

APPARATUS AND METHOD FOR ANAEROBIC TREATMENT OF WASTEWATER

5 **Field of the Invention**

The present invention relates to an apparatus and method for treatment of wastewater. More particularly, the present invention relates to an apparatus and method for anaerobic treatment of wastewater. Still more particularly, this
10 invention relates to a segmented upflow reactor used in the anaerobic treatment of wastewater.

Background of the Invention

15 It is known that biological treatment of wastewater consists of breaking down organic impurities in wastewater through the action of suspended or fixed carrier material to which microorganism culture is attached, to reduce the biochemical oxygen demand (BOD) content in wastewater.

20 A wide variety of microorganisms and environmental conditions can be utilised for treatment of different types of wastewater. In order to maximize the efficiency of the biological treatment of wastewater, proper microbes must be chosen to interact with the pollutants to be treated and a suitable environmental condition must be provided to enhance the microbial activity as well as to increase the microorganism
25 population within the reactor.

Biological treatment of wastewater may be carried out in aerobic, anoxic or anaerobic environments. The choice of environment has a profound effect on both the ecology of the microbial community and the treatment of the pollutants.

30 Anaerobic processes have been used for several decades to treat wastewater. To anaerobically treat wastewater, the wastewater must first be exposed to microorganisms. The microorganisms convert organic matter in the wastewater

into biogas, such as, methane and carbon dioxide. This conversion is done in the absence of oxygen.

5 Numerous systems have been developed for the anaerobic treatment of wastewater to remove organic matter in the wastewater. Such systems include upflow batch reactor systems, upflow continuous flow reactors, upflow anaerobic sludge blanket digestion (UASB), etc. The advantages of upflow operation are well known. However, it also is known that upflow operation may involve certain drawbacks when it is attempted to optimize processes and installations. One such
10 drawback is that the bed may fluidize during upflow operation. Several techniques have been proposed to ensure a compact bed on the bottom of the vessel during upflow operation. However, the known processes and apparatus are relatively costly to maintain.

15 **Summary of the Invention**

The above and other problems are solved and an advance in the art is made by providing an apparatus and method for anaerobic treatment of wastewater in accordance with this invention. It is a first advantage of an apparatus and method
20 in accordance with this invention that a segmented upflow reactor is provided. It is a second advantage of an apparatus and method in accordance with this invention that the segmented upflow reactor comprises a plurality of carrier skids. It is a third advantage of an apparatus and method in accordance with this invention that a method for anaerobic treatment of wastewater using a segmented upflow reactor is
25 provided.

In accordance with some embodiments of this invention, the upflow anaerobic reactor comprises an enclosed vessel having a top and a bottom, an influent liquid conduit located proximate the bottom of the vessel for feeding wastewater into the
30 vessel, an effluent liquid conduit located proximate the top of the vessel thereby establishing a flow direction through the vessel from the influent conduit to the effluent conduit for discharging the treated water, wherein the vessel comprises a plurality of compartments arranged one on top of another, each of the plurality of compartments includes a plurality of carriers to which microorganisms are attached

to each of the plurality of carriers, and wherein the plurality of carriers in an uppermost compartment having a diameter smaller than the diameter of the plurality of carriers in a lowermost compartment. In accordance with some of these embodiments, the plurality of compartments being arranged one on top of another within the vessel.

In accordance with some of embodiments of this invention, the diameter of the plurality of carriers in the plurality of compartments decreases in the same direction as the flow direction of the wastewater through the vessel such that the plurality of carriers in an uppermost compartment has the smallest diameter and the plurality of carriers in the lowermost compartment has the largest diameter. In accordance with some of these embodiments, the plurality of carriers in the plurality of compartments is arranged in a fixed state. In accordance with others of these embodiments, the plurality of carriers in the lowermost compartment is arranged in a fixed state and the plurality of carriers in the uppermost compartment is arranged in one of a fixed state, a suspended state and a combination of fixed and suspended states. In accordance with yet others of these embodiments, at least one intermediate compartment is provided and the at least one intermediate compartment comprises plurality of carriers arranged in a fixed state.

In accordance with some of embodiments of this invention, the upflow anaerobic reactor further comprises a separating means that separates first one of the plurality of compartments from an adjacent second one of the plurality of compartments.

In accordance with some of embodiments of this invention, each of the plurality of compartments comprises a carrier skid having a housing made of a mesh material having side walls, a closed bottom, a removably attached top, and a carrier zone defined within the housing for receiving the plurality of carriers.

In accordance with some of embodiments of this invention, the upflow anaerobic reactor further comprises a mixing zone defined in the vessel proximate the bottom of the vessel, and a gas collection zone defined in the vessel for collecting biogas produced in the vessel. In accordance with some of these embodiments, the

upflow anaerobic reactor further comprises a recirculation line for re-circulating at least a portion of mixed liquor back to the vessel. In accordance with yet some of these embodiments, the reactor further comprises a programmable logic controller for controlling the re-circulation of the at least a portion of the mixed liquor back to the reactor.

In accordance with another embodiment of this invention, the method for anaerobic treatment of wastewater comprises feeding the wastewater to an enclosed reactor through an influent liquid conduit located proximate bottom of the reactor, allowing the wastewater to flow in an upward direction through a plurality of compartments containing a plurality of carriers to which microorganisms are attached to each of the plurality of carriers, thereby producing a mixed liquor and a biogas, re-circulating at least a portion of the mixed liquor back to the reactor, collecting the biogas produced within the reactor in a gas collection zone provided within the reactor and collecting treated water discharged from the reactor.

In accordance with some of the embodiments of this invention, the method further comprises re-circulating the at least a portion of the mixed liquor discharged from the effluent liquid conduit at intervals or continuously by means of a programmable logic controller.

Brief Description of the Drawings

The above and other advantages and features of this invention are described in the following detailed description and are shown in the following drawings:

FIG. 1 is a sectional view showing an embodiment of an upflow wastewater treatment reactor of the present invention;

FIG. 2(a) is a perspective view of an embodiment of a carrier skid to be used in conjunction with the reactor of the present invention;

FIG. 2(b) is a perspective view of another embodiment of a carrier skid to be used in conjunction with the reactor of the present invention;

FIG. 3 is a sectional view of a compartment of the reactor in accordance with an embodiment of the present invention containing a plurality of relatively small size carriers arranged in fixed state;

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FIG. 4 is a sectional view of another compartment of the reactor in accordance with an embodiment of the present invention containing a plurality of medium size carriers arranged in fixed state;

10 FIG. 5 is a sectional view of yet another compartment of the reactor in accordance with an embodiment of the present invention containing a plurality of large size carriers arranged in fixed state.

Description of the Invention

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The present invention relates to an apparatus and method for anaerobic treatment of wastewater in which pollutants such as organic matter contained in the wastewater can be effectively removed in a system. For the purposes of illustrating the invention, there is shown in the drawings a form which is presently preferred. It is being understood however that this invention is not limited to the precise arrangements shown.

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"Wastewater," as used herein, defines a stream of waste from a residential, commercial, or industrial source having pollutants. The pollutants may be, but are not limited to biodegradable material, inorganic compounds, and/or organic compounds capable of being decomposed by bacteria or other microorganisms. As used herein, a "wastewater treatment system" is a system, typically a biological treatment system, having a biomass population of one or more types of microorganisms used to digest biodegradable material or other material. Notably, the biomass requires an environment that provides the proper conditions for growth. The wastewater treatment apparatus and method as herein described may be used for treating low to high strength wastewater.

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Referring now to the drawings, embodiments of the present invention are described more particularly.

FIG. 1 shows one embodiment of an upflow anaerobic reactor for treatment of wastewater in accordance with the present invention. The upflow anaerobic reactor includes an enclosed vessel 10. The enclosed vessel 10 has a top 12, a bottom 14, an influent liquid conduit 16 located near the bottom of the vessel for feeding wastewater into the vessel 10, and an effluent liquid conduit 18 located near the top of the vessel for discharging treated water. The configuration of the influent and the effluent liquid conduits establishes an upward flow direction through the vessel 10.

The vessel 10 may be of any geometry capable of facilitating the flow of wastewater in an upflow configuration. For example, the vessel 10 may be substantially cylindrical, parallelepiped, or spherical in structure. Preferably, the vessel 10 is of a cylindrical geometry. The bottom end of the vessel is preferably conical as shown in FIG. 1. However, one skilled in the art will recognize that the bottom end of the vessel may take on other configurations without departing from this invention.

The reactor in accordance with this invention also comprises a recirculation line 20 for re-circulating at least a portion of the mixed liquor back to the vessel 10. The reactor further comprises a recirculation pump 22 located at the bottom 14 of the vessel for maintaining an upflow velocity of more than 0.2 m/hr of the wastewater through the reactor. In a preferred embodiment of this invention, the reactor is made from non-corrosive materials, such as, stainless steel. However, one skilled in the art will recognize that the vessel may also be made from other suitable materials without departing from this invention.

The vessel 10 of the reactor is divided into a plurality of compartments for receiving wastewater. Each of the plurality of compartments includes a plurality of carriers 32 to which microorganisms are attached to each of the plurality of carriers 32. In one embodiment of the invention, the vessel 10 is divided into at least two compartments. Preferably, the vessel is divided into at least four compartments

(herein designated first compartment 24, second compartment 26, third compartment 28 and fourth compartment 30) as shown in FIG. 1. More preferably, the vessel 10 is divided into at least three compartments. However, one skilled in the art will recognize that the vessel may be divided into more compartments without departing from this invention.

In an exemplary embodiment of the invention, the first compartment 24 is located near the bottom 14 of the vessel, the fourth compartment 30 is located near the top 12 of the vessel and the second compartment 26 and the third compartment 28 (hereinafter also refers to as the "intermediate compartments") are located between the first compartment 24 and the fourth compartment 30. The compartments 24, 26, 28 and 30 are configured such that each of the compartments contains carriers 32 of different sizes. In one embodiment of this invention, the first compartment 24 is packed with carriers having a largest diameter (as shown in FIG. 5). The second compartment 26 is packed with carriers having a diameter smaller than the carriers contained in the first compartment 24 (as shown in FIG. 4). The third compartment 28 is packed with carriers having a diameter smaller than the carriers in the second compartment (not shown). The fourth compartment 30 is packed with carriers having a diameter smaller than the carriers in the third compartment 28 (as shown in FIG. 3). The carriers 32 in the plurality of compartments 24, 26, 28, 30 are arranged such that the size of the carriers 32 decreases in the same direction as the upward flow direction of the wastewater through the vessel 10, and such that the carriers 32 in the uppermost compartment 30 (located nearest to the top of the reactor) has the smallest diameter and the carriers in the lowermost compartment 24 (located nearest to the bottom of the reactor) has the largest diameter.

In one embodiment of the invention, the carriers 32 in the lowermost compartment 24 and the intermediate compartment or compartments 26, 28 are preferably arranged in a fixed state. The carriers 32 in the uppermost compartment 30 are preferably arranged in a fixed state, a suspended state or a combination of fixed and suspended states. In the exemplary embodiment of the invention as shown in FIG. 1, the carriers 32 in the first, the second and the third compartments 24, 26, 28 are arranged in a fixed state and the carriers in the fourth compartment 30 are

arranged in a fixed state, a suspended state or a combination of fixed and suspended states. However, it should also be understood that other arrangements of the carriers in each of the plurality of compartments may be employed without departing from this invention.

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Preferably, the carriers 32 used in conjunction with the reactor of the invention have a size in the range of 5 to 200 mm in diameter. In one embodiment of the invention, the first compartment 24 of the reactor is packed with carriers having a size in the range of 100 to 200 mm in diameter. The second and the third
10 compartments 26, 28 are packed with carriers having a size in the range of 25 to 100 mm in diameter. The fourth compartment 30 is packed with carriers having a size in the range of 5 to 25 mm in diameter.

It is expressly noted, for the purposes of clarity, that the above configurations and
15 relative dimensions of the carriers, are provided by way of example only. As applies to this entire description, unless otherwise indicated, the configurations and relative dimensions provided herein should generally be considered as exemplary only and should not be seen to limit the invention in anyway.

20 The carriers 32 used in the invention are preferably porous particles of organic polymer compounds. Other suitable carriers may also be used, including, but not limited to, textile cloth, sphere carrier, cubic carrier, cylindrical carrier, and rectangular carrier. Preferably, carriers which offer the microorganisms a large surface area for attachment are used. The carriers 32 are preferably made from
25 polypropylene, polyurethane, high density polyethylene, polyethylene, polyamide, ceramic. However, one skilled in the art will recognize that the carriers may also be made from other materials as long as the carriers fulfil the indicated conditions.

In one embodiment of the invention, the vessel 10 includes separating means 34.
30 The separating means 34 partitions the vessel 10 into the respective compartments. The number of separating means provided in the vessel 10 varies according to the number of compartments to be partitioned within the vessel 10. Preferably, the separating means 34 is a mesh material having a mesh size in the range of 1 mm to 50 mm. The mesh size of each separating means provided in

the vessel varies according to the size and type of carriers provided in each compartment. In all cases, the mesh size of the separating means 34 should be small enough to retain the carriers within each compartment and large enough to enable sloughed biomass to pass through. Preferably, the mesh material of the separating means 34 is made of metal; fibreglass; or plastic, such as, polypropylene, polyurethane, high density polyethylene, polyethylene and polyamide. However, one skilled in the art will recognize that other suitable materials may be employed without departing from this invention.

In another embodiment of the invention, the vessel 10 is divided into a plurality of compartments 24, 26, 28, 30 by multiple carrier skids 36 installed in the vessel 10. The multiple carrier skids 36 are aligned substantially in parallel either longitudinally or laterally within the vessel 10 or they are arranged one on top of another within the vessel 10. As illustrated in FIG. 2(a) and FIG. 2(b), each carrier skid 36 preferably comprises a housing 38 having side walls, a closed bottom 40 and a removably attached top 42. The housing 38 of each of the carrier skid 36 defines a compartment when each of the carrier skid 36 is installed in the vessel 10. The housing 38 of the carrier skid 36 is adapted to receive the plurality of carriers 32 to which microorganism culture is attached. The housing 38 may be of a rectangular, square or cylindrical configuration. Alternatively, the housing 38 may take on a configuration that complements the configuration of the reactor such that the carrier skid 36 can be fitted readily within the reactor. However, one skilled in the art will recognize that the housing may take on other shapes without departing from this invention.

The housing 38 of the carrier skid 36 is made of a mesh material. The mesh material preferably has a mesh size in the range of 1 mm to 50 mm. The mesh size varies according to the size and type of carriers provided within the housing. The side walls, the closed bottom 40 and the top 42 of the housing of the carrier skid 36 may have the same mesh size or different mesh sizes. In all cases, the mesh sizes of the side walls, the closed bottom 40 and the top 42 of the housing of the carrier skid 36 should be small enough to retain the carriers within the carrier skid and large enough to enable sloughed biomass to pass through. Preferably, the housing 38 of the carrier skid 36 is made of metal; fibreglass; or plastic, such

as, polypropylene, polyurethane, high density polyethylene, polyethylene and polyamide. However, one skilled in the art will recognize that other suitable materials may be employed without departing from this invention.

5 The carrier skid 36 or the housing 38 also comprises at least one lug 44 attached to the housing 38 to facilitate movement of the housing and placement of the housing within the reactor. The lug 44 may take any form and size that enables the carrier skid 36 to be secured to the reactor. In one embodiment of the invention, the lug 44 is in a shape of a loop as shown in FIG. 2. The lug 44 can be
10 an integral part of the housing or a separate part that is attached to the housing. The lug 44 may be made from any suitable material that has sufficient strength to withstand the weight of the carrier skid when the carrier skid is lifted.

The lug 44 may be one of a plurality of lugs attached to the housing. Preferably, at
15 least two lugs are attached to the housing. More preferably, four lugs are provided when the housing is of a rectangular or square configuration, and each lug 44 is disposed at each top corner of the housing 38. Further, one skilled in the art will recognize that the lugs may be removably attached and/or placed along other areas of the housing without departing from this invention.

20 The carrier skid 36 has a mixing zone 48 formed at the lower section of the housing 38 and below the carrier zone 21. The mixing zone 48 is formed by a mixing means disposed in the housing 38 for mixing the wastewater in the housing 38 when needed.

25 In one embodiment of the invention, the mixing means is a pipe 52 as shown in FIG. 2(a). The pipe 52 is removably attached to the housing 38, with one end of the pipe being perforated and positioned within the mixing zone 48. Preferably, the one end of the perforated pipe is shaped as a loop such that the pipe 52 has
30 more perforated surfaces within the mixing zone 48 to provide a more uniform mixing of the wastewater in the housing 38 when air is supplied through another end of the pipe. One skilled in the art will recognise that other shapes or forms may be employed as long as sufficient perforated surfaces are provided within the

mixing zone 48. The amount of air supplied to the perforated pipe varies according to the type of wastewater to be treated.

5 In another embodiment of the invention, the mixing means is an agitator or a propeller-type stirrer 50 as shown in FIG. 2(b). The agitator or the stirrer 50 is removably attached to the housing 38, with one end of the agitator or stirrer being positioned within the mixing zone 48. The agitator or stirrer 50 can be designed, for example, of a simple rod or a cable extending from the top of the housing to the mixing zone 48. The tip speed of the agitator or stirrer varies according to the type of wastewater to be treated. Furthermore, placement of the stirrer 50 in the system is a design choice left to those skilled in the art to maximize a desired flow of the wastewater.

15 Between the carrier zone 21 and the mixing zone 48, there is provided another mesh material 51 for separating the two zones. The mesh material 51 is preferably made from the same material as the housing 38. However, other suitable material may be used without departing from this invention. The size of the mesh of the mesh material 51 varies according to the type of carriers provided in the carrier zone 21. In all cases, the size of the mesh should be small enough to retain the carriers within the carrier zone 21 and large enough to enable turbulence, created by the mixing means, to flow through to the carrier zone 21. The mesh material 51 may be an integral part of the housing or a separate part removably provided between the two zones.

25 In one embodiment of this invention, the carrier skid 36 may be provided with legs 46 for supporting the carrier skid 36 within the vessel 10. When the carrier skid 36 with legs is installed in the reactor as the lowermost compartment 24, a space between the bottom 40 of the carrier skid and the bottom of the vessel 10 will be formed. In one embodiment of the invention, this space may serve as the mixing zone 53 for the reactor.

In another embodiment of the invention, plurality of carrier skids may be installed in the reactor without the legs 46. In this configuration, the mixing zone 53 of the reactor will be formed by having a mesh material 55 disposed above the bottom of

the vessel 10 such that a space between the mesh material 55 and the bottom of the vessel 10 is created, defining a mixing zone 53.

The mixing zone 48, 53 is provided in the reactor to mix the influent liquid and the re-circulated mixed liquor evenly prior to introducing the influent liquid and the mixed liquor into the reactor for treatment. The mixing of the liquor can be carried out using mechanical mixing means, for example, an agitator or a stirrer or by air mixing. One skilled in the art will recognize that more than one mixing zone may be provided within the vessel 10 without departing from this invention.

In some embodiments of the invention, the legs 46 of the carrier skid 36 may be removably attached to the bottom 40 of the housing 38 of the carrier skid or they may form an integral part of the housing 38 of the carrier skid 36.

In other embodiments of the invention, the vessel 10 may be divided into a plurality of compartments by using multiple separating means 34 or by using multiple carrier skids 36. Alternatively, the vessel 10 may be divided into a plurality of compartments by using a combination of the separating means 34 and the carrier skids 36.

When the plurality of carriers provided in the carrier zone 21 are arranged in a fixed state as shown in FIG. 3, where no mixing of the wastewater is required, the mesh material 51 can optionally be removed so that more carriers can be packed within the housing.

The reactor of the invention also comprises a gas collection zone 54 located at the top 12 of the reactor. The gas collection zone 54 is used to collect biogas, such as, methane produced during the treatment process.

When in operation, wastewater is fed into the reactor through the influent liquid conduit 16 located at the bottom 14 of the vessel 10 by a feed pump 56. The wastewater is first subject to mixing in the mixing zone 48 to evenly mix the organic matter present in the wastewater before the wastewater ascends and fills up the first compartment 24. The wastewater is retained in the first compartment 24 until

a predetermined time is reached before it ascends and fills up the second compartment 26. This step is repeated in each compartment as the wastewater ascends through the multiple compartments in the vessel 10 until the wastewater reaches the effluent liquid conduit 18. As the wastewater ascends through the multiple compartments, degradation of organic matter and nitrogen takes place. Biogas is produced during the degradation process and ascends in the same direction as the upward flow direction of the wastewater until the biogas reaches the gas collection zone 54. The biogas is collected at the gas collection zone 54 and discharged through an outlet for use as an energy source. The treated water overflows from the uppermost compartment 30 of the vessel 10 and discharges out of the vessel 10 through the effluent liquid conduit 18. At least a portion of the mixed liquor within the vessel 10 is re-circulated back to the bottom 14 of the reactor through the re-circulation line 20. The at least a portion of the mixed liquor at the bottom 14 of the reactor is then subject to mixing with fresh influent feeds through the influent liquid conduit 16 in the mixing zone 48. The well mixed wastewater then ascends and fills up the first compartment 24 again. The above steps are repeated to continue the treatment of the wastewater.

In one embodiment of the invention, the re-circulation of the mixed liquor discharged from the effluent liquid conduit into the reactor is automated. It is controlled by means of a programmable logic controller (or PLC). The PLC allows the mixed liquor to be re-circulated at intervals or continuously. The PLC can selectively pre-programme a suitable intermittent re-circulating pattern to re-circulate the mixed liquor into the reactor at intervals. Depending on the type of wastewater to be treated, the reactor can be pre-programmed to re-circulate the mixed liquor for 5 minutes or more or it can be pre-programmed to stop the re-circulation for less than or about 2 hours. In some embodiments, the reactor can be set to re-circulate the mixed liquor continuously. One of the advantages of having a PLC incorporated into the reactor is that it allows better control of the treatment process. If it is found that the wastewater discharged from the effluent liquid conduit does not meet the pre-specified requirements of treated water, the wastewater or mixed liquor can be re-circulated back into the reactor by pre-setting a suitable duration for re-circulation until the treated water meet the pre-specified requirements. This allows one to have a better control over the re-circulation

process and the overall performance of the reactor. The PLC also allows one to control the re-circulation process remotely.

5 The reactor according to the present invention has several advantages. One of which is that the reactor allows microorganisms to grow in different biofilm structures at different sections of the reactor. This optimizes the microbial activity within the reactor. The treatment efficiency of the reactor is thus improved. In addition, the reactor of the invention can also function as a filtration media when the carriers in the reactor are arranged in a fixed state and different sizes of the
10 carriers are also provided. The described configuration of the carriers allows organic contaminants and suspended growth microorganisms to be captured within the carriers. This helps optimize the microbial activity within the reactor and enhance the efficiency of degradation of organic matter in the wastewater. Furthermore, the reactor of the invention may also be operated under mesophilic
15 or thermophilic conditions.

The advantage of using the carrier skids and the separating means in the reactor in accordance with this invention is that the carrier skids and the separating means are able to retain the carriers in a designated location within the reactor. If no
20 means is provided to separate the different layers of carriers in the reactor, the carriers from one layer may migrate to another layer as the wastewater flows through the reactor in an upward direction. This will result in an uneven distribution of the carriers in each layer and in turn, result in an uneven distribution of the microorganisms within the reactor. This may adversely affect the microbial activity
25 within the reactor and the efficiency of the reactor.

The alternative embodiment of the reactor of the invention provides flexibility in terms of design choice as the use of carrier skid in the reactor allows one to customise the reactor according to the type of wastewater to be treated. The
30 carrier skid is easily movable and hence, it makes installation and removal of the carrier skid easier. The lugs attached to the housing of the carrier skid enable the carrier skid to be lifted easily from the reactor. If one carrier skid fails to function efficiently in the reactor, the entire carrier skid can be easily lifted and removed for repair purposes. A new carrier skid may then be installed without the need to wait

for the old carrier skid to be fixed in order for the reactor to be in operation again. The use of multiple carrier skids in the reactor of the present invention thus provides a more efficient and cost effective way of treating wastewater.

- 5 The above is a description of the subject matter the inventors regard as the invention and is believed that others can and will design alternative processes that include this invention based on the above disclosure.

CLAIMS:

1. An upflow anaerobic reactor for treatment of wastewater comprising:
 - an enclosed vessel having a top and a bottom;
 - 5 an influent liquid conduit located proximate the bottom of the vessel for feeding wastewater into the vessel;
 - an effluent liquid conduit located proximate the top of the vessel thereby establishing a flow direction through the vessel from the influent conduit to the effluent conduit for discharging treated water;
 - 10 a mixing zone provided proximate the bottom of the vessel for mixing the wastewater; and
 - wherein the vessel comprises a plurality of compartments arranged one on top of another, each of the plurality of compartments includes a plurality of carriers to which microorganisms are attached to each of the plurality of carriers, and
 - 15 wherein the plurality of carriers in an uppermost compartment having a diameter smaller than the diameter of the plurality of carriers in a lowermost compartment.
2. The upflow anaerobic reactor according to claim 1, wherein the diameter of the plurality of carriers in the plurality of compartments decrease in size in the
20 same direction as the flow direction of the wastewater through the vessel such that the plurality of carriers in the uppermost compartment has the smallest diameter and the plurality of carriers in the lowermost compartment has the largest diameter.
3. The upflow anaerobic reactor according to claim 1, wherein the plurality of
25 carriers in the plurality of compartments is arranged in a fixed state.
4. The upflow anaerobic reactor according to claim 1, wherein the plurality of carriers in the lowermost compartment is arranged in a fixed state, and the plurality of carriers in the uppermost compartment is arranged in one of a fixed state, a
30 suspended state and a combination of fixed and suspended states.
5. The upflow anaerobic reactor according to claim 4, wherein the plurality of compartments includes at least one intermediate compartment between the

lowermost compartment and the uppermost compartment, the at least one intermediate compartment comprises plurality of carriers arranged in a fixed state.

6. The upflow anaerobic reactor according to claim 1, further comprising:

5 a separating means that separates first one of the plurality of compartments from an adjacent second one of the plurality of compartments, wherein the separating means having a mesh size small enough to retain the plurality of carriers within each compartment and large enough to allow sloughed biomass to pass through.

10 7. The upflow anaerobic reactor according to claim 1, wherein each of the plurality of compartments comprising:

a carrier skid having a housing made of a mesh material, side walls, a base, a removably attached top, and a carrier zone defined within the housing for
15 receiving the plurality of carriers.

8. The upflow anaerobic reactor according to claim 7, wherein the carrier skid further comprising:

a mixing zone provided proximate the base of the housing;

20 a mixing means provided within the mixing zone;

a separating means disposed within the housing to separate the carrier zone from the mixing zone;

a plurality of legs removably attached to the base of the housing; and

25 at least one lug attached to the housing to facilitate movement of the housing and placement of the housing.

9. The upflow anaerobic reactor according to claim 1, further comprising:

30 a gas collection zone defined in the vessel for collecting biogas produced in the vessel.

10. The upflow anaerobic reactor according to claim 1, further comprising:

a dedicated recirculation line for re-circulating at least a portion of mixed liquor discharged from the uppermost compartment back to the vessel using a recirculation pump.

- 5 11. The upflow anaerobic reactor according to claim 10, further comprising:
a programmable logic controller for controlling the recirculation pump to recirculate the at least a portion of the mixed liquor back to the reactor.
- 10 12. A method for anaerobic treatment of wastewater, the method comprising:
feeding wastewater to an enclosed reactor through an influent liquid conduit located proximate bottom of the reactor;
mixing the wastewater at a mixing zone provided proximate the bottom of the reactor;
allowing the wastewater to flow in an upward direction through a plurality of
15 compartments, each of the plurality of compartments containing a plurality of carriers to which microorganisms are attached, and wherein the plurality of carriers in an uppermost compartment having a diameter smaller than the diameter of the plurality of carriers in a lowermost compartment, thereby producing a mixed liquor and biogas;
20 re-circulating at least a portion of the mixed liquor discharged from the uppermost compartment back to the reactor through a dedicated recirculation line;
collecting the biogas produced within the reactor in a gas collection zone provided within the reactor; and
collecting treated water discharged from the reactor.
- 25 13. The method according to claim 12, further comprising:
mixing the re-circulated mixed liquor with fresh wastewater in the mixing zone provided within the reactor.
- 30 14. The method according to claim 12, further comprising:
re-circulating the at least a portion of the mixed liquor discharged from the uppermost compartment to the reactor at intervals or continuously by means of a programmable logic controller.