



(51) International Patent Classification:

C02F 3/02 (2006.01) C02F 9/14 (2006.01)
C02F 3/24 (2006.01)

(21) International Application Number:

PCT/IN2021/051166

(22) International Filing Date:

13 December 2021 (13.12.2021)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

202011054437 14 December 2020 (14.12.2020) IN

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,

(54) Title: A MODULAR SYSTEM AND METHOD FOR ONSITE WASTEWATER TREATMENT AND RESOURCE RECOVERY

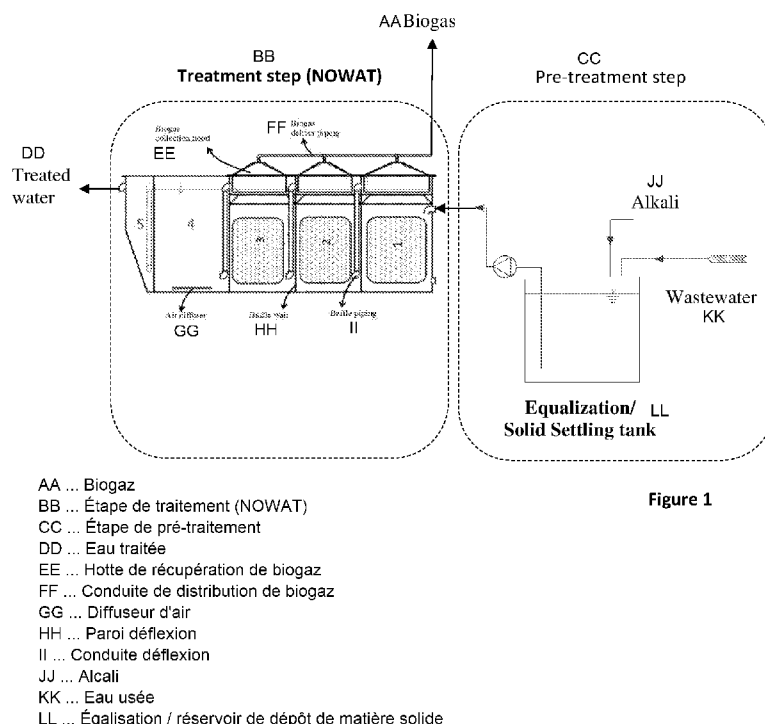


Figure 1

(57) Abstract: The present invention discloses a biological wastewater treatment system and its mode of operation that enables onsite treatment of organic wastewater, and simultaneous recovery of resources like bioenergy, reuse quality water, and organic manure. The treatment system uses microbial strains that are hydrolytic bacteria and methanogenic Archaea along with anaerobic protozoa and micro-metazoa. In comparison with the existing onsite wastewater treatment systems, the present invention has many advantages as it has immense application for small establishments like restaurants, catering units, canteens, small communities, houseboats, agro-based MSMEs, etc. and hence this will be a better substitute that will find wide application in many sectors.

UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

A MODULAR SYSTEM AND METHOD FOR ONSITE WASTEWATER TREATMENT AND RESOURCE RECOVERY

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FIELD OF THE INVENTION

The present invention relates to a modular system and method for onsite wastewater treatment and resource recovery. In the present invention, both aerobic and anaerobic microbial process modules are integrated along with a sludge handling module, which helps in the treatment of high strength organic wastewater, while simultaneously recovering valuable resources like reuse quality water, biofuel, and organic manure. The present invention also relates to the prefabrication and installation of the system at sites for treating organic-rich wastewater generated from small establishments like restaurants, canteens, community halls, agro-based MSMEs, etc. The instant invention shall help meet the 6th sustainable developmental goal of clean water and sanitation.

BACKGROUND OF THE INVENTION AND DESCRIPTION OF THE PRIOR ART

There exists a growing gap between the wastewater generated and treated in most of the developing countries. The discharge of untreated and/or poorly treated organic-rich wastewater from houses and small/medium business and industrial establishments is the main cause of water environment deterioration in many countries. Moreover, to comply with environmental regulations, there is a great demand for robust onsite wastewater treatment systems. They further pointed out anaerobic treatment as the core technology for mineralizing organic compounds in wastewater streams. Meanwhile, wastewater is considered as a renewable resource from which potable/non-potable water and energy (e.g., from anaerobic digestion processes), as well as fertilizers, could be derived; see Metcalf & Eddy (2003) Wastewater Engineering: Treatment and Reuse, fourth ed. McGraw Hills, New York, revised.

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A number of studies have reported the significance of “decentralized wastewater treatment systems” also known as “onsite wastewater treatment systems” or “off-the-grid wastewater

treatment systems”, and their potential to recover reuse quality water, bioenergy, and fertilizer. Some of the most common types of onsite wastewater treatment technologies are the Moving Bed Bio-Reactor (MBBR) process, Membrane Bio-Reactor (MBR) process, Sequence Bio-Reactor (SBR) engineered ecosystems (Phytoremediation) systems, etc. All these technologies are either one or a combination of fluidized bed type, fixed-film type reactors, and/or sludge bed type systems. However, these technologies have inherent limitations such as, not suited for high strength wastewater, large space (phytoremediation) and energy (SBR, MBBR) requirement, large carbon footprint due to the free release of CH₄, NO₂ & CO₂, secondary sludge disposal (SBR, MBBR), limited to secondary treatment alone, not designed for recovering bioenergy or fertilizer, etc. These onsite treatment systems mainly targeted sewage (with COD ~500 mg/L) from domestic and commercial establishments. However, modular, onsite treatment systems for treating both low strength as well as high strength wastewater, and simultaneously recovering reuse quality water, bioenergy, and organic manure were reported very rarely.

Among the early reports on onsite wastewater treatment systems, a high-efficiency household wastewater treatment plant employing a flow equalization, anoxic-oxic recirculation biofilm process removing organic matter and nitrogen were reported by Imura M., Sato Y., Inamori Y., Sudo R (1995) “Development of a high-efficiency household biofilm reactor”, *Water Science and Technology*, 31, 9, 163-171. The said system was tested for treating greywater. In a latter report, the same group has reported the performance of the system for treating wastewater from hotels, restaurants, etc. also. See Nakajima J, Fujimura Y, Inamori Y (1999) Performance evaluation of onsite treatment facilities for wastewater from households, hotels, and restaurants. *Water Sci Technol.* 39, 85-92. In detail, the system includes a pre-treatment process (sedimentation separation tank, anaerobic filter, or equalization tank with screens) followed by an aerobic process (contact aeration, activated sludge, etc.). However, these sanitation systems are basically designed for domestic sewage treatment.

Onsite wastewater treatment systems reported in the past have also used different media for supporting microbial growth. Both organic and inorganic materials were used as biofilter media. For example, peat-based biofilter medium was used in one study as reported

by Talbot P, Belanger G, Pelletier M, Arcand GL (1996) Development of a biofilter using an organic medium for on-site wastewater treatment, *Water Science and Technology*, 34, 435-441. The anaerobic module in this invention encloses a very unique bacteria carrier medium, a biopolymer (Structured filter bed, formed of high lignin-containing natural fiber) based filter bed, which is environment friendly and biodegradable. However, the drawbacks of the previously reported peat-based media are its availability, cost, pre-processing required and its disposal (especially for inorganic media). Compared with the existing filter beds reported, the present filter bed of present invention is based on agro-residue, it is easily available, cheaper, it provides more surface areas for biofilm formation, and since it is environment benign its disposal is easy.

Onsite wastewater treatment systems with a series of anaerobic-aerobic units were reported previously by Ghunmi LA., Zeeman G., Fayyad M., vanLier JB (2010) Grey water treatment in a series anaerobic-aerobic system for irrigation. *Bioresource Technology*, 101, 1, 41-50. The anaerobic unit is the up-flow type with a one-day operational cycle and the aerobic unit with a mechanical aeration device. The COD removal efficiency reported was up to 53%, and the treated water was meant for irrigation. However, the Onsite wastewater treatment systems was applied for treating grey water which has a low COD (<500 mg/L), also the COD removal efficiency achieved was only 53% (in summer). On the other hand, the present invention can treat high strength organic wastewater (COD>2000 mg/L), and the COD removal efficiency was >60%.

Reference may be made to US 9890067 which discloses a modular wastewater treatment system for treating organic wastewater by passing through multiple treatment steps. This unit is suggested optimal for rural communities, livestock farms, or buildings. However, the modular wastewater treatment system is designed for treating discharges from rural communities, livestock farms and building, also it has an artificial wetland at the final stage for purification that needs more space to occupy. On the other hand, in the present invention find application for any type of organic wastewater. Moreover, the terminal purification will be achieved through a compact aerobic module with sludge management mechanism.

Reference may be made to US 20190016618 which discloses an apparatus, method, and system of wastewater treatment using modular membrane bioreactor (MBR) cartridges. Through adjusting the MBR modules and wastewater processing rate, changes the quality of treated water. However, the installation and operational costs of modular membrane bioreactor (MBR) units are high. Additionally, the disposal of the MBR module is another limitation. On the other hand, the present invention comprises of a combined anaerobic-aerobic modules with additional sludge handling module that is more economical and environment friendly.

Reference may be made to US 9828 268 and US 9321 666 which report a wastewater treatment system with modular membrane bioreactor cartridges. The major component of the wastewater treatment system is a microbial fuel cell (MFC) compartment. However, the drawbacks using MBR cartridge and an MFC units are its higher installation and operational costs. The disposal of the MBR cartridge will be another practical challenge. On the other hand, the present invention comprises of a combined anaerobic-aerobic modules with additional sludge handling module that is more economical and environment friendly.

Reference may be made to US 9719704B2 that discloses a system and method for recovering energy from wastewater. The treatment system is basically a membrane bioreactor, integrated with a heat exchanger for recovering the thermal energy. However, the installation and operational costs are high by using MBR as the major treatment system. The disposal of the MBR module will be another practical challenge. On the other hand, the present invention comprises of a combined anaerobic-aerobic modules with additional sludge handling module that is more economical and environment friendly.

Many of the onsite wastewater treatment systems reported include combined anaerobic and aerobic process units with an initial sedimentation tank (equalization tank). For example, US 7820048 discloses a system and method for treating organically contaminated wastewater. The treatment system includes a sedimentation tank, an anoxic mixing chamber for denitrifying the wastewater, and a biological contactor for nitrification. However, the treatment system is basically an advanced denitrification process, and it is not suitable for onsite treatment of wastewater in residential and small commercial applications in hydraulic

sensitive areas. On the other hand, the present invention is an onsite treatment for organic wastewater for any locations.

Similarly, AU2006298434B2 covers a treatment system consisting of a sedimentation tank, anoxic mixing chamber for denitrification, rotary biological contactor for nitrification and assimilation of organics. However, this treatment system is also an advanced denitrification process. On the other hand, the present invention is an onsite treatment for organic wastewater (removing organics and nutrients), and for recovering reuse quality water and bioenergy.

Reference may be made to US 8101079B1 which discloses an onsite wastewater treatment system with baffled cells that work in conjunction with an underground septic tank. It used functionalized green filter media made up of tire crumb, sawdust, orange peel, coconut husks, leaf compost, oyster shell, soybean hulls, and one or more naturally occurring materials including peat, sands, zeolites, and clay to create a saturated anoxic or anaerobic condition. However, the onsite wastewater treatment system is meant for removing nitrogen and phosphorus from septic tank effluent, also it is an underground filter system, but not modular. Whereas the present invention is an onsite treatment for organic wastewater (removing organics and nutrients), and for recovering reuse quality water and bioenergy.

Reference may be made to US 2019010066 A1 which discloses a decentralized wastewater treatment system for removing phosphorus. The treatment system basically includes a sedimentation chamber, anaerobic treatment system, and an aerobic treatment system along with a system for removing phosphorus in the wastewater by introducing a chemical agent. However, the decentralized wastewater treatment system is primarily a system for removing phosphorus. On the other hand, the present invention is an onsite treatment for organic wastewater (removing organic and nutrients), and for recovering reuse quality water and bioenergy.

Reference may be made to US 8137544 which discloses a modular wastewater treatment system consisting of a moulded tank with baffle walls. The entire treatment system includes a pre-treatment tank and aeration chambers and a clarification chamber. The pre-treatment chamber deploys anaerobic bacterial action to precondition the wastewater. The aerobic

bacteria in the aeration chamber biologically convert the wastes into stable products. The clarification chamber settles any biologically active material and returns it to the aeration chamber. However, the drawbacks of the modular wastewater treatment system are that it cannot handle organic rich wastewater ($\text{COD} > 2000 \text{ mg/L}$), and it is not designed for recovering reuse quality water and bioenergy. Whereas the present invention is an onsite treatment for organic wastewater (removing organic and nutrients), and for recovering reuse quality water and bioenergy.

Similarly, a group of researchers from Japan have reported an onsite wastewater treatment system named Johkasou with anaerobic and aerobic tanks. It was meant for treating household wastewater with organic loading $\sim 0.076 \text{ kg BOD/m}^3/\text{day}$. However, the Johkasou is designed for treating household wastewater (sewage) with a $\text{COD} > 500 \text{ mg/L}$. On the other hand, the present invention is an onsite treatment that treat a wide range of COD (500 to 4000 mg/L), and it can recover both reuse quality water and bioenergy.

Reference may be made to Imura M., et al. 1995. Development of a high-efficiency household biofilm reactor. *Water Science and Technology*. 31, 9, 163-171, which reports a system with high virus removal efficiency. However, the existing high-efficiency household biofilm reactor is designed for treating household wastewater (sewage) with a $\text{COD} > 500 \text{ mg/L}$. On the other hand, the present invention is an onsite treatment that treat a wide range of COD (500 to 4000 mg/L), and it can recover both reuse quality water and bioenergy.

The discharge of untreated or poorly treated organic wastewater from small establishments such as hotels, restaurants, community halls, residential units, agro-based MSMEs cause severe environmental deterioration and associated public health and socio-economic problems. The existing treatment systems have many inherent drawbacks including not suitable for high strength wastewater, large space requirement, and high-operational cost. Moreover, these systems are not tuned for recovering resources from the wastewater.

Accordingly, keeping in view the drawbacks of the hitherto reported prior art, the inventors of the present invention realized that there exists a dire need to provide a novel onsite wastewater treatment system that overcomes the drawbacks of the wastewater treatment

systems reported till date and provides a better substitute for the onsite wastewater treatment along with the recovery of resources like reuse water, bioenergy and organic fertilizer while having low operational cost and low C footprint. The need of the hour is to provide a modular wastewater treatment system that consists of integrated anaerobic and aerobic process module, sludge handling, and disinfection module (optional) connected in series, wherein the system is customized with respect to the size of each process modules the liquid flow rate, solid retention time etc. with a unique sludge handling mechanism including electrically controlled cyclic oxic-anoxic conditions as well as operation of electrically controlled mechanical device which are specific and help in maintaining Mixed Liquor Suspended Solids (MLSS) level; the system further comprising a biopolymer based filter-bed in the anaerobic system; wherein the system can treat wastewater with a wide organic strength, COD in the range of 400 mg/l to 5000 mg/l and wherein nearly 80 % COD can be recovered as methane rich biogas.

15 OBJECTIVES OF THE INVENTION

The main objective of the present invention is therefore to provide a modular system and method for onsite wastewater treatment and resource recovery which obviates the limitations of the hitherto reported prior art.

20 Another objective of the present invention is to provide an engineered system for the treatment of organic-rich wastewater which is capable of recovering resources like clean water, bioenergy, and organic manure.

25 Yet another objective of the present invention is to provide a system that is modular, scalable, and wherein low carbon footprint and energy is required for operation.

Still another objective of the present invention is to provide a biopolymer-based filter-bed to support biofilm growth.

30 Yet another objective of the present invention is to provide a wastewater treatment system wherein the sludge (Bio-solid) build-up is very low.

Another objective of the present invention is to provide a modular system for onsite treatment of high strength wastewater from small establishments.

SUMMARY OF THE INVENTION

5 The present invention relates to a modular onsite wastewater treatment system comprising different process modules like anaerobic, aerobic and sludge handling. The system of the present invention is very unique in its construction as well as arrangement in terms of each process modules. More specifically, the anaerobic process module is unique in terms of the biomass support material used (biopolymer), and its gas-liquid separation device. Similarly,
10 the mode of operation of the aerobic process module is different in its cyclic oxic-anoxic conditions and associated sludge handling. The mode of operation of the sludge handling unit is also different in terms of its sludge return mechanism. Therefore, the present invention is not merely an arrangement and rearrangement of known devices, but a system with unique features and method of operation that brings in novelty and higher efficiency in terms its
15 capability to treat wastewater with wide organic strength with COD ranging from 500-5000 mg/L.

In an embodiment, the present invention provides a novel, engineered, modular system for the treatment of organic-rich wastewater, and to recover reuse quality water, bioenergy, and
20 manure. The present invention further provides a system that includes integrated anaerobic, aerobic, and sludge handling process modules in a sequence.

In another embodiment, the present invention provides a system that is useful for the onsite treatment of organic-rich wastewater (decentralized wastewater treatment), especially
25 where sewerage connections are not available. The system finds immense application for small establishments like restaurants, catering units, canteens, small communities, houseboats, agro-based MSMEs, and the like.

In still another embodiment, the microbial strains are selected from the activated sludge
30 collected from various STPs including but not limited to hydrolytic bacteria and methanogenic Archaea along with anaerobic protozoa and micro-metazoa (Rotifer). The protozoa and micro-metazoa used are Rotifer, Nematodes, etc.

In yet another embodiment, the present invention provides a novel system, and method for onsite treatment of wastewater, and recovers resources like reuse quality water, bioenergy, and organic manure wherein the said system comprises of:

- 5 1. anaerobic module
 2. aerobic module
 3. a sludge handling module; and
 4. disinfection module.

10 In another embodiment of the present invention, the anaerobic process module encloses a biopolymer-based filter bed, augmented with mesophilic hydrolytic bacteria and methanogenic Archae, protozoa, and micro-metazoa.

 In still another embodiment of the present invention, the aerobic process module comprises
15 heterotrophic microbial consortium in suspension or attached to a biopolymer-based filter bed.

 In yet another embodiment of the present invention, sludge handling module is used for concentrating and separating the excess sludge from the treated water.

20

 In still another embodiment of the present invention, the wastewater treatment system is an engineered biological system built on both anaerobic and aerobic microbial processes.

 In yet another embodiment of the present invention, a general design for the treatment
25 system, for each wastewater type, is customized e.g., size of each process modules, the liquid flow rate, solid retention time, and the like.

 In still another embodiment of the present invention, the sludge handling mechanism is unique. It includes the operation of electrically controlled cyclic oxic-anoxic condition as well as operation of electrically controlled mechanical device which is very specific.

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In another embodiment of the present invention, the biopolymer-based filter bed within the anaerobic module, provides maximum contact of the wastewater with the biofilm for more efficient working of the anaerobic system.

- 5 In yet another embodiment of the present invention, the system can handle wastewaters with wide COD strength (400 mg/L to 5000 mg/L).

In still another embodiment of the present invention, the recovery of biogas from the incoming waste stream is nearly 80%.

10

In yet another embodiment of the present invention, the operation of electrically controlled cyclic oxic-anoxic condition as well as operation of electrically controlled mechanical device is specific and helps in maintaining MLSS level, as well as controlling excess sludge build-up (which is digested in the anaerobic module).

15

In still another embodiment of the present invention, the anaerobic system involves multiple tanks connected in series as a single modular unit. The unit can be fabricated in Fibre Reinforced Plastic (FRP), Stainless steel or any corrosion resistant material.

- 20 In yet another embodiment of the present invention, the size of each process modules, and the operational conditions like HRT, SRT, MLSS level, etc. are based on the wastewater composition and volume.

25 In still another embodiment of the present invention, the biopolymer-based filter bed is made up of high lignin containing natural fibre-based needle felt, which is biodegradable. The needle felt high quality coir fibres is adopted for Biofilm support medium in this invention. It is commercially available (for different other purposes). In the present invention the material was procured from a cooperative society (under govt. of Kerala) in Thiruvananthapuram district.

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In yet another embodiment of the present invention, the developed system is capable of treating organic rich wastewater with COD in the range 500 to 5000 mg/L.

5 In still another embodiment of the present invention, the system comprises an integrated anaerobic-aerobic process module for handling high strength wastewater.

In yet another embodiment of the present invention, the packing material used is unique, as it is a natural fibre-based biopolymer, which is more environment friendly and biodegradable.

10 DETAILS OF BIOLOGICAL RESOURCES USED IN THE INVENTION

The microbial strains used in the present invention comprise hydrolytic bacteria and methanogenic Archaea along with anaerobic protozoa and micro-metazoa (Rotifer) present in the sludge obtained from activated sludge systems of a conventional wastewater treatment system. Activated sludge (AS) is composed of aerobic and anaerobic microorganisms such as
15 bacteria, archaea, fungi, and protists. It is capable of degrading organic compounds, including petroleum products, toluene, and benzopyrene. Activated sludge is also the name given to the active biological material produced by activated sludge plants

The present invention encompasses two entirely different bioprocess modules, one anaerobic
20 and an aerobic. These two process modules accommodate “self-adapted microbial systems” catalysing the treatment/removal of different pollutants in the wastewater. The design aspects of the treatment unit (provision for solid-liquid-gas separation, biofilm support medium, etc.), and its operational conditions (Redox potential, dissolved oxygen, liquid flow rate, retention time, etc.) helps to enrich a mixed microbial system (undefined consortium)
25 necessary for the removal of pollutants (organics and nutrients) in the targeted wastewater. This treatment unit will find application for the treatment of a variety of wastewater with different compositions. There will be an initial inoculum (enrichment culture) for both the modules. However, this start up microbial system in both modules gets tuned (self-adapted) gradually. This is a kind of “Engineered natural selection”. As already stated, undefined
30 consortium (mixed microbial system) in the form of activated sludge has been used in the present invention and accordingly, the same cannot be submitted to any repository.

The source of start-up culture [sludge] used for both modules is detailed as follows-

The anaerobic process module has an enrichment microbial system dominated with Bacteria, Archaea and Protozoa working under anaerobic conditions. This microbial system has been developed from the sludge collected from an existing high-rate anaerobic bio-treatment unit located in CSIR-NIIST, Thiruvananthapuram (Kerala) campus.

The aerobic process module on the other hand has an enrichment microbial system (self-adapted mixed culture) dominated with Bacteria, Archaea, Protozoa and Micro-Metazoan working under anaerobic conditions. This microbial system has been developed from the activated sludge collected from the Muttathara Sewage Treatment Plant located at Sewage Farm, Valiyathura, Bheema, Pilli St, Thiruvananthapuram city (Kerala).

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

Figure 1: Illustrates the over all process layout of NIIST Onsite Wastewater Treatment system) treatment (NOWAT) system with pre-treatment steps and the modular treatment system.

Figure 2: Illustrates a schematic view of the treatment system showing anaerobic, aerobic and sludge settling modules, drain valves and sampling ports.

Figure 3: Schematic representation of internal details of the modular onsite treatment system; wherein

1, 2 and 3 represents the anaerobic chambers with the biopolymer-based filter bed (pattern);
4 represent the aerobic module,
5 represents the sludge handling and disinfection module

Figure 4: Schematic showing the internal details of the gas liquid separator and the covering hood.

Figure 5: Represents the layout of aeration tank showing sludge return piping, positions of submersible pumps (1 and 2), and air diffuser, etc.

Figure 6: Represents a schematic of the sludge settling tank with return lines and submersible pump.

5 DETAILED DESCRIPTION OF THE INVENTION

The modular onsite wastewater treatment system developed in the present invention is a combined anaerobic-aerobic microbial process with unique microorganisms in each process unit. The modular treatment system comprises four modules:

- (1) anaerobic module
- 10 (2) Aerobic module
- (3) Sludge handling module; and
- (4) Disinfection module.

The present treatment system is developed for treating high strength organic wastewater
15 with COD in the range of 400 to 5000 mg/L, that is normally discharged from small establishments like hotels, restaurants, canteens, food processing units, agro-based small industrial units, etc. The present treatment system integrates the principles of both anaerobic and aerobic microbial processes in specially designed bioreactors system that help to recover reuse quality water, organic manure, and biogas as resources.

20

In the developed treatment system, wastewater from the equalization tank (pH ~7, ambient temperature) is initially introduced into an anaerobic treatment system (Figure 1). The anaerobic treatment system consists of an anaerobic baffled reactor with surface modified biopolymer as the biofilm support material for the sustained growth of a specially developed
25 anaerobic microbial system. The anaerobic module works at a hydraulic retention time (HRT) of around 12 hours. Nearly 70-80% of the inlet COD reduction happens at this stage, where it is converted as methane-rich (>60%) biogas. The residual COD is oxidized in the subsequent aerobic treatment module. The number of chambers of the baffled reactor depends on the strength and volume of the wastewater. For example, a 2000 L wastewater with an average
30 COD of 2000 mg/L can be treated in a baffled reactor with three chambers.

The treated effluent from the anaerobic module is directly and continuously pumped into the aerobic treatment module. The aerobic treatment system is basically a suspended microbial growth system with the rich fauna of a higher trophic microbial community that helps in a very good settling property. With the active microbial system, MLSS is maintained at 2-3 g/L level. The dissolved oxygen in the aerobic system is maintained at >2 mg/L using a fine bubble diffuser connected to an air blower. The aeration is automatically stopped intermittently to create an oxic-anoxic condition for reducing/oxidizing the nutrients (N and P) in the wastewater. The timing of the oxic-anoxic cycles depends on residual COD as well as NH₃, PO₄, TN, and TP levels.

The aerobic treatment module is followed by a sludge settling module with a short 30 min HRT. The settled sludge is frequently transferred back to the aeration tank through submerged pumps, the working of which is controlled automatically.

The excess sludge formed in the aeration tank (~30% of the inlet COD) is periodically pumped back to the anaerobic treatment module, where it is hydrolyzed and converted into biogas. The clear supernatant from the sludge settling tank is collected temporarily before distribution. A disinfection module (chlorination or ultrafiltration unit) is introduced before the discharge line. The final treated water from this system meets all discharge standards in terms of COD, BOD, NH₄-N, PO₄-P, etc.

The size of the present treatment system depends on the volume of the wastewater as well as its strength (COD or BOD). Depending on these two parameters, the size of the present treatment system is customized. The basic units (modules) of the system remain the same irrespective of its size. If there is a space constrain in placing the present treatment system, one can consider the present treatment system in distinct multiple pieces such as an anaerobic module as one-piece, aerobic module as another, and sludge handling and disinfection as separate. This will provide enough flexibility for installing the present treatment system in retrofit mode.

The present treatment system can be fabricated in Fibre Reinforced Plastic [FRP] reinforced with a metal frame. It can also be fabricated in SS (304), MS with inside epoxy coating, or with

any suitable similar material that tolerates mechanical stress, and corrosion. All internal piping can be in PVC. As already mentioned, the NOWATT (NIIST Onsite Wastewater Treatment system) is an integrated anaerobic-aerobic microbial process, with additional sludge handling and disinfection features. As a general process scheme, the wastewater after primary treatment (as detailed above), is initially treated anaerobically with a mixed microbial methanogenic culture. Nearly 60-80% of the inlet COD is removed at this stage and is recovered as methane-rich (>60% v/v) biogas. The residual COD is treated in the aerobic module with mixed aerobic culture (obtained from activated sludge). The overflow from the aerobic module is collected in a sludge settling tank. The clear supernatant (meeting all discharge standards) from the sludge handling module is released out. Alternatively, it is subjected to disinfection (chlorination) before discharging out.

The anaerobic module

The wastewater after primary treatment (solid removal and pH correction), is exposed to the anaerobic module. Nearly 80% of inlet total COD is removed at this stage and is recovered as biofuel (methane-rich biogas).

The anaerobic module as a whole is a closed tank with a chamber, baffled walls, and packed with biopolymer-based filter bed for enhanced microbial activity (Figures 2 and 3). The volume and number of chambers depend on wastewater volume and its organic strength (COD).

The design of each chamber in the anaerobic module is specific, ensuring maximum cross of the wastewater through the filter bed. The unique design of the anaerobic module also ensures efficient gas-liquid separation, and collection of the biogas into the top hood for recovery and use (Figure 4).

The filter bed is formed of biopolymer (needle felt natural fiber with high lignin content). At the start-up stage, the anaerobic chambers are filled with 1/3 volume of a mixed microbial culture dominated with mesophilic methanogens. The volatile fatty acid (VFA) and alkalinity (ALK) of the starter culture is tested and the VFA/ALK ratio should be <0.5 before starting the

system. The biogas produced from the anaerobic chambers is collectively stored in a high-quality polymer balloon, from where it is delivered further.

The Aerobic Module

5 The treated water from the anaerobic module is directly exposed to the aeration tank. The residual COD in the water is oxidized at this stage. The aeration tank is a suspended or an attached growth mixed microbial system, mostly aerobic bacteria, protozoa, and micro-metazoa. The active cell quantity in the aeration tank is around 3 g/L level (dry weight). To sustain the microbial activity, the dissolved oxygen level in the aeration tank is maintained at
10 >2 mg/L level, bypassing compressed air through fine bubble diffusers in the aeration tank. The excess sludge that builds up in the aeration tank is periodically concentrated and pumped back to the anaerobic module where the sludge is digested. A timer controlled submersible pump is used for periodic removal of sludge from the aeration tank (Figure 5).

15 Sludge handling module

The sludge handling module comprises two chambers in series. The first chamber (sludge settling tank) is directly connected to the aeration tank through piping. The overflow from the sludge settling tank get collected in a second tank (storage tank), from where it flows to the disinfection module. The continuously overflowing suspended microbes (Mixed Liquor
20 Suspended Solids or MLSS) from the aeration chamber settle in the first settling tank.

The accumulated sludge from the settling tank is periodically returned back to the aeration tank with a submersible pump (Figure 6). The top clear water from the sludge settling tank overflows into the clean water collection tank. The water from this tank is delivered out.
25 Alternatively, if disinfection (through chlorination) or ultrafiltration is required, the water will be passed through the disinfection module.

Disinfection module

To improve the treated water quality further, clean water from the second chamber (storage
30 tank) of the sludge handling module is taken for disinfection by various approaches. Standard disinfection practices like chlorination, ozonation, or UV disinfection are followed for

disinfection purposes. The disinfected water can be directly discharged or used for external purposes.

The efficiency of the present invention to treat organic-rich wastewater and to recover reuse quality water and bioenergy was tested in a case study at a pilot scale, and the details are covered in the following section.

EXAMPLE

The following examples are given by way of illustration only and therefore should not be construed to limit the scope of the present invention in any manner.

Example 1: Treatment of high strength organic wastewater from a canteen

A modular, onsite wastewater treatment cum resource recovery unit based on the system of the present invention was fabricated, and it was tested for treating ~ 2000 Litter organic rich wastewater from a canteen. The treatment system (3000 Lit capacity) in this case was fabricated in Fibre Reinforced Plastic (FRP). It consists of a three chambered anaerobic module (total volume 2000 Lit), aerobic module (750 lit), and the sludge handling module (250 Lit). The biofilm support medium was the same as described in detailed specification section. The anaerobic module was operating at a hydraulic retention time (HRT) ranging between 12-18 hours whereas, the aerobic module operated at around 12 hrs. The wastewater from the canteen after pre-treatment which included a flow equalization and pH correction step in an equalization tank was pumped into the treatment system. The treatment system was operated for about one-year period. The performance data of the treatment system including raw wastewater characteristics, from the anaerobic module, and aerobic module are summarized in Table 1.

The treated water meeting discharge standards for inland application was used for gardening purpose. The initial anaerobic treatment of wastewater (anaerobic module) produced around 400 lit biogas, with an average methane content of 62%, and carbon di oxide 37% and remaining hydrogen sulphide and ammonia.

Table 1: Performance details of a NOWAT system treating organic wastewater from a canteen

Parameters	Raw wastewater	Anaerobic effluent	Aerobic effluent
COD (mg/L)	1162	419	46
BOD (mg/L)	592	219	2.6
Total solids (mg/L)	2705	1508	292
Total suspended solids (mg/L)	397	117	4.25
Total dissolved solids (mg/L)	2307	1391	287
Dissolved oxygen (mg/L)	4.63	1.39	7.48
pH	6.45	6.73	7.36
Total Kjeldhal nitrogen (TKN) (mg/L)	48.6	20.4	0
NH ₄ -N (mg/L)	5.54	16.9	0

The above example 1 illustrates a system that can treat wastewater with COD of around 1100 mg/l.

Table 2: Performance details of a NOWAT system treating organic wastewater from a bakery unit

Parameters	Raw wastewater	Anaerobic effluent	Aerobic effluent
COD (mg/L)	2496	343	39.2
Total solids (mg/L)	3083	1386	296.5
Total suspended solids (mg/L)	835	140	6.5
Total dissolved solids (mg/L)	2248	1246	290
Dissolved oxygen (mg/L)	4.4	0.64	7.20
pH	6.6	6.73	7.36

ADVANTAGES OF THE INVENTION

- The developed system recovers re-used water or clean water, bioenergy (biogas), and organic manure from organic-rich wastewater.
- The system works on the principle of anaerobic and aerobic microbial processes, achieving the performance of both secondary (organic removal) and tertiary treatment (nutrient removal) systems.
- Suitable for onsite treatment of organic-rich wastewater from small establishments such as hotels, restaurants, canteens, marriage halls, food processing units, agro-based MSMEs, etc.
- The developed modular treatment system uses less space for installation.
- The developed system involves secondary and tertiary treatment.
- It obviates frequent sludge disposal problem.
- It is a completely biological treatment system.
- It can be installed with minimum civil work at the site.
- It can recover and reuse water and biogas as resources.
- The system can be retrofitted with existing infrastructure.
- The system treats wastewater with COD ranging between 400 to 5000 mg/L.
- Nearly 80% of the inlet COD will be recovered as methane-rich biogas.
- The system is modular (prefabricated) with a very low footprint and energy requirements for operation.

We Claim:

1. A modular system and method for onsite treatment of wastewater, wherein the said system comprising an integrated, anaerobic process module [1, 2 and 3 in figure 2], aerobic process module [4 in figure 2], sludge handling module [5 in figure 2] and disinfection module [5 in figure 2], connected in series; wherein the anaerobic process module comprises a biopolymer based filter bed [1, 2 and 3 (Pattern) in figure 2], augmented with anaerobic microbial consortium dominated with hydrolytic bacteria and mesophilic methanogens; the aerobic process module contains heterotrophic microbial consortium in suspension or attached to a biopolymer based filter bed; and the sludge handling module concentrates and separates the excess sludge from the treated water.
2. The system as claimed in claim 1, wherein the organic wastewater collected (HRT>2 hrs) in an equalization/sedimentation tank (pre-treatment) after pH correction (~7) and temperature normalization (20-35 °C) is introduced directly into the first chamber of the anaerobic module and as the wastewater passes through the different sub chambers of the anaerobic module, the enclosed biofilter media in these sub chambers recover >80 % of the total COD in the wastewater as biogas, which is collected in the hood on top of each sub chambers in the anaerobic module, together delivered out through the biogas delivery pipe, wherein the treated water from anaerobic module's last sub chamber passes directly into the aerobic module, where the residual COD is oxidized by the intermittently aerated flocculated sludge; the treated water from the aerobic module directly passes to the sludge handling module where sludge settles to the bottom, and clear water formed is discharged out after disinfection; wherein the settled sludge is periodically returned into the aeration tank and the excess biosolid buildup within the aerobic module is periodically removed and digested in the anaerobic module, eliminating the need for sludge wastage.
3. The system as claimed in claim 1, wherein different process modules such as the anaerobic module with sub-chambers, aerobic module, and the sludge handling and disinfection are assembled as a single unit or multiple units connected in series.

4. The system as claimed in claim 1, wherein the system executes decentralized (onsite/off the grid) treatment of organic wastewater with wide COD ranging from 400 to 5000 mg/L.
5. The system as claimed in claim 1, wherein the biopolymer-based filter bed is made up of high lignin containing natural fibre-based needle felt and is biodegradable.
6. The system as claimed in claim 1, wherein electrically controlled cyclic aeration-non aeration condition helps in concentrating sludge at regular intervals in the aeration module.
7. The system as claimed in claim 1, wherein the concentrated, excess secondary sludge is removed from aerobic module and biologically treated (digested) in the anaerobic module with an electro-mechanical device.
8. The system as claimed in claim 1, wherein the gas-liquid separating structure [Gas-liquid separator, figure 4] and top lid [Biogas hood, figure 4] together form a water seal that prevents biogas free escape but helps its collection.
9. The system as claimed in claim 1, wherein the system having footprint of ~0.02 sq ft/litre.
10. The system as claimed in claim 1, wherein the anaerobic module can recover >80% of the inlet COD in the wastewater as biofuel (biogas) along with clean water, biogas and organic manure from organic rich wastewater.

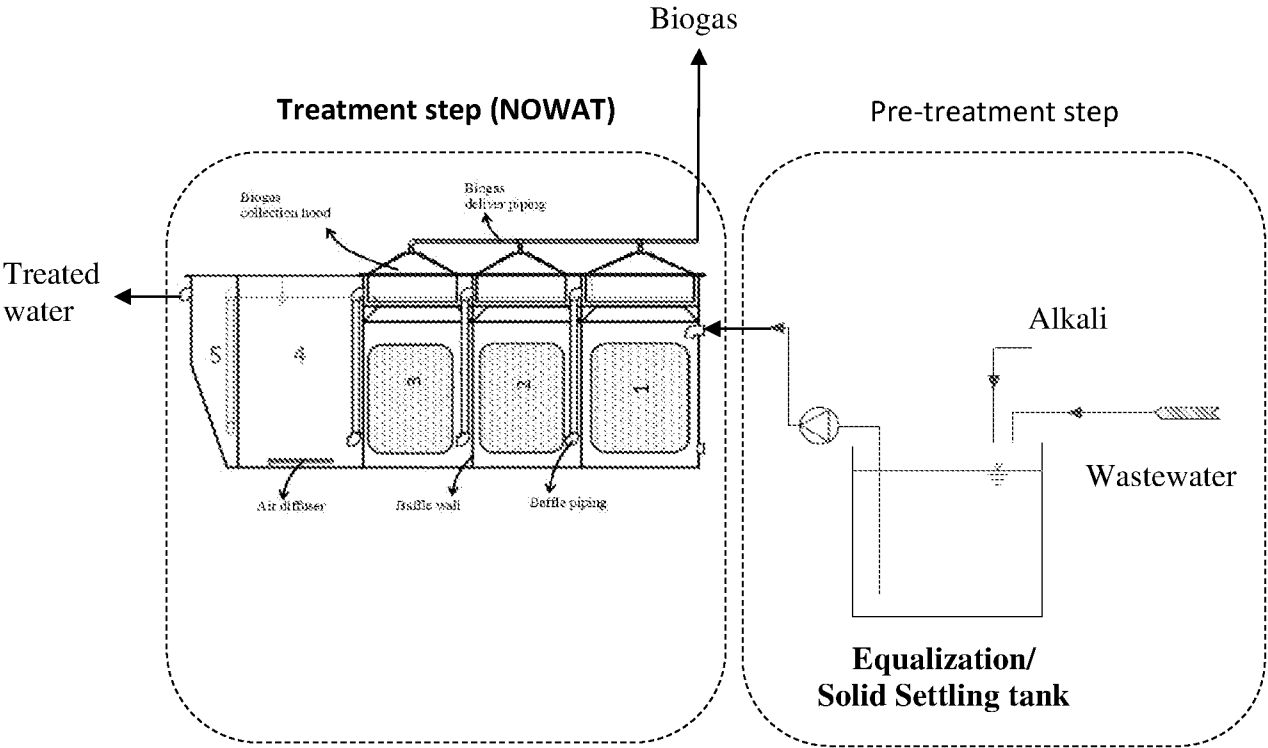


Figure 1

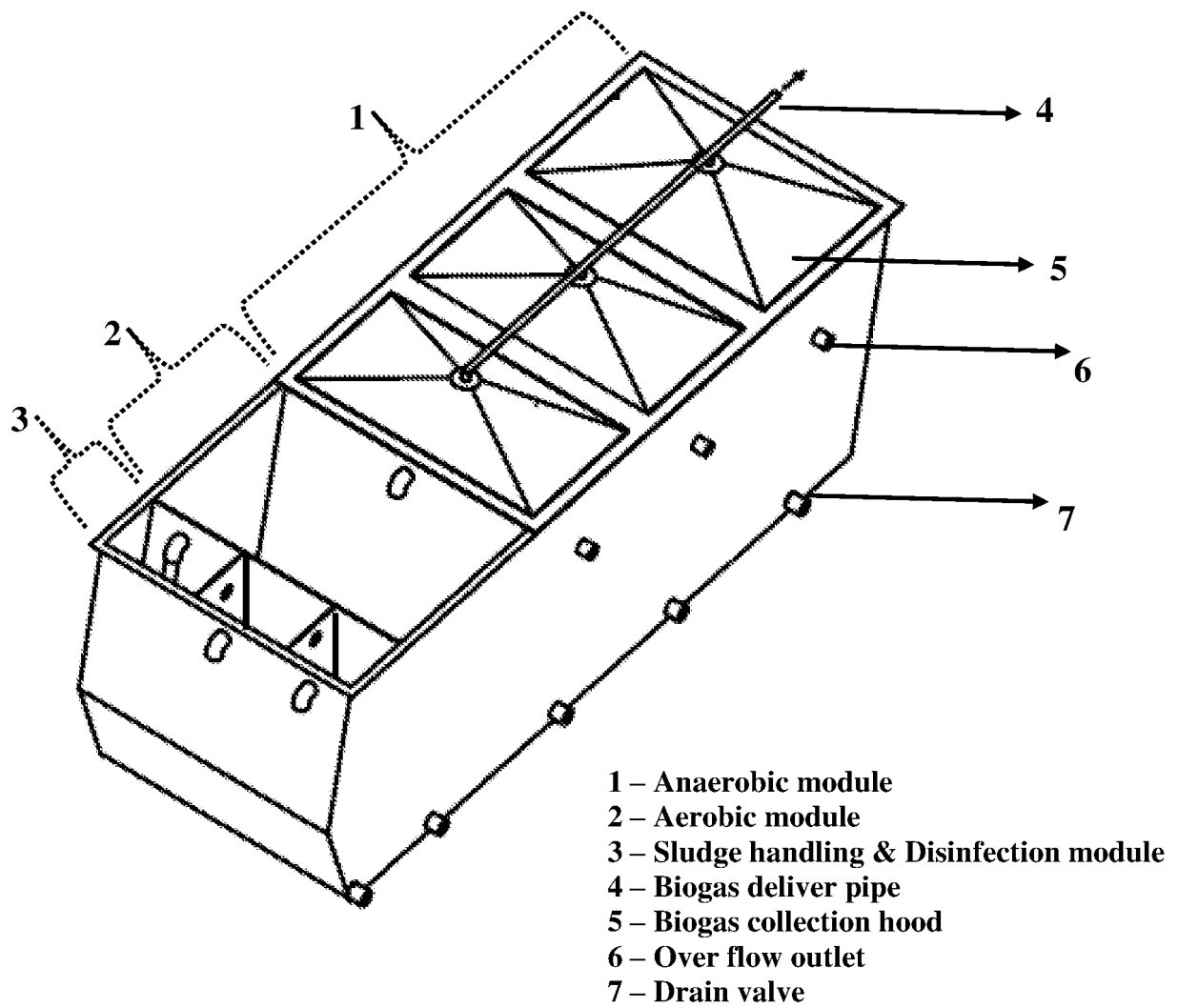


Figure 2

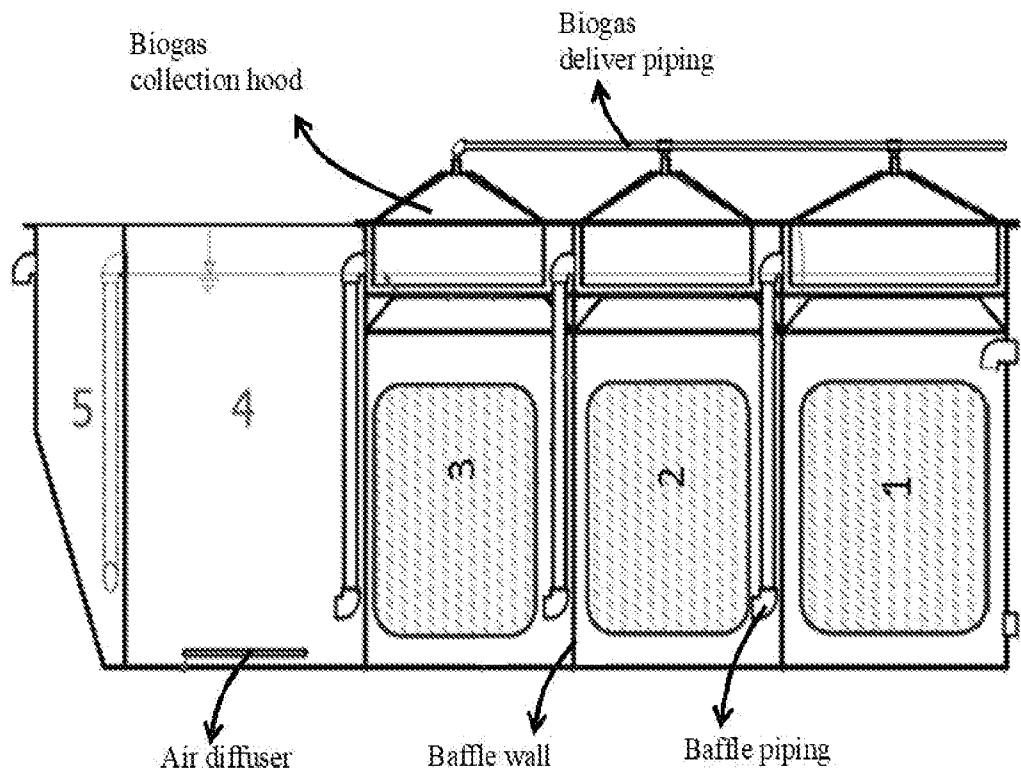


Figure 3

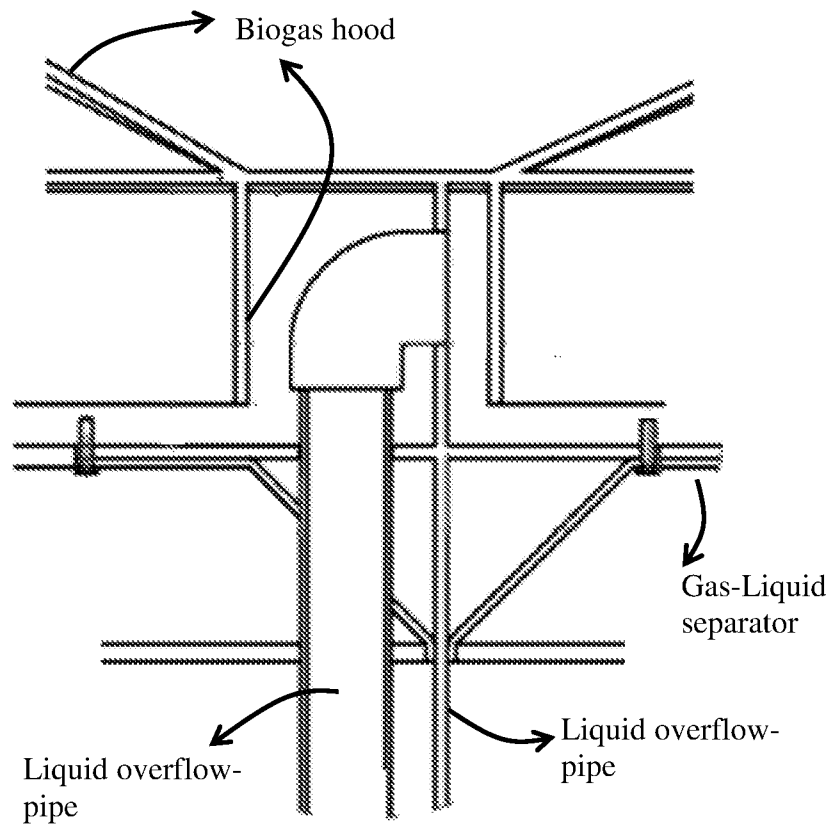


Figure 4

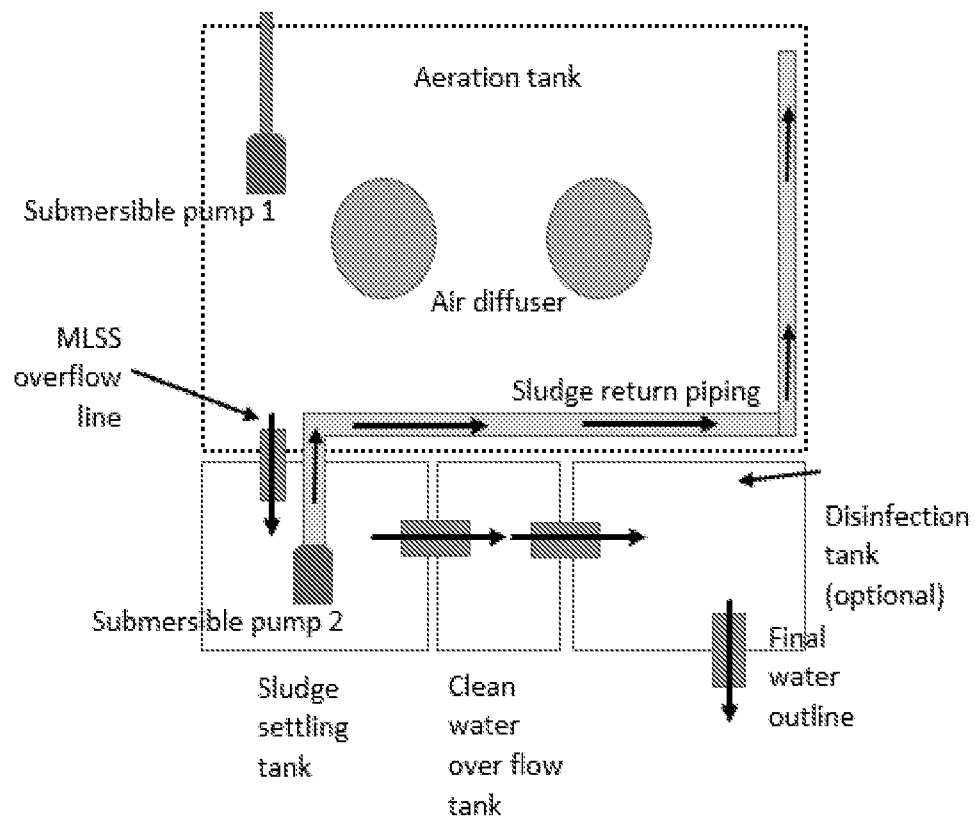


Figure 5

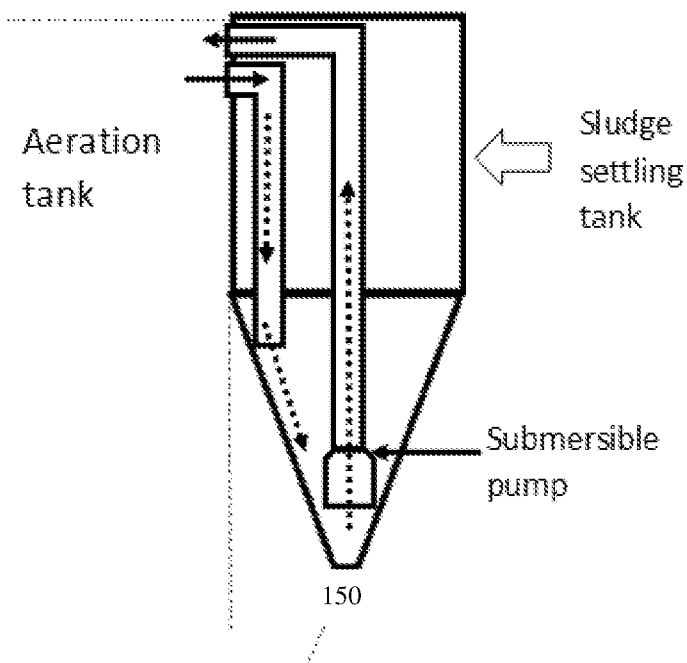


Figure 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2021/051166

A. CLASSIFICATION OF SUBJECT MATTER
C02F3/02, C02F3/24, C02F9/14 Version=2022.01

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatSeer, IPO Internal Database

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CN101767901B (YONGGUANG WANG) 04 July 2012 (04-07-2012) Abstract; Paragraphs [0011], [0013] - [0021]; Table 1 (as per English translation available on Espacenet)	1-10
Y	US20110203992A1 (SIEMENS WATER TECH CORP) 25 August 2011 (25-08-2011) Abstract; Paragraphs [0107], [0108]	1-10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

23-03-2022

Date of mailing of the international search report

23-03-2022

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IN2021/051166

Citation	Pub.Date	Family	Pub.Date
US 2011203992 A1	25-08-2011	CN 101980969 A	23-02-2011
		EP 2279152 A2	02-02-2011
		KR 20100136989 A	29-12-2010
		WO 2009120384 A2	01-10-2009