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Environmental Sciences at Universities of Applied Sciences

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Abstract: Three institutes of the Universities of Applied Sciences that are active in Chemistry and Life Sciences present a selection of their activities in the field of environmental sciences. These projects include analytical monitoring, removal of micropollutants, waste reduction and valorization.

Keywords: Ammonia reduction · Anaerobic digestion · Biosorption · Coffee cherry pulp · Food by-products · (Micro)pollutants · Phosphate recovery · Polyphenols · Sustainable production · Trace analytics · Universities of Applied Sciences · Waste valorization

Introduction

The Universities of Applied Sciences (UAS) are practice-oriented education and research establishments. Apart from education that obviously comes first in the ranking of their missions, applied research and development represents an important part of their activities. The research projects conducted by Swiss UAS lead them to work in close collaboration with other academic institutions and with industrial partners. This is important to keep abreast not only with the latest technical and scientific trends, but also with the needs and constraints of the industrial world.

This paper highlights projects and activities presently conducted in the different Swiss Universities of Applied Sciences and dealing with environment-related matters.

Environment and Waste as a Research Topic

It is admitted worldwide that human activities have put the environment under a constantly growing pressure. Pollution can take extremely diverse forms and contaminants are generated by a larger-than-expected variety of contributors. As a matter of fact not only industry and agriculture but also breeding, road traffic, rail transportation, construction and households have been identified as significant sources of both macro- and micropollutants.[1]

Management of waste-related issues can be addressed from different perspectives. They are best summarized under the form of a value pyramid such as displayed in Fig. 1, proper disposal being the first, most basic step that can be taken. Of increasing value are the subsequent measures, which finally culminate – in a logical manner – with the prevention of waste release.

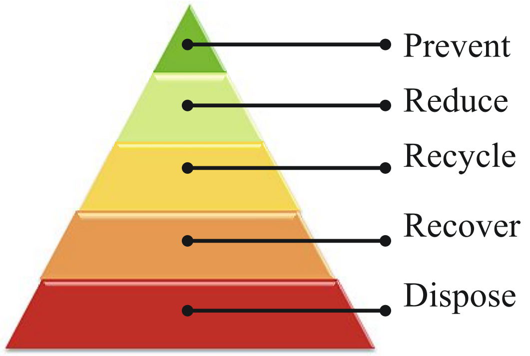

Fig. 1. Waste management pyramid.

A great deal of effort is dedicated worldwide to these various elements in order to reduce our ecological footprint. The latter can however be assessed only by detecting the presence of contaminants and monitoring their evolution in the different compartments of our environment, namely air, soil, water and sediments (as shown in Fig. 2). This is achieved by using analytical techniques that must be able to quantify a large variety of substances present at very small concentrations.

In this respect companies active in Cleantech, green chemistry, renewable energy, (bio)remediation and waste valorization technologies are bound to grow and develop their activities in an unprecedented manner.

It is part of the UAS missions to accompany and support these efforts. In this article three schools, namely HES-SO Valais Wallis (Sion) , HEIA-FR (Fribourg) and FHNW (Muttenz) present a selection of applied research and development projects that are conducted on the above-described topics.

Fig. 2. Contaminants can be found and monitored in air, soil, water and sediments (Source: Pexels / Creative Commons).

HEIA-FR – Haute Ecole d'Ingénierie et d'Architecture de Fribourg

The School of Engineering and Architecture of Fribourg, in collaboration with the company Sorba Absorber GmbH (*http://www.sorba-absorber.ch*), has developed a cost-effective filtration system to reduce ammonia emissions in the atmosphere. In Switzerland, 90% of ammonia emissions are allocated to agricultural activities, mainly by farm livestock.[2] Nitrogen losses are estimated at 48,000 tons per year.[3] Another important part of nitrogen is taken in by human food consumption and is emitted as ammonia by the wastewater treatment units. This loss of nitrogen is compensated by the purchase of industrial nitrogen fertilizers, such as ammonium phosphate, which is produced by a very energy-intensive process from atmospheric nitrogen. To reduce nitrogen loss, our filtration system, composed of corn stover impregnated with a mineral acid, allows to chemically fix ammonia into ammonium salt, which can be reused as a fertilizer.[4]

Growing grain corn produces a large amount of corn straw that is usually burned as a heating fuel. The Sorba Company recovers the spongy body from the center of the corn stalks. This substrate has good mechanical strength and a liquid-holding capacity of up to 20× its dry weight. Corn stalks impregnated with a phosphoric acid solution are the filter material of our filtration unit.

The tests carried out on the air exhaust of a pig farm, a poultry house, and a sewage sludge drying unit showed a highly efficient reduction of ammonia emissions. Measurements made on the sewage sludge drying unit of AVG plant of Bilten GL (Fig. 3) demonstrate a reduction in ammonia concentration from 125 ppm at the inlet to less than 3 ppm at the outlet.

The used filter material, composed of corn stalks impregnated with diammonium phosphate (Fig. 4), is used as a source of nitrogen for crops. This solid fertilizer is considered as farm manure and is easily spread with existing agricultural machinery. Used on the same farm, this fertilizer is not subject to registration. The innovative, efficient and inexpensive filtration system will be commercialized in 2019.

Fig. 3. Filtration prototype with a capacity of 5'000 m^3/h connected to the air exhaust of the sewage sludge drying unit at the AVG (Abwasser Verband Glarnerland) plant of Bilten (GL).

Fig. 4. Used filter material composed of corn stalks and crystallized ammonium phosphate.

FHNW Muttenz

The Institute for Ecopreneurship (IEC) at the School of Life Sciences at FHNW is the largest institute of Universities of Applied Sciences in the field of Environmental Sciences and Engineering in Switzerland. The IEC employs between 50–60 persons (professors, senior scientists, post-docs, PhDs, graduates and undergraduates) for research and education activities.[5]

The IEC receives funding from many national institutions (*e.g.* SNSF and CTI/Innosuisse) and private companies as well as financial support from many international institutions (*e.g.* UNIDO, UNEP and European Commission). Concerning European research, it is worth mentioning that the IEC has been involved in 15 Framework Programme 7 projects of the EC and coordinated/managed 4 of those. Currently, the IEC is involved in 9 Horizon 2020 projects of the EC and coordinates 2 of them (AquaNES and Prolific).

The main research fields of IEC are covered by four groups, *i.e.* Environmental Technologies (Prof. T. Wintgens), Environmental Biotechnologies (Prof. P.F.-X. Corvini), Ecotoxicology (Prof. K. Fent), and Sustainable Resource Management (Prof. C. Hugi). In these four fields, the IEC carries out research along a continuum ranging from more fundamental research related questions up to their application with industrial partners or even the creation of spin-offs. Many of the projects are related to chemicals, *i.e.* i) the prevention/removal of inorganic and organic pollutants, ii) the assessment of their damage to ecosystems and living organisms, iii) the valorization of wastewater and further untapped streams for materials and energy recovery, iv) the evaluation of the performances of pollutant removal treatment and resource recovery technologies using a suite of tools like Cleaner Production assessment tools, Life Cycle Assessments, *etc*.

The Environmental Technologies group is widely recognized in the field of membrane processes for industrial wastewater treatment and drinking water production with a special emphasis on the removal of micropollutants. The group has carried out several pilot and feasibility studies in the frame of the advanced wastewater treatments evaluating treatment trains including activated carbon or ozonation for the removal of micropollutants from different wastewaters. The group is also experienced in water resource management and has several reference projects on the reuse of treated wastewater. In addition, the group is carrying out an ever-increasing number of projects on wastewater and waste valorization for the recovery of resources (*e.g.* phosphorus) and energy (methane production in anaerobic digesters and anaerobic membrane bioreactors).

The Environmental Biotechnology group is focused on the use of microorganisms and enzymes thereof to understand/improve the removal degradation of inorganic (*e.g.* selenate) and organic pollutants (endocrine disrupting chemicals) as well as to valorize biomass (*e.g.* lignins) and industrial waste (*e.g.* red mud) to recover biogas as well as valuable chemicals such as rare earths and phenolics. The group has recently demonstrated for the first time that some bacteria are not only resistant to antibiotics, but that in some cases they are worryingly capable to even nutritionally profit from these poisonous chemicals, which are originally meant to kill them. The group has identified and reported the cluster of genes encoding for the enzymes involved in the nutritional assimilation of sulfonamide antibiotics in Actinomycetes.[6]

The group of Ecotoxicology benefits from a long-term recognition in the field of aquatic ecotoxicology. The group of Karl Fent has been working for years on the effects of micropollutants such as endocrine disrupting chemicals as well as nanoparticles on organisms in aquatic ecosystems both at *in vivo* and *in vitro* level. In addition, the group has dedicated efforts to assess the synergistic effects of mixture of micropollutants on aquatic organisms. More recently, the group has extended its research activities to terrestrial ecotoxicology and has published studies on the effects of neonicotinoids on bees.[7]

The group of Sustainable Resource Management has become a partner for the eco-efficiency evaluation of environmental technologies and industrial production processes. The group has a strong expertise in applying a series of tools such as Cleaner Production assessment, Life Cycle Analysis, Cost Efficiency Analysis and Cost Benefit Analysis. The group led by Christoph Hugi has been working on LCA applied to latest photovoltaic technologies and has been invited to join several projects to assess the sustainability and the risks of release of hazardous chemicals of organic and perovskite-based photovoltaic modules at an early stage of development.

HES-SO Sion

The Institute of Life Technologies at HES-SO Valais Wallis is host to several research groups that explore four different strategic axes. Food and Natural Products is one of them, and we present here a selection of environmentally-relevant activities.

Food and Natural Products Research Group

In EU countries 88 million tons of food are thrown away each year without being consumed, half of that quantity being discarded by the consumers themselves, due to poor management of quantities and leftovers. Efforts are being made to reverse the trend and zero-waste (or at least waste-reducing) initiatives are being taken by many. Among these, valorization of waste or by-products can lead to interesting developments. Two examples taken from the work of Prof. W. Andlauer's laboratory are summarized below.

Bioactives of Coffee Cherry Pulp and Cascara Beverage

Coffee cherry pulp is a by-product obtained during the processing of coffee beans (Fig. 5, left). This pulp, which contains considerable amounts of phenolic compounds and caffeine, has been used to produce Cascara, a refreshing beverage. Six different samples of dried coffee pulp have been characterized and a beverage prepared from each of them. Characterization included measurement of total polyphenol content, antioxidant capacity, caffeine content, chlorogenic acid, protocatechuic acid, gallic acid and rutin.[8]

Fig. 5. Valorization of coffee and wine processing by-products (Source: Pexels / Creative Commons).

Phenolic Compounds of Grape Stems and their Capacity to Precipitate Proteins from Model Wine

Reintegration of grape stem (Fig. 5, right), a by-product of wine production, into the food chain is of high interest from an economic and environmental perspective. In this study the stems from four grapevine varieties (Syrah, Cabernet Sauvignon, Merlot and Chasselas) cultivated in Switzerland were treated in different ways: drying, cutting and separation into fractions based on particle size. All fractions were then characterized for their contents in phenolic compounds. The addition of grape stems of the four different varieties to a model wine containing BSA as model protein reduced its proteic content, Chasselas being the most efficient and promising stem material.[9]

Biotechnology and Sustainable Chemistry (BioSusChem) Research Group

This research group supported by six professors and their lab teams owns a broad portfolio of expertise with the following topic specialties: Bioprocess Engineering, Biomaterials, Bioresources, (Bio-)Analytics, Biocatalysis, as well as Sustainable Chemistry and Energy. More detailed information can be found on the research group's website.[10]

Anaerobic Digestion

In Switzerland, each person generates more than 700 kg waste, 30% of which is organic (2013 figures from the Swiss Federal Office for the Environment). Anaerobic digestion (AD) represents an elegant solution since it can dramatically reduce the environmental burden by degrading the COD of biowaste. Simultaneously, it produces a natural fertilizer (the liquid digestate) and generates renewable energy through the release of biogas, a mixture of methane and CO_2.

The lab of Prof. S. Crelier was involved in the ORION FP7 project (*www.project-orion.eu*), which aimed at developing digesters with a size adapted to the needs of SMEs, namely anaerobic digestion equipment of 3–5 m^3 and able to treat approximately 50 tons of waste per year. Different types of organic waste were tested at 20 L scale (see Fig. 6) with respect to their suitability as AD substrates. It appeared that food waste from restaurants or school cafeterias were best suited in terms of gas quality and yields, thanks to an appropriate balance of proteins, lipids and carbohydrates, and a favorable C:N ratio.[11]

Adsorptive Removal of Contaminants

Adsorption appears to be one of the most efficient and versatile ways for the removal of contaminants from liquid effluents. Whether dealing with drug residues, pesticides or heavy metals, different types of adsorbents can be used. Biosorbents are obtained from residues of industrial production or agriculture, and their lower capacity as compared to industrial resins is compensated by their extremely low cost. In Sion, S. Crelier and his team tested a variety of matrices such as activated charcoal, alginate or chitosan beads or even marine algae of the *Laminaria* family.[12] The latter showed a surprisingly high capacity for the adsorption of heavy metals. Fig. 7 shows the example of an isotherm curve obtained for the adsorption of lead by algae particles, with a maximum capacity approaching 600 mg Pb per gram dry algae.

Bioelectrical Systems

In Prof. Fabian Fischer's laboratory, microbial fuel cells (MFCs) and microbial electrolysis cells (MEC) are being investigated in various contexts. In a recently published review,[13] the combination of photoelectric cells (PEC) and microbial fuel cells (MFC) is examined, including photosynthetic MFCs. There seem to be a multitude of possible designs for establishing Photo-MFCs and in addition to electric power hydrogen, methane and other solar-bioelectrofuels can potentially be produced using hybrid MFC-PEC type reactors. In a neighboring context, phosphate remobilization from digested sewage sludge

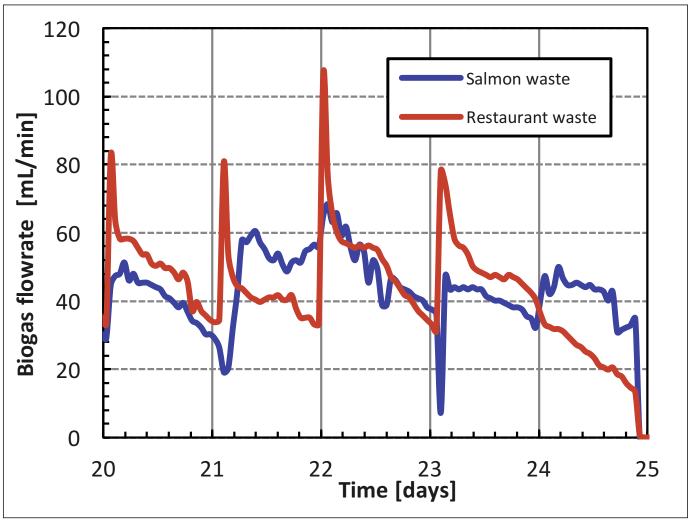

Fig. 6. Anaerobic digesters (20 L scale) in the top panel and evolution of biogas production rate over time for two different substrates (bottom panel).

containing iron phosphate was scaled-up in a microbial fuel cell (MFC). A 3-litre triple chambered MFC was operated as a microbial fuel cell and later as a microbial electrolysis cell to accelerate cathodic phosphate remobilization. The authors noted that applying an additional voltage and exceeding native MFC power accelerated chemical base formation and the related phosphate remobilization rate. This allowed a 67% recovery of sludge phosphate in 26 h, which was remarkably faster than when using microbial fuel cell conditions. Remobilized phosphate was subsequently precipitated as struvite, in a quality that more than satisfied legal requirements in terms of contaminants.[14]

This survey of activities would not be complete without mentioning the analytical developments that enable these measurements. In this respect, the analytical chemistry laboratory headed by Prof. U. Piantini has a strong competence in trace analytics and is regularly mandated to analyze environmental contaminants such as drugs, drug metabolites, pesticides or heavy metals in samples of highly diversified origins and natures.

ZHAW, Institute of Chemistry and Biotechnology (ICBT)

The topic «Chemistry and Environment» has significantly gained in importance over the past few years, within the ZHAW Chemistry Bachelor's degree program. This is expressed among others by offering a lecture course dedicated to environment chemistry, in the last BSc semester curriculum. At this advanced stage of the Chemistry BSc education, the understanding from the various chemical disciplines is available to be combined into an interdisciplinary approach needed to address climate change, air pollution or the global spread of persistent organic pollutants into the environment. It also represents an interesting showcase to implement the acquired knowledge within a concrete field with high socio-economic importance. Environmental analysis is today a key area for communicating environmental issues. By providing quantitative data and insights, it has become an integral part in the decision making process at a political and legislative level.

The lectures will be carried out with the active involvement of experts from Empa and the PSI. The influence of technological developments on global commons such as air, water and soil or shared resources like the fossil energy and raw material reserves are discussed. The limited and barely sustainable management of existing global resources is reflected in relation to successes of Swiss environmental legislation on air pollutants. Considering the importance of the subject and the interest met by the BSc students, it is planned to include the new module «Chemistry and Energy» into next year's master program «Chemistry for the Life Sciences». This module will discuss subjects such as chemical energy storage, energy production through biomass and

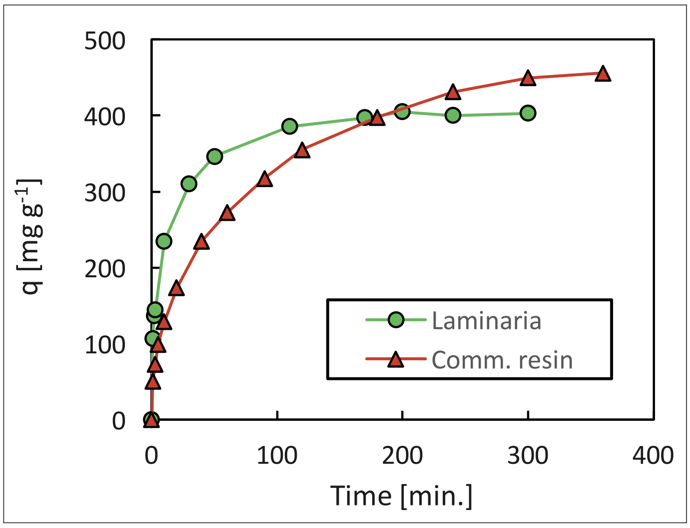

Fig. 7. Adsorption of Cu^{2+} ions on magnetic chitosan particles (left panel) and adsorption kinetics of Pb^{2+} on a commercial resin and on *Laminaria digitata* (marine algae) particles (right panel).

photovoltaics as well as the concepts used for the treatment of exhausts originating from our motorized mobility.

Projects focusing on environmental subjects are an integral part of research conducted at the Institute of Chemistry and Biotechnology (ICBT), which has state-of-the-art infrastructure and expert knowledge on environmental sciences. While smaller projects are carried out as part of analytical internships, larger projects are often conducted within collaborations with research partners (Empa, Eawag, PSI), regional government-run laboratories or federal offices. Many years of collaboration with Empa in the field of persistent organic pollutants, especially hexabromocyclodecanes (HBCDs) and chlorinated paraffins (CPs), have led to several publications.[15] The analysis of the transformation and biodegradation products of the hexabromocyclodecanes used as flame-retardants in polystyrene is a real analytical challenge and considering the many structural isomers of chloroparaffins the quantitative determination has almost become a nightmare.

Together with the «Labor Spiez» a multi-year project is currently ongoing in the field of elemental analysis. The project focuses on the monitoring of military legacies, *i.e.* sites contaminated with toxic heavy metals in Switzerland or conflict areas in other parts of the world. Also, research on the speciation analysis of chromium (III/VI) in consumer products and arsenic (III/V) in rice products has been carried out in collaboration with the «Labor der Urkantone». Furthermore, the arsenic pollution in schools caused by particulate matter from arsenic-treated animal preparations is the subject of a current Bachelor thesis.

A project to prevent fuel abuse as well as limit and supervise the unauthorized burning of wood was conducted with the regional governments of central Switzerland and the two federal offices of Energy (BFE) and of the Environment (BAFU). The objective was to establish benchmarks concerning heavy metals in wood incineration ash. Another project with a federal office was aimed at the fast detection and identification of small plastic particles in compost soil.

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