In situ radio-frequency heating (ISRFH) for enhanced soil remediation with soil vapour extraction

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Resumo

O aquecimento do solo auxilia na aplicação de várias técnicas de remediação, como a extração de vapor do solo da biodegradação de poluentes por aumento da pressão de vapor, solubilidade em água e mobilidade dos contaminantes, diminuindo a tensão superficial, deslocando os equilíbrios de adsorção para a desorção e aumentando desta forma a biodisponibilidade dos compostos nocivos. Entre os métodos térmicos, o aquecimento *in situ* por aplicação de rádio-frequências (radio-frequency heating, ISRFH) é uma ferramenta muito flexível com algumas vantagens exclusivas em relação ao alcance de temperaturas acessíveis (potencialmente até mais de 200°C) e aos tipos de solo (seco ou úmido, arenoso ou compacto). O princípio de funcionamento é caracterizado pela formação de calor diretamente no volume do solo, semelhante ao de um forno de microondas. No entanto, devido às frequências aplicadas na faixa de MHz, maiores profundidades de penetração (alguns metros) podem ser alcançadas e, consequentemente, maiores volumes podem ser tratados. ISRFH foi aplicado com sucesso tanto no laboratório quanto no campo. Dependendo do método de remediação, elétrodos com diferentes geometrias (placas paralelas suportando a degradação microbiana, elétrodos em haste em combinação com extração de vapor ou geometrias antena para aquecimento seletivo de volumes de solos altamente contaminados, especialmente concebidos para este fim) têm sido utilizados. O aumento da temperatura levou a uma maior eficiência na remoção de contaminantes do solo.

Abstract

Soil heating can be used to enhance various remediation techniques such as soil vapour extraction and biodegradation of pollutants by increasing vapour pressure, water solubility and mobility of contaminants, decreasing surface tension, shifting adsorption equilibriums

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towards desorption and increasing bioavailability of hazardous compounds. Among thermal methods, *in situ* radio-frequency heating (ISRFH) is a very flexible tool having some unique advantages such with respect to the accessible temperature range (potentially up to more than 200°C) and the soils (dry or moist, sandy or tenacious). The working principle is characterized by direct heat formation in the soil volume and therefore similar to that of a microwave oven. However, due to the applied frequencies in the MHz range, larger penetration depths (some metres) can be achieved and therefore larger volumes can be treated. ISRFH was successfully applied in the laboratory as well as in the field scale. Depending on the remediation method, various electrode geometries (parallel plates for supporting microbial degradation, specially designed rod electrodes in combination with soil vapour extraction or antenna geometries for selectively heating highly contaminated soil volumes) have been utilized. Thermal enhancement led to a marked increase of the removal rates of contaminants from soil.

Keywords soil remediation, radio-frequency heating, soil vapour extraction

1 Setup of ISRFH systems

1.1 Main components

The applied arrangements for ISRFH consisted of a RF generator (working at a constant high-frequency of 13.56 MHz, maximum power up to 30 kW), an electronic matching network which allows optimizing the energy transfer into the soil independent of the soil properties, the electrode system in the treated soil volume, analytical tools and controlling software. For thermally enhanced soil vapour extraction (SVE), electrodes can be simultaneously operated as extraction wells. Cleaning of the extracted gases may be achieved by adsorption on granular activated carbon or by catalytic oxidation. For high concentrations of organic pollutants, oxidative conversion may also be made *in situ* by placing a catalyst in the extraction well also used as electrode. The energy efficiency for the transformation of RF energy into heat in the soil is high, usually more than 90 %. This makes the technology feasible for *in situ* soil remediation from an economic point of view.

1.2 Electrode design

Although parallel plate electrodes would be the most suitable arrangement for homogeneous heating of large volumes of soil, this solution can not be easily applied for *in situ* remediation. In practice due to drilling constraints, rod type electrodes, simultaneously acting as extraction wells for the soil vapour were introduced into boreholes. Generally, the energy would be absorbed in the upper layer when the electrode is in close contact with the soil. To avoid preferential heating near the surface when the contamination is at depth, a special design was used for RF heating; whereby an air gap between the soil and the electrode is inserted in the zone where the soil does not need to be heated. As shown in Fig.1, this leads to selective heating at the desired depths (below 4 m depth in this example). Coupling to the soil and thus heating of the adjacent ground may be achieved again by filling the air gap with water [1,2].

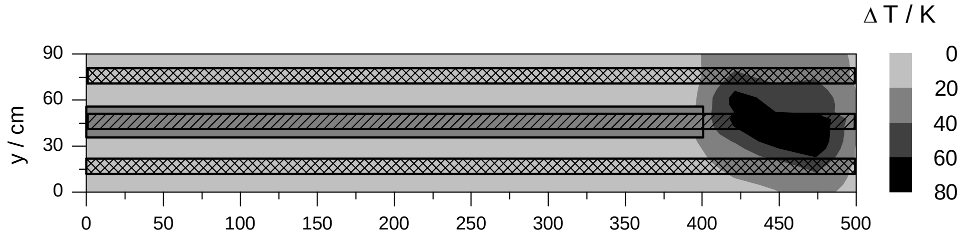

Fig. 1 Local heating at the desired depths using a special electrode design with an air

1.3 Special option for homogeneously heating the capillary fringe

In many cases, organic pollutants in the ground exist as pure non-aqueous phase liquid (NAPL) phase. Light NAPL accumulate above the groundwater, i.e. at the boundary between saturated and unsaturated zones (capillary fringe). In order to eliminate such contamination with the support of thermal treatment, large temperature gradients between both zones have to be avoided. Due to the different electric properties, the saturated and unsaturated zones would be heated differently either with low- or high-frequency energy. Therefore, the combination of both frequencies (e.g. PLF with 50 or 60 Hz and RF with 13.56 MHz) were applied simultaneously via one single electrode system. As a result, homogeneous heating was achieved throughout the whole boundary layer [1,2].

2 Field studies

2.1 General aspects of combination of ISRFH with SVE

The technology is commercially applied at full scale using a container-based modular system as shown in Fig. 2 with a set of so called “hot” electrodes. The RF generator (15 kW or 30 kW) is placed in the container while the matchbox is located near the electrode array. In another typical design, one “hot” electrode is placed in the middle and is surrounded by three or four “cold” electrodes, which are also operated as extraction wells. Thus, the vapour flow through the soil encourages heat transport and leads to a higher homogeneity of the temperature profile. The radius of influence of the “hot” electrode is up to 5 m depending on the soil properties.

As expected, the enhanced soil temperature leads to a marked increase of the concentration of organic contaminants in the extracted air. For volatile organic compounds, a temperature below 100°C is usually sufficient to achieve the remediation goals. RF heating may also be used to evaporate the water in the soil. The steam formed from pore water is a very efficient transport medium for the mobilisation of contaminants, thus accelerating the remediation by the creation of stripping effects (similar to steam injection) [3].

Fig. 2 Container-based modular system with the RF generator and the matching network in combination with an arrangement for soil vapour extraction

2.2 Demonstration project at a former petrol station

In a full scale application at a former petrol filling station, the combination of RF heating and SVE was shown to reduce the remediation time from 320 days to about 45 days while keeping the required amount of energy in comparison to traditional SVE almost constant. Thus, the total remediation costs could be markedly reduced.

3 Conclusion

RF heating was shown to be a suitable tool to support a common soil remediation method, namely SVE. With this technique, soil volumes of hundreds of cubic metres can be effectively treated at a cost comparable to other in-situ thermal technologies.

References

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