



- (51) International Patent Classification:
C12P 5/02 (2006.01) C12M 1/107 (2006.01)
- (21) International Application Number:
PCT/SE2012/050201
- (22) International Filing Date:
23 February 2012 (23.02.2012)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
1150177-2 25 February 2011 (25.02.2011) SE
61/446,769 25 February 2011 (25.02.2011) US
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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, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, 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, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, 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,

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(54) Title: METHOD AND SYSTEM FOR THE SANITIZATION OF A DIGESTATE IN THE PRODUCTION OF BIOGAS

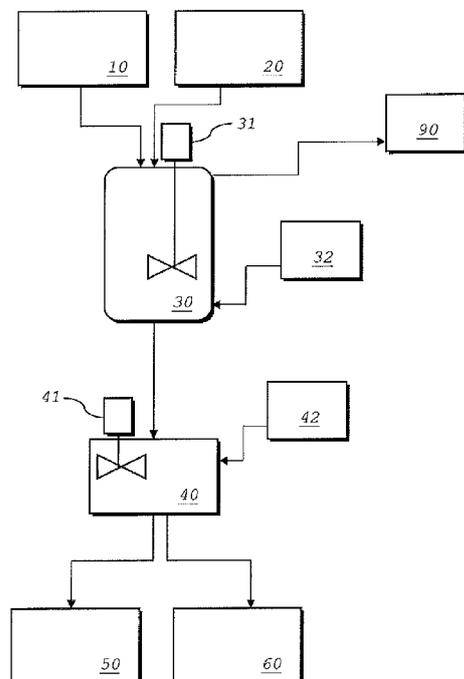


Fig. 1

(57) Abstract: A method for sanitization of a liquid waste product comprising a first step of subjecting said waste to biological treatment under anaerobic conditions resulting in a temperature increase producing biogas and a digested and heated product, and a second step wherein the pH of said digested and heated product is adjusted to an alkaline pH to produce uncharged ammonia in said product for a time sufficient to eliminate or significantly reduce the concentration of pathogens in said waste. A system for performing said method.

WO 2012/115587 A1



SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, ML, MR, NE, SN, TD, TG).

— of inventorship (Rule 4.17(iv))

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

Title**Method and system for the sanitization of a digestate in the production of biogas**Technical field

[0001] The present invention relates to the field of waste and effluent treatment, and in particular to a method and system for the production of biogas, including the sanitization of pathogen containing digestate formed in said production of biogas.

Background

[0002] There is a growing global understanding that the use of fossil fuels needs to be significantly reduced, both in order to reduce the emissions of greenhouse gases, and in order to conserve the hydrocarbon reserves for other chemical uses. A promising approach lies in the use of energy rich waste and effluent fractions, an approach which has the additional benefit of minimizing environmental pollution. The production of biogas from waste is a good example of an evolving technology with many benefits for nature and society alike.

[0003] Anaerobic digestion is a practical approach to the treatment of different organic waste fractions, waste water and effluents, also including human and animal excrements, as the anaerobic conditions, as well as the temperature increase, generally reduce the bacterial content.

[0004] Ideally, anaerobic digestion of organic waste will produce biogas, a mixture of mainly methane and CO₂, and a residual slurry, here called the digestate. In small scale biogas production, the biogas is frequently used on site, for example burned to heat the tanks and incoming material, to power engines connected to generators in order to produce electricity, or used locally for household heating, lighting and cooking purposes.

[0005] In larger production facilities, the biogas is usually upgraded by scrubbing, in order to remove H₂S and reduce the CO₂ content. Upgraded biogas containing about 95% methane has considerable potential as it can replace natural gas (fossil fuel) in all applications; as vehicle fuel, for cooking and lighting, heating and cooling, generation of electricity and heat, and in fuel cells.

[0006] Following this upgrading, the biogas is compressed and distributed. The residual slurry or digestate can then be used as fertilizer or soil conditioner, and applied for use in agriculture and/or landscaping. Provided that the digestate meets the requirements for hygiene, it may even be used to fertilize farm land used for edible crops, leading to an efficient circulation of nutrients and lower need for chemical fertilizers.

[0007] In order to maximize the scale and output of anaerobic digestion, it would be desirable if any high-energy containing waste fraction could be used. Today, farm waste is frequently mixed with energy crops, in order to compensate for the comparatively low energy content of farm waste, such as manure. One consequence of this practice is however that farm land is used for the production of energy crops, such as willows (*Salix spp*), poplar (*Populus spp*), grasses (e.g. *Phalaris arundinacea* or *Sorghum spp*) or even that edible crops, such as corn and other cereals, are used for biogas production. Simultaneously, other waste fractions, such as fat, oil and grease collected from food processing industry and restaurants, could be used. Such energy rich waste fractions can be mixed with other waste, increasing the total energy content of the mixture and improving the output from the anaerobic digestion. This is referred to as co-digestion.

[0008] Excrements from humans and farm animals are not only a potential environmental and sanitary problem; they also represent a significant source of nutrients, which could be used directly or indirectly for the production of biomass, and for the production of food and energy. In industrialized countries, the last decades have involved a shift from merely focusing on minimizing pollution and the eutrophication of water bodies, to the development of systems for the reuse of the nutrients in human and animal excrements. As excrements, regardless of their

human or animal origin, always contain pathogens, there is a considerable risk of disease transmission.

[0009] The recirculation of human and/or animal excrements and applying them, separately or in admixture, as fertilizers in the production of animal feed or human food also involves the risk of zoonoses, the transmission of diseases between animals and humans. Well-known examples of bacterial zoonoses include *Salmonella* and enterohaemorrhagic *E. coli* (EHEC) and examples of parasitic zoonoses include tape worms (*Taenia spp*) and cryptosporidiosis.

[0010] Reducing environmental pollution is a global concern. In the industrialized countries, the infrastructure for the collection and treatment of human excrements is generally well developed, and there is a growing interest in the reuse and recirculation of nutrients. In developing countries however, there is an urgent need for both improving sanitary conditions and reducing environmental pollution. The possibility to recirculate the nutrients in waste flows, such as, but not limited to, human and animal excrements, could add economic benefits, such as reducing the cost of importing fertilizers, in addition to improvements in hygiene and environmental protection.

[0011] Thus, it is a challenge to develop a sustainable and flexible process for utilizing energy-rich waste, regardless of its source; including a reliable sanitization (frequently also referred to as hygienization) method and system which prevents disease and promotes health, protects the environment, conserves water, and recycles recovered nutrients and organic matter.

[0012] Potentially also household waste and human sewage could be used, if there was a guarantee that the residual slurry is safe to use. This requires reliable and practical methods for sanitization.

[0013] A degree of sanitization is achieved during anaerobic digestion of waste, but relying on the biological treatment alone frequently requires long hold-times. In Sweden, the current requirement for sanitization of human and animal excrement is that the material must be subjected to at least 55°C for at least 10 hours

(Recommendations for professional storage, digestion and composting of waste, issued by the Swedish Environmental Protection Agency, NFS 2003:15, June 12, 2003).

[0014] Similar guidelines and requirements have been issued by international organizations, such as the World Health Organization (WHO). Further, there is currently within the European Union (EU) an ongoing effort to update and amend the Directive 86/278/EEC on agricultural use of sewage sludge, and it is expected that the requirements will only become stricter.

[0015] Additionally, successful biological treatment requires sufficiently high energy content which is frequently related to a high dry solids or dry matter (DM) content in order to maintain effective biological treatment, for example anaerobic digestion of the waste. It is estimated that a DM content of at least 2.5%, preferably at least about 4%, more preferably at least about 8% or higher, is necessary.

[0016] The desired DM content also depends on the climate in which the biological treatment is performed. In colder climates, it will not be economically feasible to treat very dilute waste streams. Thus, unless very long hold-times are used, a high DM content is preferred. With increasing DM content, the substrate becomes more viscous, which in turn is associated with problems of its own. There are however technologies suitable for this purpose, for example the method and device for the treatment of especially highly viscous substrates and for blending air into the substrate disclosed in WO 93/00302.

[0017] Sanitization using high pH is also well-known, sometimes referred to as alkaline sanitization, and the addition of hydroxides, lime, caustic soda, ammonia, and urea has been practiced. The recommendation for high pH treatment of sewage products requires pH 12 for at least 3 months. When ammonia is present, lower pH and shorter treatment times may suffice. At the same time, the addition of ammonia creates an environmental issue and constitutes an occupational hazard.

[0018] One specific problem encountered when attempting to recirculate in particular human excrements in the form of sewage is that the DM content is very low, at least until low flushing toilets have been widely installed. Sewage having a DM content below 1% (w/w) is generally held to be unsuitable for biological treatment, such as anaerobic digestion.

[0019] Another problem is that a combination of the current long hold-times and increasing sewage volumes requires very large installations to achieve a satisfactory throughput.

[0020] The background art includes different approaches addressing some of these problems:

[0021] DE 3622750 A1 relates to a process for the sanitization of sludge at a temperature of at least 60°C, involving at least two heating steps, wherein the first step is an aerobic, thermophilic process, and the second step involves external heating.

[0022] WO 96/28400 relates to composting processes for the production of a useful microbial product for either subsequent bioremediation processing of various substrates or direct application to soil as an agricultural fertilizer. The composting process involves multiple steps including an early step of creating extremely high temperature and extremely high pH, by adding alkaline materials, followed by a second composting stage, where nutrients are added to the compost pile.

[0023] WO 03/072514 discloses a method for sanitization of organic waste, based on a drying step followed by an increase in pH and/or temperature. Said drying step can be a mechanical dewatering step, and the temperature increase can be achieved by solar heating. WO 03/072514 also teaches an aerobic treatment of the waste, for example in combination with the drying step.

[0024] WO 2010/108558 relates to a biogas producing system, where nutrients harvested from an earlier biogas producing system are reused in a subsequent system in order to improve microorganism efficiency.

[0025] It remains however to find a practical and robust solution, allowing greater flexibility in the choice of starting materials for anaerobic biological treatment, and ensuring that the end product is safe to use. These problems, and others evident to a skilled person, are solved by the subject-matter of the independent claims. Preferred embodiments are set forth in the dependent claims.

Summary

[0026] One object of the present invention is to make available a method and system for effective and economical use of various sources of energy-rich waste, including a reliable sanitization of liquid waste of different origin. Another object is to make available a method and system for safe, effective and economical sanitization of liquid waste which is faster and requires a reduced input of energy and chemicals, compared to known methods and systems.

[0027] These objects and others are met by a method for the production of biogas from waste, comprising a first step of subjecting said waste to biological treatment under anaerobic conditions, producing biogas and a digestate, and a second step wherein the pH of said digestate is adjusted to an alkaline pH forming uncharged ammonia (NH_3) in the waste, for a time sufficient to eliminate or significantly reduce the concentration of pathogens in said digestate.

[0028] In the method and corresponding system, the liquid waste product comprises at least one of sewage, human excrements, animal excrements, gray water, food processing waste and biowaste, or different mixtures thereof, such as the mixture of waste water/sewage normally encountered in septic tanks.

[0029] The dry matter concentration of the liquid waste product can be in the interval of about 2 to about 20% (w/w) or higher, for example about 4 to about 12% (w/w), or preferably about 8% (w/w). According to one embodiment of the method and corresponding system, where the incoming waste has a low energy content, illustrated for example by a DM concentration of less than 2% (w/w), it is adjusted to about 8% (w/w) or higher by the addition of another waste fraction with higher DM, such as manure, biowaste, ash, biproducts and waste products from food

production, agriculture, forestry, including saw mill waste, and waste from pulp and paper production. For example an energy rich waste product from food production can be added in order to increase the energy content, whereas ash can be added to supplement microelements and to increase pH.

[0030] One step in the method, or unit operation in the corresponding system, comprises an anaerobic biological treatment of the liquid waste product, preferably the production of biogas, resulting in a temperature increase of the waste and the remaining digestate. Most preferably, the anaerobic biological treatment is performed at a temperature optimal for the production of biogas, either in the mesophilic or in the thermophilic interval. As a consequence of the anaerobic biological treatment, and possibly aided by additional heating where necessary, the digestate will reach an elevated temperature, at least about 30°C in a mesophilic process, and at least about 50°C in a thermophilic process. Preferably the digestate is maintained at this elevated temperature when subjected to further treatment.

[0031] Another step in the method, or unit operation in the corresponding system, comprises ammonia sanitization of the treated and heated product, wherein the sanitization step involves the adjustment of the pH to at least pH 7, preferably to about pH 9, and most preferably to above pH 9, resulting in the formation of uncharged ammonia (NH_3). The pH adjustment may be performed through the addition of an alkaline material, preferably nitrogen containing alkaline material, and most preferably one of urea, ammonia, hydroxides, lime or a combination thereof. Preferably urea is added to a concentration in the interval of about 0.1% to about 2.5% (w/w), more preferably to a concentration of about 0.5% to about 1.0% (w/w). Conceivably the amount of urea is in the higher interval, for example about 1.0% to about 2.5% (w/w), in particular when treating a feed from the mesophilic process.

[0032] According to one embodiment of the method, or unit operation in the corresponding system, the sanitized end product is used for fertilization purposes, or for soil amelioration or soil improvement.

[0033] As apparent from the description, the disclosed method can be realized also as a system, plant or installation for the production of biogas and the sanitization of a liquid waste product and the reuse of nutrients, comprising a reactor for performing an anaerobic biological treatment, and a sanitization reactor, wherein the product is passed from the biogas reactor into the sanitization reactor preferably only when the temperature exceeds 30°C, and where the pH in the sanitization reactor is adjusted to at least pH 7, preferably to about pH 9, and most preferably to above pH 9 in order to form uncharged ammonia (NH₃).

[0034] Said sanitization step is preferably an ammonia sanitization, where the pH of the liquid waste product is increased by the addition of an alkaline agent, such as urea, lime, ammonia, or the like. Preferably the added alkaline agent is urea. Preferably said sanitization reactor is insulated. Preferably said biological treatment step comprises an anaerobic digestion step, for example an anaerobic digestion for the production of biogas.

[0035] It is contemplated that the reactor for performing a biological treatment under anaerobic conditions, for example the production of biogas, can have a dual function, and serve also as a sanitization reactor. In such embodiments, freely combinable with other embodiments of the invention, the process is operated as parallel or sequential batches. This makes it possible to start a fresh batch by seeding it with a volume taken from another reactor, an approach that will shorten the start-up time of the fermentation, and aid in the selection of a suitable microflora.

[0036] Preferably said system also comprises means for heat recovery, wherein heat is recovered downstream, e.g. in the product storage silos, and used for heating the incoming material as it is fed to the reactor, for maintaining an elevated temperature in the sanitization reactor, or for heating adjacent buildings and spaces, such as for example living quarters, office space, animal stables etc.

[0037] One particular embodiment is a sanitization reactor adapted for use in the present method and/or system.

Brief description of the drawings

[0038] The invention is now described, by way of example, with reference to the accompanying drawings, in which:

[0039] Fig. 1 schematically shows a system for the production of biogas according to an embodiment;

[0040] Fig. 2 schematically shows another embodiment where the sanitization step is performed in two or more parallel sanitization reactors;

[0041] Fig. 3 schematically shows another embodiment where the sanitization step is performed in the biogas reactor, and where several reactors are used in parallel;

[0042] Fig. 4 schematically shows a system for the production of biogas according to an embodiment wherein an arrangement for the recovery of heat is illustrated; and

[0043] Fig. 5 schematically shows a system for the production of biogas according to an embodiment wherein another alternative or supplementary arrangement for the recovery of heat is illustrated.

Description of embodiments

[0044] Before the present invention is described, it is to be understood that the terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting, since the scope of the present invention will be limited only by the appended claims and equivalents thereof.

[0045] It must be noted that, as used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Also, the term "about" is used to indicate a deviation of at least +/- 2% of the given value, preferably +/- 5%, and most

preferably +/- 10% of the numeric values, where applicable. In addition to the above, the following terms will be used:

[0046] The term "waste" is intended to encompass all organic, energy-rich sources, such as agricultural waste including manure, crop residues and energy crops; industrial waste such as waste from the food and feed industry; food waste from restaurants, shops and households; and garden waste from parks, green areas and private property.

[0047] The term "sewage" is intended to encompass domestic, municipal and industrial liquid waste products, here with the exception of such industrial waste flows which are clearly unsuitable for biological and later use as fertilizer, for example because of their content of non-degradable toxic substance, such as but not limited to heavy metals.

[0048] The term "human and animal excrements" is intended to include both urine and feces, separately or in admixture, and in the case of animal excrements, also called manure, also a varying amount of bedding straw, peat, sawdust or the like.

[0049] The term "biological treatment" is intended to encompass any biological treatment capable of increasing the temperature of the liquid waste, as well as aiding in the reduction of the number of pathogenic microorganism therein. The currently most preferred non-limiting example of biological treatment is anaerobic digestion.

[0050] The term "eliminate" used in the context of pathogen counts means that the number of specific bacteria, virus or *Ascaris* is reduced to a level at which they no longer pose a problem considering the intended use of the digestate.

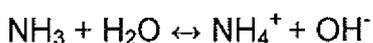
[0051] The term "significantly reduce" also used in the context of pathogen counts means at least a 3log₁₀ reduction, i.e. that the number of specific bacteria, virus or *Ascaris* is reduced by a factor 1000.

[0052] The term "sanitization" means the reduction and/or elimination of pathogens. Current rules, e.g. EC 208/2006, the Commission Regulation of 7 February 2006 regarding processing standards for biogas and composting plants and requirements for manure sets a limit for *E. coli* and *enterococcae* in manure derived compost at max 5000/g, and requires that no *Salmonella* is detected in a set of 5 samples of 25 g each. It is expected that these limits will be reduced to less than 1000/g DM.

[0053] It is also expected that future requirements will include threshold values also for helminth eggs (*Ascaris* spp), and there is a tendency that the requirements for sanitization of human and animal excrements will be harmonized. For example, EC 1774/2002, the regulation laying down health rules concerning animal by-products not intended for human consumption, which can be applied to manure treatment, already requires a 5log10 reduction of *Enterococcus faecalis* or *Salmonella senftenberg* w775. The regulation also requires a 3log10 reduction of *Ascaris* in chemical processes and a 3log10 reduction for parvo virus or other thermo tolerant viruses, in products where they are identified as a relevant hazard.

[0054] In the present description, the term "sanitization" is applicable to the treatment of waste regardless of origin, and it is conceived that the sanitization of animal excrement is equally important as the sanitization of human excrements, in order to guarantee that the end product can be safely used also in food production.

[0055] The term "ammonia sanitization" means a sanitization where the toxic properties of uncharged ammonia (NH₃) contribute to the killing of microorganisms present in the waste. In solution, ammonia is in equilibrium with its conjugate acid (NH₄⁺):



[0056] The formation of uncharged ammonia in the liquid waste is dependent on temperature, pH and the available ammonium ions (NH₄⁺). Increasing pH and temperature shifts the equilibrium towards uncharged ammonia. However, for

ammonium sanitization the concentration of ammonia has been shown to be of higher importance than the pH achieved. Thus, the addition of ammonia, or preferably urea, which is degraded into carbon dioxide and ammonia, results in an effective sanitization, here called ammonia sanitization.

[0057] In a generic set-up for the production of biogas, a feed of organic waste is led into an anaerobic digester where bacteria feed on the organic matter, producing shorter intermediate organic compounds that are eventually converted into nutrients and biogas. The digester or reactor is a closed vessel, and as the biogas is practically insoluble in water, it separates into the gas phase and can be recovered from the digester and led to further processing.

[0058] There are different options for the design of biogas reactors, including batch, fed-batch, continuous, plug-flow, series connected reactors etc. Small scale batch reactors are commonly used for the production of biogas for use in households, such as in agricultural communities and farms. In larger scale biogas production, different types of continuous or semi-continuous reactors are used.

[0059] The digestion is conducted either in a lower or a higher temperature interval, each interval being optimal for a particular microbial population. The lower temperature interval of about 30 to about 40°C is called mesophilic and characterized by a versatile and rather robust microbial population. The higher temperature interval of about 50 to about 60°C is called thermophilic, and is characterized by a lower microbial diversity, and is more sensitive to disturbances and temperature variation. Although the thermophilic interval results in a higher production of biogas and better sanitization of the digestate, the mesophilic interval is more attractive for several practical reasons.

[0060] As described above, the selection and maintenance of a suitable microbiological population can be facilitated and supported by seeding each batch with a small volume of the anaerobically treated product, taken prior to the ammonia sanitization step, or in a continuous process, by re-circulating a side-stream of the treated product leaving the anaerobic step, and mixing it with the feed of untreated materials.

[0061] Different substrates, or in the present context, different waste flows, have different potential for biogas production. Practical experience has shown that co-digestion, i.e. mixing different wastes, results in a better mix of micronutrients and thus higher biogas yields. For example adding human sewage would supplement energy crops, and adding waste from food industry and households would supplement farm waste and manure.

[0062] Thus, it remains a challenge to improve in particular the mesophilic process, so that biogas yield could be increased without compromising the safety of the digestate.

[0063] One embodiment makes available a method for sanitization of a waste product comprising a first step of subjecting said waste to biological treatment under anaerobic conditions resulting in a temperature increase and producing biogas and a biologically treated and heated product, a digestate, and a second step wherein the pH of said digestate is adjusted to an alkaline pH to form uncharged ammonia (NH_3) for a time sufficient to eliminate or reduce the concentration of pathogens.

[0064] Preferably said second step follows directly on said first step, wherein the term directly means that the liquid waste after being subjected to the biological treatment and while remaining at an elevated temperature, is led directly to said sanitization step.

[0065] In the above method and in a corresponding system, the liquid waste product comprises at least one of sewage, human excrements, animal excrements, graywater, and biowaste, or different mixtures thereof, including other waste fractions, such as fat, oil and grease collected from food processing industry and restaurants, and/or other organic, energy-rich waste, such as agricultural waste including manure, crop residues and energy crops; industrial waste such as waste from the food and feed industry; food waste from restaurants, shops and households; and garden waste from parks, green areas and private property.

[0066] The method is particularly suitable for waste with low energy content, here measured as low dry matter (DM) concentration, as it offers a reliable sanitization of the digestate also at low temperatures, and thus avoids the need for heating large volumes of waste. Examples of the DM concentration of liquid waste products that can be utilized in the method can be in the interval of about 2 to about 12% (w/w) or higher, for example about 4 to about 10% (w/w), normally about 8% (w/w). According to one embodiment of the method and corresponding system, the energy content, reflected as the dry matter concentration of the liquid waste product, is increased to at least about 8% (w/w) by the addition of manure and/or biowaste.

[0067] One step in the method, or unit operation in the corresponding system, comprises the biological treatment of the liquid waste product until a temperature of at least about 30°C following the mesophilic process, and at least about 50°C following the thermophilic process, is reached. Preferably the digestate is maintained at this elevated temperature until subjected to further treatment.

[0068] Another step in the method, or unit operation in the corresponding system, comprises sanitization of the biologically treated and heated product, the digestate, wherein the sanitization step involves the adjustment of the pH to at least pH 7, preferably to about pH 9, and most preferably to above pH 9 in order to produce uncharged ammonia (NH_3) in the liquid waste. The pH adjustment may be performed through the addition of one of hydroxides, urea, ammonia, lime or a combination thereof. Preferably urea is added to a concentration of at least about 0.2% (w/w), more preferably to a concentration of about 0.5% (w/w) or higher.

[0069] According to one embodiment of the method, or unit operation in the corresponding system, the sanitized end product, the digestate, is used for fertilization purposes, or for soil amelioration or soil improvement. An advantage of using urea is thus that urea is a source of nitrogen which is practical and safe to handle, easily available and which adds to the nutritional value of the fertilizer.

[0070] As apparent from the description, the disclosed method can be realized also as a system, plant or installation for the sanitization of a liquid waste product

and the reuse of nutrients, comprising a biogas reactor and a sanitization reactor, wherein the product is passed from the said biogas reactor into the sanitization reactor only when the liquid waste has attained an increased temperature, preferably a temperature exceeding about 30°C, and where the pH in the sanitization reactor is adjusted to at least pH 7, preferably to about pH 9, and most preferably to above pH 9 in order to produce uncharged ammonia (NH₃) in the liquid waste.

[0071] Preferably said sanitization step comprises an ammonia sanitization step. Preferably said sanitization reactor is insulated. According to one embodiment, said biological treatment step comprises an anaerobic digestion step, for example an anaerobic digestion step for the production of biogas.

[0072] Preferably said system comprises means for heat recovery, wherein heat is recovered downstream, e.g. in the product storage silos, and used for heating the incoming material as it is fed to the reactor, for maintaining an elevated temperature in the sanitization reactor, or for heating nearby installations, buildings such as living quarters, office space, animal stables, or warehouses.

[0073] One embodiment includes a sanitization reactor adapted for use in a method and/or system as described above. Said sanitization reactor can also be a separate component, suitable for incorporating in an existing waste management system, in order to modify such system to operate entirely or in part according to the present disclosure.

[0074] The method and system will now be disclosed in closer detail, with reference to the figures, for example Fig. 1, where two receiving tanks 10 and 20 are schematically shown. While one receiving tank may suffice, it may be advantageous to have two or more, for example to make it possible to receive starting materials of different origin and composition, for example municipal, industrial and agricultural organic waste, food processing waste, human excrements, animal excrements, sewage, sludge, and gray water, and to mix these in suitable proportions to ensure an even and optimal material feed to the

reactor 30. Thus, two or more receiving tanks can be used e.g. for balancing the DM concentration or the nutritional content in the material feed to the reactor 30.

[0075] The receiving tank or tanks are preferably insulated, covered or closed tanks, which makes it possible to control temperature and eliminate potential problems with smell etc. A skilled person will be capable of choosing or designing receiving tanks of a suitable construction and size, depending on the nature of the waste product to be treated, as well as considering the desired throughput of the process.

[0076] For achieving an estimated capacity of about 3000 m³/a, the size of a receiving tank could suitably be 100 to 500 m³, preferably about 200 m³. It is currently held that two receiving tanks of about 200 m³ each would afford sufficient capacity and flexibility. Preferably each receiving tank is equipped with a biofilter for absorbing unwanted smells, e.g. a peat-filled filter through which air from the receiving tank or tanks is led.

[0077] From said receiving tank or tanks, the liquid waste or sewage is pumped or otherwise led into a reactor 30. On the way to the reactor 30, the sewage is preferably macerated, and it can also be preheated. There may also be sieves or similar means for trapping objects exceeding a certain size, in order to prevent downstream problems, such as clogging of lines, damage of pumps and valves etc.

[0078] Said reactor 30 is preferably a closed, insulated tank equipped with means for mixing 31. The means for mixing can be a conventional propeller or turbine mixer, a circulation pump, or for example a device according to WO 93/00302. Preferably the reactor is also equipped with anti-foaming means, for example means (not shown) for detecting foam and for dosing anti-foaming agents into the reactor when needed. The reactor 30 may also be equipped with means 32 for feeding a starter culture, or supplementary nutrients, to the reactor. Such means can include the provisions for manual or automated feed or addition of starter culture or nutrients. Such means can also comprise pumps and an intermediate container for collecting and/or transferring material from another

reactor or from an earlier batch in the same reactor for seeding subsequent batches.

[0079] The biogas produced in the anaerobic digestion is collected and led to means for temporary storage and further processing or use, here indicated as 90. Further processing steps may include scrubbing, compressing, and storing the gas, or burning the gas in a combustion engine powering a generator, or burning the gas in a boiler, generating hot water and/or steam.

[0080] The size of the biogas reactor can be in the interval of 10 to 100m³, preferably about 25 to 50m³. A reactor having a volume of about 50m³ can be constructed as a standing cylinder having a height of about 8m, and a diameter of about 3m. As mentioned above, the reactor is preferably insulated in order to minimize the influence of varying outdoor temperatures. The degree of insulation can be determined by a skilled person, and optimized for the volume, intended throughput and intended geographical location of the set-up.

[0081] Further, in Fig. 1, a sanitization reactor 40, preferably equipped with means for mixing 41, for example a mixer, and means for feeding 42 a pH adjusting substance, for example urea. After completion of the sanitization step, the contents of the sanitization reactor 40 are emptied into one or more storage tanks, 50 and 60.

[0082] Fig. 2 shows an embodiment, freely combinable with other embodiments shown herein, where a one biogas reactor 30 is followed by two or more sanitization reactors 40' and 40'' each having mixing means 41', 41'' and means 42 for feeding a pH adjusting substance, for example urea. After completion of the sanitization step, the contents of the sanitization reactors 40' and 40'' are emptied into a storage tank 50'.

[0083] In a set-up as illustrated in Fig. 2, the anaerobic process is conducted in reactor 30, and the provision of two or more sanitization reactors makes it possible to operate the biogas reactor in a substantially continuous or semi-continuous manner, optimizing the process for the production of biogas. A volume of

anaerobically treated material can be emptied from the biogas reactor into one sanitization reactor when suitable for the biogas production process, for example before replenishing the mixture of waste materials in the biogas reactor. When the sanitization reactor is filled, the addition of a pH adjusting substance is performed, and the sanitization takes place. This makes it possible to conduct the biogas production and the sanitization steps independently of each other, optimizing the conditions for both steps.

[0084] In this set-up, as well as in others based on embodiments disclosed herein, as well as combinations thereof, it is conceived that surplus heat from the means 90 for temporary storage and further processing or use, e.g. a generator or a boiler, is collected and used to heat the sanitization tank or tanks 40, 40', 40". This has the advantage that temperature in the sanitization tank or tanks can be maintained at the temperature it had when leaving the biogas reactor, or even increased, thus making the sanitization process more efficient. A more efficient sanitization may allow shorter hold-times, reduced consumption of the pH adjusting substance, e.g. urea, and a smaller volume of the sanitization reactor, or combinations thereof. Further, reducing the volume of the sanitization reactor(s) simplifies the heating of the same, which in turn makes it possible to use a smaller volume.

[0085] An additional advantage of using two or more sanitization reactors in parallel is the added flexibility, for example that the anaerobic process can be optimized, and run independently from the sanitization, wherein partial volumes of the contents of the biogas reactor are transferred to one or more sanitization reactor(s).

[0086] It is also conceived that two or more reactors are used in parallel, in order to increase the capacity of the installation, for making the method and system less vulnerable to disturbances, for allowing maintenance without interrupting the process etc.

[0087] Fig. 3 illustrates an embodiment where several reactors (here shown as three reactors, 30, 30' and 30") are arranged in parallel, and provided with means

90 for collecting and handling the biogas, means 32 for adding nutrients or a starter culture, for example a volume taken from a parallel reactor after completion of the anaerobic treatment, and means 42 for feeding a pH adjusting substance, making it possible to conduct both the production of biogas and the sanitization in the same vessel.

[0088] Fig. 3 also illustrates an embodiment, freely combinable with the other embodiments, where only one storage tank 50' is arranged for receiving the sanitized product. Using a more efficient and reliable sanitization, such as the ammonia sanitization disclosed herein, significantly reduces the need for quarantine and storage in separate tanks before releasing the end product, wherefore only one tank is sufficient.

[0089] The reactor can be emptied in its entirety or, preferably only partially, leaving for example about 70 – 90% of the volume to be mixed with new substrate. It is conceived that partial emptying will significantly shorten the time required for the biological treatment to reach the desired temperatures, as the microorganisms remaining in the reactor will multiply rapidly when new substrate is added. It is conceived that a certain selection of microorganisms will take place, leading to the development of a flora particularly suited for the biological treatment.

[0090] Alternatively, or in addition to the above, it is conceived that part of the contents of the reactor may be returned to the receiving tank or tanks in order to inoculate the liquid waste with the microorganisms necessary for the biological treatment.

[0091] In a preferred embodiment, for example in a set-up as illustrated in Fig. 1 or Fig. 2, about 10 to about 30%, preferably about 15% of the content of the reactor 30 is transferred to the sanitization reactor(s) 40, 40', 40". The amount is determined based on the treatment time necessary for optimal biogas production in the chosen temperature interval, and the mix of waste subjected to the treatment, as well as the necessary sanitization time. There are several advantages of such partial emptying of the biogas reactor 30, one being that the conversion of the energy containing waste to biogas is maximized, by increasing

the average hold-time, and another that the volume of the sanitization reactor 40 can be minimized. The latter brings about significant cost savings, compared to the use of larger tanks and longer hold-times.

[0092] Assuming that a 21 days treatment time is optimal for the production of biogas from a particular waste, and that a 3 day sanitization period is sufficient for the sanitization of the digestate, it is conceived that about 15% of the contents of the reactor 30 is transferred every third day into the sanitization reactor 40. At the same time, fresh energy rich waste is led into the reactor 30. Thus, the sanitization tank 40 can be designed to have a volume which is about 15% of the volume of the reactor 30, and the process operated in a semi-continuous manner.

[0093] As illustrated in Fig. 1, 2 and 4, the biologically treated product, the digestate, is led from the reactor 30 into one or more sanitization reactor(s) 40, 40', 40". It is conceived that two or more sanitization reactors are used in parallel (Fig. 2), for example to increase throughput and/or in order to make it possible to analyze the pathogen count in the product before releasing it into the storage tank or tanks 50, 50' and 60. The sanitization reactor preferably has a size of 10 to 50m³, more preferably about 10 to 30m³ and most preferably even smaller. The sanitization reactor may be designed as a horizontal, insulated cylinder. Again, the degree of insulation can be determined by a skilled person, and optimized for the volume, intended throughput and intended geographical location of the set-up.

[0094] Means 42 for feeding a pH adjusting substance, e.g. a nitrogen source, preferably urea, are operationally connected to the sanitization reactor 40. Additionally, the sanitization reactor is preferably equipped with mixing means 41. The mixing means can be a circulation pump, a propeller, a turbine, a paddle mixer or the like, present in the reactor, or alternatively means for mixing the nitrogen source into the product when fed to the sanitization reactor, e.g. a motionless mixer (not shown) in the line feeding the product into the sanitization reactor 40.

[0095] The sanitization reactor can also be constructed as a plug-flow reactor, designed to ensure a sufficiently long hold-time for the digestate, considering the

temperature and pH, in order to achieve the necessary sanitization. A skilled person will be capable of dimensioning and designing the process in adherence with the principles disclosed herein, based on common general knowledge, and with support of recognized chemical engineering textbooks, such as Unit operations of chemical engineering, 7th ed., by Warren Lee McCabe, Julian Cleveland Smith, and Peter Harriott, McGraw-Hill, 2005.

[0096] The sanitization reactor (or reactors) may further be equipped with means for handling air or gas vented from the reactor (not shown). Such means can be chosen from biofilters, carbon filters, ozon treatment, and various scrubber installations, depending on the quality of the vented air, e.g. problems with smell, ammonia etc. Preferably a biofilter is used, wherein the vented air is led through a filter containing particulate organic matter, e.g. peat, saw dust, straw, wood chips etc or a mixture thereof. After use, this organic matter, now enriched with volatile substances including ammonia, can be used for fertilization or soil amelioration.

[0097] When the sanitization has been completed, the reactor 40 is emptied, and the sanitized digestate may be used directly or stored in one or more storage tanks or ponds 50, 50' and 60 before being used as fertilizer. Preferably said storage tank or tanks is/are covered, and preferably also have means for mixing, as well as means for the collection and treatment of gases released from the product.

[0098] The size of a storage tank is normally in the interval of 1000 to 2000m³, but can be smaller or larger depending on the intended storage time and throughput of the process.

[0099] Further, as shown in Fig. 4, residual heat can be recovered from the storage tanks 50 and 60 and used for heating the sanitization reactor 40. Generic means are illustrated as item 70, as shown in Fig. 4, where a heat exchanger 71 is placed for example in storage tank 50, for example a coil, plates or baffles, and another heat exchanger 72, for example a coil, plates or baffles, is placed in the sanitization reactor 40. Heat recovery can be achieved using conventional heat

exchangers and a suitable medium, e.g. water, but can also include a vapor-compression refrigeration device normally referred to as a heat pump.

[00100] Fig. 5 shows another embodiment, freely combinable with any of the embodiments herein, where heat is recovered from the storage tanks 50 and 60 using e.g. one or more heat exchangers, 81 and 82, and means 80, for example a pump or a vapor-compression refrigeration device, in order to heat the reactor 30. Additionally, or alternatively, further heat exchanging systems could be applied to recover heat from the reactor, and use it to pre-heat the material entering the reactor, in order to ensure an even temperature in the reactor, shorter start-up times etc. It is also conceived that surplus heat generated by peripheral equipment, such as pumps, compressors (for pressurizing the biogas), combustion engines and generators, fans, etc, could be used e.g. for heating the waste material before feeding it to the reactor, or for maintaining the temperature in the sanitization reactor, or for other heating or conditioning purposes.

[00101] It is also conceived that, in particular in colder areas or during cold seasons, part of the biogas generated in the anaerobic digestion is used to pre-heat the incoming waste or to provide supplementary heating to the digestion or the sanitization reaction.

[00102] An advantage of the method and system disclosed herein is that the heat that develops in the initial biological treatment process is used to amplify the effect of the ammonia sanitization step. Also heat recovered from other unit operations, or parts of the process can be used, such as residual heat in the sanitized end product, or surplus heat from generators, boilers, pumps etc. Consequently, the ammonia sanitization step can be performed at a lower pH than otherwise required, with less addition of alkaline chemicals, using shorter hold-times, in a smaller sanitization reactor, or a combination of these, without compromising the result.

[00103] Another advantage of the method and system is also that it can be implemented in existing biogas production plants as well as in the design of new plants.

[00104] Compared for example to alkaline sanitization alone, the combined biological treatment and ammonia sanitization can be performed at a lower pH, requires less time, smaller addition of alkaline chemicals, and therefore affords a larger throughput. Similarly, compared to biological treatment alone, the combined biological treatment and sanitization requires shorter hold-times, and therefore affords a larger throughput. The method and system is also suitable for scale-up, either by adding parallel lines, by increasing the volume of the biogas reactor and/or the sanitization reactor, or both.

[00105] An important advantage is that effective and reliable sanitization of the digestate offers extra security, and makes it possible to use different waste fractions for the production of biogas, for example mixing energy crops and sewage, or mixing farm waste without compromising the quality of the digestate even when the mesophilic temperature interval is used.

[00106] Another advantage is that the digestate can then be used as a fertilizer also on land intended for edible crops, providing for an improved recirculation of nutrients and reducing the need for chemical fertilizers.

[00107] When a nitrogen containing material, for example urea, is used as the alkaline material, it affords the additional advantage of increasing the nutritional value of the sanitized end product.

[00108] Yet another advantage is that the method and system as disclosed allows also the use of effluent streams having a low DM concentration. The initial biological treatment step, the production of biogas, does not have to be taken to the high temperatures normally required for sanitization by temperature alone, which reduces the hold-time and increases throughput.

[00109] An additional advantage is the relatively low investment cost compared to installing municipal sewers in areas where this is not present, for example rural and sparsely inhabited areas. The method and system is thus an alternative to expanding the municipal sewer network, and makes it possible to develop areas

that are difficult to access, and where the sewage handling has been a limiting factor for expansion and development.

[00110] The following examples are intended to illustrate but not limit the invention.

Examples

Example 1. Laboratory scale urea sanitization at different temperatures

[00111] Urea sanitization was tested at different temperatures ranging from 30 to 46°C and using different concentrations of urea, ranging from 0.35 to 0.6% (w/w). The sanitization effect was measured as the reduction of *Salmonella*, *enterococcae* and total coliform bacteria count.

[00112] For analysis of pH, a 10g sample was removed from each replicate and after dilution in de-ionized water (1:9) analyzed at room temperature, using an Inolab 720 pH meter (WTW, Weilheim, Germany).

[00113] Microbial sampling was performed in an exponential time interval from days 1, 2, 4 etc with the material mixed manually for approximately 1 min prior to each sampling. Ten (10) gram of material were mixed with 90ml of phosphate M15 pH 7.2 buffer (SVA, Uppsala, Sweden), to neutralize pH. From this, a 10-fold series was made with the first 1 ml dilute with phosphate buffer and the following steps with physiological saline solution, NaCl 0.85-0.90% (SVA).

[00114] All bacteria were detected by the standard plate methods: *Salmonella* spp. was cultivated on xylose lysine desoxycholate agar (Oxoid, Sollentuna, Sweden) containing 0.15% sodium novobicin, and *Enterococcus* spp. on Slanetz-bartley (SlaBa) agar (Oxoid) without differentiating between added *E. faecalis* and *Enterococcus* spp. the phage assay used the double agar methods according to the ISO standard 10705-1, 1995 and *Salmonella typhimurium* type 5 cultured in nutrient broth (Oxoid) as host strain for enumeration.

[00115] The urea sanitization was shown to be satisfactory already at an addition of 0.45% urea, but it was concluded that the initial pH, temperature and buffer capacity of the liquid waste influenced the results. Further, the buffer capacity of the waste also influenced the results.

Example 2. Pilot scale urea sanitization at elevated temperatures

[00116] Urea sanitization was tested in pilot scale experiments at a private farm where the end product was used for fertilization (Hölö, Sweden). Liquid waste consisting mainly of human feces and urine together with water used for flushing, was collected at a nearby camping, and from black water tanks at private homes. The DM of the liquid waste was on average about 1% as the waste was collected from installations having normal toilets. Total DM was determined by Oven Drying at 100°C for 24 hr according to standard laboratory procedure.

[00117] Microbiological analysis and pH measurements as above, see Example 1.

[00118] Batches of 30 m³ were delivered to the pilot plant and subjected to treatment. In the sanitization step, an addition of 2% urea resulted in an increase from pH 7 to 9.2 measured three months after the addition of urea. The initial pH may have been higher, however long term storage of samples show that the pH remained at 9.15 after an additional two months.

Example 3. Pilot scale serial wet composting and sanitization of sewage

[00119] Batches of 30m³ sewage water exhibiting a dry matter (DM) concentration ranging from 0.64 to 1.1% (w/w) and a slightly basic pH was received at a pilot plant (Sörby Gård, Kvicksund, Sweden) operating according to the principles outlined in the description. The DM was determined by Oven Drying at 100°C for 24h according to standard laboratory procedure.

[00120] Microbiological analysis and pH measurements as above, see Example 1.

[00121] Following the initial biological treatment, here a wet composting step, a temperature exceeding 40°C was measured. The warm, treated product was then subjected to the sanitization step, and urea was added. For example, an addition of 0.45% (w/w) urea resulted in pH 8.9. After a period of 4 days, samples were taken and the product pumped into a covered storage tank.

[00122] Samples were taken daily, and sent for microbiological analysis (The National Veterinary Institute, SVA, Uppsala, Sweden). The analysis showed that the end product met not only the current requirements (EG 2008/2006) but also the expected future requirement that the material is free from *Salmonella*, and contains less than 1000/ g DM *E. coli* and *enterococcae*.

[00123] The following table shows the temperature development in a 30m³ batch which had both a low DM, 0.64% (w/w) and low temperature, 8°C when delivered to the pilot plant.

Table 1. Temperature increase during biological treatment

Time (Days)	0	1	2	3	4	5	6	7	8
Temperature (°C)	8	10	15	21	27	32	39	42	43.5

[00124] When the temperature had reached 43.5°C on day 8, the biological treatment was interrupted, and urea was added to the warm, treated product. It is conceived that the urea sanitization step could be initiated earlier, for example at day 5, when the temperature already exceeds 30°C. The time distribution between the biological treatment step and the sanitization step depends *inter alia* on the DM concentration of the sewage. Sewage having a relatively high DM is likely to be able to reach a higher temperature in the biological treatment step, and a shorter sanitization will suffice. However, if the sewage has a relatively low DM, the biological treatment may possibly not result in temperatures higher than about 30 to 35°C, and then is conceived that a longer sanitization step, or a higher addition of urea, will be required.

[00125] The results in any case show that sewage water having a very low DM concentration can be successfully treated, and that the disclosed method and system can be applied in a large scale (30m³).

[00126] Although the invention has been described with regard to its preferred embodiments, which constitute the best mode presently known to the inventors, it should be understood that various changes and modifications as would be obvious to one having the ordinary skill in this art may be made without departing from the scope of the invention as set forth in the claims appended hereto.

CLAIMS

1. A method for the production of biogas from waste, comprising a first step of subjecting said waste to biological treatment under anaerobic conditions, producing biogas and a digestate, and a second step wherein the pH of said digestate is adjusted to an alkaline pH to produce uncharged ammonia in said digestate for a time sufficient to eliminate or significantly reduce the concentration of pathogens in said digestate.
2. The method according to claim 1, wherein the waste is chosen from municipal, industrial and agricultural organic waste, including food processing waste.
3. The method according to claim 2, wherein the waste additionally comprises at least one of human excrements, animal excrements, sewage, sludge, and gray water.
4. The method according to claim 2 or 3, wherein the waste comprises crop residues or energy crops.
5. The method according to claim 1, wherein the waste is liquid waste having an energy content expressed as dry matter concentration in the interval of about 2 to about 12% (w/w), preferably about 4 to about 10% (w/w).
6. The method according to claim 1, wherein the first step includes subjecting the waste to biological treatment under anaerobic conditions at an elevated temperature, at least about 30°C in a mesophilic process, or at least about 50°C in a thermophilic process.
7. The method according to claim 1, wherein the second step involves the adjustment of the pH to at least pH 7, preferably to about pH 9, and most preferably to above pH 9 to produce uncharged ammonia in said digestate.

8. The method according to claim 1, wherein the pH adjustment is performed through the addition of one of urea, ammonia, hydroxides, lime or a combination thereof.
9. The method according to claim 9, wherein urea is added to a concentration of at least about 0.1% to about 2.5% (w/w), preferably to a concentration of about 0.5% to about 1% (w/w).
10. The method according to any one of claims 7 – 9, wherein the digestate is incubated at a pH of at least pH 7, preferably about pH 9, and most preferably above pH 9, and at a temperature of at least 30°C to produce uncharged ammonia in said digestate.
11. The method according to any one of claims 1 – 10, wherein the digestate is used for fertilization purposes.
12. A system for the production of biogas under anaerobic conditions, comprising a biogas reactor (30) and at least one sanitization reactor (40), adapted to adjusting the pH of the digestate to at least pH 7, preferably to about pH 9, and most preferably to above pH 9, and for incubating the digestate at a temperature of at least 30°C.
13. The system according to claim 12, wherein the adjustment of the pH of the digestate comprises an addition of one of urea, ammonia, hydroxides, lime or a combination thereof.
14. The system according to claim 12, wherein the biogas reactor (30) also functions as sanitization reactor.
15. The system according to claim 12, additionally including means for heat recovery, wherein heat is recovered downstream, such as in the product storage silos; and used for heating or conditioning the incoming material as it is fed to the reactor, for maintaining an elevated temperature in the sanitization reactor, or for heating adjacent buildings.

16. A sanitization reactor (40) adapted for use in a system according to any one of claims 12 – 15.

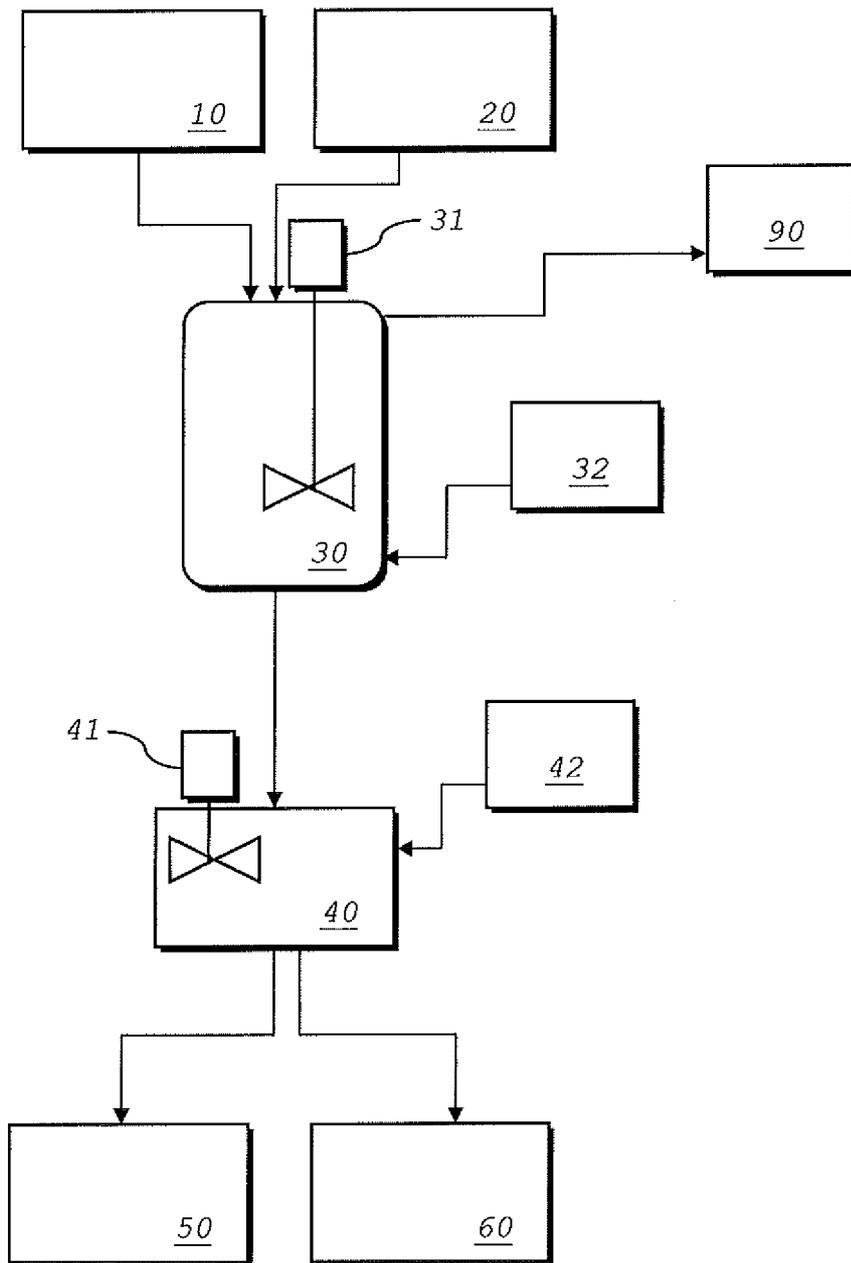


Fig. 1

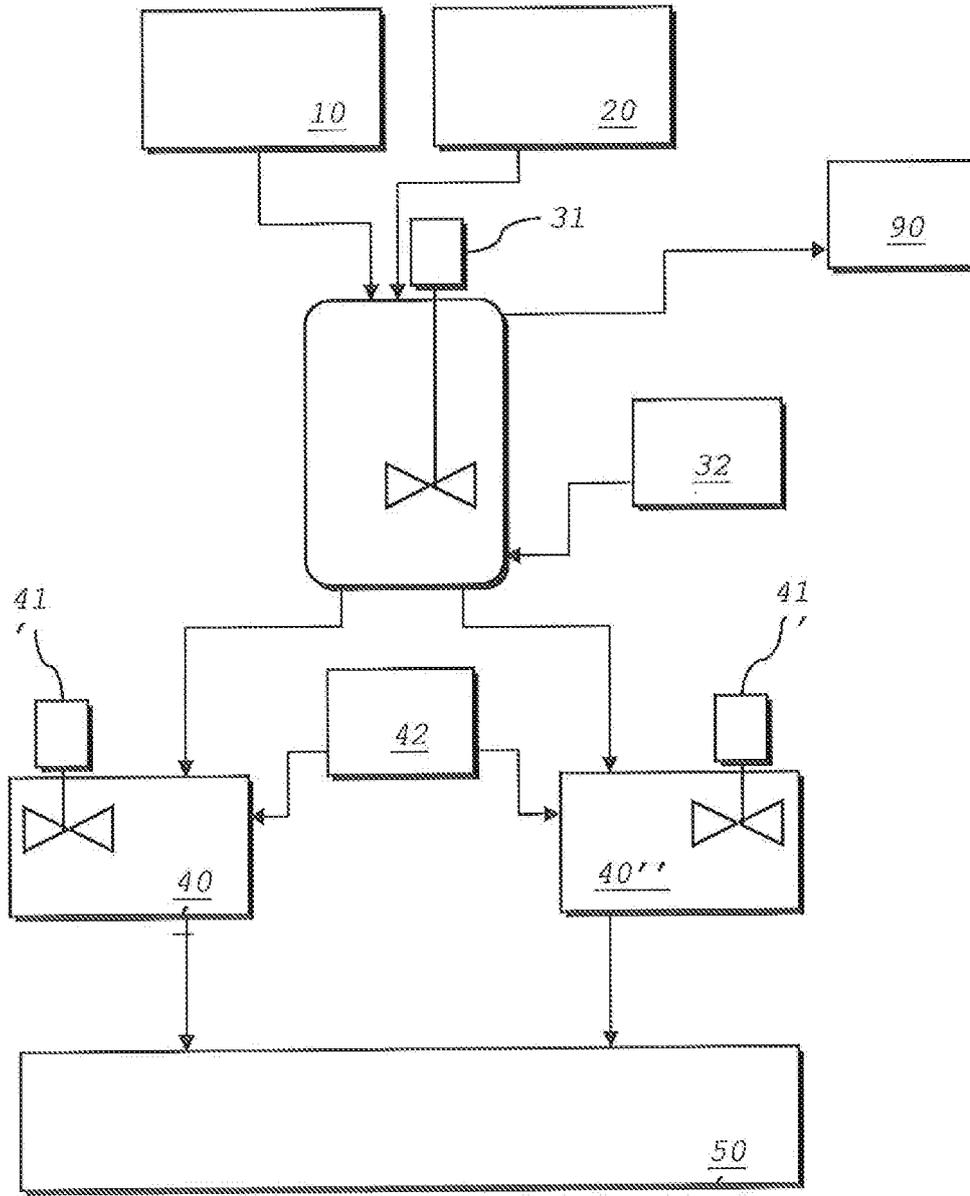


Fig. 2

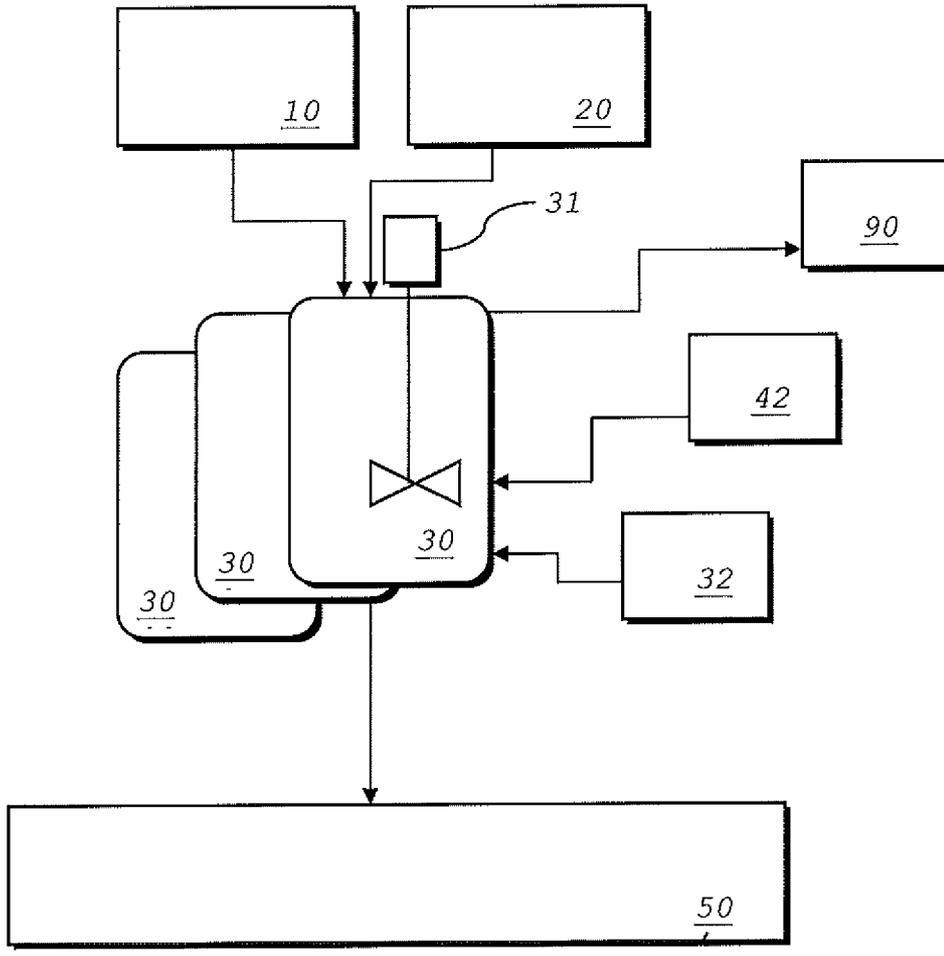


Fig. 3

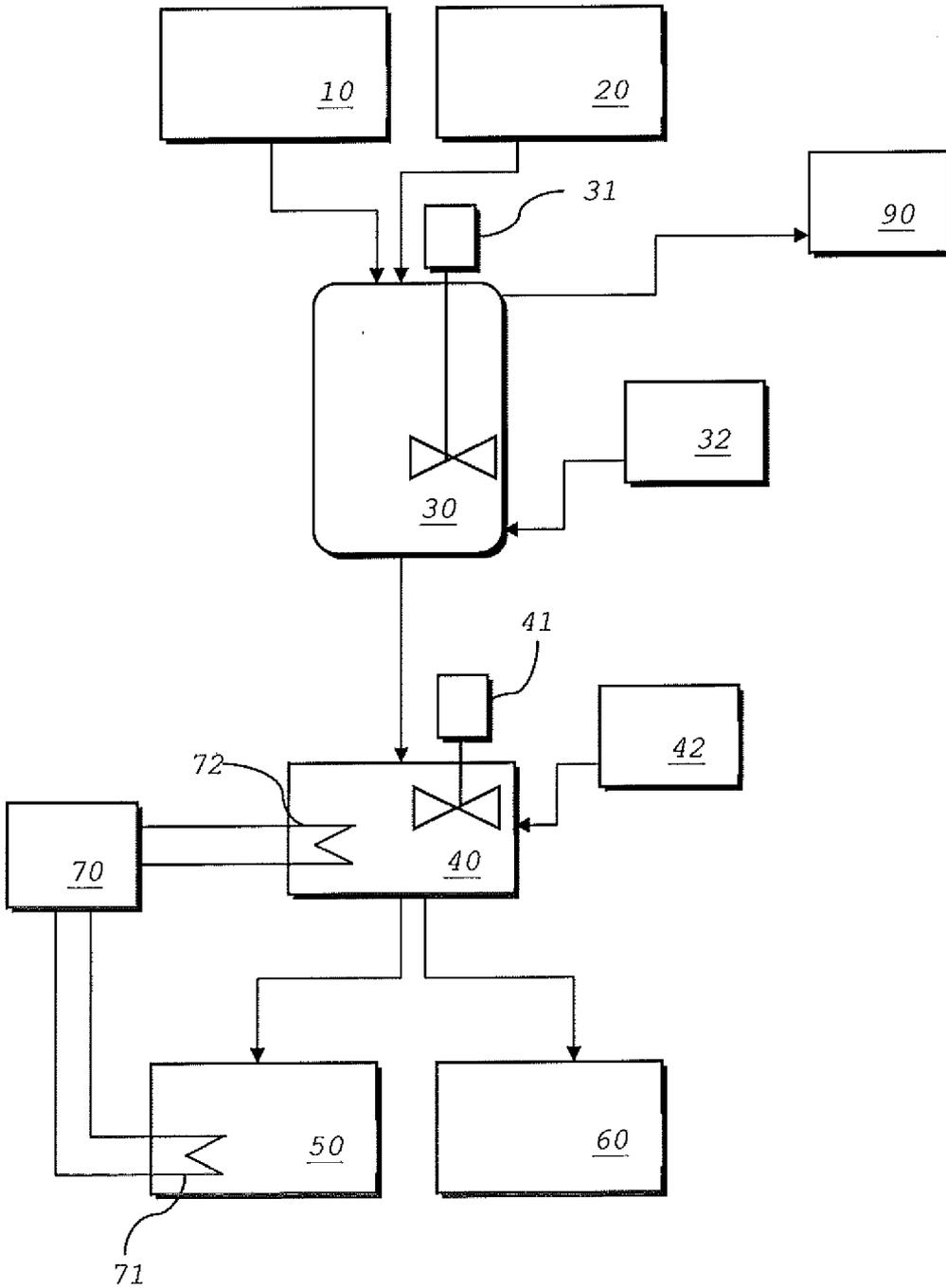


Fig. 4

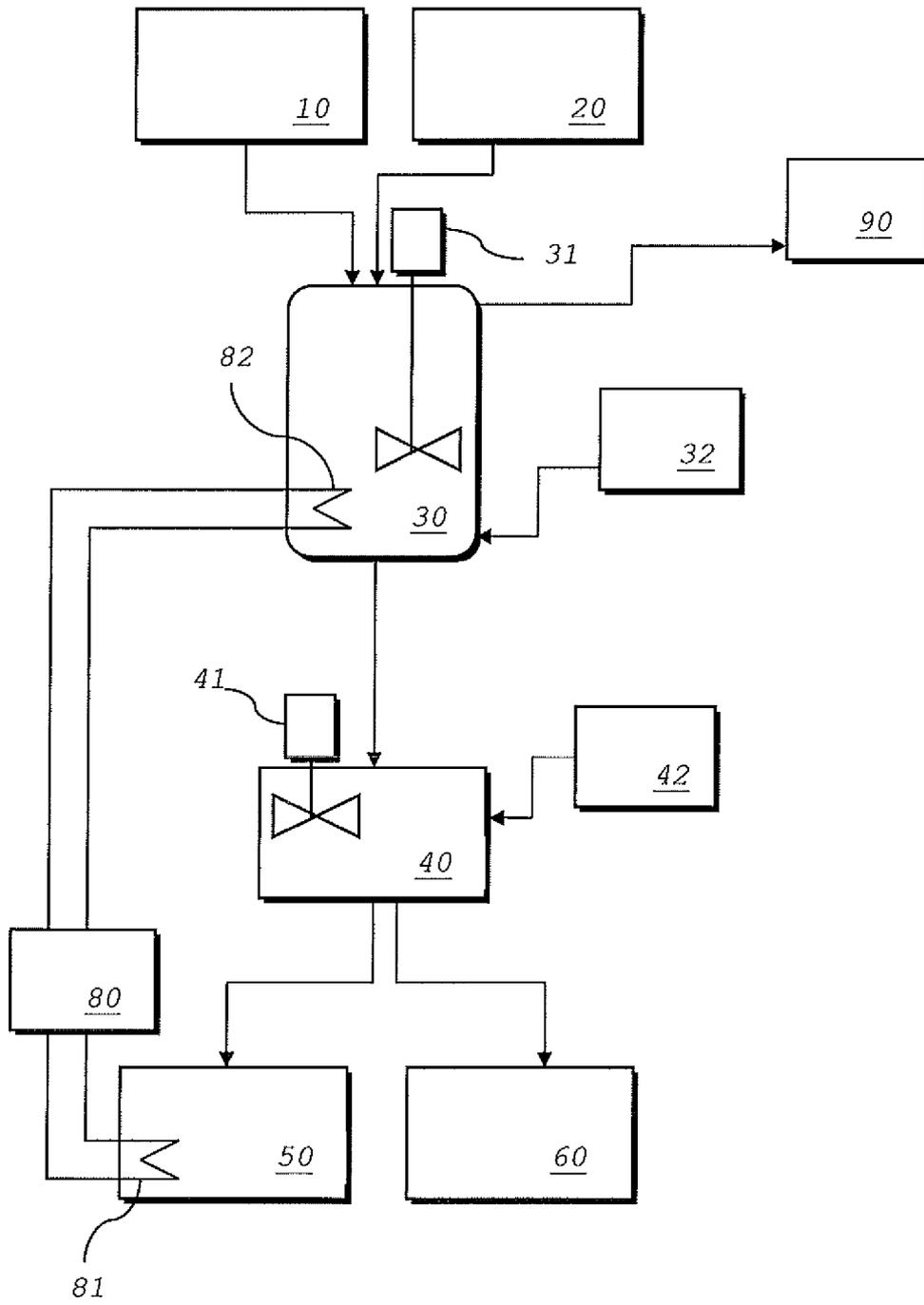


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2012/050201

A. CLASSIFICATION OF SUBJECT MATTER
INV. C12P5/02 C12M1/107
ADD.

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)
C12M C12P 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)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>OTTOSON ET AL.: "In situ ammonia production as a sanitation agent during anaerobic digestion at mesophilic temperature", LETTERS IN APPLIED MICROBIOLOGY, vol. 46, 2008, pages 325-330, XP002677130, page 326 page 328 page 329</p> <p align="center">-----</p>	1-16
X	<p>Veronika Schirm: "Entwicklung einer sicheren Methode zur Bioabfallhygienisierung mit Kalk", 2005, Giessen (Germany), XP002677131, page 6 - page 12 page 48 - page 51</p> <p align="center">-----</p> <p align="right">-/--</p>	1-16

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

"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

5 June 2012

Date of mailing of the international search report

29/06/2012

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INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2012/050201

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>Ida Sylwan: "A technique for sanitizing sewage sludge. Urea treatment with dual advantages", Sveriges lantbrukuniversitet , June 2010 (2010-06), page 61PP, XP002677132, Uppsala (Sweden) Retrieved from the Internet: URL:http://www.w-program.nu/filer/exjobb/Ida-Sylwan.pdf [retrieved on 2012-06-05] page 14 - page 17 -----</p>	1-16