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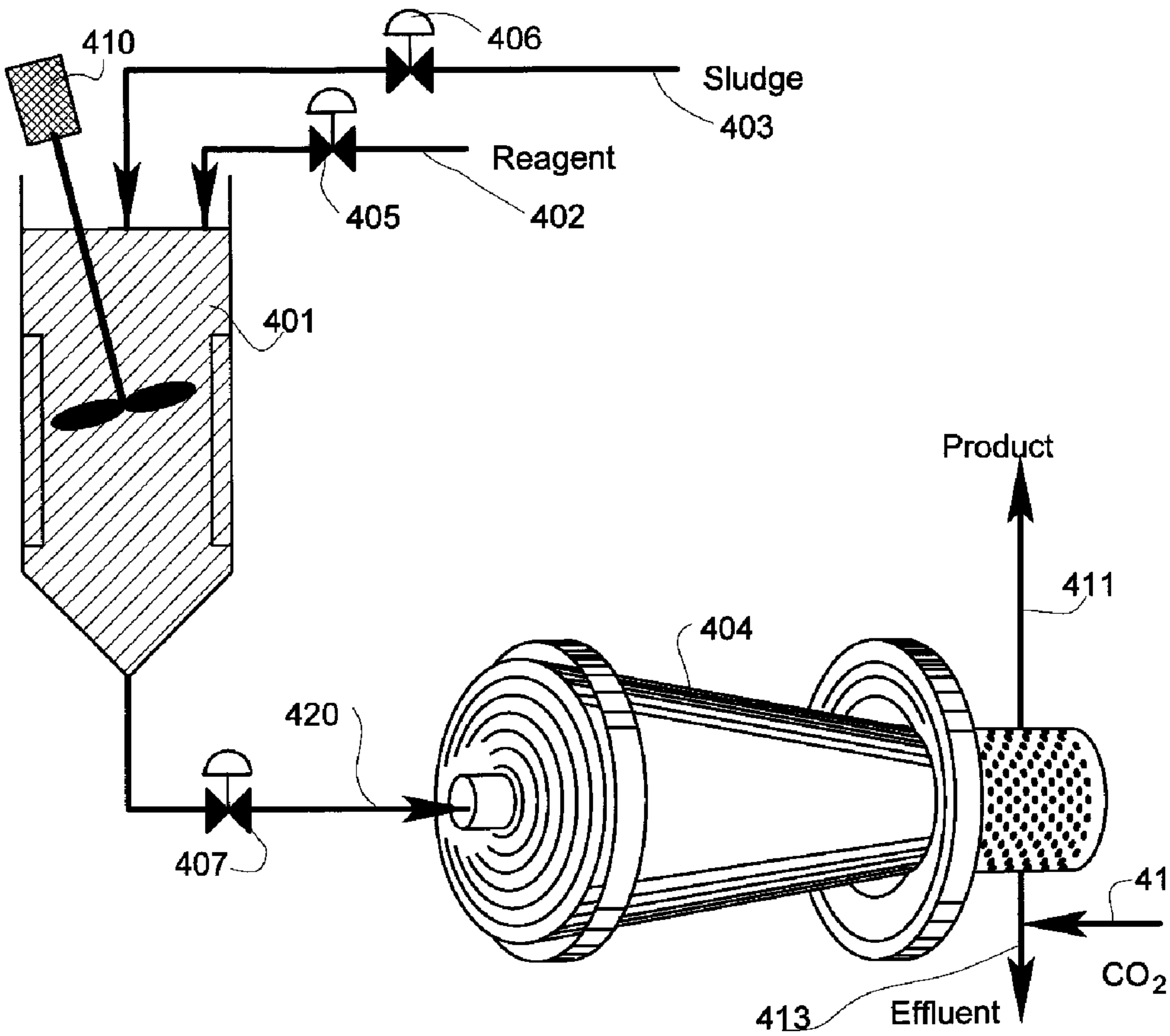
(54) Titre : BOUES DE BITUME, AGGLOMERATION DE PARTICULES ULTRAFINES ET RECUPERATION

(54) Title: POND SLUDGE BITUMEN AND ULTRA FINES AGGLOMERATION AND RECOVERY




(57) Abrégé/Abstract:
Ultrafine, bi-wetted and bitumen particles are the reason why oil sand fluid tailings will not compact much beyond 30 weight percent solids in a mined oil sands tailings pond. Most of these particles are gel forming or block the flow of water out of clay card house

(57) Abrégé(suite)/Abstract(continued):
structures comprising the fluid tailings. A bitumen agglomerating and kneading method and apparatus are disclosed in which multivalent cations serve to trap ultrafine and bi-wetted particles into the bitumen phase which bitumen is then separated from the fluid tailings by a revolving apertured oleophilic wall. The resulting effluent may be used as recycle water after the minerals are settled and compacted. Care is taken to minimize the accumulation of cations and corrosive components in the effluent. The bitumen product is either discarded or is deasphalted to prevent the return of ultrafine and bi-wetted particles to a tailings pond that provides recycle water to an oil sands extraction bitumen froth flotation plant.

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## ABSTRACT

Ultrafine, bi-wetted and bitumen particles are the reason why oil sand fluid tailings will not compact much beyond 30 weight percent solids in a mined oil sands tailings pond. Most of these particles are gel forming or block the flow of water out of clay card house structures comprising the fluid tailings. A bitumen agglomerating and kneading method and apparatus are disclosed in which multivalent cations serve to trap ultrafine and bi-wetted particles into the bitumen phase which bitumen is then separated from the fluid tailings by a revolving apertured oleophilic wall. The resulting effluent may be used as recycle water after the minerals are settled and compacted. Care is taken to minimize the accumulation of cations and corrosive components in the effluent. The bitumen product is either discarded or is deasphalted to prevent the return of ultrafine and bi-wetted particles to a tailings pond that provides recycle water to an oil sands extraction bitumen froth flotation plant.

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# POND SLUDGE BITUMEN AND ULTRA FINES AGGLOMERATION AND RECOVERY

## RELATED APPLICATIONS

This application is related to Canadian Patent application number 2,653,058 filed February 16th, 2009 entitled **"Dewatering Oil Sand Fine Tailings Using Revolving Oleophilic Apertured Wall"**, Canadian Patent Application 2,647,855 filed January 15th, 2009 entitled **"Design of Endless Cable Multiple Wrap Bitumen Extractors"** and Canadian patent application number 2,638,596 filed August 6th, 2008 entitled "**Endless Cable System and Associated Methods**", and are referenced to by title in the present specifications.

## FIELD OF THE INVENTION

The present invention relates to process devices and methods for processing aqueous suspensions containing oil sand bitumen and discloses methods to remove ultrafines and bitumen from mature fine tailings, from fresh fine tailings, from middlings of an oil sands extraction plant and from any other aqueous processed oil sand stream that contains bitumen and mineral fines. Accordingly, the present invention involves the fields of process engineering, chemistry and chemical engineering.

In particular the present invention relates to Canadian Patent Application entitled "Dewatering Oil Sand Fine Tailings Using Revolving Oleophilic Apertured Wall" in seeking to remove from fine tailings those components that prevent fine tailings dewatering. However, the present invention differs from this prior application in several major areas. In particular, the present invention makes use of various cations in solution to cause bitumen phase to agglomerate with and capture

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montmorillonite nano particles and other fine particulates, which bitumen is then removed from the fine tailings by the use of an apertured oleophilic wall. The prior application, which was only filed a few months earlier, did not make claims for the use of cations. The present invention also discloses additional agglomeration methods and equipment.

**BACKGROUND OF THE INVENTION**

A detailed description of oil sands, tar sands or bituminous sands deposits and of the processing of these ores to produce bitumen is provided in the above referenced patent applications. Some authors report that the Northern Alberta oil sands resource contains more than half of the remaining world oil reserves.

The Alberta oil sands ore consist of sand grains covered with a thin envelope of water with the voids between the grains filled with mineral fines, water and bitumen. Only part of this ore can be mined economically. Current mining methods are not commercially viable when the ore is overlain by too much overburden or when the oil sand layer is too thin or the ore is too lean to make overburden removal cost effective. About 10 percent of the oil sand ore can be mined but the remainder is covered with too much overburden. The ore contains approximately 84 weight percent mineral solids and the remaining approximately 16 weight percent comprises bitumen and water. A high grade oil sand contains about 5 percent water and 11 percent bitumen or higher, and a low grade oil sand contains about 8 percent water and 8 percent bitumen or lower. Normally an oil sand ore containing less than 6 percent bitumen is not considered economical for processing especially when covered by a thick layer of overburden. Low grade oil sands generally contain more mineral fines (silt and clay) and the associated connate water often is high in divalent cations. Low grade oil sands are more difficult to process than high grade oil sands. Some oil sand ores are found in estuary deposits, which ores usually are relatively easy to process by froth flotation, and some are found in marine deposits which are more difficult to process by current commercial flotation methods.

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There presently are several commercial facilities near Fort McMurray which extract bitumen from mined oil sands by the commercial Clark Hot Water Extraction Process which uses froth flotation to recover the bitumen. These are very large plants. For example, one plant per day mines at least 230,000 long tons of oil sand ore, uses 190,000 long tons of water, extracts 25,000 long tons of bitumen, discharges 380,000 long tons of tailings, reclaims 120,000 long tons of tailings water and rejects 12,000 long tons of oversize material. By the year 2006 three Alberta mined oil sands plants processed per day about one million long tons of oil sand ore to produce more than 700,000 barrels of bitumen per day.

In accordance with the first step of one commercial application of the Clark process, the oil sand is mixed with hot water, air and a small amount of "process aid" (usually NaOH) to produce an aqueous slurry in which sand grains, fines, bitumen droplets and air bubbles are suspended in hot water. The oil sand slurry is formed by tumbling in a drum with hot water and process aid or by turbulent mixing of ore with water and process aid in a long distance pipeline. Flotation air enters the slurry in the drum or in the pipeline after which the slurry is diluted with additional water and introduced into a primary separation vessel known as a "PSV" where additional air may be required to cause bitumen droplets to attach to air bubbles and rise to the top of the vessel to be skimmed off as the "primary bitumen froth" product.

Process aid has a high pH and this serves to release from the ore carboxylic (naphthenic) and sulfate/sulfonate detergents to allow for disengagement of bitumen from the sand grains,to provide the mineral surfaces in the slurry with a strong negative potential to disperse these minerals in the slurry, to encourage the adhesion of bitumen to gas bubbles, and to allow aerated bitumen to rise to the top of separation vessels. The resulting aqueous phase pH in the Clark process averages about 8.5 . After operating for a while, the commercial oil sand plants limit the use of fresh water for processing oil sand ore by using a large amount of recycle water from its tailings ponds. This also reduces the amount of process aid required for extracting bitumen from oil sand ore since the recycle water usually contains residual process aid and detergents.

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Most of the oil sand bitumen is recovered in the PSV and is skimmed off the top as the "primary froth". The coarse sand, together with water, some fines, some bitumen, some process aid, and some surfactants, sink and leave the PSV through a bottom outlet. This stream is referred to as "primary tailings".

Some bitumen and some fines leave the extraction process with the primary tailings, but most of the slurry fines and some bitumen in aqueous suspension collect in the mid section of the PSV. This suspension is removed from the PSV mid section in the form of an aqueous drag stream called "middlings" and is introduced into a series of induced air flotation cells. Here the middlings are contacted with a flood of minute air bubbles to cause a large portion of the residual bitumen to attach to these air bubbles and float to the top of the cells to be skimmed off as the "secondary bitumen froth" product. For most processed ores, secondary froth contains more mineral matter than primary froth and makes up only a small portion of the total bitumen recovered. A tailings product, referred to as "secondary tailings", leaves from the bottom outlet of the flotation cells, is combined with the primary tailings and is sent to a tailings pond by pipeline. The secondary tailings contain water, some fines, some bitumen, some process aid, and some surfactants. In more recent developments the tailings are processed further to recover additional bitumen.

The combined tailings are discharged onto the shore of a large tailings pond with or without the use of hydrocyclones. Here the coarse sand grains are deposited on the beach, leaving a fluid suspension of bitumen, fine solids, process aid and surfactants. This fine mixture flows into the sedimentation portion of the tailings pond where mineral fines and residual bitumen settle. Some water is released and rises to the top of the tailings pond, and this water is used is recycle water. The process water used in the current commercial extraction plants consists of about 10 percent fresh water from the Athabasca river and about 90 percent recycle water form the tailings ponds. This recycle water can contain up to about 2 percent solids. Higher solids contents tend to interfere with oil sands processing in the Clark process. Water containing a higher solids content remain in the ponds where the particulate minerals and bitumen suspension go through a sorting process and slowly

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settle until the settled suspension, called "fine tailings" or "tailings pond sludge", reaches a solids content of about 30 weight percent and a bitumen content of about 2 weight perçent. It is then called "mature fine tailings" which are thought to form microscopic card-house structures of clay due to the plate-like character of the electrically charged clay fines. These electric charges are the result of process aid additions to the original oil sand slurry.

Ultrafine mineral particles, bitumen and biwetted solids in the mature fine tailings suspension accumulate into thixotropic gel structures that severely limit further settling of the mature fine talings. Some of these components are believed to form plugs that prevent the escape of water through the pores of the cardhouse structures. Compacting of the sediment, after that, results from the combined weight of the accumulating sediment and from fine sand and silt settling into the sediment from above, and from wind blown sand from the tailings pond dykes raining down into the pond. It has been suggested that coarse mineral particles, such as sand, may break through the existing card house or gel structures and open up dewatering channels in the thixotropic sediment while the finer sand and silt particles become trapped in the gel, densify it, and provide assistance in its very slow compaction. This natural compacting is so slow that most estimates suggest hundreds or even thousands of years before mature sludge will reach consolidation.

Problems with the accumulation of settling oil sand fine tailings problem were not realized until about a decade after the first commercial oil sand plant started its operation. Initially it was assumed that the tailings would settle by gravity in the tailings ponds into a solid material that could be covered effectively by sand and overburden for subsequent site remediation. The possibility of gel forming structures in uncompacted fluid oil sand tailings was not contemplated beforehand and this unexpected problem has resulted in decades and many millions of dollars of research devoted to try and eliminate the fluid tailings problem. This research is still ongoing and has resulted in a large number of master's theses, doctor's theses, research publications, and a number of patents. By the year 2009 about 700 million cubic meters of tailings pond sludge have accumulated and are stored in huge ponds. This

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sludge is toxic. For example, when 10% pond water is mixed with 90% fresh water, about 50% of fish entering and remaining in this water mixture will die within 96 hours. Furthermore, to put 700 million cubic meters of toxic sludge in perspective: this amount is sufficient to cover a two lane highway, 10 meters wide, up to the rafters of a 6 story building, 15 meters high, for 5000 kilometers all the way across Canada from Victoria to Halifax. Should one of the pond dykes ever break due to seismic activity it would devastate the surrounding landscape.

Research that has been conducted by universities and oil sands companies on overcoming the fluid tailings problem has been exclusively devoted to understanding the mechanism of bitumen froth flotation and to overcome its problems. Much research has been devoted to gaining an understanding of how to modify fluid tailings, how to accommodate it, how to reduce the amount of fluid tailings (sludge) produced, or how to chemically treat the sludge in the hope of consolidating it into a solid mass for oil sand lease remediation. Great strides have been made in understanding the physics, chemistry, mechanism and behaviour of fluid tailings; but no conclusive and satisfactory solution has yet been found. Confirmation of this may be found in published literature and in the fact that Syncrude Canada Ltd., the company in the forefront of sludge research, is currently asking the Alberta government for permission to expand its tailings pond.

## SUMMARY OF THE INVENTION

Fluid tailings contain a wide range of particulates and several types of clay but only some of these particulates are the bad actors that prevent fluid tailings compaction and dewatering and comprise only a small percentage of the fine minerals of the fluid tailings. Bitumen particles, bi-wetted articles and nano size montmorillonite clay particles have the ability to block the release of water from fluid tailings (sludge) due to the formation of gels and plugs that are strong enough to prevent or reduce sludge compaction when left undisturbed in the tailings ponds.

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As an independent inventor I have developed an approach that uses bitumen agglomeration in a tumbler with a bed of oleophilic balls to capture into the bitumen phase those small amounts of nano size montmorillonite clay particles and bi-wetted (mostly humic) particles that prevent fluid tailings dewatering. I remove these bad actors from the fluid tailings. Bitumen already present in the tailings ponds is used to capture these detrimental particulates. The resulting bitumen phase with its captured particulates is thereafter removed from the fluid tailings by means of an apertured oleophilic wall whilst the effluent passing through the wall apertures is sent to a tailings pond for more rapid settling, compaction and release of recycle water.

In order to achieve more effective capture of nano-size clay and bi-wetted particles by bitumen, I add approximately one half mole to two moles of a multivalent salt ,oxide, or hydroxide reagent to each 100 kilo grams of montmorillonite in the suspension in order to change the surface chemistry of the clay and bitumen particulates and thereby encourage the adhesion of the ultra fine clay particulates to bitumen during kneading that takes place in the agglomeration process of a bitumen agglomerator. The multivalent chemical or reagent added can contain calcium, magnesium, iron or aluminum ions. A proper selection of the reagent and its dosage is a function of the fluid tailings composition. Both the type and dosage of reagent are influenced by a desire to maximize the adhesion of particulate matter to bitumen, but also to optimize bitumen agglomeration while minimizing the accumulation of an undesirable amount or type of ions in the resulting effluent. For example, this effluent will produce clarified water when allowed to settle for some time and this clarified water may be used as recycle water in a commercial oil sands extraction plant, where a high concentration of chlorine in such plant recycle water may result in severe corrosion when oil sand bitumen is upgraded or refined. Similarly a high concentration of calcium and magnesium ions in recycle water may have a very negative effect on bitumen recovery and froth quality during froth flotation of mined oil sands. Sulphate ions in sludge may result in the eventual release of hydrogen sulphide to the atmosphere. For that reason care is to be taken to choose a suitable

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reagent and a suitable dosage of that reagent for addition to the fluid tailings (sludge) in the process of the present invention.

Other reagents may be added to the sludge after processing before it is sent to a tailings pond for settling, compaction and released of process water for use as recycle in a commercial oil extraction plant. For example, the effluent from processing sludge in an agglomerator may be sparged with carbon dioxide in the effluent pipeline to produce precipitating calcium carbonate or magnesium carbonate and thereby reduce the accumulation of calcium or magnesium ions in the subsequently released recycle water.

In order to do all this, the present patent discloses and claims a bitumen agglomerator with an agglomerating capacity that is much larger than the bitumen agglomerators I have patented before. It also has a shape that is different from my prior bitumen agglomerators, and achieves more effective agglomeration.

The agglomerator is in the form of a revolving cone with a central inlet at the perimeter of the base and an apertured cylindrical wall outlet at the opposite end. The cone is tilted about 90 degrees to provide a generally horizontal central revolving axis from inlet to outlet. Furthermore, the newly disclosed agglomerator may revolve at speeds that are not necessarily synchronized with the surface speed of an apertured oleophilic wall mounted around or below the apertured agglomerator outlet.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1a is a side view of an agglomerator of the present invention, showing a central inlet and an apertured outlet. The agglomerator is supported by slewing rings mounted on the agglomerator external surface and supported by rollers mounted on a shaft in bearings to revolve the agglomerator with a geared motor (not shown).

FIG. 1b is a small scale perspective view of the agglomerator vessel of FIG 1a, showing the inlet and the apertured outlet and the conical shape of the agglomerator with its slewing rings.

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FIG. 1c is an illustration of balls tumbling in an agglomerator that revolves well below the critical speed to prevent the formation of a cateracting bed.

FIG. 1d is an illustration of balls tumbing in an agglomerator that revolves below the critical speed but fast enough to achieve cateracting of the balls.

FIG. 2a shows a circular cross section of the agglomerator filled with a bed of balls and filled with a level of mixture.

FIG. 2b is a sectional view of the agglomerator through section A-A of FIG. 2a. It shows the conical shape of the agglomerator partly filled with balls of various diameters and with a level of mixture. The central inlet is shown, as well as the apertured cylindrical outlet. Note, that under the outlet is an apertured oleophilic wall but this wall is not in contact with the apertured agglomerator outlet, and this provides for an opportunity to allow the surface speed of the agglomerator outlet to be different from the surface speed of the apertured oleophilic wall.

FIG. 2c illustrates one method of feeding mixture into the agglomerator.

FIG. 2d illustrates the use of a funnel with a screen to provide feed to the method of FIG. 2c. The screen is provided to prevent large particles, such as tree roots, helmets, bottles or other refuse from entering the aggomerator.

FIG. 2e illustrates another method of feeding mixture into the agglomerator. In this case there are two flanges that include a rotary seal to allow feed to flow from a stationary pipe into the revolving agglomerator.

FIG. 2f illustrates that the balls of the agglomerator may comprise two materials, for example a steel core and a rubber cover. Alternately the bed of balls may consist of a mixture of metal balls and plastic balls, and the metal balls may be made from steel or from brass or bronze or may have an oleophilic copper coating.

FIG. 3a is a schematic drawing to illustrate the agglomerator with the exit covered by an apertured oleophilic belt to serve as the separation zone while a set of squeeze rollers serve as the bitumen removal zone to allow bitumen to flow into a receptacle. In this case the agglomerator exit is in contact with the oleophilic belt and this requires that the agglomerator exit surface speed be the same as the oleophilic belt surface speed.

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FIG. 3b is a schematic drawing of two agglomerator exits mounted above a single apertured oleophilic belt. The exits are not in contact with the belt surfaces and this allows for surface speeds of the agglomerator exits to be different from the surface speed of the belt. Note, that in both cases here, the apertured oleophilic wall is inclined to achieve more effective separation as disclosed and explained in the copending patent application entitled "Design of Endless Cable Multiple Wrap Bitumen Extractors"

FIG. 4 is a flow diagram of a mixing vessel for mixing reagent with sludge before it enters the agglomerator, which agglomerator is similar to the one illustrated in FIG. 2b. Using such mixing vessel ahead of the agglomerator allows for the thorough mixing of reagent with sludge before contact is made with the balls of the agglomerator. For the sake of simplicity, the apertured oleophilic belt is not shown here but is assumed to be present to produce a bitumen product and an effluent from which at least part of the bitumen, bi-wetted particles and ultrafines have been removed.

## DETAILED DESCRIPTION

Before the present invention is disclosed and described, it is to be understood that this invention is not limited to the particular structures, process steps, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting

It must be noted that, as used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a splice" includes one or more of such splices, reference to "an endless cable" includes reference to one or more of such endless cables, and reference to "the material" includes reference to one or more of such materials.

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**Definitions**

In describing and claiming the present invention, the following terminology will be used in accordance with the definitions set forth below. When reference is made to a given terminology in several definitions, these references should be considered to augment or support each other or shed additional light.

"agglomeration" refers to increasing the size of bitumen particles in an aqueous mixture by means of an agglomeration drum prior to the removal of enlarged bitumen particles from the mixture by an oleophilic apertured wall, such as a sieve, screen, belt or cable wraps. As bitumen agglomerates it captures oleophilic mineral particulates as well as bi-wetted particles which are partly oleophilic. It also captures ultrafine hydrophilic particulates when the chemistry of the aqueous phase causes the adhesion of these ultrafines to the bitumen surface upon contact. This may occur when the aqueous phase contains divalent cations or when the pH of the aqueous phase becomes acidic. It also may occur when the particulates come in very close contact with a bitumen surface after electric surface charges have been reduced. In such cases the surface forces of repulsion can become forces of attraction.

"agglomeration drum" refers to a drum containing oleophilic surfaces that is used to increase the particle size of bitumen particles in oil sand mixtures prior to separation, and to capture bi-wetted and ultrafine particulates in the bitumen phase. Bitumen particles flowing through the revolving interior of said drum, through voids between oleophilic balls, come in contact with oleophilic surfaces and adhere thereto to form a layer of bitumen of increasing thickness until the layer becomes so thick that shear from mixture flowing through the revolving drum causes a portion of the bitumen layer to slough off, and/or to flow to the exit of the agglomerator, resulting in bitumen particles that are larger than the original bitumen particles of the mixture. Bi-wetted and ultrafine particulates become part of the bitumen phase in the agglomeration process when the aqueous phase is pre-conditioned to increase attractive forces and reduce repulsive forces between these particles and bitumen

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while retaining repulsive forces between coarse hydrophilic silica sand, silt and clay particulates and bitumen. When a bed of oleophilic balls is used in the drum, these balls agglomerate the bitumen but also kneed the collected bitumen. This kneeding normally does not occur when tower packings are used in the drum that remain stationary with respect to the drum wall. Such tower packings were sometimes used in the prior art of the inventor.

"oleophilic apertured wall" refers to oleophilic sieve, to oleophilic apertured screen, to oleophilic mesh belt, to drum with oleophilic apertured cylindrical wall or to oleophilic endless rope or wire rope cable formed into an apertured oleophilic belt by means of wrapping the cable multiple times around two or more rollers or drums. When using oleophilic apertured walls to separate bitumen from an aqueous mixture, water and suspended hydrophilic solids pass through the apertures of the drum, or belt or through the slits between sequential wraps of the oleophilic endless cable, whilst bitumen and oleophilic solids are captured by the oleophilic drum or belt surfaces or cable wraps. The captured bitumen and oleophilic solids are subsequently removed from these surfaces, along with some entrained water and entrained hydrophilic solids to become the bitumen product of separation.

"bitumen" refers to a viscous hydrocarbon that contains maltenes and asphaltenes and is found originally in oil sand ore interstitially between sand grains. Maltenes generally represent the liquid portion of bitumen in which asphaltenes of extremely small size are thought to be dissolved or dispersed. Asphaltenes contain the bulk of the metals of bitumen and probably give bitumen its high viscosity. In a typical oil sands plant, there are many different streams that may contain bitumen particles that have disengaged from the sand grains. These streams may but do not have to contain sand grains. Asphaltenes may be removed from bitumen by dissolving bitumen in straight chain hydrocarbons, resulting in precipitation of asphaltenes. Finely dispersed and partly hydrophilic asphaltenes also are thought of as being one of the residual components in sludge that prevent or reduce sludge dewatering. Asphaltenes make up part of an agglomerated bitumen product collected by an apertured oleophilic wall.

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"bitumen recovery" or "bitumen recovery yield" refers to the percentage of bitumen removed from an original mixture or composition. Therefore, in a simplified example, a 100 kg mixture containing 45 kg of water and 40 kg of bitumen where 38 kg of bitumen out of the 40 kg is removed, the bitumen recovery or recovery yield would be a 95%.

"cable" refers to a non metalic rope, a metal wire rope, a single wire, a monofilament or a multistrand filament rope.

"cable wraps" refers to the wraps of endless cable wrapped around two or more rollers where the spaces between sequential cable wraps form apertures through which aqueous phase can pass, giving up some or most of its bitumen content to the wraps as it passes through the apertures.

"central location" refers to a location that is not at the periphery. In the case of a pipe, a central location is a location that is neither at the beginning of the pipe nor at the end point of the pipe and is sufficiently remote from either end to achieve a desired effect, e.g. washing, slurry preparation, disruption of agglomerated materials, heating of bitumen on cable wraps, etc.

"coagulant" as used herein refers to a chemical, a suspension or a solution of a chemical which when mixed with sludge or when mixed with a precursor of sludge reduces the electrical charges of the particles in the sludge or in its precursor.

"conditioning" in reference to mined oil sand is consistent with conventional usage and refers to mixing a mined oil sand with water, air and caustic soda to produce a warm or hot slurry of oversize material, coarse sand, silt, clay and aerated bitumen suitable for recovering bitumen froth from said slurry by means of froth flotation. Such mixing can be done in a conditioning drum or tumbler or, alternatively, the mixing can be done as it enters into a slurry pipeline and/or while in transport in the slurry pipeline. Conditioning aerates the bitumen for subsequent recovery in separation vessels by flotation. Likewise, referring to a composition as "conditioned" indicates that the composition has been subjected to such a conditioning process.

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"confined" refers to a state of substantial enclosure. A path of fluid may be confined if the path is, e.g., walled or blocked on a plurality of sides, such that there is an inlet and an outlet, and the flow is controlled to some degree by the shape of the confining material, enclosure or housing. Confined path refers to a path that is confined by an enclosure. For example, a fluid flowing in a pipe is confined by the walls of the pipe.

"couette flow" refers to laminar flow of a viscous fluid in the space between two or more parallel or nearly parallel surfaces, one of which is moving relative to the other surfaces which are stationary. The flow is driven by virtue of viscous drag force acting on the fluid due to the moving surface, in cooperation with or against any pressure gradient parallel to the surfaces. Couette flow illustrates shear-driven fluid motion. The moving surface may be a mesh belt or multiple cable wraps and the stationary surfaces may be the sides of a confined path enclosure. Revolving endless mesh belts or cable wraps coated with bitumen passing through a confined path may cause couette flow of bitumen due to the movement of the belt or of the endless cable wraps relative to the stationary walls of the enclosure. The stationary walls may slow down the flow of viscous bitumen through the confined path and allow the accumulation of viscous bitumen to partly or completely fill a cross section of the enclosure.

"critical speed" is the speed of rotation of a drum in which the movable contents of the drum adjacent to the interior drum wall remain in contact with the drum wall at all times due to centripetal force. For a conical drum critical speed computation of the drum is based on the largest internal diameter of the conical drum.

"cylindrical" as used herein indicates a generally elongated shape having a circular cross-section of approximately constant diameter. The elongated shape has a length referred herein also as a depth as calculated from a defined top or side wall.

"endless cable" or "endless wire rope" is used in this disclosure to refer to a cable having no beginning or end, but rather the beginning merges into an end and vice-versa, to create an endless or continuous cable. The endless cable can be, e.g., a wire rope, a non metallic rope, a carbon fiber rope, a single wire, compound filament

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or a monofilament which is spliced together to form a continuous loop, e.g. by a long splice, by several long splices, or by welding or by adhesion.

"enlarged bitumen" refers to bitumen particles that have been agglomerated in an agomerating drum to form enlarged bitumen phase particles or bitumen phase fluid streamers for subsequent capture by an apertured oleophilic wall, for example by oleophilic cable wraps. Enlarged bitumen may contain captured solids.

"generally" refers to something that occurs most of the time or in most instances, or that occurs for the most part with regards to an overall picture, but disregards specific instances in which something does not occur.

"fluid" refers to flowable matter. Fluids, as used in the present invention typically include a liquid, gas, and/or flowable particulate solids, and may optionally further include amounts of solids and/or gases dispersed therein. As such, fluid specifically includes slurries, suspensions or mixtures (continuous liquid phase with suspended particulates), flowable dry solids, aerated liquids, gases, and combinations of two or more fluids. In describing certain embodiments, the terms sludge, slurry, mixture, mixture fluid and fluid are used interchangeably, unless explicitly stated to the contrary.

"long splice" refers to a splice used in the marine and in the elevator industry to join the ends of ropes, wire ropes or cables to increase the available length of such ropes or cables or to make them endless while providing good strength in the rope or cable at the splice. The diameter of the rope or cable at a long splice normally is not much larger than the average diameter of the rope or cable itself.

"metallic" refers to both metals and metalloids. Metals include those compounds typically considered metals found within the transition metals, alkali and alkali earth metals. Examples of metals are Ag, Au, Cu, Al, and Fe. Metalloids include specifically Si, B, Ge, Sb, As, and Te. Metallic materials also include alloys or mixtures that include metallic materials. Such alloys or mixtures may further include additional additives.

"multiple wrap endless cable" as used in reference to separations processing refers to a revolvable endless cable that is wrapped around two or more drums and/or

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rollers a multitude of times to form an endless belt having spaced cables. Proper movement of the endless belt can be facilitated by at least two guide rollers or guides that prevent the cable from rolling off an edge of the drum or roller and guide the cable back to the opposite end of the same or other drum or roller. Apertures of the endless belt are formed by the slits, spaces or gaps between sequential wraps. The endless cable can be a single wire , a wire rope, a plastic rope, a compound filament or a monofilament which is spliced together to form a continuous loop, e.g. by splicing, welding, etc. As a general guideline, the diameter of the endless cable can be as large as 3 cm and as small as 0.01 cm or any size in between, although other sizes might be suitable for some applications. Very small diameter endless cables would normally be used for small separation equipment and large diameter cables for large separating equipment. A multiwrap endless cable belt may be formed by wrapping the endless cable multiple times around two or more rollers. The wrapping is done in such a manner as to minimize twisting of and stresses in the individual strands of the endless cable. An oleophilic endless cable belt is a cable belt made from a material that is oleophilic under the conditions at which it operates. For example, a steel cable is formed from a multitude of wires and the cross section of a cable is not perfectly round but contains surface imperfections because of the wraps of the individual wires. Bitumen captured by such a cable may at least partly fill the voids between the individual wires along the cable surface, and will remain captured there while the bulk of the bitumen is removed from the cable surface in a bitumen recovery zone. This residual bitumen keeps the cable oleophilic even after the bulk of the bitumen has been removed from the cable and this bitumen serves as a nucleus for attracting more bitumen in a separation zone.

"oleophilic" as used in these specifications refers to bitumen attracting. Most dry surfaces are bitumen attracting or can be made to be bitumen attracting. A plastic rope, or a metal wire rope normally is bitumen attracting and will capture bitumen upon contact unless the rope is coated with a bitumen repelling coating. A plastic rope or metal wire rope that is coated with a thin layer of bitumen normally is oleophilic or bitumen attracting since this layer of bitumen will capture additional

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bitumen upon contact. A plastic rope or metal wire rope will not attract bitumen when it is coated or partly coated with light oil since the low viscosity of the light oil will not provide adequate stickiness for the adhesion of bitumen to the rope. Similarly, a rope covered with a thin layer of hot bitumen will not be very oleophilic until the thin layer of bitumen has cooled down sufficiently to allow bitumen adhesion to the rope under the conditions of the claimed methods.

"oversize solids" refers to any solids that are larger in size than the linear distance between adjacent cable wrap surfaces and preferably refers to any solids that are larger than 50% of the linear distance between adjacent cable wrap surfaces. Such solids tend to be abrasive and may cause damage to the wraps. In case of a mesh belt, oversize is similarly defined with respect to the size of the mesh apertures.

"precursor" A precursor of sludge is any suspension from an oil sands plant that eventually becomes part of the contents of a tailings pond or of a tailings stream.

"residence time" refers to the time span taken for a mixture to leave a system, a process, a vessel or an apparatus after it has entered the system, process, vessel or apparatus. It is assumed that during this time span the desired separation, compaction, settling or processing has been achieved.

"recovery" and "removal" of bitumen as used herein have a somewhat similar meaning. Bitumen recovery generally refers to the recovery of bitumen from a bitumen containing mixture and bitumen removal generally refers to the removal of adhering bitumen from a mesh belt or from cable wraps of an endless cable. Bitumen is recovered from a mixture by an oleophilic sieve when bitumen is "captured" by the sieve in a separation zone and adheres to the sieve surfaces. Bitumen is stripped or removed from an apertured oleophilic wall in a bitumen removal zone. A bitumen recovery apparatus is an apparatus that recovers bitumen from a mixture.

"retained on" refers to association primarily via simple mechanical forces, e.g. a particle lying on a gap between two or more cables. In contrast, the term "retained by" refers to association primarily via active adherence of one item to another, e.g. retaining of bitumen by an oleophilic cable or adherence of bitumen

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coated balls to bitumen coated internal walls of an agglomerator. In some cases, a material may be both retained on and retained by cable wraps.

"roller" indicates a revolvable cylindrical member or a drum, and such terms are used interchangeably herein.

"screen" refers to an apertured wall, sieve or cable belt. Apertures of a wall, of a screen or of a sieve are the holes or slits through which aqueous phase can pass.

"sieve" refers to an apertured wall and is used interchangeably with "screen" unless stated otherwise. For example, a screen may be used to remove oversize particulates and in that case may not be oleophilic.

"single wrap endless cable" refers to an endless cable which is wrapped around two or more cylindrical members in a single pass, i.e. contacting each roller or drum only once. Single wrap endless cables do not require a guide or guide rollers to keep them aligned on the support rollers but may need methods to provide cable tension for each wrap when sequential cable wraps are of different lengths. Single wrap endless cables may serve the same purpose as multiple wrap endless cables for separations. When multiple wrap endless cables are specified, single wrap endless cables may be used in stead unless specifically excluded.

"sludge" as used herein refers to any mixture of fine solids in water and contains residual bitumen. In describing or claiming certain embodiments, the term sludge, fluid tailings, fine tailings, mature fine tailings, bitumen containing suspensions and mixture are used interchangeably, unless explicitly stated to the contrary. In the oil sands industry, sludge is a term that used to be reserved for a mixture of bitumen and dispersed solids in a continuous water phase in a mined oil sands tailings pond but more recently "fluid tailings", "fine tails", "fresh fine tails" or "mature fine tails" have come in vogue for political reasons and also to provide a distinction as to how long this sludge has resided in a tailings pond. These various terms are used by various organizations and authors and often have the same meaning unless specifically defined. For example, sludge leaves the impression of something dirty and unattractive, whereas the term fine tailings has much more appeal to the human mind, similar to fine wine.

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"slurry" as used herein refers to a mixture of solid particulates and bitumen particulates or droplets in a continuous water phase It normally is used to describe an oil sand ore that has been or is in the process of being digested with water to disengage bitumen from sand grains.

"sparging" or "sparged" as used herein refers to the introduction of a gas, such as steam, carbon dioxide or other gas under pressure into a bitumen containing mixture or into fluid tailings or effluents through tubes, pipes, enclosure openings, perforated pipes or porous pipes. The type of gas used for sparging normally is described in the specifications. When steam is the sparging gas it is generally used to increase the temperature of bitumen to reduce its viscosity. Live steam may also serve to both heat bitumen and to add water to bitumen. Carbon dioxide may be sparged into an effluent or into a suspension to change the chemistry of the suspension. When a suspension contains multivalent cations, for example calcium ions, sparging the suspension with carbon dioxide may cause the calcium to react with the sparged carbon dioxide to form calcium carbonate precipitates, and thus remove calcium ions from the suspension. This is of importance when suspension water is recycled to an extraction process that has little tolerance for calcium ions.

"substantially" refers to the complete or nearly complete extent or degree of an action, characteristic, property, state, structure, item, or result. For example, an object that is "substantially" enclosed would mean that the object is either completely enclosed or nearly completely enclosed. The exact allowable degree of deviation from absolute completeness may in some cases depend on the specific context. However, generally speaking the nearness of completion will be so as to have the same overall result as if absolute and total completion were obtained. The use of "substantially" is equally applicable when used in a negative connotation to refer to the complete or near complete lack of an action, characteristic, property, state, structure, item, or result.

"surface speed" is the speed of movement of the surface of an apertured agglomerator outlet or is the speed of movement of an apertured oleophilic wall.

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"velocity" as used herein is consistent with a physics-based definition; specifically, velocity is speed having a particular direction. As such, the magnitude of velocity is speed. Velocity further includes a direction. When the velocity component is said to alter, that indicates that the bulk directional vector of velocity acting on an object in the fluid stream (liquid particle, solid particle, etc.) is not constant. Spiraling or helical flow-patterns in a conduit are specifically defined to have changing bulk directional velocity.

"wrapped" or "wrap" in relation to a wire, rope or cable wrapping around an object indicates an extended amount of contact. Wrapping does not necessarily indicate full or near-full encompassing of the object.

As used herein, a plurality of components may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a *de facto* equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary.

Concentrations, amounts, volumes, and other numerical data may be expressed or presented herein in a range format. It is to be understood that such a range format is used merely for convenience and brevity and thus should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. As an illustration, a numerical range of "about 1 inch to about 5 inches" should be interpreted to include not only the explicitly recited values of about 1 inch to about 5 inches, but also include individual values and sub-ranges within the indicated range. Thus, included in this numerical range are individual values such as 2, 3, and 4 and sub-ranges such as from 1-3, from 2-4, and from 3-5, etc. This same principle applies to ranges reciting only one approximate numerical value. Furthermore, such an interpretation should apply regardless of the breadth of the range or the characteristics being described.

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Bold headings in the present disclosure are provided for convenience only.

**SUSPENSIONS SUITABLE FOR PROCESSING**

The objectives of the present invention is to remove from or to prevent the accumulation of gel forming of ultrafines and bi-wetted mineral particulates in tailings pond sludge (tailings pond sludge having various names which include fluid tailings, fine tailings, mature fine tailings, etc.) by using bitumen to capture such ultrafines and particulates However, several oil sand streams are precursors that contain residual bitumen and contain ultrafines and/or bi-wetted particulates which eventually report to a tailings pond. Examples of such precursors include:

1) The fluid run off when oil sand tailings are deposited on the shore of a talings pond.
2) Fluid tailings that have resided in a tailings pond for less than a year.
3) Fluid tailings that have resided in a tailings pond for more than a year.
4) Fluid tailings that have resided in a tailings pond for decades
5) Fluid tailings from subaeration flotation cells which currently are mixed with primary tailings from a PSV before the combined tailings are pumped to a tailings pond.
6) Middlings from a PSV.
7) Overflow from hydrocyclones when combined tailings are separated into underflow and overflow.
8) Fluid streams from thickeners that separate tailings into aqueous streams that contain coarse minerals on the one hand and fine minerals on the other hand.
9) Aqueous streams that result from the clean up of bitumen froth, such as streams from dilution centrifuging and from paraffinic bitumen clean up after light hydrocarbons have been removed from such streams.
10) Any other aqueous oil sand plant streams that contain fines and bitumen.

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In summary, all oil sand streams that contain fines and bitumen may be considered suitable candidates for processing by the apparatus and methods of the present invention. Additional bitumen may be added to such a stream if the original bitumen content of the stream is inadequate to remove the desired amount of gel forming ultrafine particles and bi-wetted particles. Tailings ponds often contain bitumen mats that have separated from the sludge but remain suspended in the tailings ponds. Such bitumen mats are good candidates for augmenting the bitumen supply when needed in the present invention.

It is the objective of the present invention to speed up sludge compaction, so that less time is required before suitable oil sand lease remediation can start without leaving behind a landscape that is marred by huge bodies of toxic aqueous suspensions covered by a superficial layer of water.

## THE NATURE OF SLUDGE FINES

In the current tailings ponds the fluid tailings or sludge contain a huge amount of clay. This clay includes kaolinite which has a low shrink-swell capacity when mixed with water and has a low cation cation exchange capacity (1-15 meq/100g. based on dry weight of clay) when ions are added to the suspension water. It includes illite which has a low shrink-swell capacity and a low cation exchange capacity (20 - 30 meq/100 g.). It also includes montmorillonite which is a swelling clay that has a high cation exchange capacity (60 - 120 meq/100g). Montmorillonite is considered largely responsible for gel formation in oil sand sludges. It has a very large surface area because it has a layered structure. This makes montmorillonite highly adsorbent, especially for polar molecules. When montmorillonite comes in contact with water, it absorbs the water and swells up.

Montmorillonite's water content is variable and the clay particles increase greatly in thickness when these absorbs water. The surface area of dry montmorillonite clay is very large because the clay platelets are very thin and very small, and amount to about 70 square meter per gram based on dry weight when the

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external particle surface is considered only. When the internal accessible particle surface is considered, the particle surface of montmorillonite is about 800 square meters per gram dry weight. That area is larger than several football fields per gram of clay. Such a huge particle surface has a major impact on the jell forming ability of montmorillonate clay in water in the presence of cations. While kaolinite and illite can also have very small particles, the montmorillonite particles appear to be the major causes of jell formation in tailings pond sludge. As an example of the difference in surface activity of two clay types, one gram of montmorillonite absorbs about 10 milligrams of calcium in 5 minutes from a 1 millimole calcium solution while one gram of fine kaollinite with a similar average particle size as the montmorillonite adsorbs about 1.5 milligram of calcium in 500 minutes.

Specifically, montmorillonite is a layered silicate mineral with crystals that consist of three layers: a silicon tetrahedron, an aluminum octahedron, and another silicon tetrahedron. The unit structure is a very thin platelet about 1 nanometer thick and 100 to 1000 nanometers wide and long, with a negative charge on the flat surfaces. This negative charge may be neutralized by an interlayer of cations. The bonding strength between the negative charge on the surfaces and the interlayer cations of montmorillonite is low. Therefore, when montmorillonite is in contact with a solution containing another ion, the interlayer cations and in-solution cations are exchanged fairly rapidly with each other, especially when the pH of the solution is 6 or more. The surfaces of montmorillonite platelets are negatively charged, and the edges are positively charged. Since opposite charges attract, when montmorillonite is dispersed in water, the platelets bond together electrostatically to form a house-of-cards structure and the liquid becomes viscous. When this structure develops further, the montmorillonite-dispersed liquid becomes a gel that can include the total volume of a tailings pond sludge. When stirring or shearing the mixture, the gel temporarily returns to a dispersed liquid since it is thixotropic. It appears that shearing and kneading an aqueous mixture, that contains montmorillonite, bitumen and multivalent cations in a bed of oleophilic balls, result in physical and chemical reactions that bond montmorillonite ultrafine particulates with bitumen and captures these in the bitumen phase.

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Removing gel forming particles from sludge will improve sludge dewatering in a major way. The present invention removes these particles by first adding a multivalent salt, oxide or hydroxide to the suspension being processed. The suspension then enters a revolving bitumen agglomerator containing a bed of oleophilic balls, which balls provide collection, agglomeration, shear and mixing of the bitumen phase with the mineral particulates to recover bitumen from the aqueous phase and to capture the adhering particulates into the bitumen phase. In a bitumen agglomerator, the oleophilic balls temporarily capture bitumen on their surfaces, knead the bitumen, and then release a portion of this bitumen back into the mixture in the form of enlarged bitumen phase particles that flow to the agglomerator outlet. A partial separation of the bitumen phase from the aqueous phase takes place in the agglomerator and this separation is mostly completed when the mixture leaves the agglomerator and passes through a revolving apertured oleophilic wall (oleophilic sieve). There the bitumen phase is captured by the surfaces of the oleophilic wall in a separation zone whilst aqueous phase effluent passes through the wall apertures on its way to a tailings pond or to further processing. The bitumen phase is removed from the wall surfaces in a bitumen removal zones and contains dispersed water droplets and mineral particulates. The concepts of bitumen agglomeration and the use of apertured oleophilic walls is described in detail in the many patents granted to the present inventor and also in his currently pending patents. However, the present patent makes use of a new agglomerator design and of a method and operation not previously disclosed or claimed. While the present invention introduces a new type of bitumen agglomerator with a conical wall, other types of agglomerators disclosed and claimed previously by the inventor serve the same purpose but are not as effective and efficient for the purposes of the present invention.

## MORE DETAILED DESCRIPTION OF THE FIGURES

FIG. 1a is a side view of an agglomerator of the present invention, suitably supported to allow agglomerator rotation rates up to the critical speed showing a central inlet 100 and an apertured outlet 101. In this drawing the conical agglomerator shell 104 is supported by slewing rings 102 and 103 mounted on the agglomerator shell 104 and supported by 4 rollers rollers 105, 106 (two other rollers not shown) mounted on shafts 107 in bearings 108 to revolve the agglomerator shell 104 with a geared motor (not shown). The agglomerator outlet 101 is shown here as being covered by an endless multiwrap cable 130 which serves as the revolving apertured oleophilic wall. When bearings are preferred in stead of slewing rings supported by rollers, one bearing and support may be mounted on the wall near the central inlet 100 concentrically with the inlet 100 and another bearing with much larger bore may be installed on the agglomerator shell 104 before or after the apertured cylindrical outlet wall 101. Alternately, a smaller diameter bearing may be mounted concentrically on the solid endwall of the cylindrical outlet.

FIG. 1b is a small scale perspective view of the agglomerator shell of FIG 1a, showing the inlet 110 and the apertured outlet 111 and the conical shape of the agglomerator shell 109 with its slewing rings 112 and 113.

FIG. 1c is an illustration of balls 114 revolving in the agglomerator shell 115 that revolves well below the critical speed of the agglomerator to prevent the formation of a cateracting bed of balls 114. The critical speed is defined in terms of rotation rate as: $RPM_{critical} = 42.3 / \sqrt{d}$ where d is the largest agglomerator shell internal diameter in meters. For example, an agglomerator shell that has a maximum internal diameter of two meters has a critical speed of 29.9 RPM and a shell with a maximum diameter of one meter has a critical speed of 42.3 RPM. Ball loading and adhesion between ball and shell wall due to bitumen have some impact on the onset of cateracting of balls in the agglomerator shell, and adhesion is influenced by bitumen temperature and solids content. Cataracting normally does not occur at shell RPM's below 55% of the critical RPM.

FIG. 1d is an illustration of balls 117 tumbling in an agglomerator shell 116 that revolves below the critical speed but fast enough to achieve cateracting of the balls. Assuming that a shell RPM for cateracting turns at 75% of critical RPM, it is clear from the above critical RPM equation that in a conical agglomerator the balls may be cateracting in the large diameter portion of the shell but not cateracting in the smaller diameter portions of the shell. This is one of the features of the agglomerator

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of the present invention which allows for very thorough mixing of and intimate contact between the feed and the balls near the entry of the agglomerator, followed by less violent mixing but more kneading of bitumen , clay and cation further down the length of the agglomerator before leaving though the apertured cylindrical outlet.

FIG. 2a shows a circular cross section of the agglomerator shell 204 partly filled with a bed of balls 203 and partly filled with a level of mixture 202. The cross section faces the agglomerator inlet 201 and a section line 200 is indicated by A-A which applies to line B-B of FIG. 2b The cross section shows the agglomerator shell 204 through line B-B of FIG. 2b, the inlet 201, the large balls that reside near the line B-B and the mixture 202 being processed.

FIG. 2b is a sectional view of the agglomerator through section A-A of FIG. 2a. The dashed line B-B indicates the sectional location of FIG. 2a . FIG. 2b shows the conical shape of the agglomerator shell 205 partly filled with balls 206 of various diameters and with a level of mixture 207. The central inlet 208 is shown, as well as the apertured outlet 209. Details for supporting apertured cylindrical oleophilic agglomerator walls are disclosed in the referenced copending patent application entitled “Design of Endless Cable Multiple Wrap Bitumen Extractors”. An apertured oleophilic wall 210 in the form of multiple cable wraps is shown below the apertured outlet 208. The use of multiple cable wraps as the apertured oleophilic walls are disclosed in copending patent application entitled “Endless Cable System and Associated Methods”. Note, that the cable wraps 210 in FIG. 2b may not be in contact with the apertured agglomerator outlet 209 wall, and this provides for an opportunity to allow the surface speed of the agglomerator outlet 209 to be different from the surface speed of the apertured oleophilic wall 210. Thus this Figure illustrates a conical agglomerator shell partly filled with mixture and balls, where the balls may be cateracting near the entry of the shell, but not cateracting further down the shell, and with an outlet that deposits the processed mixture onto an apertured oleophilic wall that may or may not move at the same surface speed as the agglomerator outlet. Cateracting may be beneficial for some mixtures, composition or temperature conditions and not beneficial for others.

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The conical shape of the agglomerator shell achieves a sorting process when various sizes of balls are used as shown in FIG. 2b. The large size balls tend to concentrate inside that part of the conical shell characterized by a relatively large shell diameter; the small size balls tend to concentrate inside that part of the shell characterized by a relatively small shell diameter, including the apertured agglomerator exit. The intermediate size balls tend to concentrate in the mid section of the agglomerator. A bed of large balls has about the same percentage void volume as a bed of small or intermediate balls but the individual void sizes are larger between large balls than between small balls. Similarly, the voids between intermediate size balls are of an intermediate size. As a result, the permeability in the region occupied by the large balls is greater than in the region occupied by the intermediate size balls and is much greater than in the region occupied by the small balls. In fact, cutting the size of internal void dimensions by half reduces the permeability of a bed of balls by four, and cutting the size of internal void dimensions by four reduces the permeability of a bed of balls by sixteen. This change in permeability in a conical bitumen agglomerator serves initially to provide very good acceptance of mixture into the voids between the large balls at the beginning section of the agglomerator occupied by large balls, followed by a progressively increased kneading as bitumen progressively fills more of the ball voids. This exposes oleophilic bitumen surfaces to gel forming minerals as the mixture flows through the voids of progressively smaller balls towards the agglomerator outlet. The voids between the large balls capture the mixture entering the agglomerator and start the agglomeration process. The smaller voids between the progressively smaller balls knead the bitumen and particulates and transport the resulting bitumen phase towards the apertured cylindrical agglomerator outlet of the conical agglomerator. This mechanism prevents mixture from simply flowing overtop of the bed of balls to the agglomerator outlet.

FIG. 2c illustrates one method of feeding mixture into the agglomerator. In this case a flexible hose 212 is connected to the agglomerator inlet 216 and curves upward to provide for mixture inlet that is above the agglomerator contents. The hose 212 is connected with flanges 214 to a rigid pipe section 215 mounted in a set of two

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bearings 213 that keep the pipe section 215 in proper alignment, either vertical or at a slope.

FIG. 2d illustrates the use of a funnel 216 with a screen 217 to provide feed 218 to the rigid pipe section of FIG 2c. The revolving funnel conveniently accepts a feed without the need for a rotary seal and the screen 217 prevents large particles, such as tree roots, helmets, bottles or other refuse from entering the aggòmerator. The set of bearings 220 of FIG. 2d are the same bearings 213 of FIG. 2c. An optional blade 250 may be used to remove debris from the revolving screen 217.

FIG. 2e illustrates another method of feeding mixture into the agglomerator. In this case there are two flanges 221 that include a rotary seal to allow feed to flow from a stationary pipe 222 into the revolving agglomerator inlet 223.

FIG. 2f illustrates that the balls 230 of the agglomerator may comprise two materials, for example a steel core 231 and a rubber cover 232. Alternately the bed of balls may consist of a mixture of metal balls and plastic balls (for example golf balls), and the metal balls may be made from steel or from brass or bronze or may have a copper coating to increase the oleophilicicity of the ball surfaces. Unlike a ball mill, a bitumen agglomerator does not grind the mixture particulates but adheres to bitumen of the mixture. It kneads bitumen and captures solids into the bitumen phase in this particular invention. For that reason, the balls of an agglomerator may have resilient surfaces that can absorb shock. Using such balls in a ball mill simply would not grind the ball mill charge of minerals but would leave the particulate matter mostly unchanged in size. Unlike a ball mill, the objective of a ball charge in this bitumen agglomerator is to strip bitumen from a mixture and to knead the captured bitumen. The density of the bed of balls in an agglomerator must be high enough to allow release of the balls from the agglomerator drum wall before these balls reach the top of the agglomerator and to allow effective kneading of the mixture and its bitumen content. When the balls are too heavy the power required to turn the agglomerator may go up. The required optimum ball density is a function of ball loading in the agglomerator, of the RPM of the agglomerator, of the composition of the mixture and of the temperature of the mixture which control the viscosity and thickness of the

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bitumen layer adhering to the ball surfaces. Balls that are small in size have a larger surface area per mass than balls that are large in size and will have a greater tendency to stick to each other and to the upper portions of the revolving agglomerator shell. Consequently, small agglomerator balls may need to be heavier than large agglomerator balls. As explained with FIG. 2f , the permeability of a bed of small balls is much lower than through a bed of large balls.

FIG. 3a is a schematic drawing to illustrate the agglomerator 301 with the apertured cylindrical exit 302 covered for about 50 percent of its circumference by an apertured oleophilic belt 303 for the separation zone. A set of squeeze rollers 304 provide the bitumen removal zone to allow bitumen to flow into a receptacle 305. In this case the agglomerator exit 302 is in contact with the oleophilic belt 303 and this requires that the agglomerator exit surface speed is the same as the oleophilic belt speed. Effluent flows into an effluent receiver 308.

FIG. 3b is a schematic drawing of two agglomerators with apertured cylindrical exits 310 and 311 mounted above a single apertured oleophilic belt 312. The exits 310 and 311 are not in contact with the belt 312 surfaces and this allows for surface speeds of the agglomerator exits 310 and 311 to be different from the surface speed of the belt 312. Sets of squeeze rollers 313 and 313 are used to remove bitumen from the belt 312 and deposit this bitumen into bitumen receptacles 315 and 316 as effluent flows into effluent receivers 317 and 318. Besides squeeze rollers, a wide variety of methods for the removal of bitumen from apertured oleophilic walls have been disclosed and claimed in the above referenced patent applications. The belt under the agglomerator outlets is inclined in both cases to optimize separation of bitumen phase from aqueous phase as described in copending patent application entitled “Design of Endless Cable Multiple Wrap Bitumen Extractors”

FIG. 4 is a flow diagram of a mixing vessel 401 for mixing reagent 402 with sludge 403 or bitumen containing mixture before it enters the agglomerator 404, which is shown here similar to FIG. 2b. Control valves 405, 406 and 407 monitor the flow. Such a mixing vessel 401, using for example a revolving mixer 410 allows for the thorough mixing of reagent 402 with sludge or mixture 403 before the combined

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mixture 420 enters the agglomerator and contacts the balls of the agglomerator 404. For the sake of simplicity, the apertured oleophilic wall is not shown here but is assumed to be present to produce a bitumen product 411 and an effluent 413 from which at least part of the bitumen, bi-wetted particles and ultrafines have been removed. Carbon dioxide 412 may be sparged into the pipeline that transports the effluent to a tailings pond. This carbon dioxide 412 may serve to chemically react with residual multivalent cations to condition the effluent 411 so that water released in time from this effluent is low in multivalent cation content. For example, the carbon dioxide may react with calcium hydroxide in the effluent in a long distance pipeline to a pond and precipitate calcium carbonate in the tailings pond and thus remove residual calcium cations before recycle water of the pond is used for processing oil sand ore.

The reagents used in FIG. 4 are coagulants that promote adhesion of fine montmorillonite particulate matter to bitumen. Examples of such coagulants are calcium or magnesium oxide, calcium or magnesium hydroxide, calcium or magnesium sulphate, calcium or magnesium chloride, aluminum or iron based coagulants or polymer based coagulants. To achieve the ability to add a coagulant to a mixture without diluting this mixture with too much water, the reagent may be supplied in the form of a finely dispersed aqueous suspension of the coagulant or in the form of a mud or paste. For example, milk of lime, which is a concentrated suspension of calcium hydroxide in water, or a water wet paste of lime. Mixing such a reagent suspension or paste with fluid tailing very quickly makes the cation available for reacting with the fluid tailings solids and bitumen. In pilot tests for separating very tight bitumen in water emulsions, using a bitumen agglomerator and an apertured oleophilic wall, the use of fine calcium sulphate suspended in water proved to be a very effective reagent for quickly breaking the emulsion and recovering the bitumen. Any type of commercially available , and often proprietary, coagulant may be considered, provided the coagulants is inexpensive, works well to achieve the desired objective of capturing monymorillonite and will not have a detrimental effect on any resulting recycle water used for froth flotation of bitumen.

The reagent should be inexpensive enough to be economically viable for use in large quantities and it should not do serious damage to processing equipment or reduce bitumen recovery or bitumen product quality of resulting recycle water for froth flotation. For example, when recycle water is used for processing additional oil sand in a commercial oil sands extraction plant, a high content of calcium or magnesium ions in the recycle water will have a negative impact on bitumen recovery and bitumen product quality in the commercial froth flotation plant, unless removed in part. Similarly a high content of chlorine ions in recycle water may have a corrosive effect on equipment used in subsequent commercial processing of bitumen product because of residual chlorine ion content in water droplets carried by this bitumen.

Bitumen product 411 of FIG. 4 produced by the revolving apertured oleophilic wall of the present invention will contain a significant amount of very small mineral particulates which, if removed by dilution centrifuging could end up back in the tailings pond and essentially defeat the objectives of the present invention. For that reason the recovered bitumen 410 should either be discarded as landfill or processed by deasphalting with propane or higher molecular weight straight chain hydrocarbons or hydrocarbon mixtures to concentrate the fines with asphalt instead of returning dispersed fine particulates to the tailings pond that supplies recycle water for froth flotation.

There have thus been described various methods and units of equipment for capturing gel forming fines from suspensions such as tailings pond sludge, fluid tailings , fine tailings or precursors of these suspensions. These methods and apparatus units add multivalent cations to the suspension and then process that mixture in bitumen agglomerators with oleophilic balls to capture gel forming suspension components into bitumen contained in these suspensions or into additional bitumen material added to these suspensions. In many cases, tailings ponds contain bitumen mats or bitumen lenses that have separated from the settling fines. These bitumen mats would provide a very suitable augmentation source of bitumen for the purposes of the present invention. Thereafter the agglomerated mixture is passed through an apertured oleophilic wall to separate it into an agglomerated bitumen

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phase product and into an aqueous phase effluent. The aqueous phase effluent may then be processed to chemically remove ions that might interfere with commercial bitumen extraction when part of the aqueous phase ends up as recycle water. The agglomerated bitumen phase may then be discarded or processed to recover valuable bitumen while keeping the gel forming components in a form that does not allow these to disperse in tailings ponds that may produce recycle water for commercially processing of oil sands.

While the present disclosure has concentrated on the use of a truncated conical vessel with central mixture inlet and apertured cylindrical wall outlet, the present invention also contemplates the use of a more conventional bitumen agglomerator of the prior art of the inventor that is shaped in the form of cylindrical vessel with a central inlet and with an apertured cylindrical vessel wall that forms the agglomerated mixture outlet. Such a more conventional bitumen agglmerator may be used instead, but with lower efficiency, to capture ultrafine and bi-wetted particulates into the bitumen phase of sludge.

Of course, it is to be understood that the above described arrangements, and specific examples and uses, are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention, and the appended claims are intended to cover such modifications and arrangements. Thus while the present invention has been described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiments of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including, but not limited to, variations in size, materials, shape, form, function and manner of operation, assembly and use may be made without departing from the principles and concepts set forth herein.

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**CLAIMS**

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1) An apparatus for the agglomerating of bitumen from a bitumen containing mixture comprising a revolvable conical vessel in the general shape of a truncated cone with a generally horizontal axis, wherein
   a) the conical vessel is suitably supported to allow rotation of the vessel up to its critical speed of revolution , wherein
   b) the conical vessel has a central inlet at the base of the cone and has an apertured cylindrical outlet wall attached to the vessel end opposite of the vessel inlet, wherein
   c) the vessel is partly filled with a bed of balls, wherein
   d) the vessel can be rotated by means of a motor and drive.

2) An apparatus as in claim 1 wherein the tapered vessel is supported by two slewing rings resting on rollers on shafts mounted in bearings.
3) An apparatus as in claim 1 wherein the vessel is partly filled with balls of several sizes.
4) An apparatus as in claim 1 wherein the balls are metallic balls coated with an oleophilic coating of rubber, plastic or copper.
5) An apparatus as in claim 1 wherein part or all of the balls are made from copper, iron, steel, brass, plastic or rubber.
6) An apparatus as in claim 1 wherein the balls comprise a mixture of balls made from several materials.
7) An apparatus as in claim 1 wherein the apertured cylindrical outlet wall is covered in part by a revolvable apetured oleophilic wall.
8) An apparatus as in claim 1 wherein a revolvable apertured oleophilic wall is mounted under one or more conical vessel apertured cylindrical outlet walls

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allowing a difference between the surface speed of the one or more apertured cylindrical outlet walls and the surface speed of the apertured oleophlic wall.

9) An apparatus as in claim 1 wherein the central inlet is provided with a hose and a revolvable funnel to allow mixture to flow into the vessel inlet.

10) An apparatus as in claim 9 wherein the funnel is provided with a screen to prevent debris from entering the vessel.

11) An apparatus as in claim 1 wherein a rotary seal is attached to the central inlet.

12) A method for processing an aqueous mixture that contains bitumen particles by means of bitumen agglomeration using a revolving tapered vessel in the general shape of a truncated cone with a generally horizontal axis, wherein

a) the tapered vessel is supported either by revolving bearings or by rotating slewing rings supported by bearings, wherein

b) the conical vessel has a central inlet at the base of the cone and has an apertured cylindrical outlet wall at the vessel end opposite of the inlet, wherein

c) the vessel is partly filled with balls of several sizes, wherein

d) the vessel is rotated by means of a motor and drive at rotation rate not exceeding the critical speed of rotation of the vessel, wherein

e) bitumen particles of the mixture adhere to the surfaces of the balls to form bitumen coatings on the balls which coating is kneaded and gradually moves through the bed of balls to the apertured cylindrical outlet wall of the vessel, wherein

f) aqueous phase and agglomerated bitumen phase pass through the apertures of the cylindrical outlet.

g) The aqueous phase and the agglomerated bitumen phase passing through the apertures of the cylindrical outlet are separated by means of an apertured oleophilic wall into a separate bitumen product and a separate aqueous product.

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13) A method for removing gel forming ultra fines, bi-wetted fines and bitumen particles from a suspension said suspension comprising oil sand fluid tailings, tailings pond sludge, fine tailings, mature fine tailings, middlings, hydrocyclone overflow, or from any other sludge precursors said method includes mixing the suspension with multivalent cations to encourage these fines to be attracted to the surfaces of the bitumen particles upon contact, wherein

a) controlled amounts of cations are continuously introduced into a mixing tank continuously supplied with suspension to allow intimate contact between the cations and the gel forming ultrafines, bi-wetted fines and bitumen particles to continuously form a mixed suspension in the tank, wherein

b) the mixed suspension is introduced from the tank through a central inlet into a revolving cylindrical vessel with a generally horizontal axis and a cylindrical external wall that is apertured, wherein

c) the vessel is supported either by revolving bearings or by rotating slewing rings attached to the vessel and supported by bearings, wherein

d) the vessel is partly filled with balls, wherein

e) the vessel is rotated by means of a motor and drive at a rotation rate not exceeding the critical speed of rotation of the vessel, wherein

f) bitumen particles of the mixed suspension adhere to the surfaces of the balls to form bitumen coatings on the balls which coating is kneaded as a result of vessel revolutions and captures ultra fines and bi-wetted fines into the bitumen phase and gradually moves the bitumen phase and captured fines through the bed of balls to the apertured cylindrical exterior wall of the vessel for removal of agglomerated bitumen phase mixture and aqueous phase from the vessel, wherein

g) balls remain in the vessel but aqueous phase and agglomerated bitumen phase pass through the apertures of the cylindrical wall, wherein

h) the aqueous phase and the agglomerated bitumen phase passing through the apertures of the cylindrical wall are separated into a separate bitumen product and a separate aqueous product.

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14) A method for removing gel forming ultra fines, bi-wetted fines and bitumen particles from a suspension said suspension comprising oil sand fluid tailings, tailings pond sludge, fine tailings, mature fine tailings, middlings, hydrocyclone overflow, or any other sludge precursors said method includes mixing the suspension with multivalent cations to encourage these fines to be attracted to the surfaces of the bitumen particles upon contact, wherein

a) controlled amounts of cations are continuously introduced into a mixing tank continuously supplied with suspension to allow intimate contact between the cations and the gel forming ultrafines, bi-wetted fines and bitumen particles to continuously form a mixed suspension, wherein

b) the mixed suspension is introduced from the tank into a revolving tapered vessel in the general shape of a truncated cone with a generally horizontal axis, wherein

c) the vessel is supported by revolving bearings and/or by rotating slewing rings attached to the vessel supported by bearings, wherein

d) the vessel has a central inlet at the base of the cone and is provided with an apertured cylindrical outlet wall at the vessel end opposite of the inlet, wherein

e) the vessel is partly filled with balls of several sizes, wherein

f) the vessel is rotated by means of a motor and drive at rotation rate not exceeding the critical speed of rotation of the vessel, wherein

g) bitumen particles of the mixed suspension adhere to the surfaces of the balls to form bitumen coatings on the balls which coating is kneaded as a result of vessel revolutions and captures ultra fines and bi-wetted fines into the bitumen phase and gradually moves the bitumen phase with captured fines through the bed of balls to the apertured cylindrical outlet wall of the vessel for removal of agglomerated bitumen phase mixture and aqueous phase from the vessel, wherein

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h) balls remain in the vessel but aqueous phase and agglomerated bitumen phase pass through the apertures of the cylindrical outlet, wherein

i) The aqueous phase and the agglomerated bitumen phase passing through the apertures of the cylindrical outlet wall are separated by means of an apertured oleophilic wall into a separate bitumen product and a separate aqueous effluent product.

15) A method as in claim 14 wherein the surface speed of the apertured cylindrical outlet wall is the same as the surface speed of the apertured oleophilic wall.

16) A method as in claim 14 wherein the surface speed of the apertured cylindrical outlet wall is not the same as the surface speed of the apertured oleophilic wall.

17) A method as in claim 14 wherein the multivalent cation is provided by a calcium salt, calcium oxide, calcium hydroxide or calcium sulphate or is provided by a magnesium salt, magnesium oxide, magnesium hydroxide or magnesium sulphate.

18) A method as in claim 14 wherein the multivalent cation is provided by a suspension of calcium ions in water or a suspension of magnesium ions in water.

19) A method as in claim 14 wherein the multivalent cation is provided by an industrial coagulant based on calcium, magnesium, iron, aluminum, polymer or by a proprietary industrial coagulant.

20) A method as in claim 14 wherein a mixture of multivalent cations and industrial polymer is used to change the surface chemistry of the ultrafines, bi-wetted fines and bitumen to cause adhesion of ultrafines and bi-wetted fines to bitumen upon contact.

21) A method as in claim 14 wherein carbon dioxide is sparged in the aqueous effluent product leaving the apertured oleophilic wall to convert residual multivalent cations in the effluent into precipitating salts.

22) A method as in claim14 wherein bitumen removed from the apertured oleophilic wall is partly or completely deasphalted by means of straight chain hydrocarbons

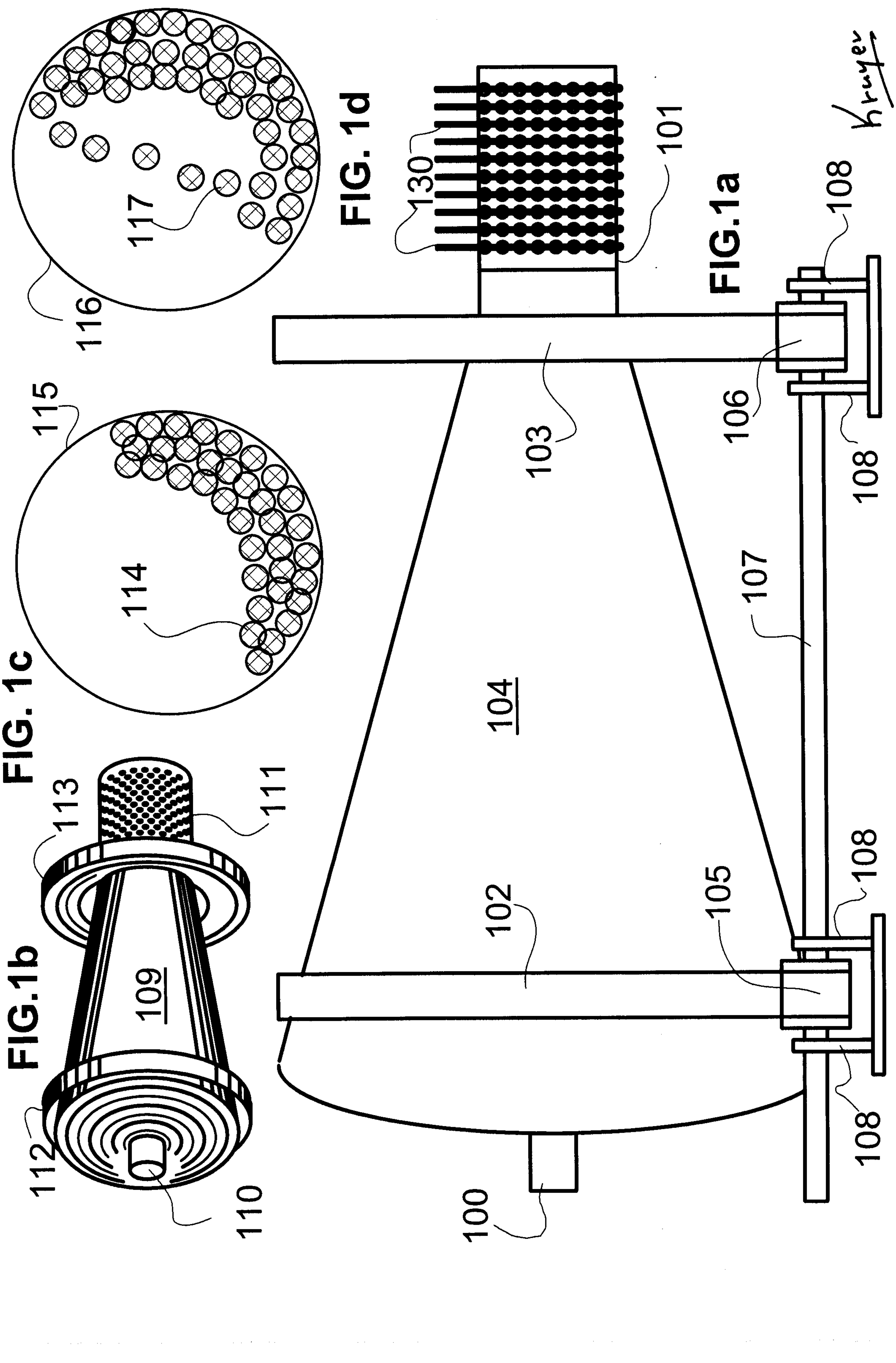


FIG.1a
FIG.1b
FIG. 1c
FIG. 1d
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
130
Kruger

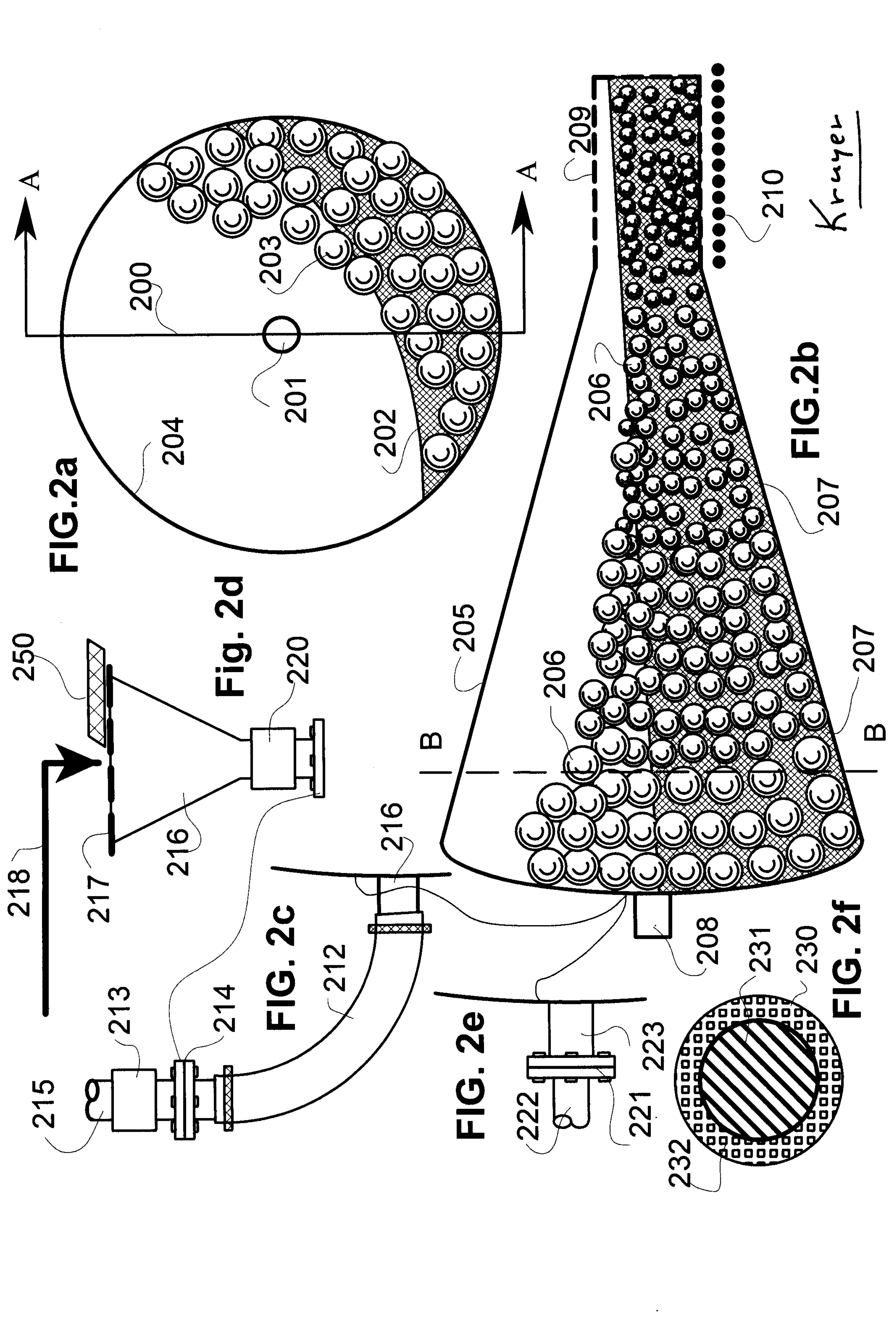


FIG.2a
A
A
200
201
202
203
204
FIG.2b
B
B
205
206
206
207
207
208
209
210
FIG. 2c
212
213
214
215
216
Fig. 2d
216
217
218
220
250
FIG. 2e
221
222
223
FIG. 2f
230
231
232
Kruger

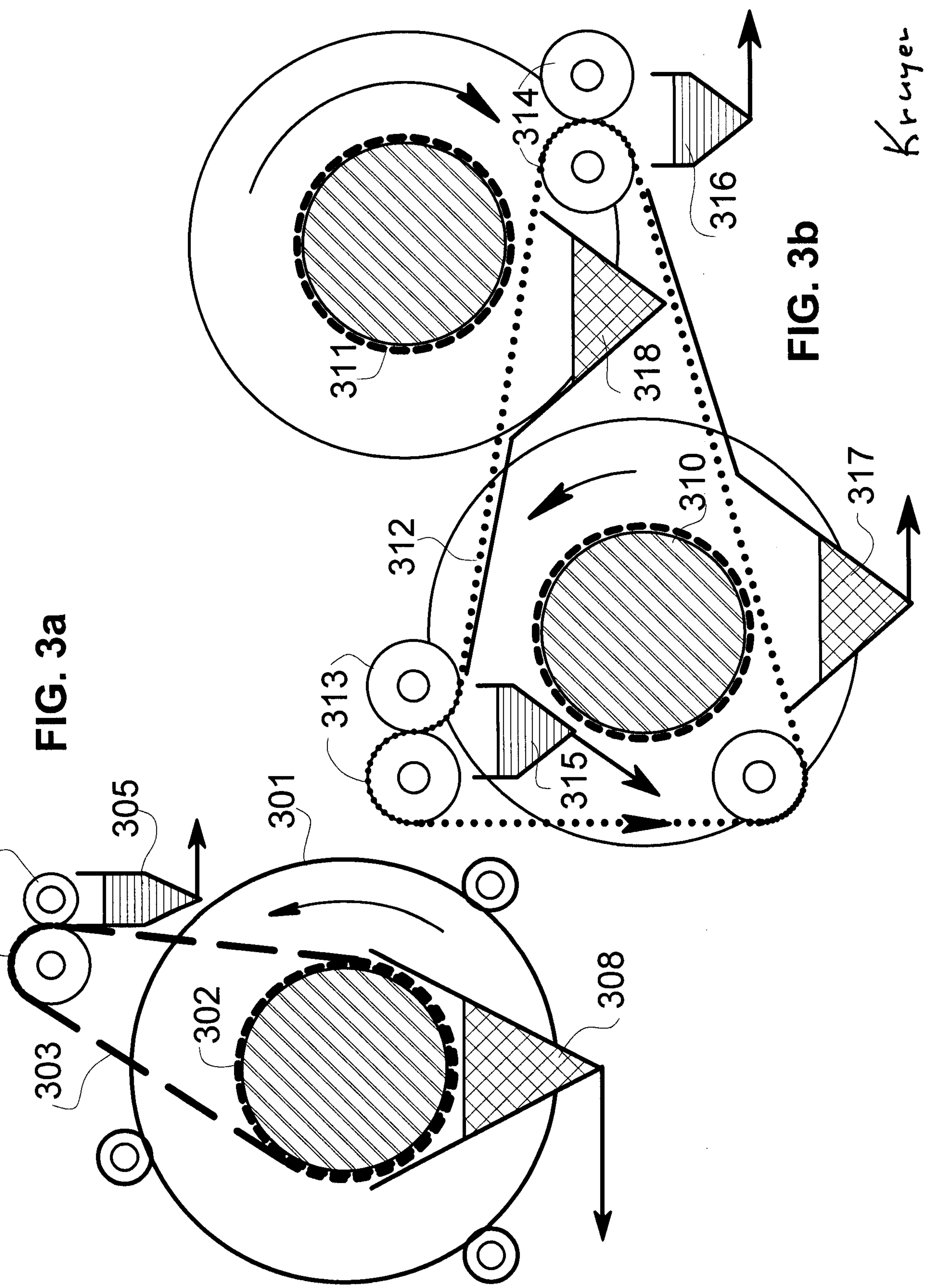



FIG. 3a

FIG. 3b

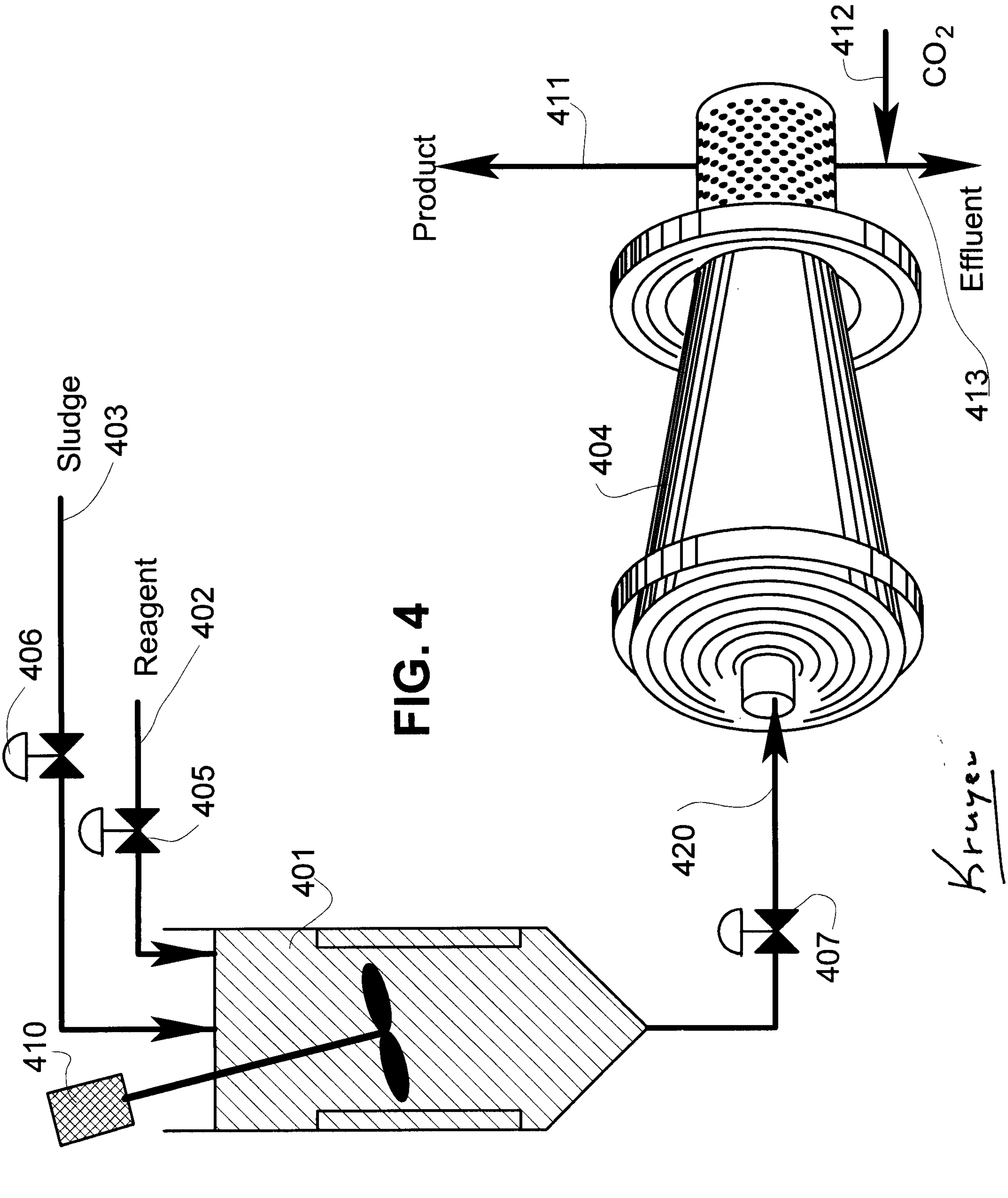
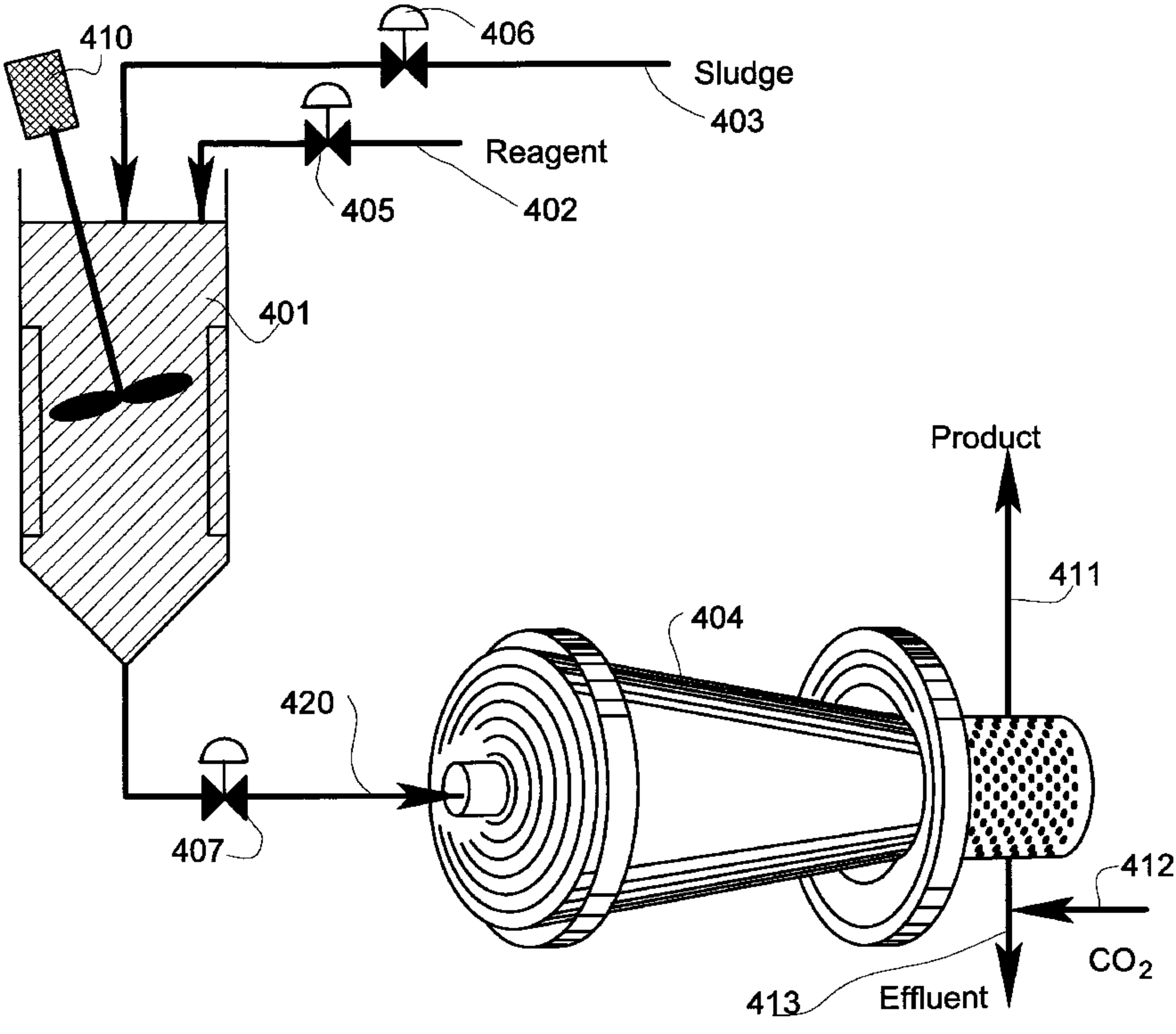

Sludge
403
406
Reagent
402
405
401
410
407
420
404
Product
411
412
$CO_2$
Effluent
413

FIG. 4



410
406
Sludge
403
Reagent
405
402
401
Product
411
404
420
407
412
413
Effluent
$CO_2$