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Chair:
Prof. Roberto Canziani

DOCTORAL PROGRAM IN SANITARY - ENVIRONMENTAL ENGINEERING

Introduction

"Although many people are concerned about the status of the environment, environmental engineers are the technical professionals who provide safe drinking water, treat and properly dispose of wastes, maintain air quality, control water pollution, and remediate sites contaminated due to spills of improper disposal of hazardous substances. They monitor the quality of the air, water, and land. And, they develop new and improved means to protect the environment". (Mackenzie L. D. Cornwell D.A., 1998, Introduction to Environmental Engineering. Mc Graw Hill 3rd Edition; Boston, Mass. USA).
The definition of Environmental Engineering, as published by the Environmental Engineering Division of the American Society of Civil Engineers - ASCE is the following:
"Environmental engineering exerts sound engineering thought and practice in the solutions of problems of environmental sanitation, notably in the provision of safe, water supply, the proper disposal of wastewater and solid wastes; the control of water, soil and atmospheric pollution, and the social and environmental impact of these solutions. Furthermore it is concerned with engineering problems in the field of public health and with the effects of technological advances on the environment."
According to these authoritative references, doctoral studies in Sanitary - Environmental Engineering at Politecnico di Milano provide engineers with advanced tools to lead research and development on technologies for pollution prevention and control.

Educational strategy

The long-desired innovation in services and industry should not be a fleeting fruit of fantasy, but a long-lasting product coming from a sound research activity which only University can grant, especially to small and medium-sized enterprises, which cannot afford the burden of autonomous research. The educational strategy of the Doctoral Programme in Environmental Engineering has been based on the transfer of fundamentals of Sanitary and Environmental Engineering to the doctoral students. The main objective is the formation of professionals that can develop autonomous research and that can easily master their field of competence, even for the most advanced topics, so that they can promote innovation and update the specific knowledge in their research field.
In the framework of its general objectives, two main elements are highlighted: a strong structure of the fundamental preparation

1. VOCs removal from gaseous emissions. Pilot-plant experiments on biotrickling filters and rotating biological contactors

2. Mobile Lab for air quality monitoring

and a more strict connection with industry and research institutes. For a typically interdisciplinary topic such as Environmental Engineering, "teaching" activities are very delicate, mainly for the wide cultural base that is requested. Specific training courses in biology and organic chemistry are offered. Preparatory training courses provide a synthesis and integration for all doctorate students: basic training courses take advantage of the long experience and know-how in laboratory activities, and offer training activities on essential research tools such as Environmental Engineering Laboratory, Environmental Monitoring, and Environmental Engineering Reactors. Contacts with bodies other than Universities have been established through the participation both to specialised seminars and refresher courses given by experts from industry, together with short training "stages" of the PhD students at highly qualified firms. Finally, stay abroad for at least 3 months is considered essential for PhD students in Sanitary-Environmental Engineering, in order to complete their formation and to exchange research experience and expertise.

Contents of the Doctoral Program in Environmental Sanitary Engineering

The full range of research themes offered by the PhD Course in Sanitary Engineering will cover the following list, in which PhD theses will be developed.

1. Water supply technology and treatment, disposal and reuse of wastewater, advanced biological and physical-chemical water and wastewater treatment, sludge minimization.
2. Solid wastes management (collection, recovery, recycling, incineration with energy recovery and final disposal).
3. Phenomenology of atmospheric environment and treatment of gaseous emissions: statistical models of air quality data, sampling and speciation of fine particulate in the

3. Analytical laboratory

atmosphere, emission models from mobile sources, emissions of micro-pollutants from waste incineration processes, organic volatile control by biofiltration techniques.

4. Contaminated soils and remediation technologies, groundwater protection and treatment, risk assessment, statistical analysis and mapping of contamination data, in-situ and on site bio-remediation;
5. Sustainability issues and environmental management systems (ISO 14001, EMAS, LCA, Ecolabel); indicators and indices: data qualification and statistical analysis.

Type of professional skills and possible positions achieved by graduated Doctors.
The typical interdisciplinary character of the environmental issues and the more and more "integrated" approach to problem solving in this field has been repeatedly underlined by U.E. directives and will require experts in environment-related topics which can not only plan and design interventions, but also assess their implications on the environment. Typical outlets into the job market are Universities, Research Centres, public bodies and Authorities, private companies. Even medium and small enterprises which cannot afford to develop a specific "know-how" on their own, may require high professional profiles that can ensure adequate updating and innovation necessary to maintain competitiveness. Finally, a PhD in Sanitary-Environmental Engineering should provide highly qualified personnel to cover key positions and roles in research centres, top level management in Public Bodies and Authorities involved in environmental policy, and senior consultants for engineering companies.

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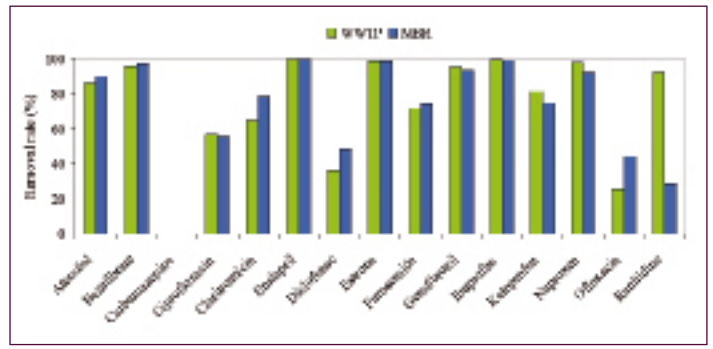
THE FATE AND REMOVAL OF PHARMACEUTICAL SUBSTANCES IN MEMBRANE BIOREACTORS

Hélène Bouju

Pharmaceutically active substances (PhACs) are referred as "pseudo-persistent" in the environment since their removal in aquatic ecosystems is balanced by a continuous discharge in water bodies. Wastewater treatment plants (WWTP) were evidenced as hot spots for the release of such substances into the environment, either through discharge of treated effluent or by dispersion of digested sludge on agricultural fields. In the last decade, the growing population and the related increasing consumption of medicines, together with a raising public concern have elevated the interest about the occurrence and associated risks related to pharmaceutical active substances in the environment.
As previously highlighted in some scientific works, MBRs may enhance micropollutants removal, especially for those which are partially removed in conventional activated sludge process (CAS). Therefore, this study aimed mainly at comparing a 280L anoxic-aerobic membrane bioreactor (MBR) pilot plant with a full scale WWTP process in terms of pharmaceutical substances removal efficiencies.
This study was part of the EU funded MBR Train project, on process optimisation and fouling control in membrane bioreactors for wastewater and drinking water treatment. It aimed at studying the fate and the removal of pharmaceutical substances in membrane bioreactors; as well as to compare the removal efficiencies between conventional activated sludge process and membrane bioreactor. For that purpose, a full-scale conventional activated sludge process (1 250 000 PE) and a 280L anoxic-aerobic pilot MBR were fed with the same influent and operated under the same hydraulic conditions for three years.
A first experiment was performed when both processes were operated at a Sludge Retention Time (SRT) of 35 days (sampling 1), and a second one when the MBR was operated at 15 days (sampling 2), while the CAS was operated at 43 days. A third sampling campaign was done when both processes were operated at 25 days SRT (sampling 3). 39 pharmaceutical substances were analysed, among which respectively 27 (sampling 1), 29 (sampling 2) and 24 (sampling 3) were detected in the influent of both processes, and 15 were present at relevant concentration during the three sampling campaigns. Results are summarized in Figure 1.
Results have shown that, for most of the substances, differences in removal rates between the MBR pilot plant and the full scale WWTP were not significant. The same conclusion was drawn for the impact of the SRT. Indeed between 15, 25 and 35 days, no significant improvement of pharmaceutical substances removal was observed. Moreover, it appeared that the significant differences observed for some of the detected substances could be explained by variations of influent concentration and/or temperature rather than SRT.
In order to study in more details one of the targeted substances, diclofenac, a ^{14}C-radiolabelled fate study was carried out in a 1.5L laboratory scale MBR, at the Fachhochschule Nordwestschweiz, Basel, Switzerland. Since the pharmaceutical substances issue is not only limited to the parent compound, diclofenac was spiked together with its main human metabolite, 4'-hydroxydiclofenac.
The reactor was first spiked with a solution of both ^{14}C-radiolabelled substances and then fed continuously with non radiolabelled diclofenac for a one month period prior to a second single pulse of ^{14}C-radiolabelled solution of diclofenac and 4'-hydroxydiclofenac. The solution contained about 25% 4'-hydroxydiclofenac, which corresponds to the ratio observed in municipal sewage water. The radioactivity was monitored for a total of 12 days in the various effluents. A complete mass balance of the system exhibited that the major part of the radioactivity left the reactor with permeate, in both cases, while a really low amount (1.1 and 2.1% respectively) was recovered in the daily excess sludge and a negligible amount was measured in the off-gas traps, as well as on the membranes. While the first spike did not exhibit any microbial degradation or transformation products formation; chromatographic analyses of permeate samples after the second spike, by means of HPLC-MS coupled to a radiodetector, displayed a different pattern than the one of the spiked solution. It showed the occurrence of three additional metabolites, among which are hydroxylated ones.
Results from the fate study were used to start implementing a model representing both adsorption/desorption and biodegradation of diclofenac and 4'-hydroxydiclofenac at the Biomath department of Universiteit Gent, Ghent, Belgium.
Microcalorimetric experiments were also set up to investigate pharmaceuticals biodegradation reactions. For this purpose, a 2L Bio-RC1 (Mettler-Toledo) was modified to reach a resolution of 5-10mW.L^{-1}. The biodegradation rate of standard substrates (ethanol and ammonia) by the activated sludge from the MBR pilot plant and the full-scale WWTP operating in parallel were measured by means of microcalorimetry.
These comparisons have shown that the total energy produced normalized with the TSS concentration and the concentration of equivalent COD spiked into the microcalorimeter, are similar for both biomasses.
It was also observed that autotroph nitrifiers' activity is highly dependent on the SRT.
Then few experiments to determine the biodegradation of selected pharmaceutical substances, as well as the eventual inhibition induced were performed. It appeared that the microcalorimeter can hardly be used for measuring biodegradation of pharmaceutical substances, even at much higher concentrations than those observed in the environment. This might be due either to a really slow biodegradation kinetic or to the too small heat production. However, it could be used for the assessment of the inhibition potential of a given substance. None of the tested substances exhibited a strong inhibition effect at concentrations much higher than usually found in domestic sewage water.
The obtained results clarify the limits of biological processes for pharmaceutical substances biodegradation. Nevertheless knowledge on their fate and removal in wastewater treatment plants is still incomplete; therefore, further research is needed on biodegradation enhancement and tertiary treatment potential.

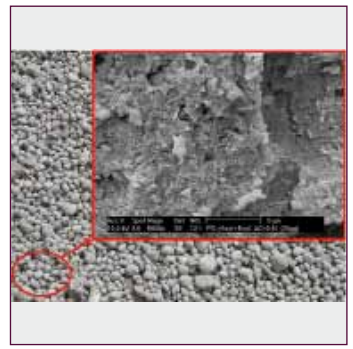


1. Average removal rate measured in the full scale WWTP and the MBR pilot plant

EXPERIMENTAL RESEARCH ON THE REMEDIATION OF CONTAMINATED SEDIMENTS

Alessandro Careghini

Millions of cubic meters of sediments are dredged every year for maintenance of canals and harbors, but also for clean-up purposes. Dredged materials should be relocated in the original water body, but treatment or controlled disposal are necessary if contamination levels are not compatible with relocation. Contaminated sediments contain a mix of different types of pollutants; a "treatment train" is usually required. Sediment remediation results in greater technical problems and/or in higher costs compared with soil one due to specific physical-chemical and mechanical properties of sediments (high moisture content, large amount of fine-grained particles, high organic matter content, etc.).
In this work, technologies for the remediation of contaminated sediments have been investigated. The main experimental activities have been done on a new treatment system for the remediation of contaminated soils and sediments based on Stabilization/Solidification (S/S) and subsequent thermal desorption. Specific tests were carried out to evaluate the feasibility of the system for the treatment of contaminated sediment, evaluating the residual concentrations of pollutants, the effect of the process parameters on the treated final materials, their leaching behaviour and the evolution of the cement hydration reactions, also studying the effect of different matrixes on the cementitious system. Chemical oxidation and reduction treatments were also investigated in two other experimentations. In particular, chemical oxidation tests using modified Fenton's reagents and chemical reduction tests using zero-valent iron were done in slurry systems to evaluate the applicability of these chemical treatments to dredged materials heavily polluted by organic compounds and to optimize the process parameters based on the removal efficiencies. Finally, chemical oxidation tests using five different compounds (hydrogen peroxide, Fenton's reagents, permanganate, activated persulfate, peroxy-acid) were carried out on sediments from an industrial canal of New York City to select the most effective oxidizer and to evaluate the potential effects of chemical oxidation on filtration resistance of dredged materials.
Tests performed on S/S plus thermal desorption system were firstly aimed at the evaluation of its feasibility for the remediation of contaminated dredged materials. The effects of the process parameters on treated materials, the concentrations of residual pollutants, the quality of the leachate and the evolutions of cement hydration reactions have been evaluated through specific tests conducted using sediments from the Augusta bay (NPS of Priolo). Results showed a proper evolution of cement hydration reactions over time, even if some interactions occurred between sediment components and products of cement hydration. The thermal desorption step removed volatile and semi-volatile organic compounds and mercury with high efficiency: referring to the raw sediment concentrations, removal efficiencies were 97% for heavy petroleum hydrocarbons, 97% for dioxins and 75% for mercury in the best thermal desorption configuration tested (vacuum condition, T 250°C, 4 hours). Thermal desorption removed free water within the cementitious matrix, stopping hydration reactions; preliminary rehydration tests showed that these reactions could be restarted sinking the desorbed materials in tap water. Mercury speciation tests showed that both S/S and thermal desorption steps changed mercury chemical forms. The concentrations measured in the leachate (leaching test performed according to EN 12457-2) were below the law limits for reuse for many parameters, but also some problems were pointed out, mainly connected to the concentrations of COD and chlorides and pH. The incidence of the matrix on the granulation step was evaluated using sediments from Orbetello bay (NPS of Orbetello) and Corno River (NPS of Grado and Marano). The matrix has heavily influenced the physical-morphological characteristics of final granular materials, but the observed chemistry in both these systems was about equal to the one previously observed in the Augusta bay sediment system. The tested technology has shown good capability for the treatment of contaminated dredged materials, but the materials could be reused in several civil engineering applications only if they fulfilled all technical, environmental and legislative requirements. Further tests will be required to solve the problems pointed out from this experimentation and to evaluate the long-term leaching behaviour, the leaching behaviour under different environmental conditions and the physical-mechanical properties of the treated materials.
Chemical oxidation with modified Fenton's reagents and reduction with microscale zero-valent iron were tested on Porto Marghera sediments, heavily contaminated by Total Petroleum Hydrocarbons (TPHs), Polycyclic Aromatic Hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs). Oxidation was effective for the removal of TPHs (removal efficiency between 80 and 95 %), but only about 50 % of PAHs were removed in the best test; PCBs were not removed significantly. Sediment downgrading for TPHs was achieved in about all the configurations tested, while no downgrading was achieved for PAH and PCB parameters. Moreover, the comparison of pre- and post-oxidation chromatographic patterns revealed the production of unidentified by-products, a common problem of every oxidation treatments. Reduction results showed high removal of TPHs (removal efficiencies between 90 and 95 %), not significant removal of PAHs and about 60 % removal for total PCBs; moreover, analyses of single PCB congeners pointed out a strong decrease of congeners with high chloride substitutions and an increase of congeners with low chloride substitutions.
The downgrading of TPH and PCB parameters was fulfilled with reduction treatments; no downgrading was detected for PAHs. Oxidation and reduction treatments alone were not sufficient for the remediation of Porto Marghera sediments; the subsequent use of a biological treatment could ensure the removal of the residual pollutants and by-products at the end of the chemical treatments.
Chemical analyses carried out on PAHs contaminated New York City sediments revealed not significant differences between concentrations of raw sediment and of treated materials for all the oxidizers tested. Moreover, mobility of some metals increased at the end of oxidation treatment, especially in the persulfate tests, but also in the permanganate and in the peroxy-acid systems. The treatment did not change significantly the resistance to filtration of the dredged material. Further tests with different amounts of oxidizers should be performed to better understand the applicability of the oxidation treatment to remediate this matrix.



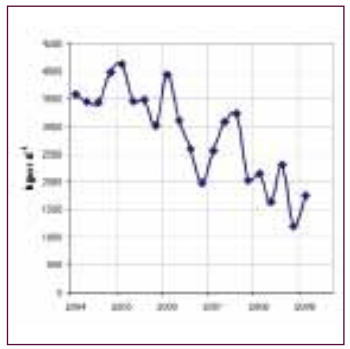
1. Granular materials after thermal desorption step, with an enlargement at microscopic scale (by scanning electron microscope)

SET-UP OF A MATHEMATICAL MODEL OF A FULL-SCALE WWTP WITH OZONATION OF ACTIVATED SLUDGE

Calibration and validation using a novel methodology

Davide Gardoni

Purpose of the research was to investigate the behaviour of a full scale WWTP with ozonation, through a detailed experimental campaign and a new mathematical model.
Excess sludge disposal is one of the most relevant issues for wastewater treatment plants, especially in those countries where landfilling is discouraged. Ozonation of activated sludges is an effective and affordable solution. In fact, ozonation allows transforming a fraction of the suspended solids into soluble matter, reducing the overall production of waste sludge. The soluble matter produced is removed by the biomass in the biological reactor and partially converted to CO_2.
The investigated full scale plant is located in Bulgarograsso, near Como (Italy). This plant is about 70.000 PE, and has a relevant industrial contribution (~80% of COD load from textile industries).
In order to understand how ozone microscopically interacts with suspended solids, a lab scale ozone production unit was used. The investigated ozonation unit operates at a very short hydraulic retention time (less than 10 seconds), if compared to reactors commonly described in the literature; this suggests that the relevance of the various ozone-mediated processes may be different from previously reported experiences. Therefore,, tests were focused on elucidating the effects of ozone on the different fractions of activated sludge, either soluble or particulate, under actual operative conditions.
It was observed that, in a short contact time reactor, ozone interacts mainly with soluble compounds and with biodegradable particulate COD. In particular, it is relevant that the interaction with soluble compounds leads only to a decay of ozone concentration, while interaction with particulate COD leads also to the solubilisation of suspended solids. In this type of reactors, the direct influence of ozone on floc-former biomass (heterotrohic and autotrophic) seems to be negligible.
However, it was observed that ozone reduces dramatically filamentous bacteria, decreasing SVI and alleviating bulking and foaming problems. The improved sludge settleability makes it possible to increase the concentration of suspended solids in the biological reactors thus increasing the treatment capacity, improving the quality of the effluent and reducing the production of excess sludge. Moreover, over a long period, ozone operates a sort of selection on heterotrophic biomasses in the reactor, promoting the development of bacteria with a lower growth yield coefficient and a higher specific decay rate. This implied a further decrease in sludge production.
Hence, the ozonation of a fraction of the recycle flow achieved with a compact plug-flow reactor featured with a simple Venturi injector/mixer allows to decrease the overall production of excess sludge, on the one hand by direct disrupting of the particulate COD and, on the other hand, by promoting the selection of favourable biomasses.
No increase in the applied ozone dosage is required to compensate the short HRT. The only significant drawback is the reduction in the phosphorus removal capacity.
The optimisation of the plant requested a more detailed analysis of the behaviour of the biological reactor. To achieve an adequate description and comprehension of the ozonation processes and of their interaction with the biological processes, a mathematical model was developed. The conventional IWA-ASM1 model was chosen for the description of the biological processes, implemented into the MostForWater-WEST simulation platform. In order to describe the ozonation reactor, a new model was built on the base of the results of laboratory experiments. They pointed out the kinetics of ozone-mediated processes is very fast, and that ozone solubilisation efficiency is influenced by both solids and ozone concentrations. These findings were integrated into the ozonation model that describes both chemical and physical relationships among components..
To calibrate and validate this model, a new method based on the integrated use of both plant data series and results of dedicated laboratory experiments was employed. Briefly, the calibration phase was used to force the model to closely reproduce the observed biomass activities assessed by dedicated experiments on biomass samples. In this way, a set of model parameters was selected. Then, the model was run by using these calibrated values in order to simulated the expected efficiency of the real plant and compared with available data series (validation phase). Repeating this procedure over different time series allows identifying an "optimum set" that can be used for the scenario analysis.
Scenario analysis allowed studying different operating conditions regarding the full scale plant. The model was used to simulate new scenarios in order to evaluate the feasibility of different objectives.
In particular, it was necessary to find out a new management scheme to reduce nitrogen concentration in the effluent, possibly without any new tank. Several scenario analyses were run based on a modified Montecarlo simulation method that allowed obtaining expected effluent concentrations as well as their confidence intervals.
It was pointed out that the required efficiency could be achieved by increasing the internal recycle flow and by dosing external COD in denitrification tank. It was also possible to highlight the best ozonation condition.
Finally, it is worth underling that the detailed experimental work allowed identifying and describing a new behaviour of the heterotrophic biomass, which is the intense production of hydrolytic enzymes when exposed to nutrient limitation. In particular, it was observed that the lack of ammonia forces the biomass to hydrolyse organic nitrogen. It was possible to model this phenomenon, by modifying the hydrolysis and ammonification kinetic equation of the original ASM1 model.
In conclusion, this research shows that ozonation of a fraction of the recycle sludge in a short retention time contactor is a useful technique to reduce the production of excess sludge. It has virtually no drawbacks, except for reduction of the phosphorus removal capacity.
The developed mathematical model describes adequately both biological and ozonation reactors, and the calibration-validation method allows a consumption of about 50% less data. Besides, the scenario analysis shows that it is possible to enhance the capability of the plant without the need for new reactors and also shows that modelling is a powerful tool to optimize existing plants.



1. Total suspended solids production. Ozonation started in the second half of 2006, reducing the production of waste solids

ULTRAFINE AND NANOPARTICLES FROM STATIONARY COMBUSTION PROCESSES

Senem Ozgen

In many health studies, associations have been observed between the ambient concentrations of particulate matter (PM) and morbidity and mortality. Interest in ultrafine (UFP - Dp < 0.1 μm) and nanoparticles (NP -Dp < 0.05 μm) have grown of late because some researchers proposed that these size fractions may have a greater biological effect than an equal mass of larger particles. Epidemiological studies show that UFP may produce pathologies in organs not directly exposed. In some toxicological studies UFP are reported to be more effective than larger particles in inducing cellular damage. Given these health effects, the determination of the UFP levels becomes very important especially in urban areas where much of the population is daily exposed to PM emissions from mobile sources and domestic heating. This fraction of the PM dominates the number concentration, however its contribution to the overall PM mass is only a few percents. Therefore, UFP concentration is usually expressed as number concentration, with additional information provided by the size distribution. Accordingly, the characterization of the PM emission sources should be done considering the number and distribution of the particles as well as the conventional mass concentration. Nevertheless, a rather limited number of studies address the particle emissions from stationary combustion processes explicitly in terms of particle number due to the fact the measurement is really complex and currently there are no standard procedures. The complexity of the measurement arises from the dynamic changes that the UFP and NP undergo because of nucleation, condensation and coagulation processes.

The present work outlines the main scientific contents of the research project, conducted by Politecnico di Milano at Laboratory for Energy and Environment (LEAP) in Piacenza, with particular reference to the most relevant aspects of the measurement approach adopted.

The main objective of the work is to provide field experiment data on UFP and NP from small to large scale stationary combustion processes which gives insight to the real emission situation. Providing this data is important because small scale combustion installations make up a significant share of the total air pollutant emissions budget in Italian urban areas, where their spatial concentration and limited flue gas release height may lead to important impacts on air quality. Furthermore, there is a great necessity to improve the knowledge on waste-to-energy (WTE) plant emissions which actually is mostly lacking on non-laboratory scale (real-world) plants. WTE emissions require special attention because of the content of metals and halogens typical of the input fuel which may give rise to the enrichment of semivolatile toxic metal species on smaller particles.

A sampling train was set up on purpose, which allowed the number concentration and size distribution measurement of particles down to 7 nm from diluted and non diluted flue gas. The sampling strategy was mainly developed to evaluate the condensable particles, considering the influence of the dilution and cooling of the flue gas, as well as the influence of the combustion efficiency.

Field sampling campaigns were performed on 4 residential heating devices fed with fuels commonly used in residential areas, and 4 WTE equipped with best available technology (BAT) air pollution control devices.

A nucleation, condensation and coagulation model was also formulated and applied to field data, in an attempt to improve the understanding of the single formation and transformation processes acting on particles under very high saturation conditions.

In particular, at such small distances and short atmospheric residence times, the saturation ratio of the condensable gases may be much higher than what is usually assumed in atmospheric models, which would change the nucleation and coagulation rates, as well as the condensation sink of the semivolatile species involved.

The overall results of the measurements on residential heating devices indicated that, except the natural gas boiler, the residential heating devices emitted on average on the order of 107 particles cm-3, about three orders of magnitude higher than the background air. With the exception of the closed fire place, UFP and NP accounted for the great part of the particle number (%UFP>90%). On the other hand the WTE plants emissions ranged between 104-105 cm-3 with a contribution from UFP for more than 90%. The result is not surprising since the investigated plants are equipped with BAT abatement devices and the combustion conditions are strictly controlled. However, the special composition of the waste fed as fuel requires attention to WTE emissions. These results are very significant, especially considering the particular health effects of this size fraction and the higher exposure of the population in urban and suburban areas where the investigated combustion sources are active.

Dilution and cooling of the flue gas is observed to have an effect on the gas/aerosol partitioning of the semivolatile species. This effect depends principally on the fuel gas primary particulate and semivolatile compounds content. Higher presence of primary particles in the flue gas may inhibit the formation of new particles with dilution. While, in case of lesser primary particle presence, enhanced nucleation processes may enlarge the particle number concentration, with a concurrent shift in the size distribution towards smaller particles; this behavior is clearly observed during the light oil burning experiments.

Findings from field measurement investigations clearly demonstrate, first of all, the unsteady nature of the particles and the consequent difficulty of defining stationary combustion source emission standards in terms of number concentration, which are strongly correlated with the dilution and sampling conditions (e.g., dilution ratio, sampling temperature). The definition of a standard requires, before all, the determination of a standardized sampling methodology. Dilution sampling approach such as used in this work helps to roughly estimate the fate of the particle emissions once released into the atmosphere.

1. Dilution sampling train

Results from the model applications based on field measurement data and under conditions of supersaturation, points out that UFP and NP presence is closely connected with the condensable semivolatile compounds and the primary particles in the flue gas. This latter suggests that control strategies based on the regulation of these two parameters may be adopted in order to limit the undesired formation of UFP and NP. This could be important not only for the design and operation of the flue gas treatment devices but also for addressing the revision of the emission standards including the condensable species.