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Green Hydrogen and Natural Gas from Digester Gas of Wastewater Treatment Plants

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1 Introduction

Emschergenossenschaft and Lippeverband are in charge of the water management in the catchment areas of Emscher and Lippe, and among other things of the wastewater treatment of ca. 4 million inhabitants and ca. 3 million population equivalents (PE) from industry. For this purpose there are 58 wastewater treatment plants (WWTP) with a capacity from 500 – 2.4 million PE. The annual sludge amount adds up to 92.000 t dry solids.

Digester gas is produced during the anaerobic stabilisation of sewage sludge. It is a high-quality renewable energy source due to its high energy content. Since the 1920s, the digester gas is collected and used for energy generation at WWTPs, which reduces the costs for energy delivery [1].

Digester gas utilisation in combined heat and power plants (CHPs) is an established method of on-site power generation, at WWTPs with a population equivalent of more than 10,000, this method is regarded as state-of-the-art. Emschergenossenschaft and Lippeverband have 34 WWTPs with CHPs. The electrical power of the CHPs range from small modules with 13 kW to the large modules at WWTP Emschermündung with a total electrical power of 5.5 MW. The utilisation of the digester gas via heat-power-coupling allows for high energetic efficiency degrees: the mechanical efficiency degree amounts to 30 %-35 %, the thermal efficiency degree is 50 % [2].

By co-fermentation, that is the co-treatment of organic substances such as residues from the food industry or biological waste in the fermentation tank, the digester gas production and thus the on-site energy generation can be boosted significantly.

In the practical WWTP operation, digester gas utilisation has so far been employed for the classical paths boiler, CHP, or direct drive. The processing of digester gas into biomethane and hence to hydrogen is one way of satisfying the demand for green fuels. The owners of WWTPs can integrate these considerations into construction and operation. The processing of digester gas will particularly tap the area of mobile energy utilisation. The economically sound employment of the produced energy sources biomethane and hydrogen will be possible if the price for mobile energy carriers considerably exceeds that for electric energy from large WWTPs and pipeline-bound transport, or if extensive co-fermentation at WWTPs will lead to energy surpluses. The discharge will be particularly lucrative for the owners of WWTPs if the internal energy demand of the treatment plant can be covered completely [3].

2 Processing of Digester Gas into Natural Gas and Hydrogen

Digester gas consists mainly of methane and carbon dioxide, but also includes a wide range of minor components [4]. The digester gas quality depends on the composition of the effluent of the WWTP – many substances which are conveyed into the wastewater from industrial and domestic sources reappear in the digester gas. In regard to digester gas utilisation in CHPs, sulphur compounds and siloxane are especially harmful.

The procedural elimination efforts differ considerably for the various components [5]. The demands on the purity of the digester gas depend on the intended purpose: the conventional utilisation of digester gas in boiler or CHP generally necessitates only dust and moisture removal, sometimes desulphurisation. If the siloxane concentrations are high, these substances must also be removed from the digester gas, lest they cause damages through silicium fouling in the CHP.

For the processing into biomethane, however, the technical efforts are considerably higher: apart from the removal of minor components such as hydrosulphide and siloxane, the carbon dioxide must be removed as well. The following methods are suitable for this procedure:

- **Pressure swing adsorption**: reversible adsorption of CO_2 to carbon molecular sieves
- **Power water scrubbing**: reversible absorption of CO_2 in pressurised water
- **Physical adsorption with organic solvents**: absorption of CO_2 in pressurised solvents
- **Chemical absorption with organic solvents**: almost pressure-less absorption of CO_2 in solvents(e. g. mono-ethanol-amine or di-ethanolamine)
- **Membrane methods**: gas separation via membranes, so far only used in pilot plants
- **Cryogenic methods**: gas separation through liquefaction at high temperatures, for biogas processing so far only used in pilot plants

The next upgrading step to hydrogen corresponds to the industrial steam reformation of natural gas. It is also possible to produce hydrogen directly from digester gas without biomethane production, but so far it has not been realised in an industrial scale.

3 EuWaK Project – Natural Gas and Hydrogen from Wastewater Treatment Plants

The processing of digester gas into biomethane and hydrogen is currently being tested and developed further by the Emschergenossenschaft in a demonstration project at the WWTP Bottrop. The project has been funded by the federal land of North Rhine-Westphalia and the European Union. Project partners of the Emschergenossenschaft during the development and realisation of the project were engineering company for water and waste management Tuttahs & Meyer ltd. (T&M), the research institute for water and waste management of the RWTH Aachen (FiW), the engineering office Redlich and Partner GmbH (IBR), and the city of Bottrop.

In the pilot project, digester gas is processed into biomethane and hydrogen. In the course of the project, the complete local hydrogen infrastructure chain from the renewable energy source sewage sludge to the final hydrogen consumer was established for the first time. The target of the project is the production of highly pure hydrogen from sewage sludge and other biomass which can then be used as fuel in fuel cell-driven vehicles. An intermediate step is the production of biomethane, in order to establish the WWTP as filling station location through the fuelling of natural gas vehicles with biomethane.

In the first processing stage, biomethane is produced from a component stream of the digester gas from the WWTP Bottrop via pressure swing adsorption (PSA). One component stream of the biomethane is discharged and delivered at a natural gas filling station to in-house vehicles running on natural gas. In a second step, the remaining biomethane is converted into hydrogen in a steam reformer with downstream upgrading (CO-shift and pressure swing adsorption). It was decided to consume the hydrogen not in a fuel cell, but in a combustion engine, as the hydrogen engine is less sensitive to changes in the hydrogen quality than fuel cells and thus more suitable for a pilot project the focus of which was not the development of fuel cell technology. Moreover, the investment costs for fuel cells are very high, and at the current technological status their service life is considerably shorter than that of the engines.

The hydrogen engine stands in a school which is about 1 km away from the WWTP and to which a swimming pool is attached. The engine serves for the supply of power and heat; the hydrogen production unit is connected to the school with a pipeline.

Communication and data exchange between the gas production unit and the consumers natural gas filling station and hydrogen CHP are steered by a superordinate control software.

After a two-year initial phase for planning, licensing, advertising, and awarding, the entire plant was built during 2007. The extensive start-up stage, test runs, and first optimisation stage stretched into 2008 and 2009. Currently, the operation of the EuWaK is being accompanied scientifically in a research project. Furthermore, in 2009/2010 a hydrogen filling station was built as another project module. It will be connected to the EuWaK plant, so that hydrogen-driven vehicles will in future be fuelled with „green“ hydrogen from digester gas.

4 Operation Results

During the start-up stage, the interfaces between the single components had to be fine-tuned to each other and the single aggregates be adjusted. The engine control of the hydrogen engine had to be adjusted to the high combustion speed of the hydrogen. Among other measures, the ignition point was optimised and the gas control path adjusted. The engine was constructed and built as a prototype especially for the EuWaK project. The necessary technical improvements and adjustments during the test runs were thus part of the research and development work of the project.

Through the tight interlacing of the plant components, which led to interconnections and occasional malfunction of single components, the start-up stage was characterised by intermittent downtimes in the operation, so that as yet relatively few measuring values and operation data from the start-up stage are available. The biomethane produced was of an excellent quality, with an average methane content of more than 97 % and a dew point of -65 °C and lower. The biomethane could so far be used without any problems by the vehicles fuelled therewith.

During the processing of the digester gas, the minor components turned out to be a major challenge, especially BTEX and longer-chain hydrocarbons. Because of the high ratio of industrial dischargers, the digester gas of the WWTP Bottrop shows significant amounts of those compounds. An activated carbon filter had been planned for the removal of the minor components, but it proved to be incapable of dealing with the unexpectedly high concentrations, so that an additional filter had to be installed, which achieved very good elimination rates. The optimisation of the gas scrubbing and the testing of alternative procedures were a crucial part of the research stage, during which the online monitoring of the minor components was implemented as well. During the test runs, the possibilities of removing BTEX from the digester gas with chemical-physical methods combined with biological treatment will be examined.

Because of several interruptions of the operation, the availability of the entire plant during 2009 amounted to only 1,400 operation hours approximately. Downtimes were mainly due to maintenance work caused by BTEX loads and alleviation of disturbances. It can be assumed that the additionally implemented activated carbon filter system combined with the online monitoring will lead to a much better availability of the plant.

The natural gas amount which could be delivered to the vehicles in 2009 is equivalent to a mileage of ca. 42,000 km. The consumed digester gas mass amounts to about 1 % of the entire digester gas amount of the WWTP Bottrop in 2009.

Apart from the availability, the efficiency degrees must still be improved as well. The energetic efficiency degree of the biomethane production reached up to 90 %, the hydrogen production from biomethane had an average efficiency degree of 50 %. Because of the cold winter, much energy had to be used for heating, which had a negative effect on the overall efficiency degree of the process. During the research operation, the energetic balance of the entire process will be analysed to identify further optimisation potentials.

5 Evaluation and Outlook

In order to achieve the stable and efficient operation of the EuWaK plant, improvement potentials must be identified and realised during the research operation, with a particular emphasis on the following issues:

- **Research operation**: How can a disturbance-free operation with high availability and minimal starting and shutdown be achieved?
- **Consumption and production:** How can the primary gas and energy demand used for the generation of the product gas be controlled in an optimal way to achieve the best possible utilisation degree?
- **Digester gas composition and product gas quality**: How can the final product hydrogen and the by-product natural gas be produced from digester gas at a continuously high quality level? Which maximum quality can be reached with the processing plant?
- **Proof of efficiency of the entire plant and profitability considerations**: Which product yield is reached with entire plant and how high is the overall efficiency degree?
- **Determination of the costs for deliverable hydrogen:** Where is the economic optimum of this technological procedure between the necessary processing efforts

and the achievable quality, given that as yet there are no general quality standards for the intended hydrogen qualities?

- **Expansion potentials and transferability of insights:** Can the insights gained from the operation of the plant and the system integration be transferred to other wastewater treatment plants and hydrogen production locations (such as biogas plants)? Which further application areas can be opened up with the achieved product gas qualities?

The chosen concept of a two-stage processing is still justifiable today, as natural gas or biomethane have been incorporated as bridging technology, the advantage of which is that biomethane can be discharged as fuel and the WWTP can be used as filling station location. Unfavourable are the high energetic efforts. In the long run, hydrogen will thus be produced directly through steam reformation of digester gas.

In future, the mobile utilisation will be in the foreground. There will be a great demand for fuel produced from regenerative sources. Hydrogen from digester gas is a zero emission concept. As soon as the stable operation of the EuWaK plant has been achieved, with product gas of a continuously high quality being produced, the public utilisation of both the natural gas filling station and the hydrogen filling station can be set up as the next target.

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