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M. Schröder, F.-W. Bolle, S. Gredigk-Hoffmann, H. Riße

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# Hydrogen at Wastewater Treatment Plants – Optimal Conditions for the Start-Up of a New System

**Markus Schröder***, **Friedrich-Wilhelm Bolle**, **Sylvia Gredigk-Hoffmann**,
TUTTAHS & MEYER Ingenieurgesellschaft mbH, Germany
**Henry Riße**, FiW Forschungsinstitut für Wasser- und Abfallwirtschaft an der RWTH Aachen e.V., Germany

## 1 Introduction

In the context of the present discussions on sustainable energy supply concepts hydrogen is often one of favoured solutions. Today however, hydrogen production is globally still based on fossil fuels. Hydrogen is generated for instance as a by-product of industrial processes (e. g. chlorine-electrolysis) or when reforming natural gas. The expected advantages as to sustainability can only be granted, if already the hydrogen generation process complies with the sustainability-principles – using regenerative energy sources.

Within this scope wastewater treatment plants (WWTP) offer two possibilities:

1. Hydrogen & oxygen generated from water with regeneratively operated electrolysis
2. Hydrogen generated from digester gas through gas purification (cleansing, reformation, reformate-conditioning)

Bearing in mind additionally that wastewater treatment plants, with an energy demand comparable to a large industrial unit, are still majorly dependent on the public power network the combination of both processes can provide for a grid-independent regenerative energy supply. The electricity surplus, e. g. from wind power, can be applied to generate hydrogen via electrolysis. For this purpose WWTP are predestinated, as the “waste-product” of the electrolysis, pure $O_2$ resp. $O_3$, can be beneficially applied to the aerobic wastewater treatment process. During periods of low feed-in from regenerative sources buffered HY-energy can be, e. g. electricified in fuel cells and the surplus in turn be fed into the power grid. The hereby generated “waste-product” heat can be efficiently applied to the treatment process, too.

Furthermore, hydrogen-based WWTP could be linked in a network of decentralised power stations (“virtual power plant”) improving their resources-management in comparison to the isolated, unlinked operation.

Aside these aspects WWTP bear a so-called “location-advantage” (optimal link-up to transport, supply- and disposal-infrastructures, expert personnel, permanently supervised operation, etc.) making WWTP favourable as future hydrogen generation sites for hydrogen-based energy concepts.

* Corresponding author, email: m.schroeder@tum-aachen.de

## 2 Hydrogen & Oxygen Gained from Water with Regenerative Electrolysis

One possibility to gain hydrogen is by electrolysing water. Electrolysis becomes important whenever non-storable regenerative energy is to be provided for continuously. During strong-wind periods, for example, surplus energy from wind power plants can be stored as hydrogen and applied as energy-source during weak-wind times ("base-load efficiency of regenerative energy"). The special advantage of WWTP here is the possibility of applying the pure oxygen, generated as by-product during electrolysis, to the wastewater treatment process. This in turn leads to a considerable reduction or even total substitution of the main energy demand of the WWTP, the aeration of the biological treatment stage (approx. 3 TWh/a energy demand on German WWTP). These circumstances will always result in a location-advantage for WWTP with regard to electrolysed hydrogen respectively pure-oxygen generation.

An additional advantage for new constructions or extensions of existing WWTP not to be neglected is the reduction of necessary volume and surface area for the biological wastewater treatment stage when applying pure oxygen to the treatment process.

With the present discussions of advanced requirements concerning wastewater treatment this location-advantage will most probably gain importance. The advanced requirements comprise in particular, the oxidisation of very slowly degradable substances and organic trace elements such as pharmaceutical residues and the disinfection of WWTP-effluent. In this case ozone ($O_3$) would be applied, which could be generated from the by-product of the electrolysis – pure oxygen.

## 3 Hydrogen from Digester and Bio Gas

Regenerative hydrogen can be recovered from methane-consisting digester gas when applying cleansing and further conditioning processes. The choice of the purification processes is strongly dependent on the further application of the resulting hydrogen.

As an intermediate product of hydrogen generation bio natural gas, resp. bio methane can be generated. Today, the process of conditioning digester gas to natural gas quality and its feed-in to the public gas grid or its application as fuel for vehicles is of more importance outside Germany, especially in the Netherlands, Sweden and Switzerland. Historically however, this application was well distributed in Germany, too. In the 1950's for example, conditioning stages were in operation at the WWTP Mönchengladbach-Neuwerk (pressure water cleansing) and Stuttgart-Mühlhausen (chemical-physical cleansing with mono ethanolamine-treatment).

The advanced treatment technologies for the hydrogen generation from digester resp. bio natural gas or methane gas are highly innovative and of model character still. The purification of digester gas to hydrogen can be implemented through reformation and following a reformate-treatment (steam-reformation, partial oxidisation, partial oxidisation with catalyst or autothermic reformation). The reformate-treatment is dependent on the projected hydrogen-application. Applying pure hydrogen in PEM fuel cells for instance, requires a CO- and $CO_2$-free gas. Possible treatment steps could then be shift-reaction resp. exothermic conversion, selective oxidisation or pressure swing adsorption. Extensive large-scale experiences with digester or bio gas as starting product are yet to be made.

The overall treatment system from digester gas to pure hydrogen with the intermediate product bio methane was firstly implemented on a large-scale base at the WWTP Bottrop of the Emschergenossenschaft (project name: EuWaK). Presently this plant is in the operation and optimisation stage.

Roughly approximately 10 $m_N^3$ gaseous hydrogen can be generated per treated population equivalent (PT). The digester gas and in turn the hydrogen yield can be increased up to 30 % with an additional sludge-disintegration stage – sludge-cell disruption releasing additional supporting enzymes.

## 4 Further Options

WWTP also offer further hydrogen production possibilities. The direct production of $H_2$ from sewage sludge and other biogenic residues through microbiological conversion or thermal treatment, such as gasification or hydrothermal $H_2$-generation can be implemented. Today however, microbiological processes with photolysis through algae, cyano or purple bacteria still seam inefficient due to low production rates. Higher production rates and a more common process realisation might possibly be the two-staged „Dark Fermentation." This process combines an anaerobic microbiological hydrolysis with $H_2$-generation and a downstream methane stage for the transformation of the substrate leftovers. The microbiological $H_2$-generation could be combined with the already well-established sludge digestion. However, the reviewed processes of microbiological $H_2$-generation are still in laboratory and early pilot plant stages. The research-demand is thus very high, not only for the fundamental process management (substrate-adaption, microbiology, process-stability) but also with regard to the scale-up.

Aside the application of hydrogen, natural gas and bio gas the application of methanol in Direct-Methanol-Fuell-Cells (DMFC) is possible, too. Then, the reformer is directly integrated in the fuel cell. Comparing the handling of methanol to that of hydrogen, this technology becomes of more interest. One approach here is methanol synthesis, the combination of digester gas with hydrogen generated through electrolysis and $CO_2$-gas, e. g. from the exhaust gas from combustion engines.

## 5 Prospects

Today, producing hydrogen and pure oxygen through electrolysis as well as generating hydrogen from bio gas at WWTP has already been implemented successfully in the context of pilot plants and research and demonstration projects. New approaches are now made towards the methanol generation at WWTP – here too offering numerous outstanding advantages.

The first advantage is that methanol has a much higher energy storage density compared to gaseous fuels – especially hydrogen. The second advantage is that the usage of methanol is possible with the existing infrastructure designed for the application of liquid fuels. The methanol synthesis also bears the possibility to fix technical waste $CO_2$ and create a real sink for $CO_2$.

These regenerative energy sources all supply for a wide spread of FC-applications reaching from mobile to stationary, large-scale to small-scale systems.

WWTP have general location-advantages for the implementation of these systems other locations do not have or at least not in such a scope:

- Wide-spread net (e. g. in Germany more than 1,000 of the total 10,000 WWTP have a suitable location);
- Existing infrastructure (electricity, gas, water);
- Technically trained expert personnel;
- High level of operational security and monitoring;
- Own vehicle-pool as consumer;
- Optimal location near towns and supra-regional integration in road network.

With operators of WWTP and hydrogen-experts recognising and applying these potentials, WWTP can essentially support the positive development of a hydrogen-infrastructure. To start-off with a special focus must be set on niche solutions with pilot-character for the entire infrastructural scope, short-term implementation periods and thus an economic advantage over single-solutions.

All these potentials for the configuration of the future public energy-supply system are combined at the location of a WWTP, as all infrastructural compounds find a clustered implementation here.