

PLATFORM TECHNOLOGY FOR INDUSTRIAL SEPARATIONS

[0001] Conventional macro-scale separation methods include floatation, sedimentation, centrifugation, and filtration. More recent developments in microfluidics include the use of micro-scale multi-physics forces for separation and enrichment. Provided is a method and system for treating a fluid stream.

[0002] Figure 1 is a spiral mixer-conditioner;

[0003] Figure 2 illustrates the velocity of fluid flow within the device of Figure 1.

[0004] Figure 3 depicts the transverse velocity vectors of flow within the device of Figure 1;

[0005] Figure 4 depicts typical curves for shear rate as a function of aggregate size;

[0006] Figure 5 is a characteristic curve for aggregation size as a function of time within a spiral mixer-conditioner;

[0007] Figure 6 is a process schematic for raw seawater or brackish water treatment;

[0008] Figure 7 is a schematic for an alternative arrangement of raw seawater or brackish water treatment;

[0009] Figure 8 is a schematic for creating hydroxide precipitates from concentrated brine;

[0010] Figure 9 is a schematic for a two-stage precipitation and separation followed by coagulation, flocculation and separation of all other suspensions from seawater or brackish water;

[0011] Figure 10 is a schematic for coagulation, flocculation and separation of suspended organics from seawater for membrane distillation (MD);

[0012] Figure 11 is a schematic for a two-stage separation of coarse particles followed by coagulation, flocculation and separation of fine particles into medium fine tails (e.g., tailing pond water);

[0013] Figure 12 is a schematic for precipitation, aggregation and separation of divalent metal ions from produce water;

[0014] Figure 13 is a schematic to pre-treat raw seawater or brackish water to directly remove suspensions without chemical coagulation;

[0015] Figure 14 is a schematic for removal of suspended organic in matter;

[0016] Figure 15 is a schematic for algae dewatering;

[0017] Figure 16 is a system employing an arrangement of Figure 15;

[0018] Figure 17 is a schematic for coagulation, flocculation and separation of process water;

[0019] Figure 18 is a schematic for two-stage separation of process water;

[0020] Figure 19 is a schematic for aggregation and recovery of volume dispersed TiO₂ nanoparticles used in an advanced oxidation technology UV sterilization system;

[0021] Figure 20 is a schematic for wastewater treatment; and

[0022] Figure 21 is a schematic for wastewater treatment.

[0023] Previous spiral mixers allow turbulent mixing of a chemical injected into a flow stream just ahead of a 90 degree turn at the mixer inlet and throughout the spiral channels of the mixer. In spiral mixer-conditioner 100 of Figure 1, aggregate conditioning capabilities are added to that mixer.

[0024] In Figure 1, mixing takes place in the first two turns 102, 104 of spiral mixer-conditioner 100 where fluid stream regime is designed for high Dean number (*i.e.*, at or above the critical number of 150) operation. In this regime, transverse fluid flows within the channels cannot reach a force equilibrium so particle (particulate) suspensions continue a helical swirl

across the channel cross-section. Enhancement to previously described spiral mixers include fluid flow in the channels corresponding to turns 106-112, attain an equilibrium. Dean number is a dimensionless quantity typically denoted by the symbol De for flow in a channel and is defined as:

$$De = \frac{\rho V D}{\mu} \left(\frac{D}{2R} \right)^{1/2}$$

where, ρ is density of the fluid; μ is dynamic viscosity; V is axial velocity; D is hydraulic diameter (other shapes are represented by an equivalent diameter, see Reynolds number); and R is radius of curvature of the path of the channel

[0025] The channels are square channels in cross section, however, other channel cross-section designs may be used. Also, while this is a six turn semi-circular spiral, the spiral mixer-conditioners as described herein may be Archimedes spirals and have more or fewer turns (*i.e.*, n -turns). The flow stream enters spiral mixer-conditioner 100 at inlet 114 and exits at outlet 116. Dashed line outlet 118 is provided to illustrate two or more outlets may be used.

[0026] Velocity distribution of fluid flow within the channel cross-section of spiral mixer-conditioner 100 is depicted in Figure 2 at turn 108, and Figure 3 represents the transverse velocity vectors for the same channel cross-section in turn 108.

[0027] In Figure 2, the image is a cross section view 200 of flow velocity occurring within the square channel at turn 108 on the left-hand side of the channel. The speed or velocity of the flow is identified with darker image 202 representing high velocity, and brighter image 204 representing lower or almost zero velocity. This flow is due to centrifugal force. This image is

taken from the left-hand side of the channel, and the centrifugal forces are moving toward the outer side of the channel.

[0028] In Figure 3, transverse velocity vectors for the same flow are illustrated 300, representing a design where neutrally buoyant particles move along velocity vectors as identified by arrow movements 302 (see USSN 11/936,729 for discussion of separation of neutrally buoyant particles). Figure 3 is the transverse view, and if a cross section of this view is taken a double vortex would be shown as the view proceeds along the channel. Also, there is a component of the transverse velocity vector flow that comes out of the plane of the image, so if one follows the particles in the stream, the helical path is being followed down the channel.

[0029] The spiral mixer-conditioner is designed with six turns, however there may be other numbers of turns (n-turns) .

[0030] In this embodiment, the first two turns and/or operation of the spiral mixer conditioner are designed so the resulting Dean number is such that fluid flow in channels of the first two turns 102, 104 is in a turbulent regime. This means that even though there is a setting up of transverse velocity vector flow it is set up such that the forces do not balance and due to that, particles continue to move around without being in equilibrium. It is only after the third turn (i.e., from the third turn to the sixth turn) that the forces within the channel enter a state of force equilibrium allowing the particles in the flow to move closer to one side wall and enter a stagnation state within the flow path. While the flow looks much the same throughout the spiral, a difference is the magnitude of the transverse velocity. In the first two turns the transverse velocity is very high, then as the flow spirals out the radius of curvature increases, which results in the dropping of forces allowing the flow to enter a steady state laminar regime where shear stress is employed for conditioning of the particles within the flow.

[0031] Centrifugal force drops in turns 106-112, creating a force balance. Transverse flow vectors are used to sweep neutrally buoyant particles and move them to the position of equilibrium. Reaching desired equilibrium is based on dropping the centrifugal force. The desired drop in centrifugal force corresponds to dropping of the Dean-number below the critical value of 150.

[0032] Conditioning (or aggregation) capability of the spiral mixer-conditioner can be achieved in two ways. First is by changing the cross section of the geometry of the spiral mixer. Second is to change the flow rate speed. Both are attempting to control shear rate of the system in the conditioning spirals. Shear rate is the gradient of the transverse velocity, and is the parameter that relates size of the aggregate emerging from the mixer-conditioner to cut-off size in the downstream separator.

[0033] Figure 4 helps explain this concept.

[0034] Spiral mixer-conditioner 100 is designed with the first two turns 102, 104 acting as the mixing portion. The channels including the first two turns are operated above the critical Dean number (i.e., at or greater than 150), causing the flow in the first two turns to be chaotic and with no flow equilibrium. The number of mixing turns in this chaotic state may vary, so the spiral mixer may include 3, 4 or more mixing turns as long as the flow in those turns is above the critical Dean number (i.e., at or greater than 150). Turns 106-112 of spiral mixer conditioner 100 are designed to achieve a required shear rate. The shear rate being selected based, for example, on the curves of Figure 4, which show that as the shear rate is increased, the aggregate size of the particles in the flow decrease (i.e., aggregate size is based on the shear rate). The shear rate is increased by increasing the velocity of the flow within a chosen channel size. As the shear rate increases, the particles tend to break up into smaller aggregates.

[0035] The structure of spiral mixer-conditioner 100 has the channel widths being selected to be the same size throughout the spiral. In this situation flow rate is then controlled to have the Dean number in the first two turns (102-104) to be above the chaotic value and the flow in remaining turns (106-112) of the spiral cause the Dean number to drop below the critical value of 150. This drop occurs due to original flow rate, size of the channels and increasing number of spiral turns 106-112.

[0036] Velocity of input fluid is selected to enter the inlet 114 so the shear rate in the first two turns 102, 104 will be above the Dean number for chaotic action, but the shear rate Dean number will be below the critical value for the remaining turns 106-112.

[0037] Figure 4 shows graph 400, which illustrates shear rate versus aggregate size. Shear rate axes range from low shear rate to high shear rate from the bottom of the page to the top, and the aggregate size axes range from low aggregate size on the left-hand side to greater size on the right-hand side. Curve 402 represents the characteristics of a robust suspension and curve 404 represents the characteristics of a weak suspension, with the locus of maximum shear rate of each suspension identified.

[0038] The spiral mixer-conditioner in the present application may be designed to be useful with aggregates of many different morphologies. One could have clay particles which are very robust and can sustain a very high shear rate before fragmenting, or one can use floc which is fluffy and susceptible to fragmentation under a very low shear rate. It is understood that these curves therefore, are general curves showing the idea of the present concepts.

[0039] Examples of shear rates versus particle sizes include a robust aggregate, such as clay particles that are resilient to high shear forces. An aggregate size in this range would be a diameter (d) of 5 μ m at a shear rate

of $g=10,000/\text{second}$ ($g=\text{shear rate}$). For a weak suspension, the aggregate may be a chemical floc (e.g., alum-treated colloidal dirt) that fragment under lower shear forces. These weak suspension aggregates have an aggregate size of a $d=30\mu\text{m}-50\mu\text{m}$ at a shear rate of $g=500/\text{second}$.

[0040] In Figure 4, consider top curve 402 which is for robust suspension. Curve 402 represents generally the locus of maximum shear rate for this robust type of particle. Basically, no aggregate of this type of robust particle can be above curve 402. Curve 404 provides a similar representation for a suspension with weak particles. Larger aggregates stay intact at low shear rates as shown on the right side of the curve. When shear rate is increased by increasing the pumping velocity then aggregates will break up to the size that can be stable at the new shear rate given by the left side of the curve. So Figure 4 can be used for system design. Given a certain desired particle size, one identifies the corresponding appropriate shear rate.

[0041] Operation and/or design of spiral mixer-conditioner 100 is made to have a custom designed shear rate in the channels of turns 106-112 to control the aggregation rate and size in conformance with the curves shown in Figure 4. Uncontrolled aggregation leads to rapid growth of very loosely bound suspensions. Higher shear rates fracture aggregates down to the size sustainable by van der Waals forces. Upper curve in Figure 4 implies stronger-aggregated suspensions compared to the lower curve. The designed shear rate, which controls the aggregate growth and size, results in dense uniformly-sized suspensions conditioned for efficient downstream hydrodynamic separation by, for example, a spiral separator.

[0042] This conditioning (aggregation) feature may be extended for the purposes of:

1. Inducing precipitation or suspension formation from dissolved materials (e.g. divalent metals to prevent scaling – such as Mg and Ca

(magnesium and calcium);

2. Promoting aggregation of smaller suspensions into larger and more robust agglomerates (e.g. aggregation of titanium dioxide (TiO₂) nanoparticles for regeneration and reuse as photocatalyst in advanced ultraviolet (UV) oxidation systems); and

3. Capturing for reuse of volume dispersed carrier suspensions functionalized to treat contaminants in liquids (e.g. activated carbon particles to absorb organics and hydrocarbons, or polystyrene beads functionalized to selectively capture target analytes for threat agent bio detection).

[0043] The suspension grows in an aggregation tank to reach the size suitable for downstream cut-off separation. Growth rates vary depending on morphology, chemistry, and material types of the suspensions. Some may not need much retention time if at all in the aggregation tank. Figure 5 illustrates characteristic aggregation size as a function of time as three sequential time intervals: T1, T2, T3, corresponding to the Impulsive Growth, Aggregate Size Limited, and Size Roll-off. The typical curve has three sequential time intervals:

- T1: Impulsive Growth - occurs during rapid mixing in narrow channels when aggregation is driven by particle concentration and orthokinetics (convection driven) to increase probability of collision events;
- T2: Aggregate Size Limited - is limited when fluid shear exceeds van der Waal force; and
- T3: Size Roll-Off - Roll-off of aggregate size due to second-order effects which may be attributed to chemical depletion,

compaction, and aggregate-aggregate interactions.

[0044] Growth is intended to mean aggregation of particles. Particularly, in a confined channel there is the same amount of flow (including particles) now in a more confined space. This narrowing increases the likelihood particles collide at a speed wherein the equilibrium state causes them, or certain percentages of them, to stick together and grow into a larger aggregate particle during impulsive growth stage (T1).

[0045] At stage T2, aggregates which have been formed reach growth plateaus, only holding together depending upon morphology (type of material) and shear applied in the channel. When shear rate is above a certain value for a certain type of material, aggregate growth is limited by shear rate, thereby limiting the overall aggregate size. At T3, after the plateau, there is a size roll off due to 2nd order effects, such as chemical depletion within the system, compaction, floc—floc interaction, among other issues which can cause the aggregate size to drop off by as much as 10% from its T2 state.

[0046] Compaction is when particles press together but do not actually cling together, and pressing removes water from the aggregates, making them more compact (e.g., smaller), but does not join separate aggregates together.

[0047] Floc-floc interaction means the aggregates abrade against each other and remove some of the particles from either or both of the aggregates.

The described novel methodology can serve as a platform technology for many industrial separations, including:

- Municipal water treatment – this application will benefit from the conditioning discussion captured in this invention.

- Seawater and brackish water desalination – pre-treatment for reverse osmosis (RO) and scalant removal (Figures 6, 7, 8 and 9) and membrane distillation (Figure 10)
- Produced water – frac water, flow-back water, oil/water separation (Figures 11 and 12)
- Ballast water – separation of organics and other suspensions from seawater (Figures 13 and 14)
- Algae dewatering – biofuels production and prior to polished wastewater discharge (Figure 16)
- Agricultural water – grape wash water, palm oil mill effluent (Figures 17 and 15)
- Aggregation and recovery of volume dispersed TiO₂ or functionalized synthetic particulates (Figure 19)
- Wastewater treatment – concentrate primary effluent to digester for increased rate and methane production (Figures 20 and 21)

[0048] Figures 6-21 are exemplary of many diverse applications for this technology. Other applications will include:

- Process water – e.g. cleaning up creamery whey water
- Bio fluids – pharmaceutical processing e.g. separation of WBC from RBC, vaccine fluid clarification
- Bio detection – high throughput screening for increased selectivity and sensitivity

- Industrial water purification – e.g. Si kerf recovery
- Scalant removal – power plant cooling, seawater pre-treatment
- Groundwater remediation – divalent ion precipitation
- Petroleum refining – oil/water separation
- Colloidal chemistry – chemical processing
- Mining
- Food and beverage

[0049] Figure 6 is a schematic for raw seawater or brackish water treatment prior to reverse osmosis (RO) in a desalination configuration using chemical coagulation. The RO membranes require very high quality feedwater to operate effectively.

[0050] System 600 includes first input filter 602 which may be a 2-5mm filter sized intake screen for filtering the raw seawater. Following filter 602, second filter 604 is provided for further filtering and may be a 100µm screen filter. Filtered water passes coagulate injection system 606 which injects coagulant of an appropriate type into the water stream. The coagulant injected water stream is mixed in spiral mixer-conditioner 608. Output of spiral mixer-conditioner 608 is then moved to aggregation tank 610 where aggregated particles are allowed to grow further such as for approximately 4 minutes for certain floc. Flow with aggregates are then moved from aggregation tank 610 to spiral separation device 612 which includes effluent output 614 (where the aggregates have been removed by spiral separator 612), and flow is further filtered by insurance filters 616 and is provided as RO feed water 618. Water from a second output of

spiral separator 612 is provided as waste stream 620, and contains the separated-out aggregates. The rate at which raw seawater is input into system 600 may be controlled by a pump represented by arrow 622.

[0051] System 600 uses In-line coagulation, flocculation and separation to pre-treat RO feedwater, and the following characteristics:

- 1) Aggregate sub-micron organic/inorganic particles for hydrodynamic separation to clarify RO feedwater;
- 2) 50% reduction in coagulant dosage with spiral mixer-conditioner compared to standard jar test protocol (*i.e.*, rapid mixing for 2 minutes followed by 28 minutes and long periods for sedimentation);
- 3) No formal flocculation step and no sedimentation needed;
- 4) Fast process – minutes instead of hours;
- 5) Continuous flow or intermittent operation with flow controls.

[0052] Figure 7 is a schematic for raw seawater or brackish water treatment prior to RO in a desalination configuration using electro-coagulation. The advantage is in situ generation of the coagulant.

[0053] System 700 is similar to system 600 of Figure 6. However, following second filter 604, the coagulant injection system 606 is replaced with electro-coagulation unit 702. Thereafter the components such as shown in Figure 6 are used. A further distinction is injection of antiscalant chlorine 704, following filtering by the insurance filter 616. The rate at which the raw seawater is input into system 700 may in one embodiment be controlled by a pump represented by arrow 722.

[0054] System 700 permits on-site chemical generation, much lower volume of sludge, and does not need harsh chemicals. System 700 uses in-line coagulation, flocculation and separation to pre-treat RO feedwater

with electro-coagulation. The process includes the following characteristics:

- 1) Electro-coagulation allows chemicals to be generated on-site;
- 2) Aggregate sub-micron organic/inorganic particles for hydrodynamic separation to clarify RO feedwater;
- 3) 50% reduction in coagulant dosage with spiral mixer-conditioner compared to standard jar test protocol (*i.e.*, rapid mixing for 2 minutes followed by slow mixing for 28 minutes and long periods for sedimentation) ;
- 4) No formal flocculation step and no sedimentation needed;
- 5) Fast process – minutes instead of hours;
- 6) Continuous flow or intermittent operation with flow controls.

[0055] Figure 8 is a schematic for creating hydroxide precipitates from concentrated brine to prevent scaling of the RO membranes by multivalent metals from brine concentrate.

[0056] System 800 includes reverse osmosis (RO) unit 802 which receives the RO feedwater and will eventually output product water 804. A second output from RO unit 802 includes a water stream (with brine) which is injected with precipitating agent 806 prior to provision to spiral mixer-conditioner 808. The stream enters aggregation tank 801 to allow for precipitate growth. Once sufficient growth has taken place, the stream is provided to spiral separator 812 which performs spiral separation for separating out the precipitates. Effluent output 814 (with precipitate removed) may optionally be recirculated back in recirculate brine loop 816,

to RO unit 802. The second output from spiral separator 812 is waste stream 818 having precipitates. The rate at which the RO feed water is input into system 800 may in one embodiment be controlled by a pump represented by arrow 820.

[0057] The system provides formation of precipitates (e.g., magnesium hydroxide) and their separation from brine concentrate during an RO process. This process is also relevant for removing divalent metal ions from brackish water. The process includes the following characteristics:

- 1) Precipitate divalent/trivalent metal ions for hydrodynamic separation;
- 2) Reduction in $\text{Ca}(\text{OH})_2$ dosage with spiral mixer;
- 3) No formal flocculation step and no sedimentation needed;
- 4) Fast process – on the scale of minutes;
- 5) Continuous flow or intermittent operation with flow controls.

[0058] Figure 9 is a schematic for two-stage precipitation and separation of carbonate and hydroxide precipitates followed by coagulation, flocculation, and separation of all other suspensions from seawater or brackish water.

[0059] System 900 includes input filter 902, which in one embodiment may be a filter with 100 μm -sized openings, for removing large particulates prior to the stream being input to first-stage spiral separator 904, where the first-stage spiral separation will separate out precipitates of a size 5-10 μm . Effluent output 906 carries the fluid stream which has precipitated material below 5 10 μm removed and is injected with a coagulant by a coagulant injection device 908. The stream is then provided to spiral mixer-conditioner 910 and aggregation tank 912 similar to Figures 6-7 to address particulates or aggregates below 5 μm in diameter. The second output from

the first-stage spiral separator 904 provides precipitate output 914. The rate at which the Precipitator is input into system 900 may in one embodiment be controlled by a pump represented by arrow 924.

[0060] Output from aggregation tank 912 is sent to second-stage spiral separator 916 for spiral separation of the flocculated aggregates. Second-stage spiral separator 916 includes first effluent output 918 which is provided to RO feedwater system 920 and the second is output waste stream 922.

[0061] The system uses two stages: (i) initial spiral separation for precipitate recovery; and (ii) coagulation, flocculation, separation to pre-treat RO feedwater. The process includes the following characteristics:

- 1) Rapid extraction of precipitates in 5 μ m–10 μ m size range;
- 2) Aggregate sub-micron organic/inorganic particles for hydrodynamic separation to clarify RO feedwater;
- 3) 50% reduction in coagulant dosage with spiral mixer-conditioner compared to standard jar test protocol (*i.e.*, rapid mixing for 2 minutes rapid mix followed by slow mixing for 28 minutes and long periods for sedimentation) ;
- 4) No formal flocculation step and no sedimentation needed;
- 5) Fast process – minutes instead of days;
- 6) Continuous flow or intermittent operation with flow controls.

[0062] Figure 10 is a schematic for coagulation, flocculation, and separation of suspended organics from seawater to provide clarified feedwater for membrane distillation (MD). MD uses waste heat at much lower temperatures than thermal distillation.

[0063] System 1000 includes a two filter input for raw seawater wherein first filter 1002 has a 2 - 5mm filter screen and second filter 1004 has a 100µm filter screen. The filtered water stream is provided to a spiral separator 1006 which has a 10µm aggregate size cut-off for separation. First effluent output 1008 provides effluent with aggregates removed to optionally provided filter 1010, which supplies filtered water to MD water tank 1012. Second output of spiral separator 1006 is waste stream 1014 for the output seawater. The rate at which raw seawater is input into system 1000 may in one embodiment be controlled by a pump represented by arrow 1016.

[0064] The system provides a pre-treatment for membrane distillation. The process includes the following characteristics:

- 1) Separation of particles in raw seawater down to 10µm;
- 2) Continuous flow or intermittent operation with flow controls.

[0065] Figure 11 is a schematic for two-stage separation; first of coarse particles then followed by coagulation, flocculation, and separation of fine particles in the supernatant into medium fine tails (e.g. tailing pond water). This application is applicable to produce water from surface oil extraction, e.g. tar sands.

[0066] System 1100 includes filter 1102 which may be a 100 µm screen filter to filter hydrocyclone overflow water, such that filtered water is provided to first-stage spiral separator 1104. The first-stage spiral separator may in one embodiment have a cutoff value for aggregate separation of 5 - 10µm. First fines output 1106 provides a stream with fines to which coagulation system 1108 injects coagulant. The coagulate-injected stream is provided to spiral mixer-conditioner 1110 which mixes and conditions the streams and provides the stream with aggregated fines to aggregation tank 1112 for up to 4 mins. Second output from first-stage

spiral separator 1104 provides a water stream with coarse tails 1114. Output from aggregation tank 1112 is sent to second spiral separator 1116 where the second spiral separator separates the remaining floc aggregates. Finally, a first output from the second spiral separator 1116 provides clear effluent 1118 for recycled water reservoir 1120. Second output 1122 provides a concentrated mature fine tails (MFT). The rate at which the hydrocyclone overflow water is input into system 1100 may in one embodiment be controlled by a pump represented by arrow 1124.

[0067] The process includes the following characteristics:

- 1) Rapid extraction of precipitates in 5 – 10 μ m size range;
- 2) Aggregate sub-micron clay particles for separation;
- 3) 50% reduction in coagulant dosage with spiral mixer-conditioner compared to standard jar test protocol (*i.e.*, rapid mixing for 2 minutes rapid mix followed by slow mixing for 28 minutes and long periods for sedimentation);
- 4) No formal flocculation step and no sedimentation needed;
- 5) Fast process – minutes instead of days;
- 6) Continuous flow or intermittent operation with flow controls/

[0068] Figure 12 is a schematic for precipitation, aggregation, and separation of divalent metal ions from produced water. Up to 10 barrels of produced water may result from 1 barrel of oil extracted from the ground. Transport costs for moving produced water away from the drilling site for evaporation and subsequent replacement with fresh water are prohibitive. The process illustrated in Figure 12 allows on-site treatment and can be

further enhanced to produce high water quality supernatant suitable for re-injection and steam generation.

[0069] System 1200 includes first input filter 1202 which may be embodied as 100µm filter screen which receives and filters a stream of Raw Produced Water which is then injected with calcium hydroxide (Ca(OH)_2) with mechanism 1204. This water stream with injected Ca(OH)_2 is provided to spiral mixer-conditioner 1206 which mixes the material and passes it to reaction tank 1208 for approximately a minute of reaction processing to produce magnesium hydroxide (Mg(OH)_2) precipitates. Thereafter, the water stream is injected with potassium carbonate (K_2CO_3) via injection system 1210. This processed stream is then sent to second spiral mixer-conditioner 1212 where it is mixed, conditioned and output to precipitation tank 1214 for approximately one minute to precipitate calcium carbonate (CaCO_3). Thereafter, the precipitated flow is provided to a spiral separator 1216 which separates out aggregates and produces effluent output 1218, and a precipitates output 1220. It should be pointed out that depending on the reaction rates, the first reaction tank in Figure 12 may not be necessary.

[0070] In an embodiment, the precipitate flow coming from tank 1214 may provide some of the flow as feedback via feedback path 1222 to the input of the reaction tank 1208 where the injection occurs after spiral mixing in the first spiral mixer 1206. This feedback introduces precipitates to “seed” and grow larger aggregates of precipitates.

[0071] In an embodiment, the flow coming from the precipitation tank 1214 could be coagulated by injecting ferric chloride (FeCl_3) via injection mechanism 1224 and then a third spiral mixer-conditioner 1226 mixes and conditions the further injected flow. Thereafter from spiral mixer-conditioner 1226, the flow stream could be put into an aggregation tank 1228 for further growth prior to being provided to spiral separator 1216.

The rate at which the raw produce water is input into system 1200 may in one embodiment be controlled by a pump represented by arrow 1230.

[0072] The system uses in-line precipitation, aggregation and separation of produce water to remove divalent ions. The process includes the following characteristics:

- 1) Precipitate magnesium hydroxide ($\text{Mg}(\text{OH})_2$) and calcium carbonate (CaCO_3);
- 2) No formal flocculation step and no sedimentation needed;
- 3) Fast process;
- 4) Continuous flow or intermittent operation with flow controls.

[0073] Figure 13 is a schematic for direct removal of suspended organic matter in seawater and dumping the seawater (waste) stream back into the source in order not to disrupt ecology (which will still need a sterilization step).

[0074] System 1300 includes input filter screen 1302 which may be an approximately 50-100 μm screen filter to receive the input seawater. The filtered seawater is provided to spiral separator 1304 for separating out particulates remaining in the filtered flow of seawater. Effluent output 1308 of spiral separator 1304 is provided to optional filter 1308 and then to ballast water tank 1310. Waste output 1312 from spiral separator 1304 is waste seawater 1314. The rate at which the Input seawater is input into system 1300 may in one embodiment be controlled by a pump represented by arrow 1316.

[0075] This system provides ballast water treatment using cut-off size separation techniques. The process includes the following characteristics:

- 1) High throughput, continuous flow separation;

2) Reduced clogging of optional filter resulting in less frequent back flush
- back flush may be dumped without treatment at in-take port;

3) Waste stream directly dumped without treatment at in-take port.

[0076] Figure 14 is a schematic to pre-treat raw input seawater or brackish water to remove most suspended solids before presenting the clear effluent to the ballast tanks (which will still need a sterilization step).

[0077] System 1400 includes first input filter 1402 to filter input seawater. Input filter 1402 may be embodied in one embodiment as a 50-100 μm filter screen. This filtered stream is then injected with a coagulant via injection mechanism 1404. The injected flow is then provided to spiral mixer-conditioner 1406 which outputs the mixed, conditioned flow to aggregation tank 1408 for additional floc growth. Output from aggregation tank 1408 is provided to spiral separator 1410 which separates out the aggregated floc according to a selected size cutoff. Effluent output 1412 from spiral separator 1410 is an effluent stream provided to optional filtering mechanism 1414, provided to ballast water tank 1416. The second output from spiral separator 1410 is waste output 1418 which is output seawater. The rate at which the input seawater is input into system 1400 may in one embodiment be controlled by a pump represented by arrow 1420.

[0078] The process includes the following characteristics:

- 1) Aggregate sub-micron organic/inorganic particles for separation;
- 2) 50% reduction in coagulant dosage with spiral mixer-conditioner compared to standard jar test protocol (*i.e.*, rapid mixing for 2 minutes followed by slow mixing for 28 minutes and long periods for sedimentation);
- 3) No formal flocculation step and no sedimentation needed.

[0079] Figure 15 is a schematic for algae dewatering for bio-fuel production, feedstock, and clarification of polished waste water prior to surface discharge. Algae typically grow in very dilute concentrations. Dewatering, or harvesting and removing water, is typically achieved by centrifugation, filtration, or floatation. Centrifugation is energy intensive, filtration is high in maintenance, and floatation is slow and requires large land area.

[0080] System 1500 includes a dual screen input for receiving open pond water. First input screen 1502 may be embodied as a 2-5mm size, whereas second input screen 1504 may be embodied as a 100µm size. The filtered water is moved to first-stage spiral separator 1506 providing first output 1508 which includes a flow stream of concentrated algae to aggregation tank 1510 for further growth of the aggregate algae. The second output from first-stage spiral separator 1506 is effluent output 1512 that may be provided to optional feedback path 1514 to the open pond. The output from aggregation tank 1510 is then sent to a second-stage spiral separator 1516 where the concentrated aggregate, which in this embodiment is algae, is output at output 1518. The alternative output is effluent output 1520 which also may be provided to optional feedback path 1514 to the open pond. The rate at which the open pond water is input into system 1500 may in one embodiment be controlled by a pump represented by arrow 1522.

[0081] The process includes the following characteristics:

- 1) Separation of algae;
- 2) two stages with 90:10 split to obtain two orders of magnitude concentration;
- 3) Distributed implementation – single setup processes 4 ponds to maximize dewatering, minimize pumping, and ensure circulation;

4) Fast process;

5) Continuous flow or intermittent operation with flow controls.

[0082] Figure 16 is an application where the structure of system 1500 may be implemented. In particular, system 1500 having multiple inputs or multiple systems 1500 is included within or generally provided to four ponds 1602, 1604, 1606, and 1608. By locating system 1500 in a centralized location with respect to ponds 1602-1608 an efficient collection of the aggregate such as in the form of algae may be accomplished.

[0083] Figure 17 is a schematic for coagulation, flocculation, and separation of process water (e.g. grape wash water) or grey wash water prior to surface discharge. The waste stream contains both bacteria and nutrients which could be channeled to an anaerobic digester for conversion to water and carbon dioxide (CO₂).

[0084] System 1700 includes first filter 1702 having filter openings of approximately 2mm. Filter 1702 filters the grey wash water into a stream that has a coagulant injected via injection mechanism 1704. The stream with the injected coagulant is provided to spiral mixer 1706 which in turn moves the coagulant injected and filtered grey wash water to aggregation tank 1708 for further growth of floc in the stream. Output from aggregation tank 1708 is provided to spiral separator 1710 where spiral separation occurs for less than approximately 4 minutes. Output of spiral separator 1710 is via effluent output 1712, and the stream is then provided to optional filter 1714 and is stored at grey water reservoir 1716. The second output from spiral separator 1710 is waste output 1718. The rate at which the grey wash water is input into system 1700 may in one embodiment be controlled by a pump represented by arrow 1720.

[0085] This system provides in-line coagulation, flocculation and spiral separation for e.g. grape wash water. The process includes the following characteristics:

- 1) Aggregate sub-micron organic/inorganic particles for separation;
- 2) 50% reduction in coagulant dosage with spiral mixer-conditioner compared to standard jar test protocol (*i.e.*, rapid mixing for 2 minutes followed by slow mixing for 28 minutes and long periods for sedimentation);
- 3) No formal flocculation step and no sedimentation needed;
- 4) Fast process – minutes instead of days;
- 5) Continuous flow or intermittent operation with flow controls.

[0086] Figure 18 is a schematic for two-stage initial separation: first stage for removal of larger debris, followed by coagulation, flocculation, and separation to produce treated water suitable for surface discharge. The waste streams can be channeled to an anaerobic digester to produce water and CO₂. This process may be suited for process water (e.g. palm oil mill effluent) with very high abundance of sub-micron debris.

[0087] System 1800 includes input stream filter 1802 which may be a 100µm screen used to filter the for screen palm oil mill effluent (POME) prior to supplying the stream to first-stage spiral separator 1804 where the first-stage spiral separator separates aggregates 5-10µm in size. Effluent output 1806 from spiral separator 1804 has a coagulant injected via injection mechanism 1808, prior to the inlet of spiral mixer-conditioner 1810. The output of spiral mixer-conditioner 1810 is provided to

aggregation tank 1812 to allow further growth of floc (e.g., for approximately 4 minutes). Second output from spiral separator 1804 is waste output 1814. From aggregation tank 1812, the stream is provided to second spiral separator 1816 where the separation operation of the aggregated floc is for approximately 4 minutes. Effluent output 1818 from spiral separator 1816 is grape water 1820, and waste output 1822. The rate at which the palm oil mill effluent is input into system 1800 may in one embodiment be controlled by a pump represented by arrow 1824.

[0088] This system operates two stages: (i) initial spiral separation; and (ii) coagulation, flocculation and separation of POME to produce treated water. The process includes the following characteristics:

- 1) Initial separation of particles in raw POME down to 5 – 10 μ m;
- 2) Aggregate sub-micron organic/inorganic particles for separation to clarify;
- 3) 50% reduction in coagulant dosage with spiral mixer-conditioner compared to standard jar test protocol (*i.e.*, rapid mixing for 2 minutes followed by slow mixing for 28 minutes and long periods for sedimentation);
- 4) No formal flocculation step and no sedimentation needed;
- 5) Fast process – minutes instead of days;
- 6) Continuous flow or intermittent operation with flow controls.

[0089] Figure 19 is a schematic for aggregation and recovery of volume dispersed titanium dioxide (TiO₂) nanoparticles used in an advanced oxidation technology ultraviolet (UV) sterilization system. Photocatalytic activity of the TiO₂ in the presence of UV effectively damages cellular

membranes. This is a non-chemical alternative for sterilization and is most effective for volume dispersed TiO_2 compared to immobilizing them onto surfaces of flow conduits. The nano-particles are small (typically 25 nm) and recovery is through filtration, which is laborious.

[0090] System 1900 includes first input filter 1902 which may be 100 μm input screen, configured to screen particulates from input waste water. The filtered input waste water from input screen 1902 is passed to an Advanced Oxidation Treatment (AOT) system 1904. Output stream from AOT 1904 is pH adjusted made by adjustment mechanism 1906 prior to the pH adjusted flow and provided to spiral mixer-conditioner 1908. Following the mixing by spiral mixer-conditioner 1908, the flow is provided to aggregation tank 1910 for further growth of the aggregated material. Output of aggregation tank 1910 is provided to spiral separator 1912 where the spiral separator separates out the TiO_2 aggregates. Effluent output 1914 from spiral separator 1912, with the aggregates removed, is then passed through filter 1916 for the output of the flow to sterilized water tank 1918. Alternative output from spiral separator 1912 is recovered TiO_2 1920 and sent back into the system as TiO_2 injection 1922 at the input of the AOT 1904. The rate at which the input waste water is input into system 1900 may in one embodiment be controlled by a pump represented by arrow 1924.

[0091] The process includes the following characteristics:

1) Advanced Oxidation Technology

- Volume dispersion and recovery of TiO_2
- Flow-through UV reactor

2) Spiral Units

- Spiral Mixer-Conditioner to mix aggregation agent

- Spiral Separator to recover aggregated TiO_2

[0092] Figure 20 is a schematic for wastewater treatment where the suspended organics, including bacteria and nutrients, are re-circulated back to the primary clarifier. The clarified effluent stream may be sterilized and treated for surface discharge. The system provides an in-line coagulation, flocculation and separation system for wastewater treatment, replacing sedimentation and significantly reducing retention time outside of the period required for digestion by sludge micro-organisms.

[0093] System 2000 includes input filter 2002 which may be a 100 μm screen filter designed to receive an input flow from a source having various stages of fluid defined as sludge 2004, primary clarifier 2006 and floaters 2008. Flow from this input is filtered by input filter screen 2002 (e.g., a 100 μm screen) and this filtered flow is then injected with coagulant via coagulant injection system 2010. The injected flow is provided to spiral mixer 2012 and the mix flow is provided to aggregation tank 2014 for further floc growth of the aggregates from the input stream. Output from aggregation tank 2014 is provided to spiral separator 2016 for separation of floc within the stream. Thereafter, effluent output 2018 is provided to optional filter 2020 and the flow is stored in clarify tank 2022. Waste output 2024 from spiral separator 2016 is provided via feedback path 2026 to the input having sludge 2004, primary clarifier 2006 and floaters 2008. The rate at which the input (2004, 2006, 2008) is input into system 2000 may in one embodiment be controlled by a pump represented by arrow 2028.

[0100] The process includes the following characteristics:

- 1) Aggregate sub-micron organic/inorganic particles for separation;
- 2) 50% reduction in coagulant dosage with spiral mixer-conditioner compared to standard jar test protocol (rapid mixing for 2 minutes followed by slow mixing for 28 minutes and long periods for

sedimentation);

3) No formal flocculation step and no sedimentation needed;

4) Fast process, continuous flow, small footprint, low power, low pressure;

5) Waste stream recycled back to primary clarifier.

[0101] Figure 21 is a schematic for wastewater treatment where the waste stream is channeled to the anaerobic digester to produce water, CO₂ and methane at a faster rate.

[0102] System 2100 is substantially the same as system 2000. However instead of waste output 2024 being recirculated back to the input stream, anaerobic digester 2102 is provided to receive the waste stream 2024. The concentration provided by this separation increases the rate of biological reaction and the rate of methane generation. The rate at which the input (2004, 2006, 2008) is input into system 2100 may in one embodiment be controlled by a pump represented by arrow 2104.

[0103] The system provides concentration of primary treatment effluent to a digester for wastewater treatment. The process includes the following characteristics:

1) Aggregate sub-micron organic/inorganic particles for separation;

2) 50% reduction in coagulant dosage with spiral mixer-conditioner compared to standard jar test protocol (*i.e.*, rapid mixing for 2 minutes followed by slow mixing for 28 minutes and long periods for sedimentation);

3) No formal flocculation step and no sedimentation needed;

4) Fast process, continuous flow, small footprint, low power, low

pressure;

5) Waste stream is concentrated organisms and nutrients to the anaerobic digester.

WHAT IS CLAIMED IS:

1. A method for treating a fluid stream by a fluid treatment system comprising:

inputting a fluid stream to an input section of the fluid treatment system;

receiving the fluid stream by a spiral mixer-conditioner positioned in operative association with the input section, the spiral mixer-conditioner mixing and conditioning the input stream;

receiving the mixed and conditioned fluid stream at a spiral separator;

separating the mixed and conditioned fluid stream received by the spiral separator into at least two fluid streams, a first fluid stream having particulates in the input fluid stream removed and the second fluid stream having the particulates in the input fluid stream concentrated; and

outputting the two fluid streams from the spiral separator.

2. The method according to claim 1 further including determining a customized shear rate in the spiral mixer-conditioner, by use of the width of the channels in the spiral mixer-conditioner and the velocity of the input stream into the spiral mixer-conditioner.

3. A method for treating a fluid stream by a fluid treatment system comprising:

inputting a fluid stream to an input section of the fluid treatment system;

receiving the fluid stream by a spiral mixer-conditioner positioned in operative association with the input section, the spiral mixer-conditioner mixing and conditioning the input stream;

receiving the mixed and conditioned fluid stream at a spiral

separator;

separating the mixed and conditioned fluid stream received by the spiral separator into at least one of two fluid streams, a first fluid stream having particulates in the input fluid stream removed and the second fluid stream having the particulates in the input fluid stream concentrated; and

outputting the two fluid streams from the spiral separator, wherein the flow of the input stream in the mixer section is at or above the critical Dean number of 150.

4. A fluid stream treatment system comprising:

an input section for receipt of a fluid stream;

a spiral mixer-conditioner positioned in operative association with the input section to receive the input fluid stream, the spiral mixer-conditioner including a mixer section and a conditioner section;

a spiral separator arrangement positioned in operative association with the spiral mixer-conditioner to receive the mixed and conditioned fluid stream, the spiral separator including a separation section and an output section the output section configured to output at least two streams, one stream with particulates from the input fluid stream removed by the separation section and a second stream with the particulates from the input fluid stream condensed by the separation section.