REDUCTION OF ENERGY AND WATER DEPENDENCE FOR SAFER CAMP MANAGEMENT: AUTONOMOUS WASTEWATER TREATMENT SYSTEMS

ENERGIA - ÉS VÍZFÜGGÉS CSÖKKENTÉSE A BIZTONSÁGOSABB TÁBOR-ÜZEMELTETÉS ÉRDEKÉBEN: AUTONÓM SZENNYVÍZKEZELŐ RENDSZEREK

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Abstract

A multitude of tragic historical examples proves that organic wastes, in particular faecal-infected wastewaters, are among the highest secondary threat in crisis situations. Untreated wastewater is a medium of most various pathogens and parasites; endangering both human and environmental health. Constructing complex wastewater treatment plants is impossible in emergency situations. The installation and operation of such systems is expensive, they require energy and chemicals from sources outside the camp, and the elimination of the produced waste sludge depends on external service providers, too. Treatment plants occupy a large surface, they are hard to camouflage and protect, and therefore they would constitute vulnerable points in the camps. Fast-installation, autonomous wastewater treatment systems are identified in this review, that depends less on external providers, can be hidden, and produce re-usable end products. Due to these advantages, they can serve both permanent refugee and peace-keeping military camps. Later on, they can be used by the local community.

Keywords

health protection, supply security, environmental safety, waste decontamination, cyclic management

Absztrakt

Tragikus történelmi példák sokasága igazolja, hogy válsághelyzetben a szerves hulladékok, azon belül is a fekália-tartalmú szennyvíz jelenti a helyszínen tartózkodókra leselkedő egyik legsúlyosabb másodlagos fenyegetést. A kezeletlen szennyvíz a legváltozatosabb kórokozó csírák és élősködők tenyészközege; az embert és a környezetet is közvetlenül veszélyezteti. Válsághelyzetben nincs lehetőség komplex szennyvíztisztító rendszereket létesíteni. Ezek kiépítése és üzemeltetése költséges, táboron kívüli forrásból villamos energiára és vegyszerekre szorulnak, és a keletkező szennyvíziszap eltávolítása is külső szolgáltatótól függ. E tisztítóművek nagy felületűek, nehezen álcázhatók és nehezen is védhetők, így a táborok sebezhető pontjai. Áttekintésünkben olyan gyors telepítésű, autonóm szennyvízkezelő rendszereket azonosítunk, melyek kevéssé függnek külső beszállítótól, elrejthetők, és újrahasznosítható végterméket bocsátanak ki. Így menekülttáborok és katonai létesítmények kiszolgálására egyaránt alkalmasak, utólag pedig a helyi közösség mindennapi életébe is integrálhatók.

Kulcsszavak

egészségvédelem, ellátásbiztonság, környezetbiztonság, hulladék-ártalmatlanítás, körforgásos gazdálkodás

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INTRODUCTION

Compared to the conditions of usual civil life, population density in both refugee and military camps is extremely dense. Therefore solid and liquid wastes are produced in high areal concentration, posing public health and environmental threats at the same time. This is why, sanitation issues have been treated with due care throughout written history, as witnessed from the biblical Old Testament until today's SPHERE standards and international regulations.

Whether caused by natural / industrial disaster or by armed conflict, crisis situations do not facilitate effective - if any - wastewater treatment. Pre-existing treatment facilities are damaged or overloaded, while time and other resources are lacking to construct new infrastructure. In *temporary camps*, sanitation often consists of simple latrines, meaning no wastewater treatment at all. Chemical water disinfection is applied in other cases, which converts immediate public health hazard to long-term environmental pollution. Complete wastewater treatment plants are sometimes built in *permanent camps*, according to the regulation of the operating country, such as in the former Swedish - Finnish PRT camp in Mazar-i Sharif (Afghanistan). But these facilities inflict the camp with a large surface, and they cannot be camouflaged, presenting a hardly defendable vital infrastructure, vulnerable to sabotage, armed attack, or floods, landslides. Moreover, such facilities are expensive to install and to operate, and they largely depend on the external supply of energy and chemicals, as well as sludge removal from the camp, while the disposed wastewater sludge is a hazardous waste, too. Identifying autonomous wastewater treatment technologies that are

- readily installable, easily transportable,
- less dependent on external supply
- easy to hide and
- produce re-usable end products

would improve all health, environmental and - when applicable - defence security of the camps.

Due to recent results in the research of electro-active microbes, development in fluid physics, and the publication of some advances of the former Soviet space exploration and artificial biosphere programme, it is now possible to set up devices that satisfy the above criteria. In the best case scenario, they may produce energy instead of consuming it, and may supply utility water for secondary use (cleaning, toilet flush, greening etc). Such autonomous systems could equally serve temporary and permanent, refugee and military camps. In case of being left in place after the emergency, they could be integrated into the everyday life of the local community.

Opportunities of improved wastewater treatment are reviewed in this paper. Solid-phase organic wastes involve no less risk to health and environment, but the remediation methods are entirely different. Therefore, they will be subject of another paper, only joining points will be highlighted here.

Reverse osmosis, electro-dialysis and other cutting-edge membrane technologies fulfil all of the four above criteria; they even suit to produce potable water. Despite this, they are not considered in this review because of their costly installation and operation.

THEORETICAL PRESENTATION OF THE TOPIC

Characterisation of wastewater

“Military bases resemble small cities and face similar sustainability challenges” - as concluded in the US Army report on transition to zero carbon emission [1]. This is why permanent military bases are either connected to neighbouring urban sewage systems, or they have their own wastewater treatment plants [1], [2]. Likewise, large permanent refugee camps are sometimes provided with treatment facilities[3], [4], or they are connected to the neighbouring sewer system, like the Kosovo IDP camp “Blazevo” near Novi Pazar, Serbia, as presented on Photo 1.

Photo 1: Blazevo IDP camp, Sandzak province, Serbia, 2008(source: the author’s photo)

The fate of wastewaters in temporary camps is entirely different. Forward operation bases, outposts, transit camps operate in unstable areas, where connection to civilian infrastructure is not an option, and there is neither time nor resources to construct treatment facilities. Still, a concentrated discharge of wastewater risks rapidly overwhelming the self-purification capacity of natural ecosystems. Table 1 compares the chemical properties of wastewater available from a typical refugee camp with the one of a typical village wastewaters in Europe, against the discharge standards of a European Union member state.

Parameter	Refugee camp wastewater [3]	Rural wastewater in Hungary [5]	Environmental discharge thresholdsin Hungary[6]
COD mg/L	1909	305	either <150
BOD5 mg/L		137	or <50
TSS mg/L	594	193	<200
TN	1440	56	<55
NH4-N	1315	27	
TP		4	<10

Table 1: Composition of camp and municipal wastewater

Since the sources of wastewater in the studied camp - if collected at all - are basically the same as in other human communities, e.g. washing, cleaning, toilet flush, personal hygiene, cooking remains, its composition is close to municipal wastewater, with local variances. As expected, wastewater in the studied refugee camp (Azraq, Jordan) is far more concentrated, due to the limited availability of water in that region. Apparently, toxic metals present no sensible danger in camp wastewater, since industrial sources are largely absent from camps. The main pollutants are

- organic carbon, as indicated by high biochemical oxygen demand (BOD) and chemical oxygen demand (COD), just as the low concentration of dissolved oxygen
- suspended solids (TSS)
- nitrogenous compounds (TN, total nitrogen), including reduced (NH4-N) species
- phosphorus content was not measured in this survey, but an excess P concentration can obviously be supposed, too.

Although unmonitored in camp conditions, the presence of hydrocarbons, persistent organic pollutants (POP) and microplastics may be reasonably expected. POP is a vast array of bioactive substances, e.g. residues or the derivatives of surfactants, antibiotics, hormones and other medicines. These molecules are particularly hazardous because they affect the physiological functions of living organisms even in trace quantities. Decaying slowly or not at all, they accumulate in the environment, and may reach humans in potable water or by transiting through the food chain.

The SPHERE minimum standards are rather flexible on waste treatment[7], in order to cope with most possible situations between the extremes of emergency onset and permanent settlement. The SPHERE principles are the following:

- containment of human faeces
- minimum number of toilets (latrines, in practice): 1 per 20 inhabitants
- 3:1 female to male toilets
- maximum distance from dwellings: 50 m
- avoid the faecal contamination of water reserves
- proximity to hand washing facilities
- safe collection and disposal

Despite all flexibility, even such standards are difficult to respect under rudimentary conditions in areas where water is a scarce resource, like in the Dashtishur IDP camp in Balkh province, or the Etehad returnee camp in Baghlan province, Afghanistan. (See Photo 2 and 3). Wastewater management is often erroneously neglected even in densely populated, long-term camps, such as those in the Algerian desert for Saharawi refugees [8]where latrines have been used for over 40 years, and secondary recycled water is desperately needed to irrigate gardens [9].

Photo 2: Dashti shur IDP camp, Balkh, Afghanistan,2009

Photo 3: Etehad refugee camp, Baghlan, Afghanistan, 2008

(Source: the author's photos)

SPHERE has recently recommended the use of human excreta to produce biogas or compost in refugee camps. Water and energy saving opportunities are intensively researched both in permanent military bases for economizing resources [1], and in temporary or forward camps in order to ease logistic duties [10].

Usual wastewater treatment methods

Municipal wastewater treatment technologies

The common objective of all wastewater treatment technologies is to separate dissolved and suspended pollutants from water. The core of all widespread technologies is microbiological treatment, even if the exact way of removing each of the principal pollutants depend on the actual implementation. The biological cleaning process usually consists of three main steps. Biodegradable organic matter is partly decomposed by microbial metabolism to carbon dioxide and water to gain energy, while the remaining part is transformed and built in microbial cells. Excess nitrogen is first oxidized, then the resulting N_xO is reduced to inert N_2 gas that is discharged in the atmosphere. Excess phosphorus is usually bound into insoluble salts, then precipitated with the sludge that consists of dead microbial biomass and suspended solid pollutants, as well. The three-step biological process is preceded by the physical filtration of large particles, and may be succeeded by chemical disinfection. The essence of any wastewater treatment technology is to mimic the self-purification capacity of natural ecosystems, while enhancing some of its particular aspects. The simplest - and the least intensive - implementations are anaerobic lagoon (imitation of lakes), and constructed wetlands (imitating marshes or meadows). Both occupy large areas and host slow biodegradation processes; therefore, they are not practical for camp applications. Wastewater treatment plants use several methods to improve the natural bioprocesses:

- spacial or temporal separation of anaerobic, anoxic and aerobic phases
- artificial aeration and stirring
- flocculants and polyelectrolytes addition for better precipitation
- separation of water treatment from sludge treatment cycles
- immobilizing the microbes to form a biofilm on granules or membranes.

Sludge recirculation is generally applied. While the separated liquid fraction runs through the treatment system within a dozen of hours, sludge fraction is recycled many times to remain for weeks, leaving sufficient time for slow bioprocesses. Wastewater treatment systems result in fair water quality, but they require capital investment, the external input of energy and chemicals, as well as external services to remove and treat waste sludge from the camp. At the same time, a system of complex bioreactors still occupies a large area and needs skilled operators. Moreover, all the chemical energy bound in the organic matter gets lost. Treatment plants are efficient in removing organic carbon, nitrogen and phosphorus compounds from water. But they cannot eliminate viruses, as discovered in recent COVID research [11]and persistent organic pollutants which have been of growing concern in recent years[12].

Biomethanisation

Anaerobic microorganisms are able to partially oxidize organic matter in the absence of oxygen, by removing hydrogen instead. This is the underlying principle of biogas digestion that is extensively used for wastewater treatment. Organic molecules are first converted to fatty acids, that are further converted to acetate and, finally, to CH_4. H_2, H_2S and CO_2 are by-products of the reaction chain. Biogas digestors always transform only a part of the available organic matter, but they produce combustible biogas that can be used for cooking, heating, lighting or electricity generation. Biogas plants operate with a far longer hydraulic retention time than wastewater treatment plants (over two months) and they need heating for optimal operation.

Nearly 18.000 high performance biogas plants were operational only in the European Union in 2017 [13] . But these high-tech installations are complicated, costly to build and to run, need expertise and maintenance to operate. Due to their size, they are particularly vulnerable to natural disasters, sabotage or armed attack. Both India and the People's Republic of China have been developing small-scale, low-tech, extremely simplified biogas digestors of household scale, which are easy to build and to operate. But without heating and continuous stirring, these installations are relatively inefficient, the yield is unreliable, and without adequate post-processing, the biogas can only be used for heating and cooking.

As opposed to municipal wastewater treatment plants, biogas digestors cover their own energy needs and rarely require external chemical input. Due to heating and long retention time, viruses and persistent organic pollutants are better eliminated, as well. But they still rely on external services for eliminating the effluent. Because they produce inflammable gases, these systems are even more vulnerable than treatment plants. Taking all limitations into account, none of the currently used biogas technologies are appropriate in temporary camp conditions, although instances in permanent refugee camps [14] and military bases [15]exist, and SPHERE encourages their use, as well [7].

Composting

Composting microbially transforms a part of the substrate into biochemically stable macromolecules, while the remaining organic matter is oxidized to CO2 and water, supplying energy for this transformation. The simplest form of the process, ripening animal manure, has been used by humanity since millennia. The industrial-scale composting of other raw materials has been spreading since the 1970s.

The process consists of three main phases: the decay of easily biodegradable substances heats the substrate above 50 °C within the first 4 - 5 days. At this temperature, slowly degradable macromolecules break down to more easily degradable substances, thus this phase is self-sustainable until sufficient oxygen is present in the pore volume of the substrate. As oxygen is gradually consumed, the temperature decreases to the mesophilic zone, 35 - 45 °C in the second phase. Aerobic reactions slow down and – in parallel with it – anaerobic reactions dominate in the sub-spaces where oxygen is missing. Without aeration, this phase may last 2 - 3 months. Stable humus precursor molecules build up during the last, „ripening" phase when, while the decay of unstable substances ceases. The whole process can be accelerated with artificial aeration, either by regularly mixing the substrate or by forcing air through it. The optimal substrate has 40 - 60% moisture content and a C/N ratio between 25:1 and 50:1. Composting is appropriate to treat wastewater sludge with carbon-rich additives, such as straw or solid organic wastes. Simple variants of this technology, as shown on Photo 4, may then be considered for use in camp conditions, especially if it is linked to solid organic waste treatment.

Photo 4: Composting in Dehrazi, Afghanistan, 2007
(Source: the author's picture)

Alternative wastewater treatment opportunities

Biofiltration

A biofilter is a packed-bed bioreactor, containing a granular or fibrous matrix material, and a microbial consortium forming a biofilm on the inner surface of this matrix. Suspended and colloid-phase pollutants are physically filtered by the matrix. A part of the dissolved organic and inorganic pollutants is adsorbed to the matrix, too. The biodegradation of the dissolved, adsorbed or filtered organic matter and other bioprocesses, such as denitrification, nitrification and phosphate reduction take place on the biofilm. The packing matrix material itself may be inorganic or organic; it should be locally available, cheap, porous with high specific surface, e.g. volcanic gravel, plastic beads, reed, coconut fibre etc. Biofilters can be heated, and operated under either aerobic or anaerobic conditions. They host far more complex biochemical processes than wastewater treatment systems or biogas digestors, therefore they may be much smaller. They are simple to operate, but because they are sensitive to fouling, high concentration of suspended inert solids should be avoided in the incoming wastewater.

Bio-electrochemical systems - MFC/MEC

Another alternative application of oxidizing organic matter by extracting hydrogen is to remove an electron and a proton separately, to transfer them through different pathways and to unite them at a remote location. Bio-electrochemical systems use exoelectrogenic microbes that, in the absence of other terminal electron acceptor, are able to implement this process. They are able to transfer electrons through their trans-membrane enzyme system to a positively charged anode, while ejecting the corresponding protons to the growth medium. If a semi-permeable (usually cation exchange) membrane separates the anaerobic anode space of the reactor from the aerobic cathode space, the protons transit to the cathode by diffusion. The electrons arrive at the same place through an external circuit, where protons and electrons combine with atmospheric oxygen to form water. This is the biochemical principle of microbial fuel cells (MFC). If oxygen is entirely excluded, protons and electrons combine on the cathode to form elementary H_2 gas, in this case an external supply of electric potential is needed to provide the driving force. This latter application is microbial electrolysis cell (MEC)[16]. Bio-electrochemical systems transform organic matter less effectively than aerobic systems, and at the present state of art, they are unable to produce a considerable amount of electric power. Meanwhile, due to utilizing a different array of substrates, they can improve the efficiency of more traditional biodegradation technologies, such as biofiltration (MFC) or biogas digestion (MEC), when combined.

Electrofermentation-assisted biomethanisation

As enzymatic redox reaction chains depend on the electrolyte potential of the medium, alternative metabolic pathways can be selected by applying a suitably chosen electric potential into the bioreactor. For example, microbial consortium in a biogas digestor can be electrically stimulated to produce more H_2 at the detriment of CH_4, or more CH_4 at the expense of CO_2, etc. Assisting biogas production with electrofermentation promises improved biogas quality, reduced fermentor size, and more sensitive process control. According to recent research[17], the potential yield gain may reach up to 84%, and productivity might double.

A recent innovation to increase overall process efficiency is the application of jet-loop system instead of simple stirring. Jet-loops make a simultaneous use of the Venturi tube principle and of turbulent flow properties. This configuration avoids harmful vortex formation by separating the central downstream flux of a swirling liquid from the peripheral upstream in concentric cylinders. Jet-loop has its own drawbacks, but utilizing the mentioned physical laws, it consumes sensibly less energy than stirring blades to keep the same amount of liquid mixing. Jet-loop reactor configuration allows for up to 70 % mass transfer increase and even higher yield gains. [18] Despite the fact jet-loop is increasingly applied in a number of sectors, it has not made its way to the biogas industry yet.

Thermophilic bioprocesses are a lot faster than mesophilic, according to Avogadro's law. Using 60 ^{o}C instead of 37 ^{o}C as operational temperature allows shorter hydraulic retention times, meaning that a thermophilic biogas digestor can be smaller than a mesophilic one, eventually less than half the size, for the same amount of substrate.

Besides wastewater, solid wastes are the other major issue of disease control and epidemics prevention in a camp. Solid wastes in refugee camps comprise of about 70 % organic matter, with approximately 50 % moisture content. On the one hand, solid organic fraction is an ideal host to pathogen microorganisms, parasitic worms and rodents propagating a multitude of diseases. It is therefore of prominent importance to rapidly remove and correctly decontaminate it. On the other hand, it contains useful chemical energy which, due to the high moister content, cannot be released simply by burning. Integration of the above improvements in biomethanisation science allows higher medium densities fed in a biogas digestor. This opens the possibility to treat wastewater combined with solid organic wastes.

Photosynthetic CO_2 supplementation with algae

Although one of the chief pollutants in wastewater is undercomposed organic matter, there is a stoichiometric lack of carbon with regard to nitrogen and phosphorus content. One possible way to circumvent this bottleneck is to photosynthetically bind sufficient atmospheric CO_2 for building excess nutrients in vegetal biomass, that is, a useful end product. “BIOS-III.”, the log-term artificial biosphere experiment attached to the Soviet space exploration programme, proved in the 1960s that Chlorella sp., algae species were able to recover nutrients while decomposing organic pollutants from wastewater, with supplementing carbon from atmospheric carbon dioxide. [19]Since then, several species, including filamentous and microalgae, have been tested in various experimental configurations worldwide. The advantages of using algal instead of vegetal photosynthesis are:

- higher overall conversion efficiency
- microalgae can be readily recycled to, for instance, a biogas digestor
- optimal growth conditions can be more comfortably regulated in a closed photobioreactor than in a constructed wetland
- a photobioreactor can be fold up in several parallel layers, thus it is more compact than a wetland
- Biocoenosis in an algal reactor is simpler than a phytocoenosis, its behaviour is more predictable, that is, numerically more modellable.

Like biomethanisation, biofiltration and constructed wetlands, a photobioreactor can be electrochemically stimulated. Using algae is possible in, for example, a microbial fuel cell to produce elementary oxygen gas directly on the cathode,[20] reducing carbon dioxide that was produced on the anode. Due to its potential advantages, a wastewater cleaning technology based on bio-electrochemically assisted algal photosynthesis may eventually suit to camp conditions.

Bio-electrochemically assisted biofiltration

Biofilters can be hybridized with bio-electrochemical systems. A microbial fuel cell, for instance, may be created within a biofilter, separated to an anaerobic and an aerobic sub-space. The anode is inserted in the anaerobic bottom sub-space, while the cathode is placed on the top of the upper aerobic sub-space, exposed to the atmosphere. The two electrodes are connected through an external resistance. An identical biofilter without the electric circuit would similarly decompose the organic matter, but would leave far higher remaining nitrogen concentration. Bio-electrochemical assistance stimulates denitrification-nitrification processes and dephosphorisation. The oxidation of slowly degradable organic carbon may improve to some degree, as well.

Electro-active rhizosphere systems

The EU CORDIS “iMETland” research project is aimed at improving the efficiency of constructed wetlands in wastewater cleaning[21]. In all the various technological implementations of constructed wetlands, wastewater is fed in a porous or fibrous matrix, where aquatic plants are growing. The rhizosphere, composed of plant roots and the associated microbial community, decomposes organic pollutants and utilizes nitrogen and phosphorus as nutrients. The natural process is slow; this is why constructed wetlands require large areas for effective operation. In this experiment electrically conductive polymer fibres were integrated in the matrix, which allowed electro-active microbes to form a biofilm. In this way, the different enzyme-catalysed redox steps of the decomposition process could take place at the distant micro-spaces of the matrix [22]. Such spacial partition of the biochemical processes replaced stirring, which would otherwise have been impossible. This multiplied the reaction speed, reaching eventually up to ten times faster biodegradation in certain cases. Other hybrid setups, based on this principle, have been successfully tested, too [23].

CONCLUSIONS AND DISCUSSION

Established, emerging and experimental wastewater treatment methods are compared in this chapter, with regard to their potential feasibility and usefulness under camp conditions. Technological, financial and defence criteria are taken into consideration in a SWOT (strengths vs. weaknesses and opportunities vs. threats) matrix. Feasible configurations will then be suggested for pilot tests, based on the SWOT analysis.

Evaluation of camp wastewater treatment choices - SWOT matrix

Technology	**Strengths**	***Weaknesses***	**Opportunities**	***Threats***
Municipal WWTPs	Ripe technology, fair water quality, high throughput	*External supplies needed, residual pollutants, slow start-up, expensive*	Produces reusable water	*Cumbersome size, vulnerable, difficult to hide, skilled work needed, only few mobile applications*
Bio-methanisation	Ripe technology, autonomous operation, nearly disinfected effluent	*Post-treatment needed, long HRT, services needed, slow start-up, expensive*	Useful end-products, energy gain, connection to solid waste management	*Cumbersome size, difficult to hide, inflammable gases, skilled work needed, immobile*
Composting	Ripe technology, fast substrate disinfection, high throughput, inexpensive	*Only treats solid substrate, external energy input needed, slow start-up*	Useful end-product, connection to solid waste management, simple operation	*Sequential batch operation, immobile*
Biofilter	Emerging technology, high throughput, small size, short start-up, inexpensive	*Fouling, need for matrix post-treatment*	Reusable water, can be intensified with energy input, simple operation, mobile	

Technology	**Strengths**	***Weaknesses***	**Opportunities**	***Threats***
Bio-electrochemical systems (BES)	Substrate disinfection, short HRT	*post-treatment needed, energy needed, long start-up, expensive*	Improves the performance of other technologies, mobile	*No standalone technology available, skilled work needed*
Electro-fermentation	Emerging technology, autonomous operation, nearly disinfected effluent, accelerated start-up	*Effluent needs post-treatment, long HRT, expensive*	Useful end-products, energy gain, connection to solid waste management, scalable size	*Inflammable gases produced, skilled work needed, only a few mobile applications*
Algal bioreactor	Emerging technology, autonomous operation, short start-up	*Effluent needs post-treatment, expensive*	Useful end-products, link to solid waste management, mobile	*Skilled work needed*
Biofilter + BES	High throughput, small size, short start-up, cheap	*Experimental system*	Reusable water, simple operation, mobile	*No established technology available*
Constructed wetland + BES	Emerging technology, autonomous operation, inexpensive	*Risk of fouling, reduced scalability, reduced control, long start-up*	Produces reuseable water, simple operation	*Seasonal operation, immobile*

Table 2: SWOT matrix of available wastewater technologies

According to the SWOT analysis, one out of three traditional treatment methods, and three of the six alternative methods fulfil the feasibility criteria of camp application: composting, biofiltration, electro-active biogas digestion, electro-active biofiltration.

Suggested setup for pilot testing

A short, three-stage sequence of the simplest wastewater treatment methods is proposed on Figure 1, for pilot testing.

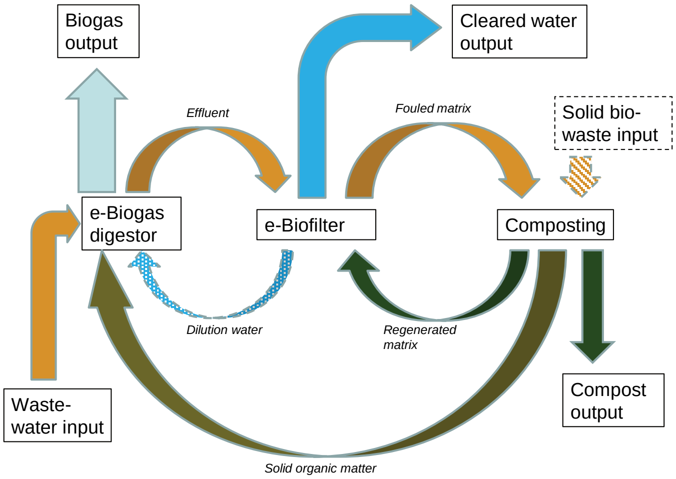

Figure 1: Flow-chart of a three-stage water management system for camp use

Stage 1: As shown in Table 1, biodegradable organic carbon concentration in camp wastewaters is high enough to feed into a regular municipal sewage sludge digestor. Wastewater is first fed in a biogas digestor for anaerobic pre-treatment. If the

- main purpose of the digestor is fast hygienisation and an anaerobic pre-treatment of raw materials, and
- is bio-electrochemically assisted, heated to thermophilic temperature zone,
- and the reactor design uses mechanical innovations such as jet-loop configuration,

a considerably reduced size with high flow-rate is allowed. With such size, the biogas digestor can be mobile, and easy to camouflage for additional protection. Toxic H_2S can be simply removed from the produced biogas within the reactor space itself, by a copper mesh inoculated with desulfurizing bacteria. Once the gas is dried in a condenser, it can fuel the engine of an aggregator to produce electricity. Under moderate climate, an average thermophilic biogas digestor consumes approximately 60 % of the waste heat produced in the aggregator, for maintaining its own temperature. The remaining heat can be used for other purposes.

Stage 2: The biogas effluent is treated in a biofilter, where bio-electrochemical assistance and mesophilic temperature secure a high throughput for aerobic biodegradation of the pre-treated organic matter, as well as for denitrification, suspended and colloid particle filtration, and phosphorus removal. The biofiltered water can be reused for nearly all purposes except for drinking, cooking and personal hygiene.

Stage 3: The matrix material needs regular regeneration because of fouling by suspended solids. The easiest way of regeneration is composting. About 85 % the filtered organic matter is ultimately decomposed to CO_2 and H_2O, while the remainder is transformed into stable macromolecule complexes. The composted material is partly reused as the biofilter matrix, partly recycled in the biogas digestor as co-substrate. The remainder can be used to fertilize eventual garden plots. Solid organic waste treatment may be linked to the system at this point through co-composting, by mixing them to the fouled biofilter matrix. In this case, a grinder, chopper or other fragmenting tool is needed to ensure maximum 25-30 mm particle size in the composting phase.

In addition, bio-electrochemically assisted constructed wetland is a powerful water polishing tool. If topological and security conditions around the camp allow, its use is strongly advisable as water post-treatment, to produce quasi-potable water. Mobile high-tech membrane technologies would implement the same duty at several times higher cost.

SUMMARY

A multitude of various pathogens and parasites proliferates in untreated wastewaters, which contain a large scale of emerging pollutants in addition to threatening both human and environmental health. Camp wastewaters do not differ much from municipal wastewaters that can be cleared with well-established, widespread technologies. But building and operating complex wastewater treatment plants are expensive, and even worse, they rely on energy and chemicals from sources outside the camp, and the elimination of the produced waste sludge depends on external service providers, too. Treatment plants occupy a large surface, they are hard to camouflage and protect, constituting vulnerable points in the camps.

A number of emerging and experimental treatment options are identified in this review. Based on an evaluation against feasibility criteria in camp conditions, fast-installation, autonomous wastewater treatment systems are identified, that depend less on external supplies, do not need highly skilled operators, can be hidden, and if possible, produce re-usable end products. A simple, three-stage hybrid system is suggested for further study and pilot-scale tests both in refugee and military settings. The proposed system is expected to reduce health and environment risks without reliance on local civil facilities, while producing useful energy, re-usable water and stabilized compost for garden soil improvement.

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