A new technology for treating municipal and/or industrial wastewater with low environmental impact

Layman’s Report

PROJECT CO-FUNDED BY LIFE ENVIRONMENT PROGRAM
EUROPEAN COMMISSION
INTRODUCTION

This is the Layman’s report of the project LIFE05 ENV/IT/000868 “A new technology for treating municipal and/or industrial wastewater with low environmental impact” whose acronym is PERBIOF. The project started on November 15th, 2005 and ended on 14th November 2008. Project total budget was 624,784 euros with an EC contribution of 294,714 euro.

The beneficiary was the Water Research Institute-IRSA (www.irsa.cnr.it) of the Italian National Research Council-CNR with the cooperation (in partnership) of IRIDE Acqua Gas SpA (one of the biggest Italian multi-utility companies; www.iride-acquagas.it) and the Université de Savoie (www.univ-savoie.fr).

The overall aim of the project was the technological transfer to demonstrative scale of an innovative technology (PERBIOF technology), which does not have the drawbacks of conventional treatment technologies, for municipal and/or industrial wastewater treatment. For further information about the Project go to: www.perbiof-europe.com

BACKGROUND

Conventional suspended biomass reactors (e.g. activated sludge systems), which are widely used for treating municipal and/or industrial wastewater, have two main disadvantages: they require big reaction volumes and produce large amounts of sludge.

The problem of high sludge production is particularly critical where industrial wastewater is concerned, as very often, together with biodegradable matter, such effluents contain pollutants that are refractory to biological degradation and/or toxic for the biomass. To remove these pollutants, a sharp increase in sludge production is expected, since after conventional biological treatment at least a physical-chemical polishing step is necessary to remove the recalcitrant compounds. In Europe, not only is sludge production continuously increasing, but disposal costs are also rising, which explains why great effort is presently being made worldwide to find innovative replacement technologies, aimed at a greater compactness and lower sludge production than conventional ones can offer.

In such a contest, the Water Research Institute (IRSA) of the Italian National Research Council (CNR), has been involved during recent years in developing a new technology, whose acronym is PERBIOF (i.e., PERiodic BIOFilter) characterised by high effectiveness and minimum sludge production.

PERBIOF is a “time oriented” submerged biofilter in which all the steps of the biological treatment take place, one after the other, in the same tank instead of moving to a second tank for the continuation of the treatment as in conventional treatment systems. In addition, this technology boasts a unique feature: the presence of aerobic granular biomass. In fact, a large fraction of the microorganisms present in the system grows as granules (see picture below) characterised by very high density, up to 4-5 times higher than that recorded for biomass growing in conventional activated sludge systems. These granules are entrapped in the pores produced by packing the reactor with a filling material which allows greater biomass retention in the reactor to be obtained (up to one magnitude order higher than that recorded in conventional biological systems). As a result, notable improvements in substrate conversion capacities and...
sludge production (i.e., several times lower) are achieved. This technology is effective also for treating industrial wastewater resistant to biological treatments. In fact, PERBIOF allows biological degradation to be integrated with chemical oxidation by dosing appropriate chemicals in the reactor. PERBIOF technology has been extensively tested at both laboratory and pilot scale for treating different wastewater types.

**PROJECT OBJECTIVES**

The overall aim of the project was the technological transfer to demonstrative scale of PERBIOF technology for municipal and/or industrial wastewater treatment. An important objective of the project was the evaluation of the effectiveness and the cost-benefit ratio of PERBIOF technology, which was assessed by means of a prototype specifically designed and built for the project during two demonstration campaigns. The first campaign was carried out using municipal wastewater, while the second was performed using tannery wastewater, chosen as representative of industrial wastewater resistant to biological treatments.

**EXPECTED PROJECT RESULTS**

The main expected result of the project was to demonstrate that, compared with conventional technologies, PERBIOF technology is characterised by:
- a greater conversion capacity and lower reaction volumes (this means smaller plants with a lower environmental impact);
- a significant reduction in sludge production with a consequent reduction in the environmental impact due to sludge treatment and disposal;
- a significant saving of operative costs.
ACTIVITIES AND RESULTS

Prototype designing and construction

The PERBIOF prototype was designed and constructed with the cooperation of the partners IRIDE Acqua Gas and Università de Savoie. The prototype (see figure below) consists of a cylindrical zinc-plated steel reactor (diameter: 1 m; height: 3 m) partly filled with biomass support material (wheel shaped plastic elements; these elements are packed between two surfaces of slabs), two pumps (for filling and recirculation operations), a blower for providing an air supply, a motorised valve for drawing operations and a programmable logic controller (PLC) for controlling and monitoring the system.

Moreover, the prototype was equipped with a chemical oxidation unit used during the tannery wastewater treatment with the aim of making recalcitrant compounds biodegradable. The ozonation unit (see figure below) consists of a pump, that extracts the biologically treated wastewater from the PERBIOF unit and drives it through an ozone reactor (c); the pump is equipped with a Venturi type injector (d) for dosing the ozone produced by means of a ozone generator (e). The ozone reactor is supplied with a residual ozone destroyer. Finally, the ozonated wastewater comes back to the biological system for the final biological degradation phase.
Prototype test for municipal wastewater treatment

Once constructed, the prototype was located at the municipal wastewater treatment plant of Bari, a town located in southern Italy, to be tested with the primary effluent coming from this plant. The results obtained during 10 months of operation showed that after the minimum residence time investigated (i.e., 4 hours), the prototype was able to remove about 80-90% of COD, total suspended solids and nitrogen content occurring in the wastewater. The process was characterised by a very low sludge production (i.e., lower than 0.1 kg of dry sludge per kgCODremoved). Finally, the removal of endocrine disrupter compounds occurring in municipal effluents was also evaluated. As is well known, the occurrence of such compounds has become a matter of growing concern in recent years for their possible effects on both wildlife and humans. Attention was focused on estrone (E1) and 17β-estradiol (E2) (natural hormones derived from the biotransformation of cholesterol), 4-tert-octylphenol (4t-OP) (a breakdown product of phenolic-based surfactants used in industrial applications) and on Bisphenol A (BPA) (used in the production of polycarbonate epoxy resins, flame retardant and many other products). The results obtained, comparing the removal efficiencies of the PERBIOF system with those of municipal plant of Bari (based on activated sludge), showed that the PERBIOF performed better than the conventional plant in removing E1, E2, BPA and 4t-OP. In fact, the average removal percentages of the above mentioned EDCs, recorded during a four month operating period, were 62.2, 68, 91.8, 77.9% and 56.4, 36.3, 71.3, 64.6% for the PERBIOF system and the municipal treatment plant of Bari, respectively.

Prototype test for tannery wastewater treatment

Once the municipal wastewater treatment campaign had been concluded, the tannery wastewater campaign was started, feeding the prototype with primary effluent coming from one of the largest Italian tannery wastewater treatment plants. The results indicated that, in spite of the rather high removal efficiencies recorded (higher than 90%), the current discharge limits for COD and surfactants were never achieved. As expected, this failure was due to the presence of a fraction of organic compounds recalcitrant to biological treatment. In order to reduce the COD and surfactants residual content, the biological treatment was integrated with chemical oxidation performed by ozonation with the aim of rendering the recalcitrant pollutants biodegradable. The results obtained by applying an ozone dosage of 150 g O3/m3 of treated wastewater showed that the prototype was able to achieve very high removal efficiencies for all parameters with residual concentrations much lower than the current discharge limits.

Observing figure shown on the right, that shows a photograph of plant effluent samples from both periods, it is possible to appreciate even visually the benefits yielded by ozone: in fact, the sample from the integrated approach looks like a tap water sample.

As for heavy metals, particular attention was paid to a possible oxidation of Cr III (largely used in leather treatment as a tanning agent) to Cr VI by ozone (the discharge limits for Cr VI are
much lower than those for Cr VI). The results obtained showed that ozone does not (at least considering the dosage used) oxide Cr III to Cr VI.

Finally, as previously observed for municipal wastewater, the process was characterised by a very low sludge production (around 0.035 kg TSS/kgCODremoved or 0.1 dry sludge/m³ of treated wastewater) during tannery wastewater treatment.

**Cost-effectiveness evaluation of Perbiof technology**

The cost evaluation of PERBIOF (on the basis of the data obtained during the project) and conventional technologies (by using literature and plant data) was carried out for both types of treated wastewater. A life cycle assessment (LCA) for both technologies was also carried out in order to evaluate the potential impact of the process by quantifying the use of resources (such as energy, raw materials, water) and environmental emissions (to air, water and soil) associated with the systems.

As for municipal wastewater, the evaluation was carried out on a plant with a capacity of 80,000 equivalent inhabitants.

The results obtained show that if in the plant the activated sludge system were replaced by a PERBIOF system it would be possible:

- to reduce by 5 times the volume of the biological unit with interesting repercussions on investment costs;
- to save 40% of the operative costs of the biological unit;
- to reduce the sludge production by 9.5 times and 25%, respectively, of the biological unit and whole plant;
- to reduce both the use of resources (up to 3 times) and environmental emissions (in particular, a 10 fold reduction of the contribution to global warming was obtained).

As for tannery wastewater, the evaluation was carried out on a plant with a capacity of 8,000 m³/d. A plant consisting of physical-chemical, biological (based on activated sludge) and polishing (based on Fenton reactive) units was used as the conventional treatment. On the contrary, the plant based on PERBIOF technology consisted in physical-chemical and biological (integrated with ozonation) units. Since the pre-treatment unit is the same, it was not considered in the analysis. In comparison with the conventional plant, PERBIOF technology resulted

- 3 times more compact;
- 30 times less productive of sludge;
- 3 times cheaper in terms of operative costs;
- 3 times less polluted in terms of human toxicity

**Visibility of the Project**

Considering the position of the Beneficiary of the project (i.e., the national reference water research Institute), the visibility and divulgation of the project results were really effective at both a national and international level. In fact, the following activities and/or tools were used:
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- n. 10 publications in international scientific journals;
- n. 9 project presentations at International specialist conferences;
- n. 6 project presentations at relevant events;
- n. 3 project workshops organised with potential stakeholders;
- n. 4 newsletters (in Italian and English language) produced;
- n. 1 web site completely dedicated to the project implementation and results ([http://www.perbiof-europe.com](http://www.perbiof-europe.com));
- n. 4 stages offered.

The project received an award during the first edition of Premio Impresa Ambiente (i.e., the Italian edition of European Business Awards for the Environment) organized by the Italian Environment Ministry.

In addition, the project was awarded at IWA Biofilm Technologies Conference held in Singapore from 8th to 10th January 2008, one of the most important international conferences of the sector.

**ECONOMIC AND ENVIRONMENTAL EFFECT OF THE PROJECT**

The present project has demonstrated that PERBIOF technology, an innovative system for treating municipal and industrial wastewater, with respect to conventional methods is capable of reducing the reactor volumes, sludge production, operative costs and environmental impact. Therefore, PERBIOF technology is able to solve the major problem that now afflicts the field of wastewater treatment worldwide, i.e., the huge amounts of sludge produced during the treatment of wastewater and their associated disposal problems. As is well known, sludge is an unavoidable by-product of wastewater treatment, since it is produced through the growth of micro-organisms that remove the pollution.

In Europe, sewage sludge production is continuously increasing, passing from 8 million tons in 1998 to 10.4 million in 2007. Moreover, as societies demand cleaner water and accordingly stricter regulations for water treatment, the building of new and the improvement of old waste treatment plants, will most likely cause a further increase in sludge production in the future. On the basis of the results obtained during this project, the use of PERBIOF technology in the treatment scheme of the plants would reduce the sludge production in the European Union from 10.4 million down to around 8 million tonnes. Considering that sludge management (from treatment to disposal) typically accounts for about half of the overall costs of wastewater treatment, which can be estimated between 350 and 750 Euros per tonne of dry solids (depending on the kind of treatment and disposal employed), a reduction of 2.4 million tonnes in sludge production would allow a saving of between 0.8 and 1.8 billion Euros per year. In addition to the reduction in the quantity of sludge produced and sludge disposal costs, a PERBIOF technology based plant for treating municipal wastewater would also lead to a reduction in the potential impact on the environment. In particular, a reduction in the use of resources (up to 3 times), environmental emissions (in particular, up to 5 fold of the global warming), human toxicity (up to 3 times) and ecotoxicity (up to 35 times) could be achieved.
The benefits of PERBIOF technology are also very impressive for tannery wastewater. It must be underlined that Italian tannery industry is one of the leaders in the world in terms of turnover (5.3 billion Euro/y), number of firms (~2,400) and workers (~30,000), and production (~176·10^6 m² leather/y).

Unfortunately, in spite of such economically relevant data, the tannery industry is characterised by a critical environmental impact for two specific reasons:
- about 350,000 ton/y of more than 100 different chemicals (organic as well as inorganic) are used and most of them are considered toxic and/or hazardous;
- over 40,000,000 m³/y of wastewater is produced (corresponding to the pollution caused by 35 million inhabitants!) with an estimated treatment cost of over 150 million Euros.

Taking into account the specific savings in operative costs and quantity of sludge produced recorded in the project by using PERBIOF compared to conventional technologies (i.e., 1.8 €/m³ and 2.4 kg/m³, respectively), 72,000,000 €/y and 96,000 ton/y could be saved by using PERBIOF.

The benefits of PERBIOF technology for treating tannery wastewater are also impressive from the environmental impact point of view. In fact, by looking the following figure which shows the environmental impact of a PERBIOF technology based plant compared to a conventional plant, it is possible to observe that the global environmental impact of PERBIOF is 3-4 times lower than that of a conventional one.

On the basis of the above results, it is possible, therefore, to assert that PERBIOF technology fulfils the international demand for “cleaner” depuration technologies than those commonly used, which, indeed, are characterised by a high negative environmental impact. In particular, a reduction in the quantity of sludge produced and an improvement in the quality of treated effluent are objectives that have been pursued for many years, but not have not been reached yet. With its decrease in environmental impact and toxicity of effluents discharged into water bodies, the proposed technology can protect the aquatic environment as well as all the related issues including the health of human beings.
TRANSFERABILITY OF PROJECT RESULTS

On the basis of the environmental and economic benefits produced by Perbiof technology at a semi-industrial scale, the Beneficiary really believes that in the future this technology could be rapidly transferred to full scale whether for upgrading the existing treatment plants or in the case of new installations.

Furthermore, the benefits obtained for tannery wastewater treatment can be transferred to any other industrial wastewater containing biorefractory compounds (such as textile, petrochemical, paper, food industry wastewater, etc.). In fact, it must be considered that the world chemical industry regularly produces new compounds that are resistant to biological degradation; all the “traditional” depuration systems fail to remove such compounds and release them into the environment by discharging treated effluents into superficial water bodies.