Project acronym: **WATERBIOTECH**

Grant Agreement number: 265972

Project title: **Biotechnology for Africa's sustainable water supply**

Funding Scheme: KBBE.2010.3.5-02

Deliverable D5.17

First scientific article on main barriers and obstacles for the implementation of innovative biotechnological technics for water treatment in the targeted countries

Due date of deliverable: May, the 1st, 2012

Start date of project: 01.08.2011 Duration: 30 months

Project coordinator: TTZ Bremerhaven, Germany

General Obstacles potentially hindering any innovative Biotechnological Wastewater Treatments implementation in African Countries: A review

Amal Zayen[1], Josiane Nikiema[2], Sana Arousse[3], Anna Garfi[4], Katie Spooner[5], Laila Mandi[6], Gerhard Schories[3]; Sami Sayadi[(1,*)]

[1] Environmental Bioprocesses Laboratory, Biotechnology Centre of Sfax, BP 1177, 3018, Sfax, Tunisia

[2] International Water Management Institute, West Africa Office – Accra, Ghana

[3] ttz Bremerhaven, Water, Energy and Landscape Management, An der Karlstadt 6 - 27568 Bremerhaven - Germany

[4] GEMMA - Group of Environmental Engineering and Microbiology, Department of Hydraulic, Maritime and Environmental Engineering Technical University of Catalonia (UPC), C/ Jordi Girona 1-3, Builing D1, 08034 Barcelona

[5]Agence intergouvernementale WSA (Water and Sanitation for Africa),03 BP : 7112

Quartier Ouayalghin, Secteur 27, 441, Rue Naba Kiiba Boulsa, Ouagadougou 03 Burkina Faso

[6] University Cadi Ayyad, Marrakech, Morocco

* Corresponding author: Pr. Sami Sayadi

Environmental Bioprocesses Laboratory, Biotechnology Centre of Sfax, BP: « 1177 », 3018, Sfax, Tunisia

Tel: 00 216 74 871 816

Fax: 00 216 74 871 818

E-Mail : sami.sayadi@cbs.rnrt.tn

Abstract

In Africa, the world's second-driest continent, the availability and access to water is more crucial to existence than it is almost anywhere else on Earth. Poverty is widespread and although it is rapidly urbanizing, the majority of its population is still rural-based and dependent on agriculture. In sub-Saharan Africa, 69 % of the population has no proper sanitation facilities, while 40 % has no reliable access to safe water.

Selection of the best treatment option for remediation of wastewater is a highly complex task. The choice of one or more processes to be combined in a certain situation depends on the quality standards to be met and the most effective treatment with the lowest reasonable cost.

WATERBIOTECH (EU funded project under the Seventh European Framework (FP 7)) is an initiative that will contribute to cope with water scarcity in Africa by providing access to relevant stakeholders in Western, Eastern and Northern Africa to know-how in biotechnologies, good practices and management solutions adapted to their local conditions for the sustainable management of polluted water resources. The targeted countries of the present Coordination Action are Algeria, Burkina Faso, Egypt, Ghana, Morocco, Senegal, and Tunisia. Libya and Ethiopia will be as well regarded and covered by the neighboring partner countries.

The idea is to disseminate best practices jointly with all the requirements and the strategy necessary for the implementation of selected biotechnologies specifically assigned to local regions within the targeted countries. Relevant actors that will benefit from this action will be farmers, providers of sewage treatment services, authorities and decision makers, specialized scientific community, local communities, and general public who live in water stressed areas.

This paper reviews the current status of the existing wastewater treatment plants (WWTPs) in two African countries taken as cases studies: Tunisia and Ghana and lists the obstacles hindering innovative biotechnological wastewater treatment process implementation. Special emphasis was placed on the worldwide full-scale application of some technologies (anaerobic processes, membrane bioreactors and constructed wetlands) as they could be of interest for African countries. Finally, according to the local conditions and the technology requirements, some recommendations for the upgrading of existing WWTPs or the introduction of new technologies are given.

Key words: Biotechnological processes, wastewater treatment, Innovative technology, obstacles, African countries

1. Introduction

The need for sustainability in the management of water resources is becoming day-by-day more necessary due to their levels of contamination and the frequency of shortages. Indeed, the environment is repeatedly experiencing highly stressing phenomena related to deficient or non-existent wastewater and waste treatment plants, compromising the accessibility to water and sanitation with the resulting health troubles.

The goal of environmental sustainability should be pursued to reduce all discharge dilution phenomena, maximize treated wastewater reuse and by-products recovery. The treatment technologies should be efficient and reliable, with low costs for construction, management and maintenance that support self sufficiency and acceptance by stakeholders and the general public [1].

Developments in wastewater treatment processes enhance a plant's ability to improve effluent quality; ensure the robustness and reliability of equipment; and aim for high automation and low maintenance.

A range of approaches are used to treat wastewater to achieve a required final effluent quality, and manufacturers develop technologies and advanced equipments to effect such treatment. Recent developments in technology also emphasis the need for certain existing treatment facilities to be upgraded [2]. Treatment requirements change for a variety of reasons. Strict discharge consents set by regulators, notably for nitrogen and phosphorus, may necessitate plant upgrade to improve effluent quality. Hydraulic loads tend to increase with time requiring capacity expansion through the development or consolidation of intermittent catchment discharges. Continuous monitoring of the effluent stream to detect treatment deterioration or plant failure can prevent contamination of the receiving environment from discharges.

Many existing municipal wastewater treatment plants use conventional activated sludge, rotating biological contactor or trickling filter secondary treatment processes, together with associated sludge treatment technology. But these basic treatment systems will need upgrading in order to achieve stricter limits on nutrient removal and reduced solids and COD. Plant enlargement or the installation of additional treatment units using conventional technology help meet increased capacity demands, but space limitation and the high capital costs entailed often prove prohibitive. Advanced technologies can then offer a viable alternative.

The traditional solution for wastewater treatment in Africa and south Mediterranean region was just to use cesspits or septic systems. This system is very simple but it is only acceptable for very small groups of houses and under very well defined conditions on the receiving (determined soil permeability, certain depth to the water table, etc). This system can lead to groundwater contamination, foul odors and it does not allow for safe water re-use to any extent.

A more common efficient system is activated sludge plants. This process is based on the aerobic digestion of wastewater with flocculating biological growth, followed by separation of treated wastewater from this growth. This system is fairly efficient in general, although it produces bulky sludge, provide insufficient disinfection for water reuse and have high-energy consumption.

The high costs of conventional treatment processes have lead experts and authorities to search for creative, efficient and environmentally sound ways to control water pollution. The development of simple and cost effective biotechnological water treatment technologies is particularly interesting for African countries. These processes that use relatively more land and are lower in energy and operational costs are becoming attractive alternatives for many wastewater treatment applications.

In the first feature of this review, the state-of-the arts of the existing biotechnological processes used for wastewater treatment in Tunisia and Ghana are highlighted. In the second hand, some technologies employed in the field of wastewater treatment are described. A special focus was given to anaerobic treatment, membrane bioreactor technology and finally constructed wetlands as they can be good options for establishing sustainable wastewater treatment and management in Africa. Besides, obstacles hindering the implementation of such technologies in targeted countries are cited and finally some recommendations for the upgrading of existing WWTPs or the introduction of new technologies are given according to the local conditions and the technology requirements.

2. State-of-the art of the existing biotechnological processes used for wastewater treatment in Tunisia and in Ghana

2.1.Case of Tunisia

Tunisian Republic is the northernmost country in Africa. It is a Maghreb country and is bordered by Algeria to the west, Libya to the southeast, and the Mediterranean Sea to the north and east. Its area is almost 164 150 km2, with an estimated population of just over 10.4 million. Its name is derived from the capital Tunis located in the north-east. Tunisia is the smallest of the nations situated along the Atlas mountain range. The south of the country is composed of the Sahara desert, with much of the remainder consisting of particularly fertile soil and 1,300 km of coastline.

In Tunisia, wastewater collection and treatment is managed by a public company. The National Sanitation utility (National Sanitation Office: short name OFFICE) was established by law N° 73/74, dated 3 August 1974, which was subsequently by law N° 41/93, dated 19 April 1993. It is a public institution of an industrial and commercial character, enjoys civil status and financial autonomy and is placed under the authority of the Ministry of the Environment.

OFFICE missions include the following fields:

- Combating all forms of water pollution
- Management, operation, maintenance, rehabilitation and construction of all sanitation facilities in OFFICE action zone, of which, in particular, wastewater treatment plants, pumping stations and sea outlets.
- Promoting the sector of distribution and commercialization of treated wastewater and sludge,
- Conducting sanitation studies and works on be-half of the state or local government.
- Preparation and implementation of integrated projects.

Currently, 109 wastewater treatment plants are in operation with 11,801 Km of wastewater network collecting 246 million m^3 (table 1). Up to 80 % of the wastewater is treated by activated sludge processes:

- 76 WWTPs: activated sludge at low-load
- 9 WWTPs: activated sludge at medium-load
- 3 compact activated sludge in the rural areas

6.48 % of the wastewater is treated in 7 naturally aerated lagoons, 6.48 % is treated in 7 aerated lagoons, 1.83 % is treated in 2 trickling filter stations and 3.67% is treated in 4 constructed wetlands (fig. 1).

OFFICE, which is responsible for the collection, treatment, and the disposal of wastewater, faces varying costs of treatment depending on the age and type of the plant, its location, and capacity with a high energetic cost of 6.36kWh/kg BOD_5 removed (Haffouz WWTP, low-load activated sludge process, capacity 276m^3/day) to a low of 0.02 kWh/kg BOD_5 removed (Gafsa WWTP; Natural lagoon; capacity 2,614 m^3/day). For some of the WWTPs, the high energetic cost is due to the low flow compared to the station capacity.

The activated sludge process ensures an average removal efficiency of 94 % in term of BOD_5 with energy consumption of 1.47 KWh/kg of BOD_5 removed (Fig. 2 and3).

In the activated sludge system, provided that reactor is well operated, a very good removal efficiency of organics and suspended solids can be achieved. The need for high energy inputs makes the technology expensive to operate and maintain. As the system is also of high complexity and strongly mechanised, it is mainly adapted for centralised systems where energy, mechanical and technical spare equipment and skilled staff are available.

The trickling filter ensures comparable treatment efficiency but the energy required is much higher (1.94 KWh/kg of BOD_5 removed). In fact, in spite of the high effluent quality in terms of BOD and suspended solids removal, the trickling filter requires high energy input (breakdown during power-cuts and pump failures).

The least effective system is the lagoon with only 82 % of BOD_5 removed. This system is known to use less energy than the most wastewater treatment methods (only 0.34 kWh/kg of BOD_5 removed).

Tunisia represents the case of a middle-income country that has pursued a conscious strategy of treated wastewater reuse in agriculture with a fair measure of success. However, in most the existing WWTPs, effluent is treated only to the primary and secondary levels. Tertiary treatment was recently introduced in a few wastewater treatment plants (of which Kairouan, Jerba Aghir, Hencha, El Fahs…) and concerns plants whose treated wastewater is reused for irrigation purposes or discharged in sensitive areas. The tertiary treatments mainly used are: sand filtration, maturation and UV radiation.

2.2. Case of Ghana

Currently, 73 wastewater and fecal sludge treatment plants (TPs) are accounted for in Ghana, most of them being small-scale decentralized systems. These were constructed since the early 1960s. However, in Ghana as in most developing countries, failure has been the norm for many wastewater (WW) or fecal sludge (FS) treatment plants. Through a study published in 2011 [3], it was noted that the success of such treatment plants operation cannot be directly correlated with individual factors, such as the scale, age or type of technology. Instead, it is the result of a complex combination involving the pre-cited factors and several others.

In Ghana, existence of successfully operated TPs applying complex technologies such as activated sludge combined with chlorination (tertiary treatment) confirms that it is possible to get good results even from the application of “sophisticated” technologies. But such cases are usually in the hand of well-resourced private sector (like hotels) and the results are therefore not easily transferable unless an enabling environment to sustain their continuous and proper operation is in place.

3. Innovative wastewater treatment biotechnologies that could be of interest in the African Countries: A short review

3.1. Anaerobic processes

The anaerobic treatment process is increasingly recognized as the core method of an advanced technology for environmental protection and resource preservation and it represents, combined with other proper methods, a sustainable and appropriate wastewater treatment system for developing countries [4].

Decades of developments and implementations in the field of high-rate anaerobic wastewater treatment have put the technology at a competitive level. With respect to sustainability and cost-effectiveness, anaerobic treatment has a much better score than many alternatives. Particularly, the energy conservation aspect, i.e. avoiding the loss of energy for destruction of organic matter, while energy is reclaimed from the organic waste constituents in the form of biogas, was an important driving force in the development of such systems. At present, other advantages such as the extremely low production of excess sludge and the system compactness are important selection criteria.

Key to the worldwide interest in anaerobic treatment is the development of high-rate reactor systems allowing an extreme uncoupling of the solid retention time from the hydraulic retention time. This uncoupling can be achieved by various ways of sludge retention, such as sedimentation, immobilization on a fixed matrix or moving carrier material and granulation. High-rate systems can be divided in suspended growth and attached-growth processes including expanded/fluidized bed reactors and fixed film processes. In suspended growth systems, bacterial sludge is present as flocs or granules, whereas in attached growth systems, microorganisms are adhered to a moving or fixed medium. In an expanded/fluidized bed reactor, suspended carrier media (such as sand or porous inorganic particles) are used to develop an attached film. Fixed film processes rely on the bacteria attached to a fixed media, like rocks, plastic rings, modular cross-flow media, etc. Some systems, such as the anaerobic hybrid process, combine suspended-and attached-growth processes in a single reactor to utilize the advantages of both types of biomass.

Within the spectrum of anaerobic sewage treatment technologies, the upflow anaerobic sludge blanket (UASB) reactor offers great promise, especially in developing countries that usually have hot climates. It remains a robust high-rate reactor system, generally without moving parts, limiting both capital and operating costs. Like many high-rate systems, the UASB retains a high amount of biomass in the form of a dense sludge, granules or aggregates of microorganisms. Furthermore, good contact between biomass and wastewater is ensured due to mixing as a result of recirculation and biogas production. Indeed, the UASB process represents one of the best anaerobic treatment processes developed so far [5].

Since 1986, full scale UASB systems are used for treatment of municipal wastewater. Currently several reactors (35-500 m^3) are in operation in Colombia and in Brazil. Most of the reactors have a hydraulic retention time of 4-6h and an average COD removal of 30-40%. The largest units are 2,200 m^3 reactors, treating 25,000 IE with a hydraulic retention time of 8 h and a removal of 60-80% BOD. In 1990 a full scale UASB installation went in operation at Mirzapur, India, treating some 14,000 m^3/d. The results of some of these full scale installations are given in table 2. It can be seen that considerable purifications are reported but for the plants operated below 20°C, the effluent characteristics leave much to be desired [6].

This process has gained popularity, with over 200 installations worldwide. It is applied in many countries today to treat domestic sewage, e.g., in Brazil, Mexico, Colombia, Cuba and Uruguay. As already highlighted, its feasibility for sewage treatment is particularly well demonstrated in many tropical countries, where artificial heating can be avoided.

High rate anaerobic pre-treatment followed by aerobic post-treatment using biofilm reactors has been shown on numerous occasions to be a very cost effective way to remove organic compounds from wastewaters. The IC (Internal Circulation) anaerobic reactor followed by the CIRCOX airlift aerobic technology (Fig. 4) has been recently selected to treat the effluent from a large brewery in The Netherlands. After a year of operation, this innovative combination was reported to have overall total and soluble COD removals of 80 and 93.5%, respectively. Current volumetric loading rates have averaged 14 kg m^{-3} day^{-1} in the IC and 10 kg m^{-3} day^{-1} in the airlift system [7].

3.2.Membrane bioreactor (MBR)

As a relatively new technology, MBRs have often been disregarded in the past in favor of conventional bio-treatment plants. MBR technology is widely viewed as being state of the art, but by the same token is also sometimes seen as high-risk and prohibitively costly compared with the more established conventional technologies such activated sludge plants and derivatives thereof. Whereas activated sludge are viewed as average cost/ high value, and biological aerated filters (BAFs) as low-average cost/ average value, MBRs are viewed by many customers as high cost/high value. Therefore, unless a high output quality is required, organizations generally do not perceive a need to invest large sums of money in an MBR. However, a number of indicators suggest that MBRs are now being accepted increasingly as the technology of choice.

MBRs provide numerous advantages in wastewater treatment because they:

- are capable of simultaneous biological treatment and disinfection of the effluent. The resulting treated water should be of high quality.
- provide complete separation of hydraulic retention time (HRT) and suspended solids retention time (SRT) provides optimum control of biological reactions and greater reliability and flexibility in use;
- are able to deal with variations and fluctuations in both the hydraulic (m^3 wastewater h^{-1}) and organic (kg BOD m^{-3} reactor volume h^{-1}) loading to the system;
- give complete control of sludge age which is important to allow development of slow-growing microorganisms such as nitrifying bacteria, or organisms able to degrade recalcitrant compounds;
- provide process intensification through high biomass concentrations;
- give significantly reduced sludge production compared to other aerobic processes;
- are able to treat high strength wastewaters-new market potential;
- have a smaller footprint compared to, for example, the activated sludge process due to lack of clarifier and a significantly smaller aeration tank.

Since 1992, when the first Kubuta MBR installation in Europe (situated on the Dorset coat near Porlock, UK) was commissioned, there have been very significant changes in the economics of MBR systems. These changes include the following:

- Membrane flux rates doubled due to enhancement of the design of the membrane modules, and increased understanding of the linkages between trans-membrane pressure, biomass concentration in the reactor, and gassing rate across the membrane.
- Reduced plant size and power consumption has been achieved through better understanding of the linkage between the engineering design and operating strategies and the microbiology/ biochemistry taking place within the treatment tank. Engineering can be used to control the biology, or conversely better understanding of the biology can be used to improve the engineering and operation
- Reduced maintenance and labor have been achieved due to increased monitoring and control, and increasing confidence in the reliability and robustness of MBR process operation
- Scale-up manufacture and increase in the number of MBR installations has resulted in a factor of 10 reduction in membrane fabrication costs (fig. 5)
- Projected membrane life increased from 3 to 10 years giving significantly reduced replacement costs.

A number of scientists are dedicating research time and effort to MBR studies all around the world. Authors from 30 different countries or regions have contributed research articles to the body of peer-reviewed information. However, over 75% of all studies on MBRs were

conducted at the following eight countries UK, USA, Japan, France, China, South Korea, Germany and Canada (Fig. 6).
Early development efforts on MBR technology were concentrated in UK, France, Japan and South Korea, whereas extensive research in China and Germany began after 2000.
Studies originating from countries, which hosted a total of less than 10 research publications, have primarily been conducted in the last 5 years. This indicates that much of the research there is building on pioneering work from the UK, France, Japan and South Korea [8].
Since research on membrane bioreactor (MBR) technology began over 30 years ago, several generations of MBR systems have evolved. Up to this date, MBR systems have mostly been used to treat industrial wastewater, domestic wastewater and specific municipal wastewater, where a small footprint, water reuse, or stringent discharge standards were required. It is expected, however, that MBR systems will increase in capacity and broaden in application area due to future, more stringent regulations and water reuse initiatives.
In North America, full-scale commercial applications of MBR for treatment of industrial wastewaters dated back to 1991. In the early 1990s, MBR installations were mostly constructed in external configuration, in which case the membrane modules are outside the bioreactor and biomass is re-circulated through a filtration loop. This limited wider application in treatment of municipal wastewater in North America because of high power consumption. After the mid 1990s, with the development of submerged MBR system, MBR applications in municipal wastewater extended widely. In the past 10 years, MBR technology has been of increased interest both for municipal and industrial wastewater treatment in North America. In fact, MBR applications in municipal wastewater treatment increased to more than two hundred plants but still occupy a small share of the overall market [8].

3.3. Constructed wetlands

Constructed wetlands are among the recently proven efficient technologies for wastewater treatment. Compared to conventional treatment systems, constructed wetlands are low cost, are easily operated and maintained, and have a strong potential for application in developing countries, particularly by small rural communities. However, these systems have not found widespread use, due to lack of awareness, and local expertise in developing the technology on a local basis [9]
Wetlands are transitional areas between land and water and are distinguished by wet soils, plants that are adapted to wet soils, and a water table depth that maintains these characteristics. Since land and water can merge in many ways, there is no single correct definition for all purposes.
On the basis of the dominant plants, wetlands can be classified into three groups: salt and freshwater swamps, marshes and bogs. Swamps are flooded areas dominated by water-tolerant woody plants and trees, marshes are dominated by soft-stemmed plants and bogs are dominated by mosses and acid-loving plants.
Constructed wetlands for wastewater treatment involve the use of engineered systems that are designed and constructed to utilize natural processes. These systems are designed to mimic natural wetland systems, utilizing wetland plants, soil, and associated microorganisms to remove contaminants from wastewater effluents.
The total amounts of SCI articles including searching keywords in titles only during the last 50 years were counted and are displayed in Fig. 7. Along with the development of SCI, wetland research continually grew in this long period, started to go up significantly in the year of 1975, and rocketed in the past 18 years [11].
In Ireland for example, there are about 140 CWs sites. It is believed that CWs have been successfully established in all parts of Ireland without any exception. There is no reported negative effect from the Irish climate on the performance of the CWs. In particular, the

systems show a particular advantage of aesthetical appearance with Irish climate and lower energy consumption for their performance [12].
Table 4 gives some examples about the application of sub-surface flow constructed wetlands around the world.

4. Obstacles facing the implementation of innovative technologies in African countries

4.1. Case of Tunisia

A potential adopter of an innovation bases his decision on the benefits of the new technology in comparison to other alternatives in which the current technology is included. Initial requirements for adopting a new technology are its availability, the ability to acquire it, and its capability to satisfy the needs or solve the problems. The spectrum of factors taken into consideration includes financial costs, environmental impacts, practicability, aesthetics as well as potential risks. The obstacles facing the good operation of existing WWTPs or the implementation of innovative technology in the field of wastewater treatment are mainly:

4.1.1. Technical

Unconformity of raw wastewater

According to the standards of discharge in the sewage system (NT 106.02), the influent must have a $BOD_5$of 400 mg/L, a COD of 1000 mg/L and SS of 400 mg/L. However, 30 WWTPs are receiving influents non-compliant with these standards. The “Bouargoub” station for example (low-load activated sludge; 2700 m^3/d), receives an influent with more than 1000 mg BOD_5, 2615 mg COD and 832 mg SS. As a consequence, the same plant rejects an effluent which does not meet the standards.

For most of these WWTPs, this pollution is mainly due to the discharge of industrial wastewater in the sewage system such as: slaughterhouse wastewater, olive mill wastewater, oils and fats, organic and inorganic pollutants, etc…and causes then a disruption of these plants operation. It is therefore recommended to take measures to encourage companies to perform their own pre-treatment stations.

Capacity of existing WWTPs

25 WWTPs are over-loaded either hydraulically or organically or both of them. The plant of “North Coastal” works at a hydraulic saturation rate of 281 % and an organic saturation rate of 278 %. 18 of these WWTPs are activated sludge processes, mainly with low-load (which represents 20.45 % of total WWTPs). 50% of the lagoon processes are overloaded. Some of these plants need to be urgently rehabilitated given the dilapidated state of the equipments and infrastructures: Kalaat andalous (aerated lagoon, 1500 m^3/d), Sidi mehrez (aerated lagoon, 3000m^3/d), Zarzis Ville (Low-load activated sludge, 1335 m^3/d) and El hamma (Low-load activated sludge, 4061 m^3/d). This will need huge financial requirements either for rehabilitation of old plants or for building new ones.

4.1.2. Financial

Aging of some of the existing WWTPs

In 2010, the operating costs for all the WWTPs totaled 25,850562 dinars, with an increase of 4 % over the last year. A great part is allocated for the equipment maintenance (7.74 %). This cost recorded an increase of 39 % between 2009 and 2010.

Energetic cost

Some of the existing WWTPs are not well dimensioned. They have a particularly high energetic cost (especially the activated sludge based WWTPs), This is due to the low flow compared to the station capacity.

4.1.3. Political

When it comes to developing and introducing new technologies, mutual exchange and perspective-taking are crucial for a successful project. Not only are the engineers experts of technological issues, but the future users of the technology are just as well experts of their everyday situation. In Tunisia, as it was mentioned before, the activated sludge process represents more than 80 % of the existing WWTPs. It is then, the most established process. It ensures more than 94 % BOD_5 removal. The skilled labors, technicians and engineers, are familiar with this process and master it very well. That's why; the alternative technology should be really competitive with the already existing WWTPs in terms of removal efficiency, long-term operation, maintenance and energetic cost….The government should have the political will to invest in the implementation of new technologies or the upgrading of the already existing ones. As regard to the implementation of a new technology (MBR) in Soukra wastewater treatment plant (north of Tunis) in order to improve the quality of treated waster for reuse, it was clearly reported (OFFICE manager: Personal communication) that this new technology was not introduced due to the risk of unsuccessful operation and maintenance by the inexperienced OFFICE staff.

4.2. Case of Ghana

4.2.1. Financial

Operational (energy, maintenance and personnel) costs are one key factor that can hinder TPs successful operation.

It is essential to design a plan to cover in a timely and responsible manner ongoing cost. This requirement is critical for many public institutions in Ghana. Current experience shows that technical maintenance problems of TPs are initially "minimal" if addressed in time and include burst pipes, blocked pipes, breakdown of pumps, frequent electricity outages. In order not to worsen the initial condition, by damaging more sensitive components of the TPs, and to ensure smooth running of the unit, money for repairs should be available upon request.

It is therefore essential for a TP to have a sustainable and dedicated revenue stream which can fully cover ideally the operational costs (especially in the public sector) or at least contribute to lowering the required financial input from the managing entity. It is to be recalled that in Ghana, many WWTPs are operated by small communities, schools, hospitals, hotels, military camps and other self-contained entities. So far, conventional revenue streams are constituted by the revenue generated from tipping cesspit emptiers (for fecal sludge TPs) or households connected to the TPs (wastewater TPs). Unfortunately, the financial system is not always well managed or the general management of revenue contains some flaws. For example, Waste Management Divisions (WMD) within Municipal Assemblies are in charge of managing and maintaining some public TPs in Ghana but do not have control over revenues they collect through tipping fees, which, in theory, are supposed to ensure proper functioning of sanitation facilities. In some other cases, it was observed that the billing system was not efficient (people would be forgotten or simply refuse to pay).

There is also a need to develop incentives to encourage institutions and operators in the public sector to properly manage the TPs, i.e. monitor and respond. Institutions and their individuals should account responsibility for management of the TPs and good ones should be "rewarded". Incentives must in particular concern the workers of these entities and encourage them to work with dedication. So far, "lax behavior" of workers has been reported to negatively affect performance of some institutions. They should report in due time unusual behavior of the TP to allow proper actions to be taken. Currently we see the same responsible persons in charge of TPs broken down a decade ago, receiving the same salaries as before the breakdown.

4.2.2. Social

In Ghana, the population growth rate is around 1.8% (2012 estimates) while, as in many African countries, cities are growing even faster (for example, annual increase for Accra was 3.4 %) [13]. This should be taken into consideration in the design of new TPs in still growing areas, especially in the case of fecal sludge and drinking water TPs, to ensure their long-term viability. Currently, some TPs in Ghana are operated close to or above their design capacity, which reduces their performance. However, a continuous problem is retrofitting TPs into high-density areas of city centers.

Some public TPs have suffered from thefts of devices (e.g. electrical parts, power lines). TPs surroundings should be continuously secured (e.g. hiring security personnel) and properly walled.

It is urgent to sensitize the population on the benefits of a functional treatment plant. In one case, it was observed that citizens connected to sewage would refuse to pay their bills while others are forgotten during the billing process. However, willingness of users to pay requested fees might increase if the billing process is improved and the benefits obvious.

4.2.3. Technical

In Ghana, many WWTPs are operated by entities that do not have waste management as primary function [e.g. schools, hospitals, small communities]. As a consequence, in-house capacity and decision making motivation to ensure proper operation of the TP may be lacking. They also need funding to attract qualified personnel or capacity building in their human resources. This later will allow them to develop an appropriate sense / knowledge of the technology in order to:

- operate the new processes
- conduct the routine and preventive maintenance checks

If this is not guaranteed, outsourcing the management of treatment plants to private experienced companies will have a positive effect on the process viability.
The reliance of a WWTP on electricity is another critical technical aspect. If this is the case, then it will be essential to make sure that a generator is available for use when needed as Ghana is facing regular power outages, over hours or days.

4.2.4. Institution and regulation

- Public institutions are known to operate in a laborious way. Simplifying administrative procedures (e.g. lowering the number of people through whom a repair request must go) will have a positive impact on the repairs’ delays (which can sometimes reach months or years).

- To ensure continuous supply of electricity, settling of electricity bills in a timely and responsible manner is essential.

- A dedicated maintenance protocol – defining preventive maintenance (e.g. routine checks of all equipment and replacement/repairs when needed, desludging) - must be followed. Spare parts of key basic components must be available within the unit (or locally available) and should not be ordered only when a fault is observed.

- Regulations on environment and public health protection are not enforced in Ghana for WWTPs. EPA should regularly control the TPs and failures should result in significant disciplinary actions and punitive fees (e.g. above what is normally required to fix the problem). Such enforcement could become an incentive to properly operate and maintain the processes. Currently, all non-functional WWTPs are discharging the untreated or partially treated outflow into the environment, and despite EPA is aware of this, there is no action.

- Managing entities must be empowered to allow them to use the collected revenue to properly maintain the TPs.

5. Recommended Biotechnologies

5.1. Case of Tunisia

In Tunisia, all the big and coastal cities are equipped with treated wastewater treatment plant (48 WWTPs) also the majority of medium one (55 WWTPs). In some cases, upgrading of existing wastewater treatment plants will become the more challenging task than erection of wholly new plants, as most of the plants do exist already. The MBR process is an emerging advanced wastewater treatment technology that has been successfully applied at an ever increasing number of locations around the world. This technology has not only attracted increasing interest for the set up of new wastewater treatment systems but also it has high potential looking at upgrading tasks of already existing WWTPs. The addition of filtration modules upstream of the activated sludge process will allow meeting the discharge standards (30 WWTPs are currently rejecting effluents which not meet the standards of rejection in terms of BOD_5, COD and SS). Besides, high effluent criteria such as removal of suspended solids or absence of pathogens can be achieved. So, the resulting effluent can be eventually be reused for irrigation purposes. The results of the FP6 EU project PURATREAT experienced in a pilot scale at Sfax wastewater treatment plant demonstrates the potential for using MBRs in decentralized domestic water treatment in the North African region, at energy consumption levels similar or lower than a conventional activated sludge system, with the added benefit of producing treated water suitable for unrestricted crop irrigation.

In Tunisia, wastewater treatment is mainly based on central disposal systems which include a widely ramified sewer network connecting a multitude of households to one main sewage plant. This centralized system developed over several decades has regularly been adapted to increasing demands. Undoubtedly, central sewage systems were able to solve many hygienic problems and enabled far-reaching ecological improvements in the past. Today, however, the conventional disposal systems are increasingly criticized. The criticisms mainly refer to ecological problems, e.g. the accumulation of persistent harmful substances in the water body. The complete elimination of these substances in the treatment plants seems to be hardly feasible, even if additional purification levels are employed. A further point of critique is the mixture of wastewater of different qualities originating from domestic and industrial use that is discharged into one facility and thus difficult to treat and reuse (The case of many WWTPs in Tunisia where industrial wastewater is discharged into the sewer system). Central disposal systems can also be questioned from an economic point of view. High investments are needed for building and maintaining their infrastructure. The major share of these expenditures is needed for transporting the wastewater in the sewers, and not for the purification process itself. Besides, high costs arise from both the purification of wastewater from nutrients and

the production of nutrients for agricultural use. The shortcomings of central wastewater disposal systems have triggered a search for technological alternatives. As a result, series of new technologies has been developed or rediscovered over recent years. Most of these solutions are characterized by a small-scale, decentralized structure and a source control approach. In contrast to the conventional end-of-pipe concept, decentralized technologies aim at minimizing the required resources and treat and reuse the different substance flows in an adaptive way at an early stage in the purification process. Thus, the technology can be adapted to the particular pollutants and to the demands on the quality of the purified water.
In Tunisia, there is an initiation for the rural settlements; the year 2010 reported the completion of the servicing of 6 new rural settlements. Only 2 of these WWTPs are constructed wetlands. The results of long-term operation of these stations are not yet available. However, constructed wetlands can be considered as a suitable solution since they are low cost, are easily operated and maintained, and have a strong potential for application in developing countries, particularly by small rural communities. Besides, at the rural areas, land is available and of a low-cost.

5.2. Case of Ghana

Currently, Waste Stabilization ponds are common for community and municipal-level treatment for wastewater and fecal sludge because of their lower operation and maintenance cost. However, mechanized aerobic systems such as activated sludge are popular on site at private entities and elsewhere because of their lower footprint (espec. space requirements).

Some pilot studies have been conducted on the use of various technologies in Ghana for wastewater treatment.

- Waste stabilization ponds using macrophytes such as water lettuce and duckweed was tested recently and compared with a conventional algal type stabilization ponds system. 3 pilots units, each composed of 4 ponds were operated in Kumasi for that purpose. Influence of key parameters such as pH was investigated. Removal of organic matter, nutrients and pathogens was followed. Results confirmed that duckweed ponds perform at least as well as conventional ponds and additionally helped to address drawbacks such as mosquito breeding or high levels of total suspended solids in the effluent, which result from the use of conventional ponds. Production of macrophytes (287 tons/ha/year), with proteins' content as high as 34 % allows recovery of nutrients in the wastewater and could represent an attractive incentive, especially if combined with treated water reuse for agriculture or aquaculture [14].
- A horizontal sub-surface constructed pilot scale wetland using cattails (*Typha latifolia spp*) plants species was also tested in Kumasi for the treatment of grey water [15]. Results obtained were not conclusive since removal efficiencies of organic matter were < 80 % for both BOD and COD while only about 34 % of the nitrogen was eliminated. One reason, according to the author, was the inadequate loading of the unit (0.17 $m^3/m^2/d$, for a retention time of 15h).
- By creating economic demand for treated product and by-products (water, sludge), processes allowing reuse might contribute to cost recovery at the facilities. Also, reuse will lower operational costs by decreasing treatment and/or disposal requirements.

6. Conclusions

As a conclusion, there is still a lot to be done for the implementation of innovative technologies in African countries. More effort is needed in a number of directions: financial, political, social, technical…Among these efforts, dissemination of existing knowledge in the other African countries could be of a great importance. In fact, Tunisia and Ghana have both, gained a good experience in wastewater treatment and management. Now, these countries are facing many challenges in implementing innovative technologies or upgrading the existing WWTPs.

Acknowledgement

Authors are grateful to the European Commission for the financial support of the WATERBIOTECH project (Grant Agreement N°: 265972).

References

All the data related to the wastewater treatment in Tunisia were taken from the annual report of the OFFICE, **2010**.

[1] Giovanni Libralato, Annamaria Volpi Ghirardini, Francesco Avezzù, To centralise or to decentralise: An overview of the most recent trends in wastewater treatment management. Journal of Environmental Management 94 **(2012)** 61-68.

[2] Antony Bennet, Wastewater treatment: Green technologies raise to the bait. Filtration+Separation September (**2006).**

[3] Murray A and Drechsel P (2011) *Why do some wastewater treatment facilities work when the majority fail? Case study from the sanitation sector in Ghana*. Waterlines, 30(2): 135-149.

[3] Lucas Seghezzo, Grietje Zeeman, Jules B. van Liel, H. V. M. Hamelers h & Gatze Lettinga. A Review: The Anaerobic treatment of sewage in UASB and EGSB deactors. Bioresource Technology 65 **(1998)** 175-190.

[4] Sunny Aiyuk, Ilse Forrez, De Kempeneer Lieven, Adrianus van Haandel, Willy Verstraete. Anaerobic and complementary treatment of domestic sewage in regions with hot climates—A review. Bioresource Technology 97 **(2006)** 2225–224.

[5] K. Mergaert, B. Vanderhaegen and W. Verstraet. Applicability and trends of anaerobic pre-treatment of municipal wastewater. Water Research Vol. 26, No. 8, pp. 1025-1033, **1992**.

[6] C. Nicolella, M.C.M. van Loosdrecht, J.J. Heijnen. Wastewater treatment with particulate biofilm reactors. Journal of Biotechnology 80 **(2000)** 1–33.

[7] Wenbo Yang, Nazim Cicek, John Ilg State-of-the-art of membrane bioreactors: Worldwide research and commercial applications in North America. Journal of Membrane Science 270 **(2006)** 201–211.

[8] M. Gander, B. Jefferson, S. Judd. Aerobic MBRs for domestic wastewater treatment: a review with cost considerations Separation and Purification Technology 18 **(2000)** 119–130.

[9] Amelia K. Kivaisi The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. Ecological Engineering 16 **(2001)** 545–560.

[10] Liang Zhang, Ming-Huang Wang, Jie Huc, Yuh-Shan Ho. A review of published wetland research, 1991–2008: Ecological engineering and ecosystem restoration. Ecological Engineering 36 **(2010)** 973–980.

[11] A.O. Babatunde, Y.Q. Zhao, M. O'Neill, B. O'Sullivan Constructed wetlands for environmental pollution control: A review of developments, research and practice in Ireland. Environment International 34 **(2008)** 116–126.

[12] Jan Vymazal, Lenka Kröpfelováa Removal of organics in constructed wetlands with horizontal sub-surface flow: A review of the field experience. Science of the total environment 407 **(2009)** 391 1 – 3922.
[13] CIA (2012). The world Fact book - Ghana. https://www.cia.gov/library/publications/the-world-factbook/geos/gh.html Visited in April 2012.

[14] Awuah E. (2006) Pathogens removal mechanisms in macrophyte and algal waste stabilization ponds. Ph.D. dissertaition, 147 p. Published by Taylor & Francis/Balkema.

[15] Niyonzima s. (2007) http://www.switchurbanwater.eu/outputs/pdfs/W5-3_GEN_PHD_D5.3.12_MSc_Niyonzima_Greywater_treatment_with_constructed_wetland.pdf

Figures Captions

Figure 1: Wastewater treatment plants in Tunisia

Figure 2: Average energy consumption in KWh/Kg of BOD_5 removed in WWTPs in Tunisia

Figure 3: Average treatment efficiency in term of BOD_5 removed in WWTPs in Tunisia

Figure 4: Full scale Paques CIRCOX (front, 140 m^3) and IC (back, 385 m^3) reactors at a brewery in Brazil.

Figure 5: Change in relative membrane costs for Kubota MBR membranes between 1992 and 2005

Figure 6: Geographical distribution of studies on MBRs. Symbol (*) denotes including Austria, Mexico, Poland, Denmark, Croatia, Taiwan, Spain, Colombia, Switzerland, Scotland, Malaysia, South Africa, Israel and Brazil, less than five publications for each country or region.

Figure 7: Number of SCI publications referring to "wetland" and "wetlands" in the title during the last 50 years.

Table 1: Key Sanitation indicators in Tunisia

OFFICE key performance indicator	Unit	2010
Number of municipalities in OFFICE action zone	municipality	160
Number of inhabitants in the municipalities in OFFICE action zone	Million inhabitants	6.3
Number of inhabitants connected to the public sewerage network in the municipalities in OFFICE action zone	Million inhabitants	5.6
Connection rate in the cities in OFFICE action zone	%	89.3
Number of OFFICE subscribers	1000 subscribes	1559
Number of OFFICE new subscribers	1000 subscribes	57
Number of additional connection boxes	1000 boxes	18
Quantity of water consumed by OFFICE subscribers	Million m^3	267
Number of wastewater treatment plants (WWTPs)	WWTPs	109
Quantity of collected wastewater	Million m^3	246
Quantity of wastewater treated in WWTPs	Million m^3	240
Quantity of reused treated wastewater	Million m^3	68
Length of operated network liable to clean-up/flushing	Km	11801
Length of cleaned-up operated network	Km	7666

Table 2: Some full scale installations of UASB systems in the world (adapted from ref. [5])

	The Netherlands Bergambacht		**USA Knoxville**	**Brazil São Paulo**	**Columbia**	
					Bucaramanga	Cali
Process design						
Reactor type	UASB	UASB	FFAB	UASB	UASB	UASB
volume (m3)	20	6	19	120	35	64
HRT (h)	10	8	24	9	5	6
T (°C)	15-16	15-19	10-25	21-25	23-27	25
Reduction						
BOD (%)	-	-	70	80	80	66
COD (%)	49	55	60	70	66	78
TSS (%)	60	60	60-70	79	70	75
Effluent characteristics						
BOD (mg/L)	69	-	40	31	39	25
COD (mg/L)	220	220	100	96	145	120
TSS (mg/L)	51	-	53	35	70	30

UASB: Upflow Anaerobic Sludge Blanket

FFAB: Fixed Film Anaerobic Bioreactor

Table 3: Commercial MBR plants available for treating domestic wastewater (adapted from ref. [8])

Company	MBR process	Membrane configuration	No. of plants treating domestic wastewater	No of plants treating industrial wastewater	Capacity (m^3 day^{-1})	Type of waste
Rhodia/Orelis, France	Pleiade	Submerged and side-stream; UF	56	14	7-500	Urban, grey water, black water
Kubota, Japan	Kubota	Sbmerged; MF	92	50	10-2000	Municipal, grey water, domestic
Zenon, Canada	Zeeweed and ZenoGem	Submerged, MF	150 Total		340-5500	Municipal and industrial
AquaTecch, Korea	Biosurf	Side-stream; UF	12	6	40-3000	Municipal
Degrement, France	MBR	Side-stream	2	3		Municipal

Table 4: Example of application of horizontal sub-surface flow constructed wetlands in the world (adapted from ref. [12])

Location	**Country**	**Area**	**Flow**	**BOD_5**		**COD**	
		m^2	m^3d^{-1}	In	Out	In	Out
Onšov	Czech Rep.	2100	92	5.9	2.7	26.5	12.3
Leek Wootton	UK	825	306	8.5	2.3	82	35
Ashby Folville	UK	825	164	14.8	3.0	103	43
Himley	UK	463	90	16	3.1	89	41
Fare	Denmark	1500	19.5	30	3.0	85	27
Sejerslev	Denmark	7931	492	54	7.0	137	34
Wodonga	Australia	97	4	76	13	226	49
Baggiolino	Italy	96	6	81	7.2	226	33
Uggerhalne	Denmark	2640	103	115	6.0	330	63
Ondrejov	Czech Rep.	806	50	143	14.8	334	36
Holtby	UK	612	30	189	18.5		
Kolodeje	Czech rep.	4495	176	204	15	398	47
Hasselt-Kiewit	Belgium	896	23.3	232	6.0	536	46
Brondum	Denmark	437	8.1	330	16	780	78
Middleton	UK	168	10	390	25	831	195
Glavotok	Croatia	360	40	427	56	611	76
Carrión de los Céspedes	Spain	229	5.8	513	67	1034	134
Agronomica	Brazil	450	6.6	979	19	1005	19

Fig.1

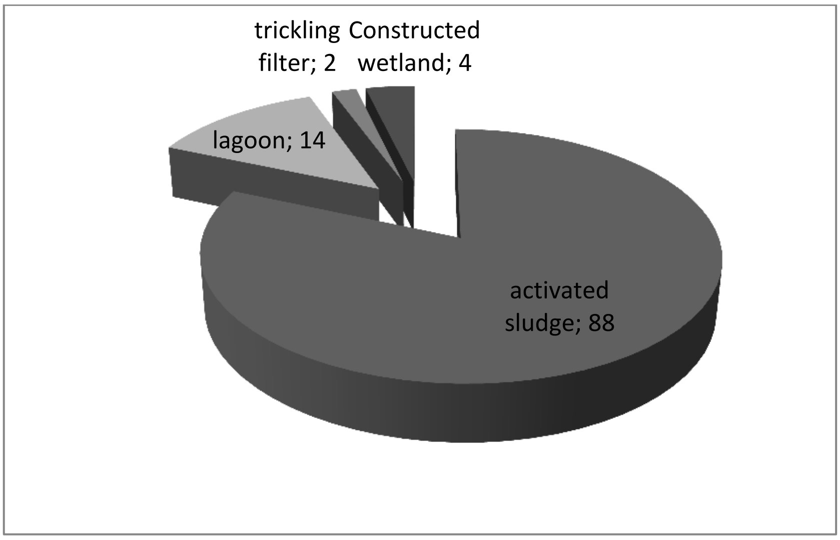

trickling filter; 2
Constructed wetland; 4
lagoon; 14
activated sludge; 88

Fig. 2

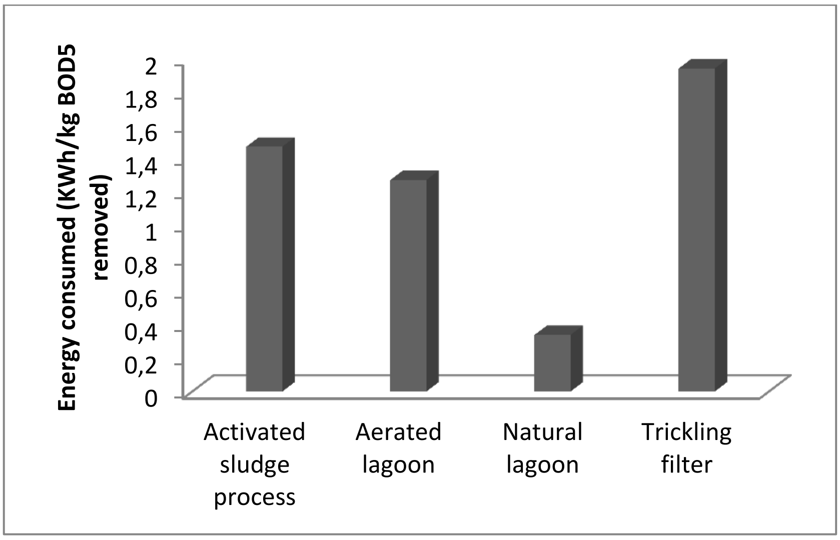
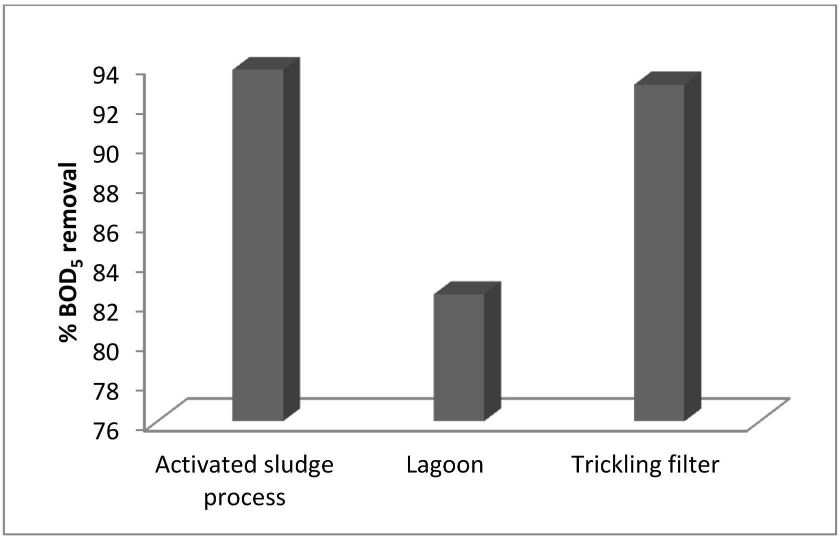

Energy consumed (KWh/kg BOD5 removed)
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
Activated sludge process
Aerated lagoon
Natural lagoon
Trickling filter

Fig. 3



% BOD5 removal
94
92
90
88
86
84
82
80
78
76
Activated sludge process
Lagoon
Trickling filter

Fig. 4

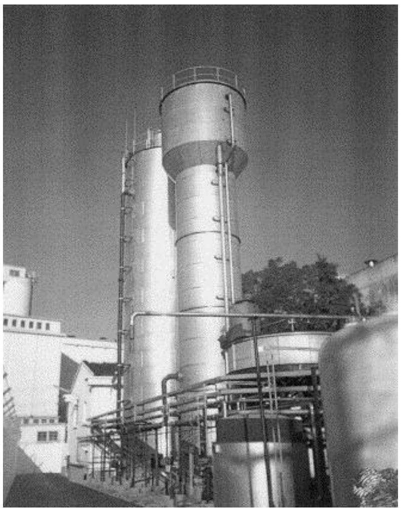
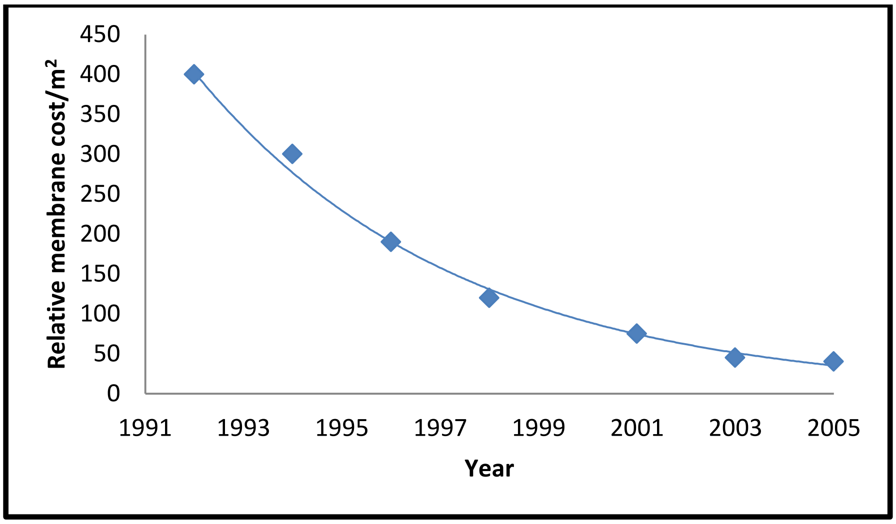
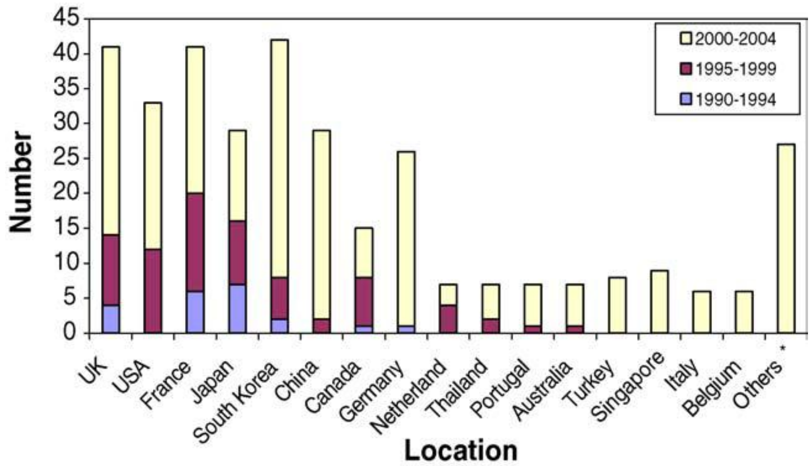


Fig. 5



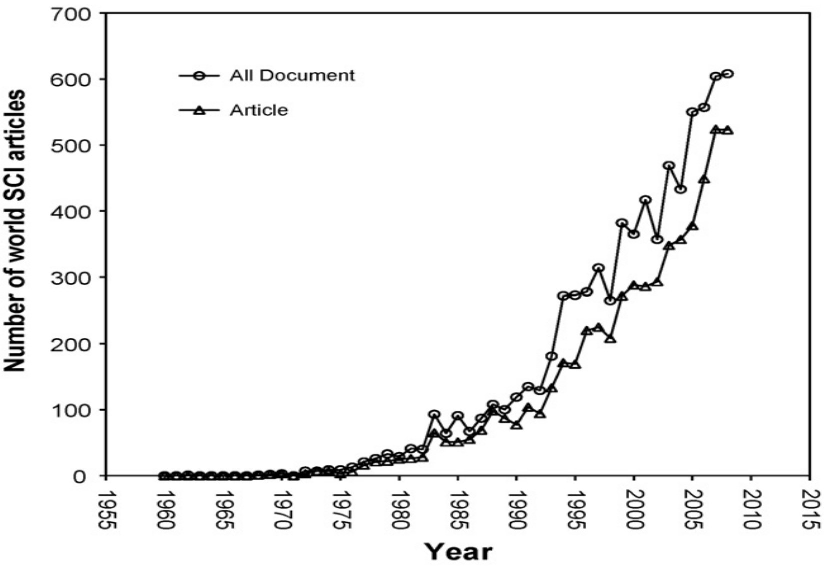
Relative membrane cost/m²
450
400
350
300
250
200
150
100
50
0
1991
1993
1995
1997
1999
2001
2003
2005
Year

Fig. 6



Number
45
40
35
30
25
20
15
10
5
0
2000-2004
1995-1999
1990-1994
UK
USA
France
Japan
South Korea
China
Canada
Germany
Netherland
Thailand
Portugal
Australia
Turkey
Singapore
Italy
Belgium
Others *
Location

Fig. 7



Number of world SCI articles
700
600
500
400
300
200
100
0
All Document
Article
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year