From Drying Masonry to "Burning Water" – Current Research on Radio-Frequency Applications in Leipzig

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Introduction

The potential of both microwave (MW) and radio-frequency (RF) heating has been known for decades[1,2], and many applications have found their way into the market. The advantages of these dielectric heating methods in comparison to conventional heating (which is often limited by heat transfer processes or the relatively low heat capacity of gases) are obvious: Due to volumetric heat formation, more homogeneous temperature distributions and larger heating rates can be achieved when certain preconditions such as suitable applicator or electrode geometries are fulfilled. The varying absorption properties with respect to the electromagnetic waves (represented by the imaginary part of the dielectric constant) can additionally be utilized to realize different heating rates within one system which is not possible for heating methods based on thermal conductivity.

The presence and the extent of non-thermal effects of MW and RF heating are still a fascinating topic of current research and matter of ongoing discussion in literature. Although some established applications of RF heating such as drying of textiles or timber are nowadays established in industrial processes, MW-based technologies are today by far more common in industry and generally, especially catalyzed by the triumphal success of MW heating in food processing. As a consequence, investment costs for MW devices decreased to such an extent that for example MW ovens have become a consumer product. Also, research on many processes in materials science led to new operational areas of MW technologies in different scales. The potentially large specific power input and the possibility of high local heating rates are only two interesting features of these innovative MW applications, namely when employing higher frequencies than the most-common 2.45 GHz.

However, the manifold options of RF heating should not be ignored and the sometimes already "historical" ideas for its application not be forgotten. The most obvious advantage of utilizing RF is based on generally larger penetration depth which allows treatment of volumes in the technical scale of liters or even cubic meters. Interference effects often increasing the temperature gradients for MW heating are less relevant for typical geometries of RF heating. Additionally, the heating principle in this frequency range (e.g. 1 to 100 MHz) is not based on the orientation polarization of water molecules as for many MW applications. The variety of energy absorption effects in the MHz frequency range allows heating a wide spectrum of materials including dry ones.

A prominent example is the option to heat hydrophobic and hydrophilic zeolites, a class of inorganic materials with an ordered Si/Al/O framework and a defined network of pores. These materials are widely used in chemical and environmental engineering, e.g., as ion exchangers, molecular sieves, catalyst supports or catalysts, adsorbers for non-polar organic pollutants or drying agents. In these materials, heating is usually based on relaxation processes related to the site exchange of structural cations within the zeolite framework[3,4]. Furthermore, the use of an electronic matching network is common for RF heating thus ensuring an optimal energy transfer from the generator to the load corresponding to relatively high energy efficiencies of more than 90 % in the technical scale.

Soil remediation

The specific advantages of RF heating for larger volumes were the motivation of UFZ to develop this technology (applying 13.56 MHz) in order to support soil remediation processes by increasing the soil temperature. The removal of organic pollutants from soil can be enhanced due to the beneficial impact of temperature on vapor pressure, water solubility, mobility of contaminants, their reactivity with constituents of the soil matrix and rate of microbiological detoxification processes. The research was focused on both basic and engineering aspects. Namely, the influence of water and steam formation on the extraction of pollutants from soil was characterized[5,6], the compatibility of RF application with microbial degradation of soil contaminants was proved[7,8]. While for biological applications with low acceptable temperature variations parallel plate electrodes were employed for an off-site treatment of the contaminated soil, such geometry would be very costly for most in-situ applications in the field. Therefore, rod-like electrodes with an air gap were used for practical remediation projects[9]. They were introduced into boreholes and simultaneously used as extraction wells for the contaminated soil vapor. Thus, the inhomogeneity of heating could be partially compensated by exploiting the heat transport by the air flow within the soil when directed from hot to cold wells. This RF-based thermally enhanced soil vapor extraction was successfully applied in real scale using an automated container system with up to 30 kW RF power[10]. The arrangement with the electrode/extraction well system covered aboveground by boxes for electromagnetic shielding is shown in Fig. 1 at an industrial site operated by the commercial partner Ecologia Environmental Solutions Ltd. in London/UK.

Figure 1. Arrangement for RF heating and thermal enhancement of soil vapor extraction at an industrial site in London (*photo: Ecologia Environmental Solutions Ltd., Kent, UK*).

The remediation of a former petrol station with a ground heavily contaminated with mineral oil hydrocarbons is a typical example showing the advantages of RF heating for the removal of the contamination “hot spot” with a volume of some hundreds of cubic meters. The remediation time until the decontamination goals were achieved could be significantly shortened by thermal enhancement (by about 85 %). Using a similar electrode design, various combinations of heating and soil vapor extraction were applied[11]. For high hydrocarbon contents of the soil vapor, an oxidation catalyst may be placed directly into the perforated electrode/extraction well in the respective depth and ventilated by air for providing oxygen. The oxidation heat can then be used to further heat the soil in the vicinity of the electrode.

When unsaturated and saturated (groundwater) soil compartments are contaminated, a combination of low-frequency (50 or 60 Hz) and RF heating (13.56 MHz) can be used to reduce the temperature gradients between the two layers and to avoid re-condensation of the pollutants mobilized into the gas phase be heating[12]. The field tests showed that RF heating can compete with other thermal methods (thermal wells, power line frequency heating, steam injection) appropriate for contamination source removal.

Building restoration

Some principles of soil remediation can be transferred to tackle challenges in construction engineering and especially restoration. Due to acute damaging events such as flooding, as a result of constructional defects or simply due to their considerable age, building structures can be imbued or contaminated by fuel oil or other hydrocarbons. In this context, RF heating is also a suitable tool to initiate or accelerate restoration processes[13,14]. Whereas for drying, temperatures up to 100°C are sufficient, the boiling points of most relevant hydrocarbons are markedly higher. Although heating to such high temperatures is feasible by RF, economic reasons and risks for the structural integrity usually prevent realizing such temperatures. However, due to effects of steam distillation (stripping) as shown for soil remediation[6], the content of semi-volatile hydrocarbons can be significantly reduced already at 100°C when the initial water content is high enough[13,15].

RF heating could be demonstrated for a variety of materials such as sandstone, clay brick, concrete and aerated concrete, gypsum (very temperature-sensible), lime sandstone and timber. By controlling the heating rate, the internal mechanical stress can be reduced and the formation of frictions avoided. Whereas the application of parallel plate or grid electrodes as favorable design in terms of temperature homogeneity can be easily realized for walls accessible from both sides, adequate RF heating is more demanding for building structures accessible from only one side (basement ground and walls). For this purpose, another engineering option representing a series connection of two capacitors (capacitive coupling) was developed and successfully tested. Here, the "hot electrode" connected with the RF voltage output and the grounded "shielding electrode" surrounding the "hot" electrode are placed on the accessible side of the wall as schematically shown in Fig. 2. On the other side, a "coupling electrode" with a size in the range of the "shielding electrode" is positioned. This "coupling electrode" may be either a massive metal electrode similar to the "shielding electrode" or it can also be composed of a natural structure exhibiting a sufficient RF conductivity (e.g. a moist soil, see also Fig. 2).

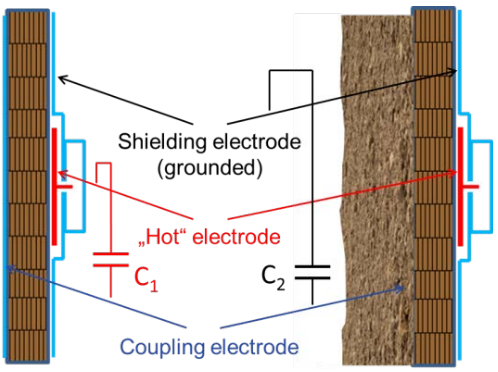

Figure 2. Schematic representation of the working principle of RF heating using capacitive coupling with a massive coupling electrode (*left*) and a natural soil compartment (*right*) acting as coupling electrode.

Usually, the overlapping area of the "hot" and the "coupling" electrodes is small in comparison to that of the "shielding" and "coupling" electrodes (25 % or less). Depending on the ratio of these two areas, the heating is focused on the volume between "hot" and "coupling" electrodes. This layout is especially favorable for historical buildings where non-invasive treatment methods are mandatory and for successive heating of larger masonry parts by shifting the "hot" electrode. This electrode design with capacitive coupling was demonstrated in a cellar of an inhabited house and, as a main result, the mean moisture content of the walls could be reduced from above 10 to about 1 wt.-%, which is below the equilibrium value corresponding to the usual humidity of the ambient air.

The applied RF arrangement and the infrared image of the masonry surface after heating to about 100°C are represented in Fig. 3.

Besides drying and decontamination, thermal pest control avoiding the use of hazardous chemicals is a promising application option of RF heating. Taking into account the stricter requirements for the indoor air quality, the use of wood preservatives is seen more and more critical, and thermal alternatives have a good chance to be established on the market.

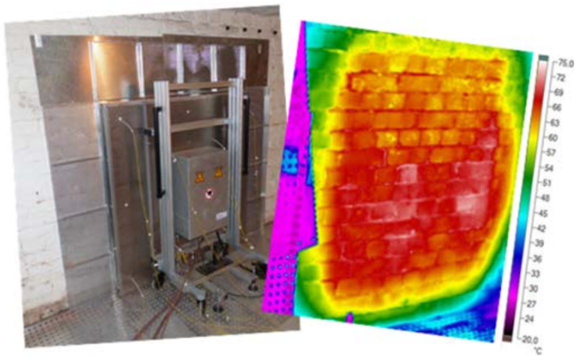

Figure 3. RF heating system using the design with capacitive coupling for masonry drying and infrared image obtained after removal of the electrode from the wall at the end of the heating process.

The idea of employing MW or RF is rather old[16]; however, a technical breakthrough is still missing. Detailed experiments on the mortality of various pests (e.g. common furniture beetle and house longhorn beetle) have shown that a temperature of 55°C is sufficient for elimination of the pest larvae. The low temperature in-homogeneities achievable by RF heating (in comparison to infrared or MW heating) enable pest control with acceptable maximum temperatures. This opens *in situ* as well as *ex* *situ* application areas not only for construction wood but also for objects of art such as picture frames or sculptures. For the applied field strengths (up to some kV/m), no indications were found for non-thermal effects of RF treatment[15,17]. Although some experiments and simulations showed certain potential of slightly overheating the pest or the matrix in their vicinity under specific conditions (e.g. the orientation of cylindrical larvae with respect to the local electrical field), the chances for practical exploitation of this selectivity seem to be quite limited.

In principle, the shift to higher frequencies and larger heating rates should be advantageous for selective overheating. The relationship of the dielectric parameters of pest organisms and typical matrix materials are however optimal in the RF range, and therefore the selectivity phenomenon is less probable in the GHz range. Nevertheless, even when only relying on thermal effects of RF heating, this method has large potential for minimal-invasive elimination of pests from timber in many contexts including historical artwork.

The potential of an exact temperature adjustment by controlled RF heating can also be exploited for optimizing the performance of building materials during their production. One example is the controlled heat treatment of fresh concrete in order to enhance the early age strength values and to support the hydration process in a well-designed manner. This allows a fast re-use of the formwork in the production of precast concrete elements. In contrast to conventional heating (heat tunnels) where thermal conduction is the main mechanism for internal temperature increase, RF heating provides the option to realize pre-defined temperature curves by compensating the hydration heat formation by adequately reducing the RF input power[18].

Another example is the preheating of recycled asphalt before introducing it into the production process for the new asphalt material. This allows avoiding thermal damage of the sensitive bitumen phase when in the conventional production process the cold recycled asphalt is mixed with an overheated fraction of stone and bitumen. Consequently, the recycling content for asphalt can be enhanced by pre-heating.

Zeolite regeneration

The treatment of gas streams for removing undesired components has great importance in chemical technology. A prominent example is the removal of volatile organic compounds in gas cleaning where hydrophobic zeolites or activated carbon are presently used. While adsorption on activated carbon and thermal or thermo-catalytic combustion work efficiently for low and high hydrocarbon concentrations, a technological gap exists for medium or fluctuating contents of hazardous substances. Here, processes consisting of adsorption and thermal regeneration steps represent adequate solutions.

For efficient regeneration of the packed bed reactors, RF heating is a suitable tool applicable for a wide range of adsorbing materials including a variety of zeolites. The temperature increase during RF regeneration independent of the gas flow as heat carrier can be used to initiate desorption of the collected substances without undesired dilution in the effluent. The dielectric properties of zeolites cover a wide range thus representing very different loads for dielectric heating. Due to the fact that aluminum atoms in the zeolite framework have to be charge-compensated by structural cations, the Si/Al ratio of zeolites is most relevant for both polarity and dielectric heating.

The adsorption behavior of zeolites corresponds to the polarity leading to a preference of hydrophobic zeolites with high Si/Al ratio for the removal of non-polar hydrocarbons from the gas phase. In contrast, hydrophilic zeolites are very favorable for drying various gas streams. Therefore, fine drying of natural gas, biogas or hydrogen by zeolites and thermal regeneration by RF heating are promising options in the energy sector, especially when renewable energy sources are considered. In contrast to MW heating, RF heating is also applicable for high Si/Al molecular sieves such as dealuminated Y zeolites[19].

The relaxation processes leading to the absorption of RF energy are rather complex and mainly correspond to the mobility of structural cations in the zeolite framework. The dielectric loss factor is strongly influenced by the presence of water since the positions of the cations and their relaxation behavior are modified with varying moisture content. The result for some zeolites (namely of Y type) is a maximum RF energy absorption for mean water contents[4]. This is the origin of a very fascinating phenomenon of RF heating using these zeolites.

When water is injected to a granular packed bed purged by a gas flow, a steep temperature increase by 150 to 200 K, depending on the electrical field and the purge flow, is established. The enhanced temperature leads to desorption of water into the gas phase, migration of water vapor within the packed bed to a zone with lower temperature and re-adsorption. Then, the cycle starts again which results in the formation of a coupled temperature-water pulse, a so-called thermo-chromatographic pulse (TCP), continuously moving through the zeolite bed[20]. An example for zeolite Y is shown in Fig. 4.

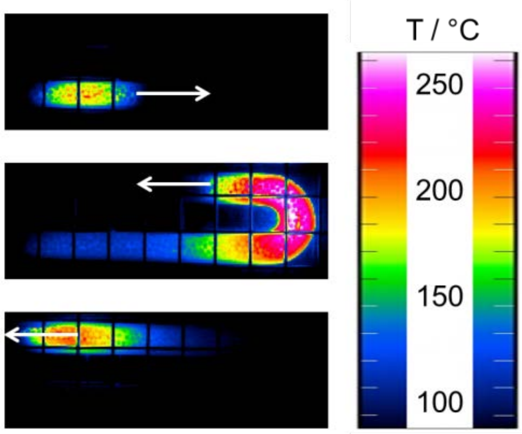

Figure 4. Thermo-chromatographic pulse as an example of selective RF heating in a zeolite Y packed bed with the direction of the purge gas flow marked by a white arrow.

The TCP phenomenon can be described by a model including the cation relaxation leading to the dielectric loss in the RF range, the interference with water, and the migration of water molecules within the zeolite framework[21]. Since the energy absorption in such systems is largest for medium water content, the TCP can be used to efficiently regenerate a partially loaded bed of a drying agent, because the TCP automatically starts at the loading boundary. For this purpose, an operation in the counter flow mode is most appropriate.

For off-gas cleaning, two special features of selective RF heating can be utilized to create more efficient regeneration processes after adsorption on a preferentially hydrophobic adsorber phase. First, a hydrophobic component can be mixed with a catalyst phase (e.g. a metal cluster) supported on a more hydrophilic component with higher RF absorbance. When starting regeneration by RF, the temperature of the catalyst rapidly increases to its operation temperature whereas the adsorber phase is heated with a lower rate. Thus, the contaminants are slowly released from the adsorber component, transferred to the catalyst and in-situ oxidized. Secondly, the thermal regeneration incorporating desorption as well as thermal activation of the catalyst and catalytic oxidation can be initiated by a TCP, i.e. by the injection of a small amount of water at the inlet of the packed-bed reactor[22].

Burning water

While all the applications of RF heating described above are more or less based on the advantageous use of dielectric energy input for appropriate heating, the "burning water" phenomenon which was first described by Kanzius[23] in 2008 was initially interpreted by direct interaction of water with RF radiation. The results are the formation of a H_2/O_2 gas mixture, and the emission of light depending on the salt ions in the electrolyte solution, e.g. yellow in the case of NaCl. In our own studies, the phenomenon was reproduced with a different experimental setup exhibiting a restriction in a glass tube. However, the two main features H_2/O_2 formation and light emission were also observed[24] (Fig. 5).

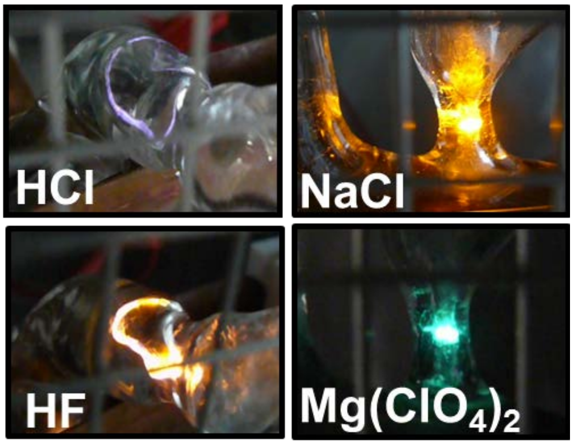

Figure 5. "Burning water" phenomenon as an RF-initiated plasma formed in the restriction of a glass tube reactor for different electrolyte solutions.

A detailed analysis using various experimental arrangements and electrolyte compositions, and supplemented by modelling calculations, resulted in a plausible model consisting of three main steps for the interpretation of “burning water”. At first, selective heating of the solution within the restriction, caused by the occurring high current densities, was observed. Subsequently, when local temperatures within the heated volume of the restriction reached the boiling point of the solution, water vapour bubbles were formed periodically with increasing frequency. Finally, after establishing a quasi-stationary vapour bubble positioned in the tube restriction, a continuous discharge accompanied by gas formation of molecular hydrogen and oxygen, and emission of light occurred. The phenomenon can be explained by a strong field enhancement at the boundary between thin water film at the wall of the restriction and the gas bubble leading to a plasma discharge. The stable gas molecules are formed from radicals in the discharge[24,25].

Interestingly, the oxyhydrogen gas is not ignited by plasma, and therefore this method can be considered as an “electrodeless” water scission. Despite the advantages of using salt water or seawater without prior treatment and of eliminating direct contact of the electrodes with the electrolyte, the chances of practical application as alternative to conventional electrolysis have to be stated as not very high. This is, at least for the present state of realization, mainly due to the low energy efficiency (electrical energy to chemical energy stored in hydrogen).

The presence of both oxidizing and reducing active species, especially radicals, can be utilized for converting undesired components of the electrolyte, especially water pollutants[25]. Nevertheless, this special RF effect (MW would be absorbed by the water) is another example of the unique opportunities of electromagnetic waves in the MHz frequency range.

Outlook

After a couple of years of research on RF applications, many options for practical use in chemical engineering, environmental technology, construction engineering and in the energy sector could be identified and developed to larger scales. Besides the classical operational areas for drying materials, other promising specific options taking benefit from direct energy transfer into the treated media were found or “rediscovered”. The actual tendency of increasing use of regenerative energy sources, namely wind or sun energy, changed the role of electrical energy. Under the new conditions, a flexible electrical method that can be quickly switched on and off benefits from the cost development on the electricity market. Thus, RF heating in addition to MW heating can be expected to have an auspicious future in many application fields.

For further reading:

1. A.C. Metaxas, R.J. Meredith, *Industrial microwave heating*, Peter Peregrinus Publ., Hearts 1988.
2. G. Roussy, J.A. Pierce, *Foundations and industrial applications of microwave and radio-frequency fields*, John Wiley & Sons, New York 1995.
3. U. Simon, U. Flesch, *Cation-cation interaction in dehydrated zeolites X and Y monitored by modulus spectroscopy*, J. Porous Mater. **6** (1999) 33-40.
4. M. Kraus, F.-D. Kopinke, U. Roland, *Influence of moisture content and temperature on the dielectric permittivity of zeolite NaY*, Phys. Chem. Chem. Phys. **13** (2011) 4119-4125.
5. U. Roland, F. Holzer, F.-D. Kopinke, *Ambivalent role of water in thermodesorption of hydrocarbons from contaminated soil*, Environ. Sci. Techol. **45** (2011) 732-737.
6. U. Roland, S. Bergmann, F. Holzer, F.-D. Kopinke, *Influence of in situ steam formation by radio frequency heating on thermodesorption of hydrocarbons from contaminated soil*, Environ. Sci. Technol. **44** (2010) 9502-9508.
7. U. Roland, F. Holzer, D. Buchenhorst, F.-D. Kopinke, *Results of field tests on radio-wave heating for soil remediation*, Environ. Sci. Technol. **41** (2007) 8447-8452.
8. U. Roland, F. Holzer, F.-D. Kopinke, *Influence of low- and high-frequency heating on biodegrading microorganisms in soil: Microbial degradation*, J. Microwave Power Electromag. Energy **47** (2013) 280-289.
9. U. Roland, F. Holzer, M. Kraus, U. Trommler, F.-D. Kopinke, *Electrode design for soil decontamination with radio-frequency heating*, Chem. Eng. Technol. **34** (2011) 1652-1659.
10. F. Holzer, D. Lippik, T. Heimbold, U. Roland, F.-D. Kopinke, J. Schenk, *Modular system concept for soil heating using radio-frequency energy*, AIP Conf. Proc. **1247** (2010) 136-144.
11. G. Huon, T. Simpson, F. Holzer, G. Maini, F. Will, F.-D. Kopinke, U. Roland, *In situ radio-frequency heating for soil remediation at a former service station: Case study and general aspects*, Chem. Eng. Technol. **35** (2012) 1534-1544.

12. U. Roland, F. Holzer, F.-D. Kopinke, *Combining different frequencies for electrical heating of saturated and unsaturated soil zone*, Chem. Eng. Technol. **34** (2011) 1645-1651.
13. C. Franzen, M. Zötzl, U. Trommler, C. Hoyer, F. Holzer, B. Höhlig, U. Roland, *Microwave and radio-wave supported drying as new options in flood mitigation of imbued decorated historic masonry*, J. Cult. Herit. *in press.*
14. U. Roland, F. Holzer, U. Trommler, C. Hoyer, C. Rabe, M. Kraus, J. Schneider, F.-D. Kopinke, *Applications of radio-frequency heating in environmental technology*, Procedia Eng. **42** (2012) 186-189.
15. U. Roland, U. Trommler, C. Hoyer, C. Pfütze, R. Plarre, C. Rabe, B. Höhlig, F. Holzer, M. Kraus, D. Schmidt, F.-D. Kopinke, *Radio-frequency heating for pest control, decontamination and drying of timber and masonry*, Proc. 14th AMPERE Conf. on Microwave and High Frequency Heating, pp. 112-115, G.A. Dimitrakis (Ed.), Nottingham 2013.
16. T. J. Headlee, *The differential between the effect of radio waves on insects and on plants*, J. Economic Entomology **24** (1931) 427-437.
17. C. Hoyer, C. Pfütze, R. Plarre, U. Trommler, S. Steinbach, K. Klutzny, F. Holzer, C. Rabe, B. Höhlig, F.-D. Kopinke, D. Schmidt, U. Roland, *Chemical-free elimination of pests by dielectric heating with radio waves and microwaves (German)*, Chem. Ing. Tech. **86** (2014) 1187-1197.
18. B. Höhlig, D. Schmidt, V. Mechtcherine, S. Hempel, C. Schröfl, U. Trommler, U. Roland, *Effects of dielectric heating of fresh concrete on its microstructure and strength in the hardened state*, Const. Build. Mater. **81** (2015) 24-34.
19. M. Kraus, F.-D. Kopinke, U. Roland, *Comparison of Microwave and Radio-Frequency Heating of Dealuminated Zeolites and Al_2O_3*, J. Microwave Power Electromagn. Energy **49** (2015) 225-244.
20. M. Kraus, U. Roland, *Migrating temperature thermo-chromatographic pulses (TCP) in different zeolites and other microporous materials*, J. Micro-wave Power Electromagn. Energy **49** (2015) 29-45.
21. M. Kraus, F.-D. Kopinke, U. Roland, *Modeling of a thermo-chromatographic pulse (TCP) as radio-frequency-induced selective heating effect*, J. Micro-wave Power Electromag. Energy **47** (2013) 24-45.
22. U. Roland, M. Kraus, F. Holzer, U. Trommler, F.-D. Kopinke, *Selective dielectric heating for efficient adsorptive-catalytic cleaning of contaminated gas streams*, Appl. Catal. A : General **474** (2014) 244-249.
23. R. Roy, M. Rao, J. Kanzius, *Observations of polarized rf radiation catalysis of dissociation of H_2O-NaCl solutions*, Mater. Res. Innov. **12** (2008) 3-6.
24. J. Schneider, F. Holzer, M. Kraus, F.-D. Kopinke, U. Roland, *Water dissociation in a radio-frequency electromagnetic field with ex situ electrodes – Process characterization*, Plasma Sources Sci. Technol. **22** (2013) 015010.
25. J. Schneider, F. Holzer, C. Rabe, T. Häupl, F.-D. Kopinke, U. Roland, *Water dissociation in a radio-frequency electromagnetic field with ex situ electrodes – Modelling of discharge initiation*, Plasma Source Sci. Technol. **22** (2013) 025007.
26. J. Schneider, F. Holzer, M. Kraus, F.-D. Kopinke, U. Roland, *Water dissociation in a radio-frequency electromagnetic field with ex situ electrodes – Decomposition of perfluorooctanoic acid and tetrahydrofuran*, Plasma Source Sci. Technol. **25** (2016) 055003.

About the Author

Ulf Roland studied Physics at the University of Leipzig in 1987. After a position at the University of Applied Sciences in Leipzig, Department of Sensor Technology, he got a grant of the Max Planck Society and worked for one year at the Fritz-Haber-Institute in Berlin. During his work at the Institute of Analytical Chemistry at the Dresden University of Technology in 1983 he finished his PhD at the University of Leipzig dealing with activated mobile hydrogen species and their role in heterogeneous catalysis. An award of the German Academy of Scientists Leopoldina allowed him a research stay at the Université Catholique de Louvain in Belgium. He could realize further research activities mainly in the field of heterogeneous catalysis at the University of Leipzig, the Eberhard-Karls-University Tübingen and the University of Hamburg. Since 1996, he is a Senior Scientist at the Centre for Environmental Research – UFZ in Leipzig in the Department of Environmental Engineering. There he started to work on radio-frequency applications for optimizing several processes in environmental technology and for energy applications. He habilitated in Applied Environmental Physics at the Technical University Bergakademie Freiberg in 2006 on radio-frequency enhanced soil remediation and other aspects of dielectric heating. In 2012 he got the Kurt-Schwabe-Award of the Saxonian Academy of Sciences. His research interests are focused on environmental and energy technologies with projects on dielectric heating, non-thermal plasma processes, heterogeneous catalysis and renewable energy applications.

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