Struvite dissolves very slowly, thereby ameliorating the loss of nutrients from the soil and providing effective nutrition to plants. The relatively low solubility of such fertilizers also helps to prevent the plant roots from being “burned” by the high salinity that can be caused by more water soluble fertilizers. Since many agricultural, municipal, and industrial wastewater streams contain high amounts of nutrients, particularly phosphorus and nitrogen, struvite has the potential to be recovered from these waste streams.

[0005] There are for example a number of processes for phosphorus recovery from waste streams in the form of struvite and other phosphate compounds. Many existing struvite recovery processes extract it in the form of small, powder-like particles that are very hard to dry and separate from impurities, which is a significant drawback for the final fertilizer product. Therefore, there is a need for a process that can produce a high quality struvite fertilizer product in the form of small granules, or pellets, that can be easily separated from the wastewater and other impurities, and can also be easily dried, transported and stored.

SUMMARY

[0006] Processes and apparatus are disclosed for recovery of dissolved species from wastewater streams, in the form of sized precipitates. Processes are for example provided for removing a dissolved species from an aqueous inflow stream, the dissolved species comprising a dissolved nitrogen and/or a dissolved phosphorous and/or a dissolved potassium species. These processes may includes steps of segregating the aqueous inflow into streams that are directed into a reactor, with a precipitating agent also being injected into the reactor. The precipitating agent may for example be provided in a distinct material stream, e.g. as a solid or liquid, or the precipitating agent may be present in one or more of the aqueous inflow streams.

[0006a] In one aspect, the present disclosure refers to a process for removing a dissolved species from an aqueous inflow stream, the dissolved species comprising a dissolved nitrogen and/or a dissolved phosphorous and/or a dissolved potassium species, the process comprising:

segregating the aqueous inflow stream into a plurality of reactor inflow streams, and directing the plurality of reactor inflow streams upwardly into a base of a reaction conduit segment in a reactor vessel so as to create a turbulent upward flow in the reaction conduit segment;

injecting a precipitating agent into the base of the reaction conduit segment under conditions maintained in the reaction conduit segment so as to provide a supersaturated concentration of a reaction product of the precipitating agent reacting with the dissolved species, providing a saturation index of at least 2 for the reaction product, the reaction product forming a solid precipitant species entrained in an upward reaction conduit fluid flow;

directing the upward reaction conduit fluid flow to a contiguous clarifier segment of the reactor vessel, the clarifier segment of the reactor vessel being dimensioned to reduce the upward flow rate of the upward reaction conduit fluid flow, and maintaining an upward clarified fluid flow rate in the clarifier segment so as to permit entrained solid precipitant species to descend in the clarifier segment of the reactor vessel and return to the reaction conduit segment while a clarified discharge fluid flow continues to flow upwardly out of the clarifier segment of the reactor vessel;

maintaining conditions in the reactor vessel to permit the progressive agglomeration of the precipitant species to form agglomerated granules of a size and density sufficient to cause the agglomerated granules to settle towards the base of the reaction conduit segment in the presence of the turbulent upward reaction conduit fluid flow;

injecting an upward channeled fluid flow through a channel in fluid communication with the base of the reaction conduit segment, the channel being dimensioned to permit metering of the upward channeled fluid flow so as to permit agglomerated granules of a selected size and density to descend through the channel while returning un-selected precipitant species upwardly to the reaction conduit segment, thereby segregating a sized solid granule product by elutriation that descends through the channel into a contiguous pellet hopper sized to accommodate a settled volume of the sized solid granule product.

[0007] The aqueous inflow stream may for example be segregated into a plurality of reactor inflow streams, for example in a manifold in fluid communication with the reaction conduit. The plurality of reactor inflow streams may be directed

may for example have a desired product purity, for example of at least about 60%, 70%, 80%, 90% or 96%.

[0015] The desired solid granule product may for example be one or more of: struvite, K-struvite, calcium ammonium phosphate $CaNH_4PO_4$, and/or hydroxyapatite $Ca_5(PO_4)_3(OH)$, brushite $CaHPO_4 \cdot 2H_2O$, newberyite $MgHPO_4 \cdot 3H_2O$, and/or magnesium phosphate $Mg_3(PO_4)_2$. In select alternative ~~embodiment~~examples, the purity of the desired solid granule product may for example be at least 70%, 75%, 80%, 90% or 95%.

[0016] In one ~~aspect~~example, processes may involve recirculating a portion of the clarified fluid flow from the clarifier to the hopper, using this recirculated fluid flow to mediate the upward channeled fluid flow through the channel. An upward hopper fluid flow in the hopper may for example be provided that mediates the upward channeled fluid flow in the channel, and the hopper may be sized so that the upward hopper fluid flow is less than the upward channeled fluid flow.

[0017] One ~~aspect~~example of select implementations of the present processes is the ability to cope with inflow streams that have relatively high levels suspended solids. For example, the inflow stream may include up to 1%, 2%, 3%, 4% or 5% by weight suspended solids. In some ~~embodiment~~examples, from 50-95% of the suspended solids in the inflow stream pass through the reactor to the clarified discharge fluid flow.

[0018] The present processes may be carried out in a reactor with a system of controls, constituting a reactor system operable to remove the dissolved species from the aqueous inflow stream (the dissolved species comprising a dissolved nitrogen and/or a dissolved phosphorous and/or a dissolved potassium species). One or more screens may be positioned in the aqueous inflow stream, before the aqueous inflow stream enters the manifold, and these screens may for example have a smaller mesh than the diameter of injection nozzles positioned inside the reactor.

[0018a] In another aspect, the present disclosure refers to a reactor system operable to remove a dissolved species from an aqueous inflow stream, the dissolved species comprising a dissolved nitrogen and/or a dissolved phosphorous and/or a dissolved potassium species, the reactor system comprising:

a manifold segregating an aqueous inflow stream into a plurality of reactor inflow streams, and directing the plurality of reactor inflow streams upwardly into a base of a reaction conduit segment in a reactor vessel in fluid communication with the manifold, so as to create a turbulent upward flow in the reaction conduit segment;

an intake pump upstream of the manifold to provide a pressurized aqueous inflow stream;

injection nozzles directing the plurality of reactor inflow streams upwardly into the base of the reaction conduit segment; wherein the injection nozzles are elevated above a bottom portion of the reaction conduit segment; wherein a superficial upflow velocity is provided inside each nozzle of between 5-15 m/s;

a screen positioned in the aqueous inflow stream before the aqueous inflow stream enters the manifold; wherein the screen has a smaller mesh than the diameter of the injection nozzles;

a precipitating agent inlet port in fluid communication with the base of the reaction conduit segment, adapted for injecting a precipitating agent into the base of the reaction conduit segment under control of reactor system controls adapted to maintain conditions in the reaction conduit segment so as to provide a supersaturated concentration of a reaction product of the precipitating agent reacting with the dissolved species, providing a saturation index of at least 2 for the reaction product, the reaction product forming a solid precipitant species entrained in an upward reaction conduit fluid flow;

a clarifier segment of the reactor vessel, upwardly contiguous with the reaction conduit segment, the clarifier segment of the reactor vessel being dimensioned relative to the reaction segment so as to reduce an upward flow rate of an upward reaction conduit fluid flow directed into the clarifier segment from the reaction conduit segment, under the control of clarifier system controls operable to maintain an upward clarified fluid flow rate in the clarifier segment so as to permit entrained solid precipitant species to descend in the clarifier segment of the reactor vessel and return to the reaction conduit segment while a clarified discharge fluid flow continues to flow upwardly out of the clarifier segment of the reactor vessel;

a jacket on the clarifier segment configured to collect the clarified discharge fluid flow;

wherein the reactor system controls are operable to maintain conditions in the reactor vessel to permit progressive agglomeration of the precipitant species to form agglomerated granules of a size and density sufficient to cause the agglomerated granules to settle towards the base of the reaction conduit segment in the presence of turbulent upward reaction conduit fluid flow; and,

a channel in fluid communication with the base of the reaction conduit segment having a channel fluid source to provide an upward channeled fluid flow through the channel into the base of the reaction conduit segment, the channel being dimensioned to permit metering of the upward channeled fluid flow so as to permit agglomerated granules of a selected size and density to descend through the channel while returning un-selected precipitant species upwardly to the reaction conduit segment, thereby segregating a sized solid granule product by elutriation that descends through the channel into a contiguous pellet hopper sized to accommodate a settled volume of sized solid granule product.

[0019] The reactor system may include the manifold for segregating the aqueous inflow stream into a plurality of reactor inflow streams, and directing the plurality of reactor inflow streams upwardly into the base of the reaction conduit segment in the reactor vessel, for example so as to create a turbulent upward flow in the reaction conduit. An intake pump may for example be located upstream of

channel while returning un-selected precipitant species upwardly to the reaction conduit, thereby segregating a sized solid granule product by elutriation that descends through the channel into a contiguous pellet hopper sized to accommodate a settled volume of sized solid granule product.

[0023] Injection nozzles may be provided directing the plurality of reactor inflow streams upwardly into the base of the reaction conduit. The injection nozzles may for example be elevated above the bottom portion of the reaction conduit. There may for example be at least 2, 3, 4, 5 or 6 injection nozzles. The injection nozzles may be generally evenly distributed throughout a cross-sectional area at the base of the reaction conduit, In select ~~embodiment~~examples, a superficial upflow velocity may be maintained inside each nozzle of between 5-15 m/s, or about 10 m/s.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] **Figure 1** is a schematic elevational illustration of an apparatus for carrying out processes disclosed herein.

[0025] **Figure 2** is a schematic elevational illustration of an alternative apparatus for carrying out processes disclosed herein.

DETAILED DESCRIPTION

[0026] Processes and apparatus are disclosed for recovery of dissolved species from wastewater streams, in the form of precipitates sized by elutriation. In some embodiments, the recovered solids may for example be plant nutrients. The extracted nutrients may for example include solid species of phosphorus (P), and/or nitrogen (N) and/or potassium (K). The processes may be carried out on a wide range of aqueous feeds, for example from wastewater streams of various origins, such as agricultural (manure), municipal (sewage), or other industrial origin.

[0027] In select embodiments, the nutrients are extracted through the process of crystallization of phosphate containing sparingly soluble compounds. Such compounds may for example include, but are not limited to, struvite (magnesium ammonium phosphate, MAP), K-struvite (magnesium potassium phosphate, MKP), and other sparingly soluble phosphate compounds. In one aspect of the processes,

CLAIMS

1. A process for removing a dissolved species from an aqueous inflow stream, the dissolved species comprising a dissolved nitrogen and/or a dissolved phosphorous and/or a dissolved potassium species, the process comprising:

segregating the aqueous inflow stream into a plurality of reactor inflow streams, and directing the plurality of reactor inflow streams upwardly into ~~the~~ a base of a reaction conduit segment in a reactor vessel so as to create a turbulent upward flow in the reaction conduit segment;

injecting a precipitating agent into the base of the reaction conduit segment under conditions maintained in the reaction conduit segment so as to provide a supersaturated concentration of a reaction product of the precipitating agent reacting with the dissolved species, providing a saturation index of at least 2 for the reaction product, the reaction product forming a solid precipitant species entrained in an upward reaction conduit fluid flow;

directing the upward reaction conduit fluid flow to a contiguous clarifier segment of the reactor vessel, the clarifier segment of the reactor vessel being dimensioned to reduce the upward flow rate of the upward reaction conduit fluid flow, and maintaining an upward clarified fluid flow rate in the clarifier segment so as to permit entrained solid precipitant species to descend in the clarifier segment of the reactor vessel and return to the reaction conduit segment while a clarified discharge fluid flow continues to flow upwardly out of the clarifier segment of the reactor vessel;

maintaining conditions in the reactor vessel to permit the progressive agglomeration of the precipitant species to form agglomerated granules of a size and density sufficient to cause the agglomerated granules to settle towards the base of the reaction conduit segment in the presence of the turbulent upward reaction conduit fluid flow;

injecting an upward channeled fluid flow through a channel in fluid communication with the base of the reaction conduit segment, the channel being dimensioned to permit metering of the upward channeled fluid flow so as to permit agglomerated granules of a selected size and density to descend through the channel

while returning un-selected precipitant species upwardly to the reaction conduit segment, thereby segregating a sized solid granule product by elutriation that descends through the channel into a contiguous pellet hopper sized to accommodate a settled volume of the sized solid granule product.

2. The process of claim 1, further comprising periodically restricting the upward channeled fluid flow in the channel and downwardly releasing the contents of the hopper, to collect the ~~desired~~ solid granule product.

3. The process of claim ~~1 or~~ 2, further comprising recirculating a portion of the clarified fluid flow from the clarifier segment to the hopper to mediate the upward channeled fluid flow through the channel.

4. The process of ~~any one of claims 1 to~~claim 3, further comprising providing an upward hopper fluid flow in the hopper that mediates the upward channeled fluid flow in the channel, and sizing the hopper so that the upward hopper fluid flow is less than the upward channeled fluid flow.

5. The process of ~~any one of claims 1 to~~claim 4, further comprising segregating the aqueous inflow stream into the plurality of reactor inflow streams in a manifold in fluid communication with the reaction conduit segment.

6. The process of ~~any one of claims 1 to~~claim 5, wherein the precipitating agent comprises an alkali, a magnesium salt, $MgCl_2$, $MgSO_4$, MgO, $Mg(OH)_2$, magnesite, brucite, a combustion bottom ash or a fly ash.

7. The process of ~~any one of claims 1 to~~claim 6, wherein the ~~desired~~ solid granule product comprises one or more of: struvite, K-struvite, calcium ammonium phosphate $CaNH_4PO_4$, and/or hydroxyapatite $Ca_5(PO_4)_3(OH)$, brushite $CaHPO_4 \cdot 2H_2O$, newberyite $MgHPO_4 \cdot 3H_2O$, and/or magnesium phosphate $Mg_3(PO_4)_2$.

8. The process of ~~any one of claims 1 to~~claim 7, wherein the inflow stream comprises up to ~~1%, 2%, 3%, 4% or~~ 5% by weight suspended solids, ~~optionally~~ and wherein 50-95% of the suspended solids in the inflow stream pass through the reactor vessel to the clarified discharge fluid flow.

9. The process of ~~any one of claims 1 to~~claim 8, wherein the channel has an average channel cross-sectional area C_{Xarea}, the pellet hopper has an average pellet hopper cross sectional area PH_{Xarea} and the reaction conduit segment has an average conduit cross sectional area RC_{Xarea}, wherein $C_{Xarea} < PH_{Xarea}$, and $C_{Xarea} < RC_{Xarea}$.

10. The process of ~~any one of claims 1 to~~claim 9, further comprising collecting the sized solid granule product on a sieve; ~~optionally~~ and further washing ~~the sized solid granule product on the sieve; optionally~~and drying the sized solid granule product on the sieve.

11. The process of ~~any one of claims 1 to~~claim 10, wherein the purity of the ~~desired~~ solid granule product is at least ~~70%, 75%, 80%,~~ 90% ~~or 95%~~.

12. The process of ~~any one of claims 1 to~~claim 11, wherein the upward channeled fluid flow rate is maintained ~~at about 10%, optionally~~ in a range of 5-50%~~,~~ of the upward reaction conduit fluid flow rate.

13. The process of ~~any one of claims 1 to~~ claim 12, wherein the initial saturation index SI at the base of the reaction conduit segment for the reaction product is maintained in the range of 2.0-3.0~~, optionally at about 2.5~~.

14. The process of ~~any one of claims 1 to~~ claim 13, wherein the upward reaction conduit fluid flow rate is maintained between 20-80 cm/min~~, optionally approximately 50 cm/min~~.

15. The process of ~~any one of claims 1 to~~claim 14, wherein a hydraulic retention time in the reaction conduit segment is maintained between 1-10 min~~, optionally between 2-5 min~~.

16. The process of ~~any one of claims 1 to~~claim 15, wherein the upward clarified fluid flow rate is maintained between about 1-5 cm/min~~, optionally at about 2 cm/min~~.

17. The process of ~~any one of claims 1 to~~claim 16, wherein the clarifier segment is a frustum shaped ~~clarified~~clarifier, ~~optionally~~ where the frustum shaped clarifier comprises sloped walls having a slope angle of from about 45-85°~~, optionally from about 60-70°~~.

18. The process of ~~any one of claims 1 to~~claim 17, wherein the removal of one or more of the dissolved species from ~~an~~ the aqueous inflow stream to provide the clarified discharge fluid flow is at least 60%~~, 70%, 80% or 89%~~.

19. The process of ~~any one of claims 1 to~~ claim 18, wherein sized solid granule product has an average product size, and the average product size is from about 1-2 mm.

20. The process of ~~any one of claims 1 to~~claim 19, wherein the sized solid granule product has a product purity of at least about ~~60%, 70%,~~ 80%~~, 90% or 96%~~.

21. A reactor system operable to remove a dissolved species from an aqueous inflow stream, the dissolved species comprising a dissolved nitrogen and/or a dissolved phosphorous and/or a dissolved potassium species, the reactor system comprising:

a manifold segregating an aqueous inflow stream into a plurality of reactor inflow streams, and directing the plurality of reactor inflow streams upwardly into a base of a reaction conduit segment in a reactor vessel in fluid communication with the manifold, so as to create a turbulent upward flow in the reaction conduit segment; an

intake pump upstream of the manifold to provide a pressurized aqueous inflow stream; injection nozzles directing the plurality of reactor inflow streams upwardly into the base of the reaction conduit segment; wherein the injection nozzles are elevated above a bottom portion of the reaction conduit segment; wherein a superficial upflow velocity is provided inside each nozzle of between 5-15 m/s; a screen positioned in the aqueous inflow stream before the aqueous inflow stream enters the manifold; wherein the screen has a smaller mesh than the diameter of the injection nozzles;

a precipitating agent inlet port in fluid communication with the base of the reaction conduit segment, adapted for injecting a precipitating agent into the base of the reaction conduit segment under ~~the~~ control of reactor system controls adapted to maintain conditions in the reaction conduit segment so as to provide a supersaturated concentration of a reaction product of the precipitating agent reacting with the dissolved species, providing a saturation index of at least 2 for the reaction product, the reaction product forming a solid precipitant species entrained in an upward reaction conduit fluid flow;

a clarifier segment of the reactor vessel, upwardly contiguous with the reaction conduit segment, the clarifier segment of the reactor vessel being dimensioned relative to the reaction segment so as to reduce an upward flow rate of an upward reaction conduit fluid flow directed into the clarifier segment from the reaction conduit segment, under the control of clarifier system controls operable to maintain an upward clarified fluid flow rate in the clarifier segment so as to permit entrained solid precipitant species to descend in the clarifier segment of the reactor vessel and return to the reaction conduit segment while a clarified discharge fluid flow continues to flow upwardly out of the clarifier segment of the reactor vessel; a jacket on the clarifier segment configured to collect the clarified discharge fluid flow;

wherein the reactor system controls are operable to maintain conditions in the reactor vessel to permit ~~the~~ progressive agglomeration of the precipitant species to form agglomerated granules of a size and density sufficient to cause the agglomerated granules to settle towards the base of the reaction conduit segment in the presence of ~~the~~ turbulent upward reaction conduit fluid flow; and,

a channel in fluid communication with the base of the reaction conduit segment having a channel fluid source to provide an upward channeled fluid flow through the channel into the base of the reaction conduit segment, the channel being dimensioned to permit metering of the upward channeled fluid flow so as to permit agglomerated granules of a selected size and density to descend through the channel while returning un-selected precipitant species upwardly to the reaction conduit segment, thereby segregating a sized solid granule product by elutriation that descends through the channel into a contiguous pellet hopper sized to accommodate a settled volume of sized solid granule product.

~~22. The reactor system of claim 21, further comprising an intake pump upstream of the manifold to provide a pressurized aqueous inflow stream.~~

~~23. The reactor system of claim 21 or 22, further comprising a jacket on the clarifier configured to collect the clarified discharge fluid flow.~~

~~24. The reactor system of any one of claims 21 to 23, further comprising injection nozzles directing the plurality of reactor inflow streams upwardly into the base of the reaction conduit; optionally wherein the injection nozzles are elevated above a bottom portion of the reaction conduit; optionally wherein there are at least 2, 3, 4, 5 or 6 injection nozzles; optionally wherein the injection nozzles are generally evenly distributed throughout a cross-sectional area at the base of the reaction conduit; optionally wherein a superficial upflow velocity is provided inside each nozzle of between 5-15 m/s, or about 10 m/s.~~

~~25. The reactor system of any one of claims 21 to 24, further comprising a screen positioned in the aqueous inflow stream before the aqueous inflow stream enters the manifold; optionally, wherein the screen has a smaller mesh than the diameter of the injection nozzles.~~

~~26. The reactor system of any one of claims 21 to 25, wherein the precipitating agent is dosed in close proximity to the injection nozzles.~~

~~27. The reactor system of any one of claims 21 to 26, for use in carrying out the process of any one of claims 1 to 20.~~