SUSTAINABLE SEWAGE TREATMENT AND RE-USE IN DEVELOPING COUNTRIES


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ABSTRACT

Most of developing countries often suffer from the absence of efficient institutions; lack of technological knowledge and empirical Know-How of wastewater treatment processes and their implementation; also inappropriate management practices. Trying to get some solutions of the wastewater problems in those countries, Natural Oriented municipal Wastewater Treatment and Reuse concept (NOWTR) will be implemented as a naturally oriented low cost technology for wastewater treatment and re-use, where the wastewater will be anaerobically treated using a natural UASB pond reactor (UCY Pond Type UASB-reactor) to win all of the anaerobic treatment benefits as winning of biogas as an alternative source of energy as well as less quantity of sludge with a very good stabilization status, and cost effective benefits as low capital, operation and maintenance cost. The treated wastewater will be naturally disinfected in polishing/disinfection pond at low cost manner by means of sunlight, then the produced disinfected treated wastewater will be re-used for the agriculture purpose as a potential to recovery of the high valuable nutrients in wastewater like Nitrogen, Phosphor, and Potassium which have an effective value for soil reclamation and its productivity improvement. Also the NOWTR Concept include an effective solutions of safe sludge hygienization and drying for disposal and/or re-use as a fertilizer to improve the soil reclamation.

Keywords: Sustainable treatment Systems; Municipal Wastewater; UASB-pond; anaerobic; Developing Countries

INTRODUCTION

A supply of clean water is an essential requirement for the establishment and maintenance of diverse human activities. Water resources provide valuable food through aquatic life and irrigation for agriculture production. However, liquid and solid wastes produced by human settlements and industrial activities pollute most of the watercourses throughout the world. The increasing scarcity of water in the world
along rapid population increase in urban areas gives reason for concern and the need for appropriate water management practices. Very little investment has been made in the past on sewage treatment facilities; water supply and treatment often received more priority than wastewater collection and treatment. However, due to the trends in urban development, wastewater treatment deserves greater emphasis.

Currently there is a growing awareness of the impact of sewage contamination on rivers and lakes; therefore, wastewater treatment, water and wastewater fees and environmental education according to water saving is now receiving greater attention from a lot of international organizations and government regulatory bodies. However, in the water and sanitation sector the greatest challenge over the next two decades will be the implementation of low cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purposes. Developers should base the selection of technology upon specific site conditions and financial resources of individual communities. Although site-specific properties must be taken into consideration, there are core parts of sustainable treatment that should be met in each case such as: No dilution of high strength wastes with clean water; Maximum of recovery and re-use of treated water and by-product obtained from the pollution substances (i.e. irrigation, fertilization); Application of efficient, robust and reliable treatment/conversion technologies, which are low cost (in construction, operation, and maintenance), which have a long lifetime and are plain in operation and maintenance; Applicable at any scale, very small and very big as well; Leading to a high self-sufficiency in all respects; Acceptable for the local population and comply with the regulations and standards.

In developing world, around 300 million urban residents have no access to sanitation and they are mainly low-income urban dwellers that are affected by lack of sanitation infrastructure. Approximately two-thirds of the population in the developing world has no hygienic means of disposing excreta and an even greater number lack adequate means of disposing of total wastewater [1]. Inadequate sanitation is one of the prime causes of disease. In the developing countries, the provision of sanitation is not keeping up with population growth. The total numbers of population with and without sanitation in all developing countries is higher than 1,500 and 3,000 million respectively, in which the gap is always increasing [2].

In Egypt as an example for developing MENA countries, more than 95% of the Egyptian villages are not provided with wastewater collection and treatment facilities. There are about 4000 Egyptian rural-areas with a population ranging from 1000 to 20000 capita. The wastewater produced from houses in these rural areas is mainly treated in septic tanks. Communities without municipal water range between 23 and 36%. As concerns the lack of sanitation, the coverage is between 6 and 17%. The former communities rely on unimproved water supplies (e.g., wells, rivers, ponds, canals and unprotected springs) and the latter on unimproved sanitation facilities as holes in the ground, bushes and other places where human waste is not contained to prevent it from contaminating the environment. Communities with improved water and sanitation do not all have the same services. It should be noted that the functioning
or the improvements in sanitation facilities also depends on its connection to a sewer system. However, only some of the urban households have access to sewer systems.

The waste water treatment systems in developing countries are not successful and therefore unsustainable because they were simply copied from Western treatment systems without considering the appropriateness of the technology for the culture, land, and climate. Often local engineers educated in the Western development programs supported the choice for the inappropriate systems. Many of the implemented installations were abandoned due to the high cost of running the system and repairs [3].

In the growing number of conflicts between agricultural and domestic use of scarce water resources, an increased use of treated wastewater for irrigation purposes is vital. Wastewater is composed of over 99% water. In a developing urban society, the wastewater generation is usually approximately 30-70 m³ per person per year. In a city of one million people, the wastewater generated would be sufficient to irrigate approximately 1,500-3,500 hectare [4]. Innovative and appropriate technologies can contribute to urban wastewater treatment and reuse. The benefits of reusing treated (waste) waters must also be measured against the cost of not doing so at both the economic and environmental level. The costs of implementing zero-discharge organic waste to agriculture recycling schemes may not be expensive.

Based on the presented situation, it becomes important to investigate and improve further the functioning and performance of wastewater treatment technologies currently in use specially in developing region. The present trend is to use conventional systems in large-sized cities, while for medium and small-sized towns non-conventional technologies are usually considered. The systems commonly implemented in the latter years are waste stabilization ponds and a variety of anaerobic reactors (i.e. septic and imhoff tanks, anaerobic filters, UASB reactors, and anaerobic digesters). Combinations of all these systems are also currently in use in various countries in an effort to find cost-effective alternatives for pollution control. Nevertheless, it is necessary to carry out more investigations on these wastewater treatment technologies.

**SUSTAINABILITY IN WASTEWATER TREATMENT**

In order to achieve ecological wastewater treatment, a closed-loop treatment system NOWTR-Concept is recommended. Many present day systems are a “disposal-based linear system”. The traditional linear treatment systems must be transformed into the cyclical treatment to promote the conservation of water and nutrient resources. Using organic waste nutrient cycles, from point-of-generation to point-of-production, closes the resource loop and provides an approach for the management of valuable wastewater resources. Failing to recover organic wastewater from urban areas means a huge loss of life-supporting resources that instead of being used in agricultural for food production, Fill Rivers with polluted water. The development of ecological
wastewater management strategies will contribute to the reduction of pathogens in surface and groundwater to improve public health. “The goal of ecological engineering is to attain high environmental quality, high yields in food and fiber, low consumption, good quality, high efficiency production and full utilization of wastes” [1]. This can be done centralized or decentralized [5-8].

There is currently a wide variety of systems, which can be successfully applied for wastewater treatment. They should however be selected on the basis of the specific local context. Generally, in industrialized countries the number of suitable alternatives may be more limited due to stricter regulations. In developing countries, however, the number of choices may be higher as a result of the more diverse discharge standards encountered. In this sense, effluent standards vary from the very conservative to the very relaxed. Likewise, the cost component and the operational requirements, while important in industrialized countries, play a much more decisive role in industrializing countries. Also the high contrast between urban and rural areas is an important feature.

**Anaerobic technology for wastewater treatment**

Answering to the high priority request concerning the sustainability criteria of the wastewater treatment technology, the anaerobic wastewater treatment should be regarded as the core method of a sustainable wastewater management strategy due to its benefits and enormous potentials such as: Little (if any) use of mineral resources and energy; Enabling production of resources/energy from wastes; Pairing high efficiency with long term of lives; Applicable at any place and at any scale; Plain in construction, operation and maintenance. Moreover, although conventional aerobic treatment systems generally provide excellent treatment efficiency, they do not fully meet the criteria needed for a sustainable wastewater management strategy [6, 9, 10].

**Application of anaerobic technology**

Nowadays, the anaerobic technology has a very wide application in the field of anaerobic digestion whether for liquid or bio-solid waste. Figure 1 shows the main overall application of the anaerobic digestion.

![Figure 1: Main overall application of the anaerobic digestion](attachment:image.png)
Benefits and drawbacks of anaerobic municipal wastewater treatment

Based on the past experiences and learned lessons in the municipal wastewater treatment, the anaerobic technology proved a very good performance and efficiencies due to its positive advantages against aerobic ones. The main advantages of anaerobic over aerobic treatment are in detail:

1. Instead of using 1 kWh of electricity, 1 kWh of electricity can be produced
   - Positive, instead of negative energy balance
2. Lower sludge production is between 0.02 and 0.2 kg/kg COD-eliminated instead of 0.3 – 0.5 kg/kg COD-eliminated.
   - Lower secondary costs for sludge dewatering, transport and disposal/use
3. Higher volumetric reactor loading rates
   - 3 – 15 kg COD/(m$^3$ reactor d) instead of 0.3 – 1 kg/(m$^3$ d)
4. Nutrients are not removed and remain available

Moreover, the technologies are simple in construction, operation, monitoring, and maintenance, consequently they are cost-effective technologies. Also the systems can be applied everywhere and at any scale and working with high treatment efficiencies [11].

NOWTR-CONCEPT OF ANAEROBIC WASTEWATER TREATMENT AND RE-USE

The main aim of the NOWTR-Concept is the treatment of municipal wastewater and sustainable re-use for natural eco-systems maintaining by the development of a low cost technology in developing countries. It offers environmentally sound and economical attractive solutions for wastewater treatment and re-use in developing countries. The wastewater is anaerobically treated using a natural UASB-Pond (Figures 4, 5) to win all of the anaerobic treatment benefits as winning of biogas as an alternative source of energy as well as less quantity of sludge with a very good stabilization status, and cost effective benefits as low capital, operation and maintenance cost. The treated wastewater will be naturally disinfected in polishing pond and re-used for agriculture purposes to recover the high valuable nutrients N, P and K.
Also with the NOWTR Concept not only a water resource for irrigation is achieved but also an alternative sources of energy in form of biogas to be converted to heat or electricity to save the usual energy resources, also it produces a good stabilized sludge which can be used as a fertilizer to enrich and improve the soil characteristics. The treated wastewater will be used as a source of nutrients for soil, i.e. soil reclamation.

**Construction and Performance of UCY Pond Type UASB Reactor**

The results from the used UASB pond in the tropical conditions show a reduction in BOD up to (80-90) %. The UASB pond technology is feasible in an urban developing world context because of its high organic removal efficiency, simplicity, low-cost, low capital and maintenance costs. Typically UASB ponds have low sludge production (0.02-0.2 kg/kg COD removed) and low energy needs. The biogas yield will be about 60-75 % CH₄ and 20-30% CO₂, and then it will be a good, feasible renewable energy source to be used at a low cost concept. With average of 8h HRT the reactor can be loaded with the waste of approx. 20 P.E./m³. At COD-removal of 65-75 % the specific biogas production is approx. 18 L/(C·d). With domestic waste water the equivalent of CH₄ production to oil is approx. 0.25 L/(m³·d). At present oil prices (0.3 €/L) 27 €/(m³·a) could be substituted and therefore ESNES-concept could be economical. The investments for UASB-pond technology for sewage treatment seems to be possible in the range of (80-160) €/m³ or (4-40) €/P.E., so the straight pay back is between 3 and 6 years.
The UCY Pond Type UASB-reactors kit contents [12]:

- Plastic foil
- Waste water distribution unit
- Three-phase separation for gas, sludge and water (patented)
- Gas storage
- Outlet pipe system
- Process monitoring system
and optional the gas-usage-unit:
- generator with or without hot water generation,
- connection to an existing steam vessel,
- or direct aggregates.

![Flow diagram of a UASB Treatment Plant](image)

**Figure 5**: Flow diagram of a UASB Treatment Plant

*Components of large anaerobic treatment plant in Developing countries*

Because of the limited financial resources, there is a definite need for a cost-effective appropriate technology for sewage treatment system. The UASB reactor technology may be mostly attractive option for sewage treatment for developing countries, because it can be used at small or large scale, in technically simple, lower cost. In developing countries such as India and Colombia the UASB was executed in full scale to treat the municipal wastewater [13].

Each anaerobic treatment plant consists of the following main elements, illustrated in Figure 4:
- overflow bypass and flow measurement structures
- preliminary treatment structure
- coarse and fine screens
- grit trap
- enhanced primary treatment structures (UASB reactor modules)
- by-product handling structures (biogas handling and using; sludge handling)
- post-treatment structures (simple, low cost technique)
Table 3 gives the average removal efficiencies the UASB anaerobic treatment for oxygen consuming substances (BOD$_5$ and COD) and total solids for the four treatment plants visited, including three treating municipal wastewater at Bucaramanga, Colombia; Mirzapur and Kanpur in India and one treating a mixture of tannery and municipal wastewater effluents, also in Kanpur [13].

**Table 3:** Comparison of average influent and reactor effluent quality and removal of four full scale UASB reactors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Municipal Wastewater</th>
<th>Mixed wastewater</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bucaramanga, Colombia</td>
<td>Mirzapur, India</td>
</tr>
<tr>
<td>Design peak capacity (MLD)</td>
<td>42</td>
<td>14</td>
</tr>
<tr>
<td>Operating capacity (MLD)</td>
<td>36</td>
<td>10</td>
</tr>
<tr>
<td>Average organic loading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td>400</td>
<td>360</td>
</tr>
<tr>
<td>BOD$_5$ (mg/l)</td>
<td>150</td>
<td>180</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>230</td>
<td>360</td>
</tr>
<tr>
<td>Average removal efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD (%)</td>
<td>65</td>
<td>61</td>
</tr>
<tr>
<td>BOD$_5$ (%)</td>
<td>75</td>
<td>66</td>
</tr>
<tr>
<td>TSS (%)</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Average HRT (h)</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Influent temperature range</td>
<td>23-25</td>
<td>21-30</td>
</tr>
<tr>
<td>Gas production (m$^3$/d)</td>
<td>3300</td>
<td>500</td>
</tr>
</tbody>
</table>

**OPTIONS FOR POST TREATMENT OF ANAEROBICALLY TREATED WASTEWATER**

Aerobic treatment of an anaerobically treated enhance primary effluent stabilizes the residual oxygen demand in the highly reduced effluent and can be designed to remove significant amounts of nutrients.

Although anaerobic reactors are effective at stabilizing organic material by degrading carbonaceous oxygen demand to methane and carbon dioxide, a typical anaerobic enhanced primary effluent has substantial residual oxygen demand, mostly from the reduced form of nitrogen, ammonia. The readily oxidizable residual oxygen demand may be dealt with in an additional aerobic treatment step or conversion to plant biomass in an integrated treatment and production system.

A normally functioning UASB reactor can remove an average of 65% of COD (range: 50-75%), 80 % of BOD$_5$ (range 70-90 %) and 75 % of SS (range 60-85%). Beginning with a typical municipal raw wastewater, this level of treatment will generally result in a treated effluent that corresponds to an “enhanced primary” quality, intermediate between primary and secondary (between 30-70 mg/l for BOD$_5$) [11]. An effluent less than secondary quality will generally not meet environmentally sound effluent discharge standards and will definitely need further treatment to be safe for reuse in agriculture.
The post-treatment should be designed to improve the effluent quality in the following parameters [14]:

- pathogen contamination (measured by the index of *E. coli*);
- residual organic material (COD/BOD$_5$);
- oxygen demand from the reduced forms of N and S;
- residual suspended solids (TSS);
- inorganic N and P (nutrients).

The treatment systems, which could be used for post treatment, can be summarized as follows:

1. Activated Sludge
2. Aerated bio filters
3. Expanded granular sludge bed reactor
4. Rotating biological contactor (RBC) [15]
5. Dissolved Air Flotation (DAF)
6. Chemical post treatment
7. Trickling Filters
8. Waste stabilization ponds
9. Polishing ponds
10. Constructed wetlands
11. Aquating farming systems
12. Land treatment

**STANDARD OF REUSE OPTION FOR IRRIGATION**

The use of treated wastewater for irrigation needs to consider following aspects:

- Protection of human health
- Protection of the soil (salinity, nutrient)
- Protection of the distribution system (pipelines, valves)
- Reuse of the nutrients (especially N and P) of the wastewater (close the nutrient cycle)
- Acceptance by consumers, farmers and field workers

Irrigation water needs to follow microbiological, chemical and physical requirements

- microbiological (WHO):
  - Category A Treatment to Engelberg “unrestricted” guidelines essential
  - Category B Further measure may be needed
  - Category C Protection needed only for field worker
- chemical and physical (FAO): classified irrigation water into three groups based on salinity, infiltration, toxicity and miscellaneous hazards
<table>
<thead>
<tr>
<th>Category</th>
<th>Reuse conditions</th>
<th>Intestinal Nematode (arithmetic mean of no. eggs per litre)</th>
<th>Feecal coliforms (geometric mean of no. per 100 ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Irrigation of crops likely to be eaten uncooked, sport field, public park</td>
<td>≤1</td>
<td>≤1000</td>
</tr>
<tr>
<td>B</td>
<td>Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees</td>
<td>≤1</td>
<td>No standard recommended</td>
</tr>
<tr>
<td>C</td>
<td>Localised irrigation of crops in category B if exposure to workers and the public does not occur</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

- Water should be free from filterable substances, mud and smell
- The load of depreciating substances (salt, metals) for soil, plants and groundwater should be so small, that these will not be harmed
- Water should be free from toxic substances
- Organic matter always has to be eliminated, because high loadings of organic matter can cause excessive build-up of soil microorganisms. This can cause a microbial slime layer to form on the soil surface, which can lead to soil surface clogging, and in turn, surface pounding, unpleasant odors, and vegetation decay. (EPA limits on BOD₅ range from 10 mg/l to 30 mg/l)
- Substances in wastewater should not cause corrosion on the irrigation technique
- The treatment objective (nutrient content vs. nutrient removal) should be adjusted to the vegetation periods
- Water from wastewater treatment has to be disinfected

**CONCLUSION**

Currently there is a growing awareness of the impact of sewage contamination on rivers and lakes; therefore, wastewater treatment, water and wastewater fees and environmental education according to water saving is now receiving greater attention from a lot of international organizations and government regulatory bodies. However, the waste water treatment systems in developing countries are not successful and therefore unsustainable because they were simply copied from Western treatment systems without considering the appropriateness of the technology for the culture, land, and climate. Often local engineers educated in the Western development programs supported the choice for the inappropriate systems. Many of the implemented installations were abandoned due to the high cost of running the system and repairs.

Answering to the high priority request concerning the sustainability criteria of the wastewater treatment technology, the anaerobic wastewater treatment should be
regarded as the core method of a sustainable wastewater management strategy due to its benefits and enormous potentials. For this, the NOWTR-Concept with the UCY Pond UASB-type was developed and applied. The main aim of the NOWTR-Concept is the treatment of municipal wastewater and sustainable re-use for natural ecosystems maintaining by the development of a low cost technology in developing countries. It offers environmentally sound and economical attractive solutions for wastewater treatment and re-use in developing countries. The UCY Pond UASB-type is easy in construction and operation and available as a construction kit which contents: plastic foil; waste water distribution unit; a patented three-phase separation for gas, sludge and water; gas storage; outlet pipe system and process monitoring system.

With average of 8h HRT the reactor can be loaded with the waste of approx. 20 P.E./m³. At COD-removal of 65-75 % the specific biogas production is approx. 18 L/(C·d). With domestic waste water the equivalent of CH₄ production to oil is approx. 0.25 L/(m³·d). At present oil prices (0.3 €/L) 27 €/(m³·a) could be substituted and therefore NOWTR-Concept could be economical. The investments for UASB-pond technology for sewage treatment seems to be possible in the range of (80-160) €/m³ or (4-40) €/P.E., so the straight pay back is between 3 and 6 years.

With the NOWTR-Concept was created not only an alternative sources of energy in form of biogas (to be converted to heat or electricity to save the usual energy resources) also a water source for irrigation. Moreover, a good stabilized sludge is produced which can be used as a fertilizer to enrich and improve the soil characteristics and support soil reclamation.

REFERENCES


