**Electrochemical Production, Downstream Processing and On-Site Application of Hydrogen Peroxide**

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**Highlights**

* Green electrochemical synthesis of hydrogen peroxide
* Purification and concentration of H2O2 by means of membrane distillation units
* Process analysis for monitoring H2O2 concentration
* On-site production and forward integration of H2O2 streams into subsequent reaction processes (here: selective oxidations)

**1. Introduction**

Today, in many countries the percentage of produced electricity that is obtained from renewable sources is significantly rising. This energy transition has led to the generation of low-carbon electricity, which opens up new pathways for the design of current-driven (›power-to-X‹) chemical processes.

Hydrogen peroxide H2O2 is considered one of the most versatile and powerful chemical oxidants for a wide range of chemical reactions. It is environmentally friendly, selective and also highly active for various oxidation processes including chemical production, paper and pulp bleaching, waste water treatment or disinfection processes. Today, hydrogen peroxide is mainly produced in world-scale production facilities consuming not only huge quantities of energy and organic solvents but also generating substantial quantities of waste. Moreover, large scale production processes of hydrogen peroxide require significant logistical resources concerning transport, storage and safety. Many users of smaller and medium quantities, however, would prefer to avoid the complicated logistics and storage, and to produce H2O2 themselves as required at their own location, using simpler methods.

**2. Methods**

We have developed a demonstration process for the decentralized electrochemical production of hydrogen peroxide and its continuous supply to a downstream chemical process. The key element of the here presented small-scale process is an on-site and on-demand production concept for H2O2 to avoid the transport, storage and handling of huge amounts of highly concentrated hydrogen peroxide.

**3. Results and discussion**

The demonstration process enables the continuous, electrochemical production of H2O2 in the aqueous reaction system through the cathodic partial reduction of atmospheric oxygen. Key issues were the development of suitable electrocatalysts and the design of the electrochemical reactor including the up-scaling of appropriate gas diffusion electrodes.

The synthesis is conducted in acidic electrolytes which are later separated in the process. Continuous processing techniques, some of which use micro-structured process components, have been developed for the subsequent purification and separation of the produced H2O2 from the electrolyte, and for the reuse of the electrolyte in the electrochemical process. The produced hydrogen peroxide can be directly connected to subsequent chemical processes where H2O2 solutions are required. As a consequence, the downstream processing of the electrochemical synthesis includes also a concentration step, where beforehand purified H2O2 is concentrated to the single-digit percentage range as it is typically required in fine chemical oxidation processes. Both separation units are based on membrane distillation. Raman spectroscopic process analysis allows tracking of the hydrogen peroxide concentration almost in real-time along the entire process chain (synthesis, separation, concentration, and hand-over to subsequent process).

The forward integration of the pre-treated H2O2 stream has been demonstrated using the example of a selective oxidation reaction being applied for the desulfurization of fuels. Through the parallel development of suitable oxidation catalysts, full conversion and fast desulfurization rates were demonstrated using low-concentrated (e.g. 3%) H2O2 solutions.

**4. Conclusions**

The application potential of decentralized, small-scale units for the continuous on-site production of H2O2, which can ideally be operated with 100% sustainable electricity, goes far beyond classical chemical synthesis processes. There is an increasing demand for environmentally-friendly oxidation and bleaching processes in numerous other sectors, such as medical and hygiene technology, food technology, agriculture, water treatment and the textile and cleaning industry.