

DEVICE AND METHOD

Field of the invention

- 5 This invention is related to a device and method for separating particles or contaminants in a fluid. In particular, the invention relates to a device and method for the magnetic separation of particles or contaminants in a fluid.

Background of the invention

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Wastewater from homes, commercial establishments, industry, and agriculture farms need to be treated before the effluent can be discharged into a river or sea to limit the damage to the environment and people because of potential harmful compounds or matter in the wastewater.

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The treatment of waste water is taking on increased significance as sources of clean water is fast depleting. Common approaches to waste water treatment involve the coagulation of contaminants by chemical, biological or electro-coagulation process. The product of these processes is a mixture of sludge with water – slurry. Sludge generated from the coagulation process is then separated from the water.

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A typical wastewater treatment may involve one or a combination of physical, chemical, and biological methods to remove and breakdown the harmful compounds. Physical methods include filtration through membranes, sand or activated carbon, reverse osmosis, separation of water-organic layers and sedimentation.

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Chemical methods by adding chemical compounds, like alum, aluminium sulfate, ferrous sulfate, ferrous chloride, to cause coagulation of solids. In a colloidal suspension, particles will settle very slowly or not at all because the colloidal particles carry surface electrical charges that mutually repel each other. A coagulant (like those listed above) with the opposite charge is added to the water to overcome the repulsive charge and “destabilise” the suspension. This causes the particles to cling together and form solid particles that will settle more easily. Another way to introduce the charged ions is to use electrolysis to generate the aluminium or iron cations, which is termed electrocoagulation. Another method is flocculation which involves the addition of polymers that

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clump the small destabilised particles together into larger aggregates (solid particles) for faster settlement. Flocculation and coagulation can be done in the same tank.

Biological methods include the addition of bacteria and protozoa to consume biodegradable organic matter like sugars, fats, short-chain carbon molecules.

One of the methods used in the separation of sludge from water is sedimentation using a clarifier. Sedimentation is a physical waste water treatment method that relies on gravity to settle coagulated solids. Typically, it requires 2-3 hours to achieve the required clarity. A conventional clarifier uses gravity force (applied force) and drag force for the settling of solid particles in the fluid.

According to Stokes Law, the settling velocity is derived as

$$V_s = g (\rho_p - \rho) D_p^2 / 18\mu \text{ ----- Equation 1}$$

where:

V_s is the settling velocity (m/s),

g is gravitational acceleration which is 9.81 m/s^2 ,

ρ_p is mass density of the particle (kg/m^3),

ρ is mass density of fluid (kg/m^3),

D_p is radius of the particle (m),

μ is dynamic viscosity of water which is $1 \times 10^{-3} \text{ kg/ms}$.

If electrocoagulation using iron or steel blades occur before the clarifier, the particles settling in the clarifier tank are iron based sludge. The density of iron is 7870 kg/m^3 , density of water is 1000 kg/m^3 and radius of the iron is 92 pm. Substituting the above values into Equation 1 gives the following:

$$V_s = 31,690 \times 10^{-24} \text{ m/s ----- Equation 2}$$

The following Table 1 indicates the settling rate for a series of particle sizes from 1 - 500 micron, calculated based on equation 1 and is shown graphically in Figure 3. We can see that the settling velocity (rate) increases with particle size. The fastest settling particles are huge, heavy, spherical molecules. The slowest settling particles, which sometimes do not settle well, floating in the water medium, are tiny, light, irregularly shaped molecules. The longer the settling rate, the longer the time required for the liquid to be retained in the tank, which correspondingly limits the volume of wastewater that can be treated.

Table 1

Particle Size (μm)	Settling Rate (m/hr)
500	736
250	184
100	29.4
75	16.6
45	5.96
30	2.65
20	1.18
15	0.662
10	0.294
5	0.074
1	0.003

The particles to be settled in a typical clarifier tank may vary widely in particle sizes. This lead to an inefficient process as smaller particles need a longer time or bigger tank to process the same volume of wastewater. This limits the throughput which is the volume of wastewater that can be treated per unit time. An alternative is to use multiple sedimentation tanks either for particles of different sizes or to store large volumes of wastewater. Either way this requires a lot of space and is not applicable in land scarce countries or for a potable water purification system.

The sludge produced in a conventional clarifier tank has a high water content due to the poor settling rate, which results in more effort and cost to dewater in the subsequent sludge treatment before disposal.

Summary of the invention

In accordance with a preferred aspect, there is provided a tank for separating contaminants out of a flow of contaminated fluid and for discharging a clarified fluid, the tank comprising: (a) a topmost portion and a bottommost portion; (b) an inlet for delivering the contaminated fluid to the tank, the contaminants in the fluid affected by a magnetic field; (c) a clarified stream outlet for discharging the clarified fluid; (d) a sludge outlet for discharging the contaminants; and (e) at least one magnetic member positioned on a surface of the tank, wherein the at least one magnetic member is configured to generate a magnetic field of sufficient strength to attract the contaminants in the fluid within an interior of the tank to allow separation of the contaminants in the contaminated fluid to produce the clarified fluid.

By “tank”, it is meant to refer to any receptacle or storage chamber that is used to hold a fluid, especially a liquid. The interior volume of the tank will hold the fluid. A typical tank has a wall structure, a base structure, and optionally a top cover. As such, the tank’s wall structure will have two surfaces: one that is interior and faces the interior volume; and another that is exterior and faces the exterior of the tank. The tank can be of any shape and size suitable for the purpose. Examples of suitable shapes include a circular tank, a rectangular tank, a conical tank, an inverted pyramidal tank, or combinations thereof. The wall structure of the tank defines an interior of the tank and encloses the interior volume of the tank. The other surface of the wall structure forms the exterior of the tank.

By “topmost portion” of the tank, it refers to the portion of the tank including the cover or opening of the tank, the adjacent wall structure and the enclosed interior volume of the tank. By “bottommost portion” of the tank, it refers to the base structure, possibly a part of the wall structure adjacent to the base structure, and the enclosed interior volume of the tank. The topmost and bottommost portions of the tank may or may not need to be adjacent to each other.

By “clarified liquid”, it is meant to refer to a liquid solution that is clear and substantially free of solid insoluble matter, particularly solid matter which is attracted to a magnetic field. The discharge standard for treated waste water varies between countries. For example, in Singapore, the discharge standard of Total Suspended Solids (TSS) is set at 400mg/l and below. In Bangladesh, TSS level must be below 500mg/l for discharge into the public sewer and below 150mg/l for discharge into inland surface water. The clarified liquid could meet the discharge standard or may require further treatment steps depending on the initial waste water. By “contaminated liquid”, it is meant to refer to a liquid mixture that contains solid insoluble matter, particularly the solid matter is attracted to a magnetic field.

By “sludge”, it is meant to refer to a mixture of liquid and solid components in varying compositions.

By “magnetic member”, it is meant to refer to a component made of a material that is able to generate a magnetic field permanently or temporarily.

In an embodiment, the at least one magnetic member and the sludge outlet are positioned at the bottommost portion of the tank, and the clarified stream outlet is positioned at the topmost portion of the tank to allow the contaminants in the fluid to agglomerate towards the bottommost portion

of the tank. More preferably, the magnetic field has sufficient strength to increase the rate of agglomeration of the contaminants. An advantage of this arrangement is that the clarified liquid will continuously flow out of the clarified stream outlet when the level of the fluid in the tank reaches the opening of the clarified stream outlet, while the magnetic force and gravity works in unison to increase the settling rate of the contaminants.

By “agglomerate”, it is meant to refer to the collection of the magnetic particles in an area and they need not be bonded.

Preferably, the tank further comprises a first baffle arranged within an interior volume of the tank. The first baffle providing a guide for guiding / directing / controlling the flow of the fluid towards the bottommost portion of the tank, or keeping the flow of the fluid within the interior volume of the tank that is adjacent or near the bottommost portion of the tank. More preferably, the tank further comprises a second baffle arranged within an interior volume of the tank for keeping the settled contaminants within the bottommost portion of the tank. In an embodiment, the first and second baffles are integrally formed as a single unit.

By “baffle”, it is meant to refer to a device or structure that may be used to restrain or control the flow of a fluid within the interior of the tank or to prevent the spreading of the fluid in a particular direction. The baffle could be of any shape and size appropriate for the function.

Preferably, the inlet forms a conduit within the interior of the tank to deliver the contaminated fluid at or adjacent the bottommost portion of the tank.

The interior volume of the tank may be uniform. Preferably, the interior volume of the topmost portion of the tank is larger than the interior volume of the bottommost portion of the tank.

Preferably, the sludge outlet further comprises a valve. A valve is any device that controls the passage of fluid through a pipe or duct, especially in a single direction. Examples of some common valve types include a ball valve, a butterfly valve, a check valve, a diaphragm valve, a gate valve, a globe valve, a knife valve, a pinch valve, a piston valve, a plug valve, electric actuator and pneumatic actuator.

In another embodiment, the at least one magnetic member and sludge outlet are positioned at the topmost portion of the tank, and the clarified stream outlet is positioned at the bottommost portion of the tank to allow the contaminants in the fluid to agglomerate towards the topmost portion of the tank. An advantage of this arrangement is that it allows for fine solid matter that may float /
5 agglomerate in the water to be removed more easily.

Preferably, the tank further comprises a first baffle arranged within an interior volume of the tank, the first baffle provides a guide for controlling the flow of the fluid towards the topmost portion of the tank, or keeping the flow of the fluid within the interior volume of the tank that is adjacent or
10 near the topmost portion of the tank.

By "adjacent", it is meant to include terms such as close to, near to, next to, abutting, alongside, abreast of, contiguous with, proximate to, attached to, touching, joining, neighbouring or the like. As such, a key feature of the present invention is to have the sludge outlet adjacent the magnetic
15 member such that any agglomeration of the containments may be discarded or discharged from the tank with ease. Advantageously, the process of separating contaminants from a flow of contaminated fluid may be carried out in a continuous process without having the need to halt the process to remove any part of a component of the system.

20 Preferably, the interior volume of the bottommost portion of the tank is larger than the interior volume of the topmost portion of the tank.

Preferably, the clarified stream outlet further comprises a valve.

25 Preferably, the at least one magnetic member is positioned substantially adjacent the sludge outlet.

In an embodiment, the at least one magnetic member is water proofed and is positioned on an interior surface of the tank. Alternatively, the at least one magnetic member is positioned on an exterior surface of the tank.

30 Preferably, the at least one magnetic member is formed integral with the tank.

Preferably, the at least one magnetic member is selected from the group consisting of: permanent magnets, induction magnets, electro-magnets, induction coils, electrical coils, electrical wire sections or any combination thereof.

- 5 Preferably, the bottommost portion of the tank is tapered.

Preferably, the tank further comprises a sensor for sensing the amount of contaminants in the fluid.

- 10 Preferably, the tank is made from a non-magnetic material. More preferably, the non-magnetic material may be any material selected from the group comprising: plastic, concrete and ceramic. The plastic could be fibre-reinforced plastic or acrylic.

Preferably, the contaminants contain iron. The term "iron" here refers to any compounds or mixtures with elemental iron, iron cations, iron complexes, and/or iron based compounds.

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- In accordance with another preferred aspect, there is provided a method for separating contaminants out of a flow of contaminated fluid, the method comprising: (a) delivering the contaminated fluid to a tank having a topmost portion and a bottommost portion, the contaminants in the fluid affected by a magnetic field; (b) generating a magnetic field of sufficient strength within
20 an interior volume of the tank to attract the contaminants to agglomerate adjacent a surface of the tank; (c) separating the contaminants from the contaminated fluid to produce a clarified liquid.

- In an embodiment, the method further comprises allowing the contaminants to agglomerate towards the bottommost portion of the tank, wherein at least one magnetic member and a sludge
25 outlet is positioned at the bottommost portion of the tank. More preferably, the method further comprises discharging the contaminants via the sludge outlet by decreasing or eliminating the strength of the magnetic field. The magnetic field strength could be decreased or eliminated by removing or redirecting the magnetic field with a magnetic shield, or decreasing the current for an electromagnet, or switching off the electromagnet.

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Preferably, the method further comprises discharging the clarified liquid via a clarified stream outlet positioned at the topmost portion of the tank.

In an embodiment, the method may further comprise allowing the contaminants to agglomerate towards the topmost portion of the tank, wherein at least one magnetic member and a sludge outlet is positioned at the topmost portion of the tank. More preferably, the method further comprises skimming the contaminants from the topmost portion of the tank.

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Preferably, the method further comprises discharging the clarified liquid via a clarified stream outlet positioned at the bottommost portion of the tank.

10 Preferably, the method further comprises directing the contaminated fluid into the magnetic field with the aid of at least one baffle.

Preferably, the method further comprises determining the amount of the contaminants and removing the contaminants from the tank when the amount reaches a pre-determined threshold level.

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The embodiments of the present invention are extremely simple, compact and mobile in construction, and is highly efficient and economical in its operation.

20 Advantageously, the present invention allows for an increased concentration of solid matter contaminants, which are attracted to a magnetic field. This results in a higher throughput for the wastewater treatment and allows for a smaller clarifier tank and/or a shorter retention time in the clarifier tank. The rate of separation can also be adjusted as per requirements to adapt the process to a higher throughput or a lower operating cost. The sludge output is more concentrated with a lower water content such that subsequent treatment of the sludge is more efficient as well.

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Brief description of the figures

30 In order that the present invention may be fully understood and readily put into practical effect, there shall now be described by way of non-limitative examples only preferred embodiments of the present invention, the description being with reference to the accompanying illustrative figures.

Like reference numerals are used to designate like parts throughout the different embodiments of the present invention.

In the Figures:

Figure 1 is a schematic cross section view of a tank according to a first embodiment of the present invention;

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Figure 2 is a top view of a schematic of an electromagnet unit suitable for use with an embodiment of the present invention;

Figure 3 is a schematic cross section view of a tank according to a second embodiment of the present invention;

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Figure 4 shows the parameters used in the Biot-Savart law.

Figure 5 is a graph showing the Settling Rate against Particle Size for a known sedimentary tank;

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Figure 6 is a graph showing the Magnetic Force against Current; and

Figure 7 shows a graph of a normal clarifier tank compared to an embodiment of the present invention.

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Figure 8 shows a graph of a normal clarifier tank compared to an embodiment of the present invention with a smaller operating current.

Detailed description of the preferred embodiments

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Referring to Figure 1, a tank 100 of a first embodiment of the invention is shown. The tank 100 comprises a wall structure 12 and a base structure 14. The tank 100 may be an open tank or be provided with a fixed or removable cover. The physical structure of the tank 100 will enclose an interior volume or space of the tank 100 that is used to accommodate a liquid to be clarified or to allow sedimentation to occur. The tank 100 should be made of a non-magnetic material, examples of which are non-ferrous material, plastic, concrete, and ceramic. A specific type of plastic is fibre reinforced plastic and acrylic.

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The base structure 14 of the tank 100 can be flat or sloped such that the tank tapers for part or whole of the bottommost portion. The tank 100 can be elevated from the ground by external supports or placed partially in the ground with the required connections and support in the ground.

5 The tank 100 can be viewed as comprising of two portions with different purposes. The topmost portion 16 of the tank refers to the portion of the tank where a cover if any is present or the tank opening, a section of the wall structure 12 and the interior volume. The bottommost portion 18 refers to the base structure 14, possibly a section of the wall structure 12 adjacent to the base structure 14 and the interior volume. Depending on the inclination of the slope, the bottommost
10 portion 18 may include a section of the vertical wall section. When the base structure 14 is flat, the bottommost portion 18 must include a wall section 12 of the tank to define a bottommost portion 18 and volume for the sedimentation to occur as explained later. The dotted line in Figure 1 shows an example of possible topmost and bottommost portions. In this embodiment, the topmost portion 16 has a larger volume than the bottommost portion 18 of the tank.

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It is understood to the skilled person that any suitable tank may be used. The interior volume of the tank may be uniform, or may be tapered at the bottom half as is shown in Figure 1.

The tank 100 includes an inlet 20 for delivering a fluid to the tank 100. The tank 100 can function as a
20 typical sedimentation or clarifier tank 100 but preferably the fluid contains solid matter that will be attracted by a magnetic field to allow the sedimentation process to occur in a shorter period of time. The inlet 20 can be positioned to feed the tank 100 with the fluid at any position. But preferably the inlet 20 is shaped or positioned to feed the fluid towards the bottommost portion 18 of the tank 100 to minimise interaction with the fluid in the topmost portion 16 of the tank. The inlet 20 can further
25 form a conduit in the interior of the tank 100 to deliver the fluid at or adjacent the bottommost portion 18 of the tank 100.

The tank 100 includes a clarified stream outlet 22 for discharging the clarified liquid. The clarified stream outlet 22 is preferably located in the topmost portion 16 of the tank to allow the clarified or
30 cleaned fluid to be removed from the tank 100.

The tank 100 includes a sludge outlet 24 to discharge the sediments or contaminants in the fluid that accumulate or agglomerate at the bottommost portion 18 of the tank 100. Ideally when the base 14 is sloped, the sludge outlet is at the lowest edge of the sloped base 14. The sludge outlet 24 may

include a valve 30 to control the discharge of the sludge from the tank 100. The valve 30 can be manually controlled by a user or automatically controlled by a control unit.

The tank 100 may further include a first baffle 31 arranged within the interior volume of the tank 100 to guide the fluid from the inlet 20 towards the bottommost portion 18 of the tank. The position and size of the first baffle 31 is dependent on the positioning of the inlet 20, and is adjusted accordingly to minimise the interaction or disturbance of the clarified or clean fluid in the topmost portion 16 of the tank. The tank 100 may have a second baffle 32 arranged within the tank for keeping the settling or settled contaminants in the bottommost. The optimal position for the second baffle 32 depends on the tank 100 interior design. A possible position for second baffle 32 for the embodiment in Figure 1 will be in the centre of the tank 100 above the sludge outlet 24. The first baffle 31 and second baffle 32 could be integrally formed as a single baffle unit, for instance an L-shaped baffle. A third baffle 33 may be positioned in front of the clarified stream outlet 22 to minimise any solid matter from exiting the tank via the clarified stream outlet 22. Each of the baffle 31, 32, 33 could be attached separately to the tank 100 or be integrally built with the tank 100.

The tank 100 may further include a sensor 34, for example a Mixed Liquor Suspended Solids sensor, for sensing or detecting the amount of contaminants or solid matter in the bottommost portion 18 of the tank 100.

The sensor 34 should be positioned in the bottommost portion 18 or at the interface between the topmost 16 and bottommost portion 18 of the tank. The sensor 34 can be suspended from above through the tank opening, through the cover, from the cover and/or secured to the wall 12 of the tank 100 by a holder 36. The sensor 34 could send an output signal to a control unit or display panel to allow a user to monitor the amount of concentrated contaminants or solid matter in the bottommost portion 18 of the tank 100. The user will discharge the sludge in the bottommost portion 18 accordingly. The discharge of the sludge could also be automatically performed once a selected amount of contaminants or solid matter is reached. The control unit and sensor 34 could be an integral unit.

The tank 100 includes at least one magnetic member 26 positioned at the bottommost portion 18 of the tank 100. The magnetic member 26 must be able to generate a magnetic field in the tank 100. The magnetic field should be concentrated or strongest in the bottommost portion 18 of the tank 100 to attract the magnetic solid matter or contaminants towards the base 14 of the tank 100. The

magnetic member 26 could be a permanent magnet, an electromagnet 50, an induction magnet, an induction coil, an electrical coil, a section of electrical wire or any combinations thereof. The magnetic member 26 could surround the base 14 or bottommost portion 18 of the tank. Alternatively, multiple magnetic members 26 could be used instead. Optimally, the magnetic member 26 is placed as close as possible or substantially adjacent to the sludge outlet 24. The magnetic field of the magnetic member 26 should be sufficiently strong to increase the rate of concentration of the contaminants, especially the ferrous based contaminants. In an example, a pair of magnetic members 26 are placed on each side of the sludge outlet 24.

The magnetic member(s) 26 can be positioned at the interior or exterior of the tank 100, or more specifically on the interior surface or exterior surface of the base structure 14 of the tank 100. If the magnetic member 26 is placed in the interior of the tank 100, the magnetic member 26 should preferably be protected from direct contact with the fluid to prolong the lifespan of the magnetic member 26 by preventing rust formation and corrosion of the magnetic member 26, and potential problems with the electrical wiring in the case of an electromagnet 50. The magnetic member 26 could be provided with an external case 28 for this purpose. The external case 28 should be a non-magnetic material that is resistant to corrosion by the fluid, especially being water proofed or water resistant. A suitable material could be a plastic material. For an externally placed magnetic member 26, the external case 28 will protect the magnetic member 26 from the external surroundings. The magnetic member 26 can be possibly formed integrally with the tank 100 or specifically in the base structure 14 of the tank 100. Alternatively, the external case 28 is formed integral with the tank 100 and the magnetic member 26 is placed such an external case 28. Some common examples of ferrous material that can be used to make the magnetic member 26 include iron, nickel, cobalt, and most of their alloys, and a few naturally-occurring minerals like lodestone.

For the first embodiment 100, the magnetic member 26 applies a magnetic field in the bottommost portion 18 of the tank 100. Ideally, the magnetic field should cover and is concentrated in the whole bottommost portion 18. However, this is dependent on the tank 100 design and position of the magnetic member(s) 26 as well. The magnetic member 26 may extend along the wall 12 if required or desired. The magnetic field increases the rate of separation of a contaminated fluid containing solid matter that is attracted to the magnetic field.

A basic electromagnet 50 has an electrical wire wound around a magnetic core to allow the magnetic core to concentrate the magnetic flux and produce a more powerful magnet. A possible

design of an electromagnet unit 50 as the magnetic member 26 is shown in Figure 2. The electromagnet 50 comprises an inner copper core 52, a plurality of outer copper conductor layers 54, an external case 28, and at least one clamp 58 to attach the electromagnet unit to the tank 100. The electromagnet 50 is preferably operated at a constant magnetic field strength each time, with the ability to vary the magnetic field strength with the current.

The tank 100 is operated by delivering a contaminated fluid containing insoluble solid matter into the tank 100, and directing the fluid towards the bottommost portion 18 of the tank 100. For optimal use of the tank 100, the solid matter should be attracted to a magnetic field, for example the solid matter is ferromagnetic. In an example, the solid matter should contain ferrous or ferric based compounds, (i.e. Fe^{2+} , Fe^{3+} compounds) or any compounds that are able to be attracted by the magnet. This can be introduced in a prior chemical mixing step by adding chemicals like FeSO_4 or FeCl_2 , or by electrocoagulation methods comprising using an electrolytic cell to release iron cations into the solution by using iron or steel, or any other suitable ferromagnetic material, as the anode material. The coagulation of particles by the use of aluminium based chemicals alone, like alum, will not be affected by the magnetic field.

The flow of the contaminated fluid into the tank 100 via the inlet 20 can be continuous, periodic or user controlled. As the amount of fluid in the tank 100 increases, the fluid level in the tank increases towards the top of the tank. The solid matter in the tank 100 settles to the bottommost portion 18 of the tank 100 and the water in the topmost portion 16 of the tank is substantially free of solid matter. When the fluid level in the tank 100 reaches the level of the opening of the clarified stream outlet 22, the fluid exits the tank via the clarified stream outlet 22 and is discharged into the next treatment tank or into the environment. The rate of fluid flow in the inlet 20 is controlled to provide for sufficient time for the solid matter to settle or agglomerate in the bottommost portion 18. In an ideal scenario the inlet fluid flow is continuous and gentle such that it does not stir and disturb the accumulated solid matter in the bottommost portion 18. The first and second baffle 31, 32 serve to guide the contaminated fluid from the inlet 20 to the bottommost portion 18. This minimises the disturbance caused by the fluid flow and the recontamination of the clarified fluid in the topmost portion 16.

To allow the accumulated magnetic solid matter to be removed from the tank 100, the magnetic field is reduced or removed. If the magnetic member 26 is an electromagnet 50, removing the current from the electromagnet 50 should reduce or remove the magnetic field, allowing the solid

matter to be discharged from the tank 100 via the sludge outlet 24. If a permanent magnet is used, then the permanent magnet may be removed physically from the tank 100 or a commercially available magnetic shield is used to redirect the magnetic field away from the bottommost portion 18 of the tank 100.

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The magnetic force generated by an electromagnet 50 is a function of the applied current to the conductor, length of the conductor and magnetic flux density.

$$F_B = I * L * B \text{ ----- Equation 3}$$

10 where:

F_B is the magnetic force,

I is the applied current to the conductor,

L is the length of the conductor,

B is the magnetic flux density.

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$$\text{The magnetic flux density, } B = \mu * H = \mu * I / 2\pi * R \text{ ----- Equation 4}$$

where:

μ is the permeability of magnetic material,

H is the magnetic field strength,

20 R is the radius of the conductor.

As shown in Equations 3 and 4, the strength of magnetic force generated is dependent on the current and the radius of the conductor. As the radius of the conductor is constant, the current applied to the magnets can be varied to get different magnetic field strength. When the current is increased, the magnetic field strength is also increased. This increases the magnetic force and thus increases the settling velocity of the particle and in turn decreases the settling time of the particle.

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The magnetic flux density at a point dB is inversely proportional to the square of distance from the conductor to a point as shown in Figure 4. This is explained by Biot-Savart Law,

$$30 \quad dB \propto I * dl * \sin \theta / r^2$$

$$dB = k * I * dl * \sin \theta / r^2 \text{ ----- Equation 5}$$

where:

$$k = \mu_0 / 4\pi \quad (\mu_0 = 4\pi \times 10^{-7} \text{ N/A}^2)$$

I is current

dl is length of conductor carrying electric current I

r is the distance between the conductor and a point o

From Equation 5, the induced magnetic field is inversely proportional to the square of the distance between the conductor and the point in which the magnetic field is measured. Hence, the magnets attract the material which is closer to the magnets rather than those that are further. The baffle(s) 31, 32 is used to direct the contaminants towards the magnetic member(s) 26 and reduce the distance from the magnet field to the particles for better performance.

10 In an embodiment, the current is varied from 1 to 15A with a conductor length of 250m and conductor radius of 0.001m. The resultant magnetic force is shown in Table 2 and Figure 6.

Table 2

Current I (A)	Magnetic force F_B (N)
1	0.05
2	0.20
3	0.45
4	0.80
5	1.25
10	5.00
15	11.25

15 The key advantage electromagnets 50 have over permanent magnets is the ability to easily manipulate its magnetic field strength by varying the amount of electric current supplied to the electromagnets such that the electromagnetic clarifier's performance can be easily adjusted.

Without being limited by theory, by applying an additional external magnetic force in the first embodiment of the invention 100, the tank 100 uses magnetic force in addition to gravity force (applied force) and drag force to increase the rate of separation of the contaminants from the fluid. The magnetic force acts in unison with gravitational force to pull the solid matter towards the bottommost portion 18 of the tank, specifically the base 14, and be removed from the bottommost position 18 of the tank. The bottommost portion 18 of the tank need not necessarily be the base 14 but may be any portion in the tank where the contaminants accumulate or agglomerate. The

charged particles become attracted to each other in the magnetic field applied, and agglomerates to form larger particles which leads to a faster settling rate as shown in Table 1 previously.

In the alternative embodiment where the magnetic member is positioned at the topmost portion of the tank, the forces that keep the contaminants at the top of the tank are the magnetic force, surface tension and flotation, i.e. the combined forces overcome the gravitational force allowing the contaminants to float and be removed from the top of the tank. As is with the first embodiment of the invention, the topmost portion 16 of the tank may be anywhere near or at the top of the tank. However, it may be any portion in the tank where the contaminants accumulate or agglomerate.

With reference to Stokes Law in Equation 1, the settling velocity of particles when magnetic force is introduced is derived as

$$V_{sm} = (g + F(MF)) (\rho_p - \rho) D_{p1}^2 / 18\mu \text{ ----- Equation 6}$$

where:

V_{sm} is the magnetic clarifier settling velocity (m/s),

g is gravitational acceleration which is 9.81 m/s^2 ,

$F(MF)$ is the function of magnetic force in which $MF = I * L * B$ (I = current, L = Length of the conductor and B = magnetic flux density)

ρ_p is the mass density of the particle (kg/m^3),

ρ is the mass density of fluid (kg/m^3),

D_{p1} is radius of the particle after applying magnetic force (m),

μ is dynamic viscosity of water which is $1 \times 10^{-3} \text{ kg/ms}$.

Tables 3a and 3b shows the actual settling rate of a conventional clarifier and a clarifier tank 100 of the first embodiment of the invention. Figures 7 and 8 show the data in Table 3a and 3b respectively in graphical format and clearly shows that the rate of separation in the first embodiment of the invention is higher than a conventional clarifier.

Table 3a

Particle Size (μm)	Conventional Clarifier Settling Rate (m/hr)	Clarifier Settling Rate (m/hr) with Magnetic Force		
		1.25N	5.00N	11.25N
1	0.0134	0.015	0.02	0.03
5	0.336	0.379	0.5	0.72
10	1.344	1.52	2.03	2.89

15	3.02	3.41	4.57	6.49
20	5.38	6.06	8.12	11.54
30	12.09	13.64	18.26	25.97
45	27.21	30.68	41.09	58.43
75	75.6	85.23	114.13	162.29
100	134.4	151.52	202.89	288.5
250	839.98	947.01	1268	1803
500	3360	3788	5072	7213

Table 3b

Particle Size (μm)	Conventional Clarifier Settling Rate (m/hr)	Clarifier Settling Rate (m/hr) with Magnetic Force			
		0.05N	0.20N	0.45N	0.80N
1	0.0134	0.0135	0.0137	0.014	0.0145
5	0.336	0.338	0.343	0.351	0.363
10	1.344	1.351	1.371	1.41	1.45
15	3.02	3.04	3.09	3.16	3.27
20	5.38	5.4	5.49	5.62	5.81
30	12.09	12.16	12.34	12.65	13.08
45	27.21	27.35	27.77	28.46	29.443
75	75.6	75.98	77.14	79.07	81.76
100	134.4	135.08	137.14	140.56	145.36
250	839.98	844.26	857.11	878.51	908.48
500	3360	3377	3428	3514	3634

5 Figure 3 shows a second embodiment 200 of the present invention. Similar to the first embodiment, the tank 200 has a wall 12 and a base 14 with a topmost 16 and bottommost portion 18. In the second embodiment 200, the clarified stream outlet 22 is located at the bottommost portion 18 of the tank 200, while the sludge outlet 24 of the clarifier tank 200 is now located in the topmost portion 16 of the tank 200. Separate valve(s) 30 could be provided to allow control of the flow of clarified liquid and sludge from the respective clarified stream outlet 22 and sludge outlet 24. In an embodiment, the base 14 of the tank 200 is tapered towards the center leading to the clarified stream outlet 22. Alternatively, the base 14 may be flat with the clarified stream outlet 22 placed at the bottom of the tank. The base 14 could be shaped as described in the first embodiment 100. In any case, in all embodiments of the present invention, it is understood to the skilled person that the shape of the tank may take any suitable form, e.g. angular, circular etc. In any such tank, there can be any number of sludge outlets positioned in the tank with any number of magnetic members placed adjacent to such sludge outlets.

The tank 200 includes at least one magnetic member 26 positioned at the topmost portion 16 of the tank 200. The at least one magnetic member 26 could be placed at the topmost portion 16 of the

tank 200, either on its interior or exterior surface, adjacent to or near the sludge outlet 24. For the second embodiment, the magnetic member(s) exerts a magnetic field in the topmost portion 16 of the tank 200. The magnetic member(s) and field should preferably be near or substantially adjacent to the sludge outlet 24 for easier and more effective removal of the contaminants. As in the first embodiment, a first baffle 31 and/or second baffle 32 is shaped to guide the contaminated fluid from the inlet 20 into a region whereby the magnetic field of the at least one magnetic member 26 acts upon (in this embodiment the topmost portion 16 of the tank 200). This attracts the magnetic contaminants towards the top of the fluid surface. Preferably, the magnetic field is sufficiently strong to attract and retain the magnetic contaminants near the top surface of the fluid but allows the contaminants to remain suspended in the fluid or on the surface of the fluid.

In use, the tank 200 is filled by the contaminated fluid from the inlet 20. The first baffle 31 guides the fluid into the magnetic field in the topmost portion 16 thus attracting and retaining the magnetic contaminants in the topmost portion of the tank. The sludge outlet 24 is ideally positioned near the top of the tank to maximise magnetic attraction and concentration of the contaminants. This allows the contaminants to accumulate or agglomerate as a layer on the water surface. The skimming of the contaminants from the topmost portion 16 of the tank could be performed by allowing the sludge layer that builds up on the surface of the fluid to reach the opening of the sludge outlet 24 and thus overflow into the sludge outlet 24. This has the advantage that no additional operation need be performed. Alternatively, the at least one magnetic member or a mechanical skimmer could be used to guide the magnetic contaminants into or adjacent the sludge outlet 24.

The clarified water on the other hand remains in the tank and flows towards the bottommost portion 18, and towards the clarified stream outlet 22. A sensor 34 could also be provided as in the first embodiment near the sludge outlet 24 to allow for the automatic or user controlled discharge of sludge upon reaching a selected value of contaminants or solid particles. A control unit is connected to the sensor 34 and valve(s) 30 to allow for the control of the discharge of clarified fluid and sludge from the tank 200 as in the first embodiment.

When electrocoagulation is applied before the clarification, the generation of hydrogen and oxygen gases during the electrocoagulation process causes bubbling that float the solid matter to the water surface. Thus, this embodiment would be useful for solid material that has a tendency to float and requires a long settlement time. The use of the magnetic member(s) helps to attract and retain the

contaminants towards the surface of the fluid, increasing the rate of separation of contaminants from the contaminated fluid.

It may be possible for the tank of the first embodiment 100 and second embodiment 200 to be used in succession, as compartments or in a single tank design to remove solid matter with different physical properties more efficiently, thus producing water of higher purity.

The embodiments of the present invention can be used as a compact water clarification tank, in wastewater treatment plants, or as portable water treatment units in rural or disaster hit areas.

With a faster separating rate of the contaminants from the fluid, the retention time of the wastewater in the tank 100, 200 is reduced and allows a greater volume of wastewater to be treated per unit time compared to a conventional clarifier of the same size. The size of the tank 100, 200 can also be reduced compared to a conventional clarifier tank. This is important in any wastewater treatment projects where land or space to set up the necessary tanks and equipment is scarce. The magnetic force allows more solids to be collected per unit volume of sludge making the process more efficient when the sludge is treated subsequently to remove the water. In an example, the slurry collected from the tank 100 of the first embodiment has approximately 10% of solid matter content compared to 3 to 5% of solid matter content in a conventional clarifier, the remainder being water. This is a substantial and technically unexpected difference.

With the use of an electromagnet 50, the current can be adjusted according to the volume of wastewater to be treated for the most economical process. For instance, when the volume is low the current used is lower such that the magnetic force is lower and the settling time required is higher. Conversely, when the volume is high, a larger current is used for greater throughput.

In Table 4, a comparison between a conventional clarifier tank and embodiments of the present invention illustrates the benefits and differences.

Table 4

Conventional Clarifier Tank	Embodiments of the present invention
Addition of polymers required to effect the settlement of flocculation/sludge.	No polymers / chemicals required (if electrocoagulation is used in a prior step)

Due to the polymer dosing, excess sludge is produced.	No excess sludge produced (if electrocoagulation is used in a prior step)
Long retention time	Reduced retention time
Complex construction	Simple construction
Slurry has high water composition – 3-5% solids with the remainder as water. Low sludge collection efficiency as the quantity of solids to water ratio is low.	Slurry from the magnetic clarifier contains 5-10% of solids with the remainder as water. Sludge collection is more efficient as more solids can be collected per volume of slurry.
Slower separation rate	Higher separation rate
Fixed separation rate	Flexible separation rate
Larger footprint	Smaller footprint
Can be applied for all waste water treatment processes.	Can only be applied to waste water treatment processes that generate ferrous (magnetic) based sludge.
TSS removal efficiency is 70-75%	TSS removal efficiency is >90%
Turbidity removal efficiency is 90 – 95%	Turbidity removal efficiency is 90 – 99%
Different flow rates require different sized clarifier tanks.	Same sized clarifier tanks can be used for different flow rates / volumes by adjusting the magnetic field strength

Whilst there has been described in the foregoing description preferred embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations or modifications in details of design or construction may be made without departing from the present invention.

CLAIMS

1. A tank for separating contaminants out of a flow of contaminated fluid and for discharging a clarified fluid, the tank comprising:
 - 5 (a) a topmost portion and a bottommost portion;
 - (b) an inlet for delivering the contaminated fluid to the tank, the contaminants in the fluid affected by a magnetic field;
 - (c) a clarified stream outlet for discharging the clarified fluid;
 - (d) a sludge outlet for discharging the contaminants; and
 - 10 (e) at least one magnetic member positioned on a surface of the tank, wherein the at least one magnetic member is configured to generate a magnetic field of sufficient strength to attract the contaminants in the fluid within an interior of the tank to allow separation of the contaminants in the contaminated fluid to produce the clarified fluid.
- 15 2. The tank according to claim 1, wherein the at least one magnetic member and the sludge outlet are positioned at the bottommost portion of the tank, and the clarified stream outlet is positioned at the topmost portion of the tank to allow the contaminants in the fluid to agglomerate towards the bottommost portion of the tank.
- 20 3. The tank according to claim 2, wherein the magnetic field generated has sufficient strength to increase the rate of agglomeration of the contaminants.
4. The tank according to any one of claims 2 to 3, further comprising a first baffle arranged within an interior volume of the tank, the first baffle provides a guide for controlling the flow of the
25 fluid towards the bottommost portion of the tank.
5. The tank according to claim 4, further comprising a second baffle arranged within an interior volume of the tank for keeping the agglomerated contaminants within the bottommost portion of the tank.
- 30 6. The tank according to claim 5, wherein the first and second baffles are integrally formed as a single unit.

7. The tank according to any one of claims 2 to 6, wherein the inlet forms a conduit within the interior of the tank to deliver the contaminated fluid at or adjacent the bottommost portion of the tank.
- 5 8. The tank according to any one of claims 2 to 7, wherein the interior volume of the topmost portion of the tank is larger than the interior volume of the bottommost portion of the tank.
9. The tank according to any one of claims 2 to 8, wherein the sludge outlet further comprises a valve.
- 10 10. The tank according to claim 1, wherein the at least one magnetic member and sludge outlet are positioned at the topmost portion of the tank, and the clarified stream outlet is positioned at the bottommost portion of the tank to allow the contaminants in the fluid to agglomerate towards the topmost portion of the tank.
- 15 11. The tank according to claim 10, further comprising a first baffle arranged within an interior volume of the tank, the first baffle provides a guide for controlling the flow of the fluid towards the topmost portion of the tank.
- 20 12. The tank according to any one of claims 10 to 11, wherein the interior volume of the bottommost portion of the tank is larger than the interior volume of the topmost portion of the tank.
- 25 13. The tank according to any one of claims 10 to 12, wherein the clarified stream outlet further comprises a valve.
14. The tank according to any one of the preceding claims, wherein the at least one magnetic member is positioned substantially adjacent the sludge outlet.
- 30 15. The tank according to any one of the preceding claims, wherein the at least one magnetic member is water proofed and is positioned on an interior surface of the tank.
16. The tank according to any one of claims 1 to 14, wherein the at least one magnetic member is positioned on an exterior surface of the tank.

17. The tank according to any one of the preceding claims, wherein the at least one magnetic member is selected from the group consisting of: permanent magnets, induction magnets, electro-magnets, induction coils, electrical coils, electrical wire sections or any combination thereof.
- 5 18. The tank according to any one of the preceding claims, wherein the bottommost portion of the tank is tapered.
19. The tank according to any one of the preceding claims, the tank further comprising a sensor for sensing the amount of contaminants in the fluid.
- 10 20. The tank according to any one of the preceding claims, wherein the tank is made from a non-magnetic material.
21. The tank according to claim 20, wherein the non-magnetic material is any one selected from
15 the group comprising: plastic, concrete and ceramic.
22. The tank according to claim 21, wherein the plastic is selected from the group consisting of fibre-reinforced plastic and acrylic.
- 20 23. The tank according to any one of the preceding claims, wherein the contaminants contain elemental iron, iron cations, iron complexes, and/or iron based compounds.
24. A method for separating contaminants out of a flow of contaminated fluid, the method comprising:
- 25 (a) delivering the contaminated fluid to a tank having a topmost portion and a bottommost portion, the contaminants in the fluid affected by a magnetic field;
- (b) generating a magnetic field of sufficient strength within an interior volume of the tank to attract the contaminants to agglomerate adjacent a surface of the tank;
- (c) separating the contaminants from the contaminated fluid to produce a clarified
30 liquid.
25. The method according to claim 24, further comprising allowing the contaminants to agglomerate towards the bottommost portion of the tank, wherein at least one magnetic member and a sludge outlet is positioned at the bottommost portion of the tank.

26. The method according to claim 25, further comprising discharging the contaminants via the sludge outlet by decreasing or eliminating the strength of the magnetic field.

5 27. The method according to any one of claims 25 to 26, further comprising discharging the clarified liquid via a clarified stream outlet positioned at the topmost portion of the tank.

28. The method according to claim 24, further comprising allowing the contaminants to agglomerate towards the topmost portion of the tank, wherein at least one magnetic member and a
10 sludge outlet is positioned at the topmost portion of the tank.

29. The method according to claim 28, further comprising skimming the contaminants from the topmost portion of the tank.

15 30. The method according to any one of claims 28 to 29, further comprising discharging the clarified liquid via a clarified stream outlet position at the bottommost portion of the tank.

31. The method according to any one of claims 24 to 30, further comprising guiding the contaminated fluid into the magnetic field with the aid of at least one baffle.
20

32. The method according to any one of claims 24 to 31, further comprising determining the amount of the contaminants.

33. A tank for separating contaminants out of a flow of contaminated fluid substantially as
25 herein described with reference to any one of the examples or to any one of the accompanying figures.

34. A method for separating contaminants out of a flow of contaminated fluid substantially as
hereinbefore described with reference to any one of the examples or to any one of the
30 accompanying figures.