flocculant without electrocoagulation.
18. The method of any one of the foregoing claims, which results in improved removal of fine, slow settling clay particles, persistent contaminants, and/or residual bitumen as compared to electrocoagulation alone or flocculation alone.
19. The method of any one of the foregoing claims, which results in a treated tailings composition comprising a lower solids content as compared to tailings treated with electrocoagulation alone or flocculation alone.
20. The method of any one of the foregoing claims, which results in a treated tailings composition comprising a lower turbidity as compared to tailings treated with electrocoagulation alone or flocculation alone.

21. The method of any one of the foregoing claims, which results in a treated tailings composition comprising a lower carbon oxygen demand (“COD”) as compared to tailings treated with electrocoagulation alone or flocculation alone.
22. The method of any one of the foregoing claims, which results in a treated tailings composition comprising a lower solids content as compared to tailings treated with inorganic coagulant, wherein said tailings were optionally also treated by electrocoagulation.
23. The method of any one of the foregoing claims, wherein increasing the dosage of said one or more flocculants results in a corresponding decrease in solids content of a treated tailings composition.
24. The method of any one of the foregoing claims, wherein the use of electrocoagulation and one or more flocculants results in synergistic effects.
25. The method of claim 24, wherein said synergistic effects include one or more of reduced turbidity values, reduced supernatant solids content or greater fines capture, reduced formation of non-segregated tailings, reduced carbon-oxygen demand, increased water release, a desirable degree of floc formation; or a combination of any of the foregoing.
26. The method of claim 24, wherein said synergistic effects include greater fines capture resulting in better overflow clarity.
27. The method of any one of the foregoing claims, wherein at least one electrocoagulation procedure is effected using an iron-based electrode.
28. The method of claim 27, wherein said iron-based electrodes comprise an anode and a cathode of a cell in which electrocoagulation occurs.
29. The method of any one of the foregoing claims, wherein electrocoagulation comprises the application of 5 V or less, 5 V or more, 10 V or more, 12 V or more, or 15 V or more to effect said electrocoagulation.
30. The method of any one of the foregoing claims, wherein the dosage of said one or more flocculants is from about 50 g/ton or more to about 5000 g/ton or more.
31. The method of any one of the foregoing claims, wherein said electrocoagulation utilizes a small amount of iron ions to perform coagulation.

32. The method of any one of the foregoing claims, wherein said one or more flocculants comprised therein include one or more low molecular weight, medium molecular weight, and/or high molecular weight flocculants.
33. The method of any one of the foregoing claims, wherein said one or more flocculants comprised therein include one or more anionic, nonionic, and/or cationic flocculants.
34. The method of any one of the foregoing claims, wherein said one or more flocculants comprised therein include AMD and acrylic acid.
35. The method of any one of the foregoing claims, wherein use of electrocoagulation results in a thick layer of solids formed on an anode of a cell used for said electrocoagulation.
36. The method of claim 35, wherein said thick layer of solids is removed by use of a mechanical scraper.
37. The method of claim 35 or 36, wherein said thick layer of solids settles to the bottom of the cell by gravity following mechanical scraping and is then removed after said settling.
38. The method of any one of claims 35-37, wherein switching of a current used for electrocoagulation removes said layer of solids.
39. The method of claim 35, wherein said thick layer of solids settles to the bottom of the cell by gravity following said switching of said current and is then removed after said settling.
40. The method of any one of the foregoing claims, including an electrocoagulation procedure which results in the formation of hydrogen gas and/or hydrogen gas bubbles on a cathode of a cell used for said electrocoagulation procedure.
41. The method of claim 40, wherein formation of said hydrogen gas and/or hydrogen gas bubbles float flocculated particles to the surface of the tailings solution, thereby providing better separation of contaminants as compared to flocculation alone.
42. The method of any of claims 35-41, wherein said one or more flocculants comprise one or more high molecular weight flocculants as compared to other flocculants generally used to treat tailings.
43. The method of claim 42, wherein use of said high molecular weight flocculants results in more gas trapped from the electrocoagulation process occurring in the cathode and further raises more flocculated particles to surface of the tailings solution, thereby providing better separation of contaminants as compared to flocculation alone.

44. The method of any one of the foregoing claims, wherein an increase in voltage used to effect electrocoagulation results in a corresponding increase in the formation of hydrogen gas and/or hydrogen bubbles.
45. The method of claim 44, wherein said hydrogen gas and/or hydrogen bubbles interact with the coagulated particles being formed during electrocoagulation to promote floatation of flocs formed as a result of said method.
46. The method of any one of the foregoing claims, wherein current applied during electrocoagulation is reversed one or more times.
47. The method of claim 46, wherein said reversal of current one or more times results in a continuous electrocoagulation process.
48. The method of any one of the foregoing claims, wherein said method results in formation of a trafficable deposit.
49. An apparatus or system for use in the treatment of tailings, wherein said apparatus comprises a cell for effecting electrocoagulation and chemical flocculation, wherein said cell comprises one or more anodes and one or more cathodes, and further comprises tailings to be treated and one or more flocculants.
50. The apparatus or system of claim 49, wherein said anode and/or said cathode comprise iron-based electrodes.
51. The apparatus of claim 49 or 50, wherein said apparatus further comprises a power supply and/or a means to effect mixing.
52. The apparatus or system of claim 51, wherein said means to effect mixing comprises a magnetic stirrer.
53. The apparatus or system of any one of claims 49-52, wherein using said apparatus to effect both electrocoagulation and chemical flocculation provides for enhanced flocculant performance.
54. The apparatus or system of any one of claims 49-53, wherein use of said apparatus to effect both electrocoagulation and chemical flocculation provides for one or more of the following: (i) reduction in solids content in tailings, (ii) reduction of turbidity in tailings, (iii) reduced chemical oxygen demand, (iv) improved flocculation at lower flocculant dosages, and (v) reduced solids content in treated tailings and changed tailings composition.

55. The apparatus or system of any one of claims 49-54, wherein said tailings comprise oil sands tailings.
56. The apparatus or system of any one of claims 49-55, wherein said tailings comprise mature fine tailings.
57. The apparatus or system of any one of claims 49-56, wherein said tailings comprise undiluted tailings.
58. The apparatus or system of any one of claims 49-56, wherein said tailings comprise diluted tailings.
59. The apparatus or system of any one of claims 49-58, wherein an electrocoagulation procedure is effected prior to a subsequent chemical flocculation procedure when using said apparatus to treat said tailings.
60. The apparatus or system of any one of claims 49-59, wherein at least one chemical flocculation step is effected prior to and/or during an electrocoagulation procedure when using said apparatus to treat said tailings.
61. The apparatus or system of any one of claims 49-60, wherein chemical flocculation is effected by the use of one or more flocculants when using said apparatus to treat said tailings.
62. The apparatus or system of any one of claims 49-61, wherein chemical flocculation comprises the addition of an acrylamide flocculant ("AMD").
63. The apparatus or system of any one of claims 49-62, wherein chemical flocculation comprises the addition of one or more high molecular weight flocculants.
64. The apparatus or system of claim 63, wherein said one or more high molecular weight flocculants comprise a molecular weight greater than about 500,000; about 5,000,000; about 10,000,000; about 15,000,000; about 20,000,000; or about 25,000,000 Daltons, preferably in the range of from about 500,000 to about 30,000,000 Daltons.
65. The apparatus or system of any one of claims 49-64, wherein chemical flocculation comprises the addition of one or more charged flocculant compounds.
66. The apparatus or system of claim 65, wherein chemical flocculation comprises the addition of one or more anionic charged flocculant compounds.
67. The apparatus or system of any one of claims 49-66, wherein the one or more flocculants comprises an anionic flocculant which comprises from greater than 0% or more to about

- 100 mol% of a charged monomer or from about 20 mol% to about 95 mol% of a charged monomer, or from about 50% or more to about 95% or more mol% of a charged monomer.
68. The apparatus or system of any one of claims 49-67, wherein the one or more flocculants comprise at least one flocculant comprises an acrylamide flocculant that comprises from greater than 0 mol% or more to about 100 mol% of a charged monomer, such as an anionic monomer, or from about 50% or more to about 95% or more mol% of a charged monomer, such as an anionic monomer or 20-45 mol% or 50 mol% or more of a charged monomer such as an anionic monomer.
69. The apparatus or system of any one of claims 49-68, wherein chemical flocculation comprises the addition of one or more high molecular weight, charged flocculant compounds.
70. The apparatus or system of any one of claims 49-69, wherein said one or more flocculants comprise one or more anionic flocculants.
71. The apparatus or system of any one of claims 49-70, wherein one or more polysaccharides is added to said cell of said apparatus.
72. The apparatus or system of any one of claims 49-71, wherein said one or more polysaccharides comprise xylan units.
73. The apparatus or system of claim 71 or 72, wherein addition of said one or more polysaccharides when using said apparatus results in synergistic effects.
74. The apparatus or system of claim 73, wherein said synergistic effects include one or more of reduced turbidity values, reduced supernatant solids content or greater fines capture, reduced formation of non-segregated tailings, reduced carbon-oxygen demand, increased water release, a desirable degree of floc formation; or a combination of any of the foregoing.
75. The apparatus or system of claim 73 or 74, wherein said synergistic effects include greater fines capture resulting in better overflow clarity.
76. The apparatus or system of any one of claims 49-75, wherein the use of said apparatus or system to effect electrocoagulation to treat said tailings improves flocculation of said tailings effected by said apparatus.

77. The apparatus or system of any one of claims 49-76, wherein said use of said apparatus or system to treat said tailings results in improved removal of fine, slow settling clay particles, persistent contaminants, and/or residual bitumen, in particular as compared to electrocoagulation alone or flocculation alone.
78. The apparatus or system of any one of claims 49-77, wherein use of said apparatus or system to treat said tailings results in a treated tailings composition comprising a lower solids content as compared to tailings treated with electrocoagulation alone or flocculation alone.
79. The apparatus or system of any one of claims 49-78, wherein use of said apparatus or system to treat said tailings results in a treated tailings composition comprising a lower turbidity as compared to tailings treated with electrocoagulation alone or flocculation alone.
80. The apparatus or system of any one of claims 49-79, wherein use of said apparatus or system to treat said tailings results in a treated tailings composition comprising a lower carbon oxygen demand ("COD") as compared to tailings treated with electrocoagulation alone or flocculation alone.
81. The apparatus or system of any one of claims 49-80, wherein use of said apparatus or system to treat said tailings results in a treated tailings composition comprising a lower solids content as compared to tailings treated with inorganic coagulant, wherein said tailings were optionally further treated by electrocoagulation.
82. The apparatus or system of any one of claims 49-81, wherein increasing the dosage of said one or more flocculants present in said apparatus or system results in a corresponding decrease in solids content of the treated tailings composition when said apparatus or system is used to treat said tailings.
83. The apparatus or system of any one of claims 49-82, wherein use of said apparatus or system comprises use of said apparatus or system to effect an electrocoagulation procedure and a chemical flocculation procedure results in synergistic effects.
84. The apparatus or system claim 83, wherein said synergistic effects include one or more of reduced turbidity values, reduced supernatant solids content or greater fines capture, reduced formation of non-segregated tailings, reduced carbon-oxygen demand, increased

water release, a desirable degree of floc formation; or a combination of any of the foregoing.

85. The apparatus or system of claim 83 or 84, wherein said synergistic effects include greater fines capture resulting in better overflow clarity.
86. The apparatus or system of any one of claims 49-85, which delivers a voltage selected from 5 V or less, 5 V or more, 10 V or more, 12 V or more, or 15 V or more to effect said electrocoagulation.
87. The apparatus or system of any one of claims 49-86, wherein the dosage of said one or more flocculants is from about 50 g/ton or more to about 5000 g/ton or more.
88. The apparatus or system of any one of claims 49-87, which is capable of effecting electrocoagulation utilizing a small amount of iron ions.
89. The apparatus or system of any one of claims 49-88, wherein said one or more flocculants comprised therein include one or more low molecular weight, medium molecular weight, and/or high molecular weight flocculants.
90. The apparatus or system of any one of claims 49-89, wherein said one or more flocculants comprised therein include one or more anionic, nonionic, and/or cationic flocculants.
91. The apparatus or system of any one of claims 49-90, wherein said one or more flocculants comprised therein include AMD and acrylic acid.
92. The apparatus or system of any one of claims 49-91, wherein the use of said apparatus or system to treat said tailings results in a thick layer of solids formed on said one or more anodes of said cell.
93. The apparatus or system of claim 92, in association with a mechanical scraper.
94. The apparatus or system of claim 93, wherein the use of said apparatus or system to treat said tailings results in a thick layer of solids which settles to the bottom of the cell by gravity following mechanical scraping and is then removed after said settling.
95. The apparatus or system of any one of claims 49-94, which provides for the switching of current during electrocoagulation which facilitates the removal of a layer of solids which is produced by electrocoagulation.
96. The apparatus or system of any of claims 49-95, wherein the use of said apparatus or system to treat said tailings results in a thick layer of solids settles to the bottom of the

cell by gravity following said switching of said current and is then removed after said settling.

97. The apparatus or system of any one of claims 49-96, wherein use of said apparatus or system to effect an electrocoagulation procedure results in the formation of hydrogen gas and/or hydrogen gas bubbles on said one or more cathodes of said cell.
98. The apparatus or system of claim 97, wherein formation of said hydrogen gas and/or hydrogen gas bubbles float flocculated particles to water surface of the tailings solution, thereby providing better separation of contaminants as compared to flocculation alone.
99. The apparatus or system of any one of claims 92-98, wherein said one or more flocculants comprise one or more high molecular weight flocculants.
100. The apparatus or system of claim 99, wherein use of said high molecular weight flocculants results in more gas trapped from the electrocoagulation process occurring in the cathode and further raises more flocculated particles to surface of the tailings solution, thereby providing better separation of contaminants as compared to flocculation alone.
101. The apparatus or system of any one of claims 49-100, which provides for an increase in voltage to effect electrocoagulation which results in a corresponding increase in the formation of hydrogen gas and/or hydrogen bubbles.
102. The apparatus or system of claim 101, wherein said hydrogen gas and/or hydrogen bubbles interact with the coagulated particles being formed during electrocoagulation to promote floatation of flocs formed as a result of said method.
103. The apparatus or system of any one of claims 49-102, which provides for current to be applied and reversed one or more times during an electrocoagulation procedure.
104. The apparatus or system of claim 103, wherein said reversal of current one or more times results in a continuous electrocoagulation process.
105. The apparatus or system of any one of claims 49-104, wherein use of said apparatus or system to treat said tailings results in a trafficable deposit.

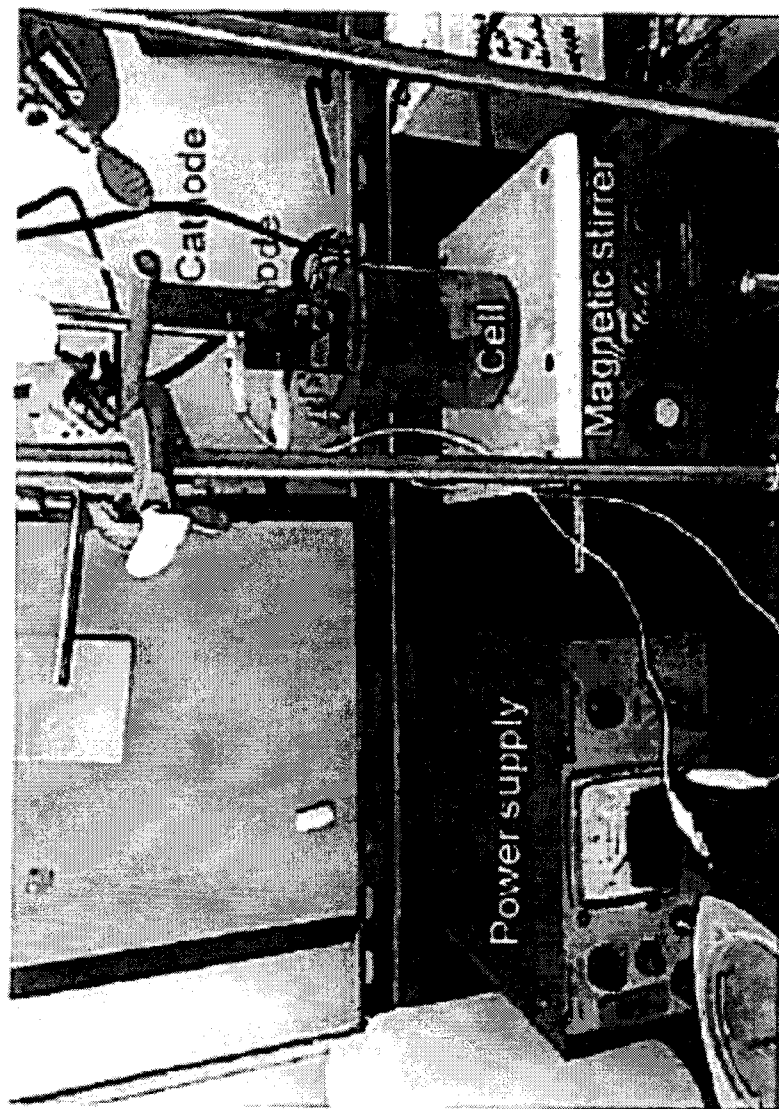
FIGURE 1

FIGURE 2A-FIGURE 2F

FIG. 2A FIG. 2B FIG. 2C FIG. 2D FIG. 2E FIG. 2F

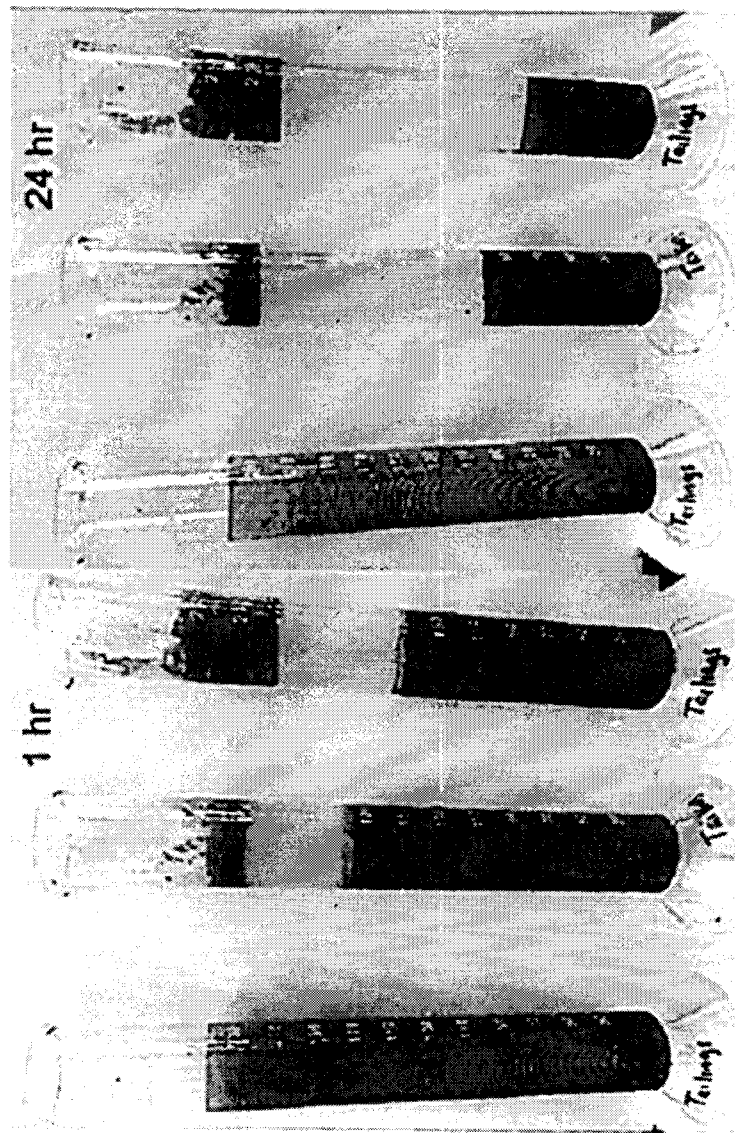


FIGURE 3A-FIGURE 3E

FIG. 3A FIG. 3B FIG. 3C FIG. 3D FIG. 3E

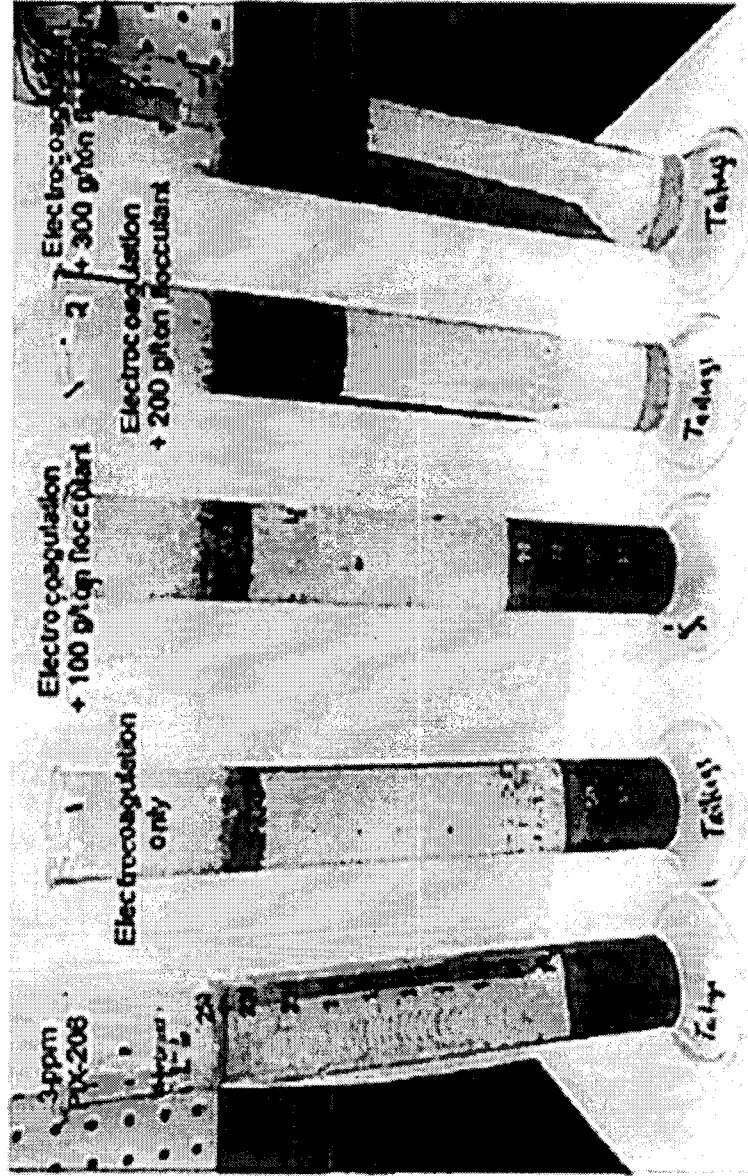


FIGURE 4A-FIGURE 4C

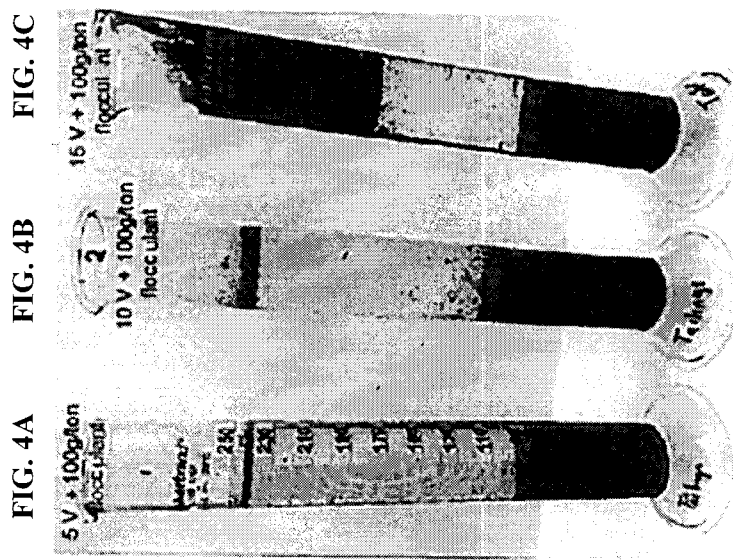


FIGURE 5

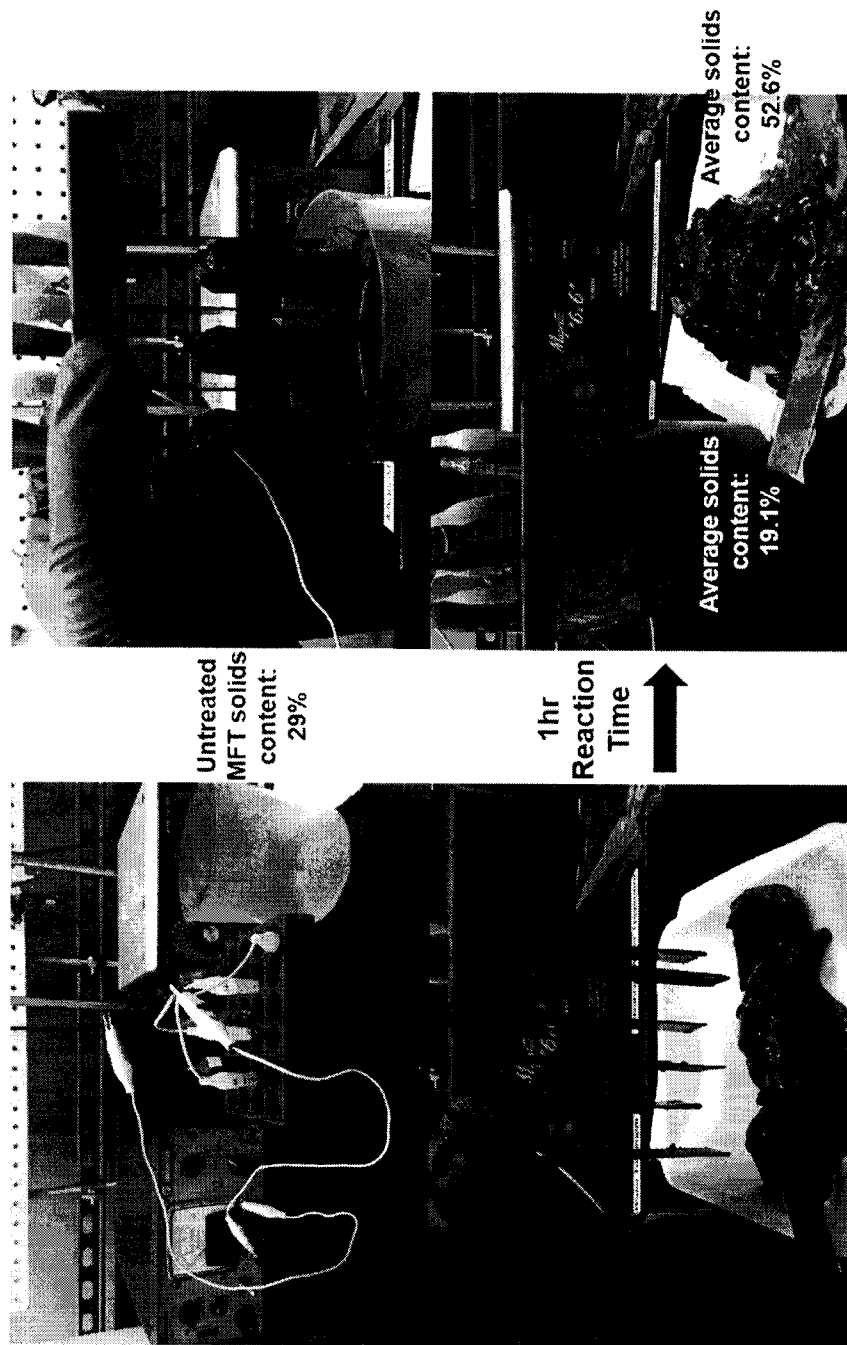


FIGURE 6

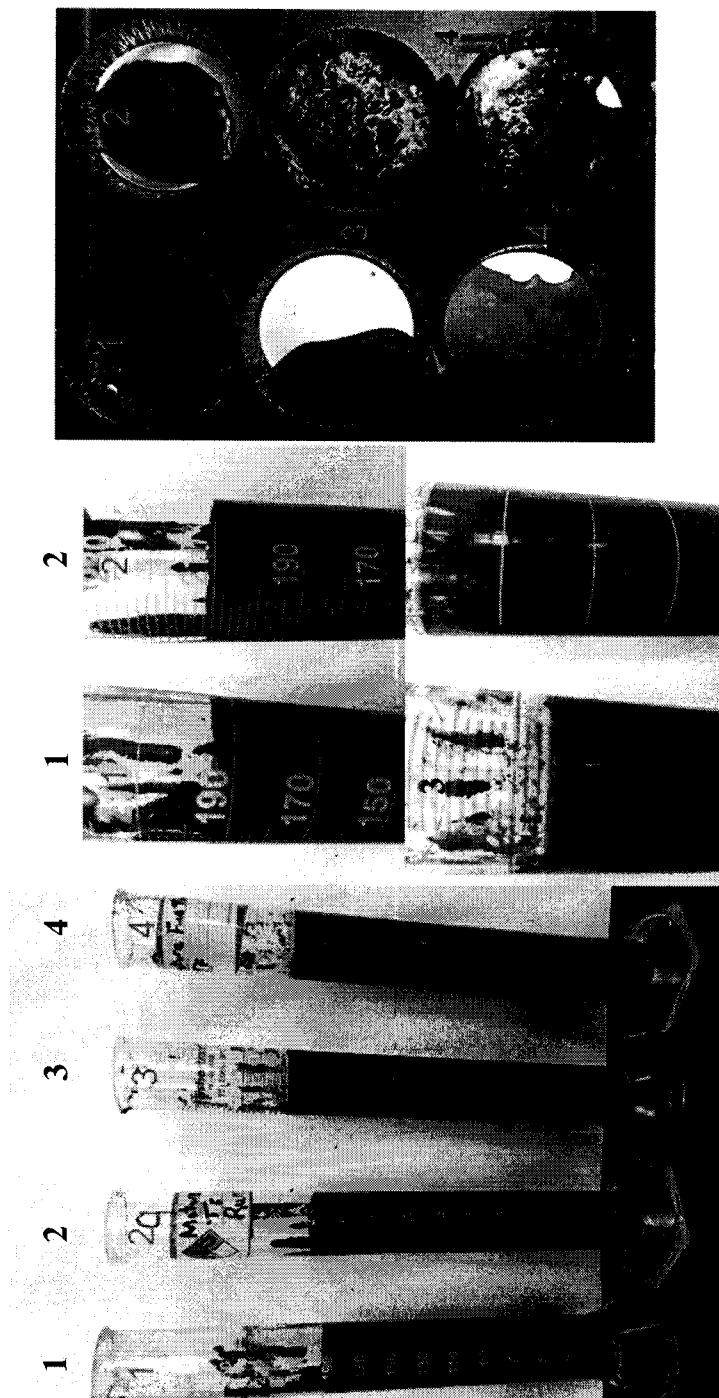


FIGURE 7

