OVERVIEW OF LEAN GAS TREATMENT IN BIOGAS UPGRADING SYSTEMS

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Content

1. Introduction and Motivation

Lean gas emanating during the process of biogas upgrading as a "waste stream" features a certain residual methane content depending on the treatment technology (and the methane yield). This methane content depends on the methane slip of the processing plant. The methane slip denotes the amount of methane that cannot be fed into the grid, related to the amount of methane supplied with the raw biogas. Through chemical washing this methane slip is the lowest, followed by physical washing with water (1 - 2 vol%) or organic solvent (2 - 4 vol%), membrane technologies depending on the plant layout (0.5 - 5% by volume) and PSA plants depending on the manufacturer and system layout (1 – 10 vol%).

Since methane has a strong greenhouse effect (higher global warming potential than carbon dioxide), it is essential for the overall sustainability of the biomethane production chain that the methane emissions to the atmosphere are kept as low as possible. It should be mentioned that in most European countries the amount of methane emissions from biogas plants is regulated by law. In addition higher methane concentrations in the lean gas lead very often to higher specific gas upgrading costs which might deteriorate the economics of the process. The situation is even more complicated because in most technologies a compromise of increasing investment and operating costs as well as higher methane yields and thus lower methane content in the lean gas must be found. It follows that in many cases the most economical system design requires accepting some methane content of the lean gas while providing a special treatment for the lean gas in order to remove methane quantitatively. What counts here is an intelligent integration of the biogas upgrading facility into the biogas plant itself as well as the overall concept of the biomethane production facility. Only few biogas treatment technologies with very specific system configuration have nowadays such a high methane yield to result in methane content in the lean gas, which is allowed by law for the direct release to the atmosphere.

The most common form of methane removal from the lean gas is oxidation (combustion) while releasing heat. This heat can be supplied either directly as process heat to the biogas plant (as they often have self-heating requirements that must be met) or may be transferred to a district heating network. If neither is possible the heat needs to be discharged to the environment through cooling. Another way of lean gas treatment is the mixture with raw biogas and co-combustion in a CHP gas engine or a micro-gasturbine. Both of these options require in any case a careful sizing and system design, as the lean gas of a modern biogas upgrading plants seldom contains enough methane for stable combustion and often requires addition of raw biogas or natural gas.

The treatment of lean gas with lower methane content than about 4% by volume proves to be increasingly difficult as during combustion not enough energy for the maintenance of the oxidation reaction (due to technical radiation losses of the system) is delivered and the addition of raw biogas or biomethane for stabilizing combustion is required. For this reason methods have been developed which still maintain - by catalytic action or by sophisticated cyclic heat storage - an autothermal operation (without further addition of higher caloric supporting gas) even at lower methane contents.

2. Description of the currently available Technologies for Lean Gas Treatment

2.1. Gas Engines

The combustion of methane-rich gases in internal combustion engines is the usual form for using the energy content of biogas. With efficiencies between 35 and 40 % electric power can be generated, by using the waste heat in the exhaust gas of the gas engine the overall efficiency can be increased to 82 to 88%. The ignition of a gas and thus its usefulness in a gas engine depend crucially on the methane content of the gas. Together with the lower energy content of decreasing methane content the rising level of carbon dioxide also acts retarding on the combustion reaction of methane. Scientific papers quantify the absolute minimum methane content that can be burned with a gas engine in a stable operation to be around 21 vol% under ideal conditions. But the same papers notice that in real gas engines due to the non-ideal mixing, the intensity of turbulence in the combustion chamber and because of the requirements of leaner-than-stoichiometric operation for a stable combustion at least 30 vol% (better 35 vol%) of methane is required. Challenging for the operation of a gas engine is a permanent high H_2S content in the biogas (depending on the manufacturer usually about 500 ppm). The combustion in the engine leads to sulphuric acid in the wet exhaust gas, which is absorbed by the film of oil on the bearing surfaces and thus causes the rapid aging of the engine oil.

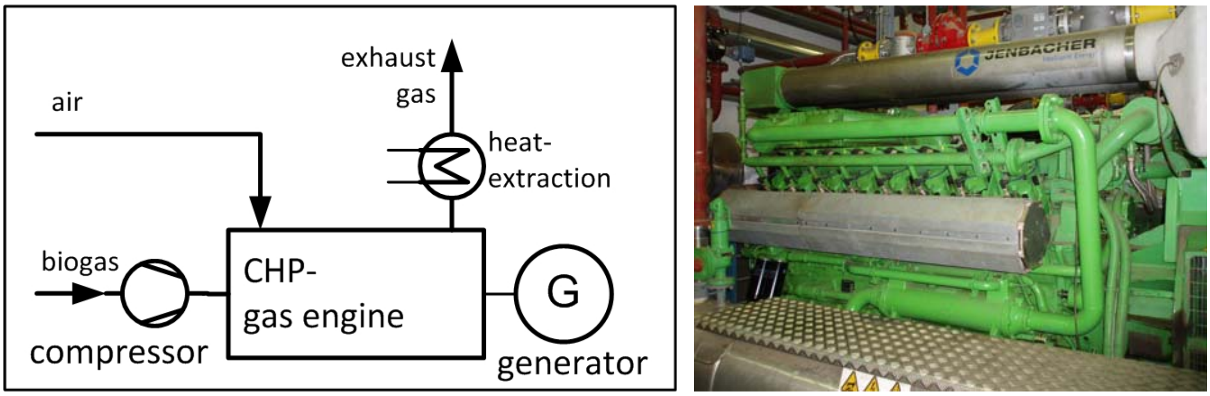

Figure 1: Flowsheet of a gas engine for the combined generation of electricity and heat; picture of a gas engine at the biogas plant Bruck/Leitha, Austria (Source Vienna University of Technology, Biogas Bruck GmbH)

2.2. Micro-gasturbines

Micro-gasturbines are characterized by their simple engineering in addition to their attractive power range for biogas plants of 30 to 4000 kWel. Due to the low inlet temperature of the turbine (about 800 °C) cooled turbine blades can be avoided. Efficiency is enhanced through recuperative preheating of the compressed air prior to entry into the combustion chamber with the exiting exhaust heat. The exhaust gas is thereby cooled from 600 ° C to 300 ° C. The combustion chamber pressure is at 3 to 4 bar, the turbine rotates at speeds of 30.000 to 100.000 rpm. With such a system electrical efficiencies of 30 to 35% can be achieved. By the use of a waste heat utilisation system efficiencies of 85 % can be achieved. With air bearings in most micro-gasturbines the H_2S problem in lubricating oil circulation is largely overcome. Nevertheless, because of the tendency of corrosion at higher sulphur levels prior desulfurization is advisable. Commercially available micro-gasturbines require minimum methane contents of 30 to 35 vol% to ensure stable operation, approximately the same range as gas engines. Well tested and commercially successful is the Capstone© micro-gasturbine which is available in a compact design with a wide performance range. Compared to gas engines gas turbines are much more expensive in the initial investment however have significantly reduced maintenance costs.

Figure 2: Flowsheet of a gas turbine for the combined production of electricity and heat; illustration of a Capstone© micro-gasturbine system and sectional drawing of a Capstone© micro-gasturbine

2.3. Lean Gas Burner

A lean gas burner is a special gas burner which can be operated with low methane contents. The required minimum methane content is usually 4-7 vol% in the mixture with the combustion air. Since nowadays the lean gas stream from modern biogas treatment plants has usually much lower methane contents, a targeted admixing of higher caloric gas (raw biogas or biomethane) is required to maintain the ignitability. A second possibility is that the treatment plant is deliberately designed and operated at a higher methane slip. As already mentioned this may in many cases be the most economical operation point. Particularly often used as lean gas burners are the so-called Flox© burners (Flameless Oxidation), which are commercially available as a complete system. In this method the mixed gas is combusted flameless by preheating the combustion air and optionally by preheating the lean gas. The exhaust gas of the burner has a temperature of 600 to 700 °C. The method is based largely on the recirculation of large quantities of hot exhaust gases into the reaction zone and intense air preheating respectively.

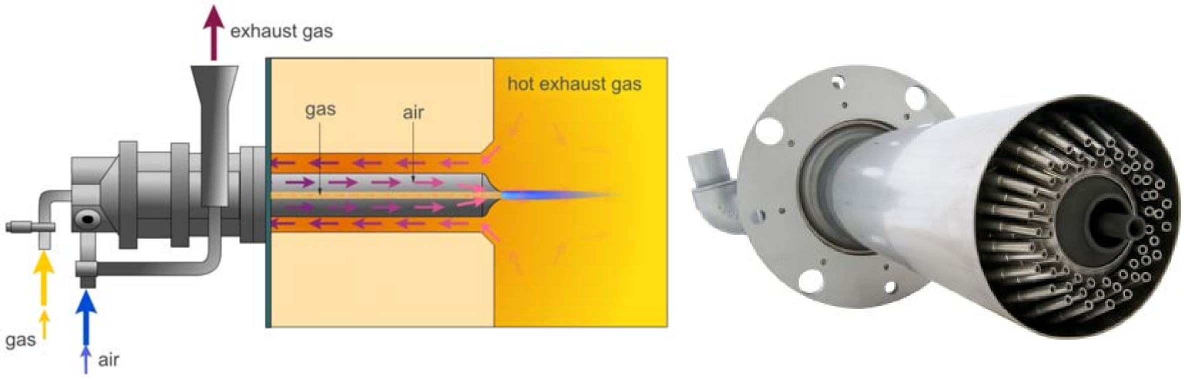

Figure 3: Functional diagram of a flameless combustion of lean gas and view of a burner head for the FLOX©-Principle (Source: WS Wärmeprozesstechnik GmbH, www.flox.com)

2.4. Catalytic Oxidation

Trough catalytic action of certain metals (platinum, palladium, cobalt) the activation energy of the oxidation reaction of methane with oxygen in the air is significantly reduced so that even with a low level of methane content a complete combustion with lower temperatures than otherwise usual is ensured. Too high methane concentrations, however, are to be avoided due to the risk of overheating of the catalyst, which is mostly provided as a solid sintered body. The combustion usually takes place at temperatures between 400 and 500 °C wherein the lean gas needs to be warmed up to that temperature recuperatively with the heat of combustion. After starting the system the method works autothermally. It should be noted that this method is very sensitive to catalyst poisons such as H_2S which within a short time may lead to deactivation of the catalyst. A commercially available process is branded ZETECH4©. About 70 to 80 % of the heat in the methane content of the lean gas can be extracted and further utilised using this system.

Figure 4: Pictures of two systems for the catalytic oxidation of combustible gases, view of the catalytic MatriX burner in operation (Source: Dürr Clean Technology Systems AG, R.Scheuchl GmbH, Viessmann GmbH & Co. KG)

2.5. Regenerative-thermal Oxidation (RTO)

This process works with a number of very well isolated heat storages (usually 2 to 3) which can absorb the heat of oxidation in the methane combustion. With this heat the lean gas of the biogas upgrading plant can be heated up to the reaction temperature necessary, followed by the exothermic reaction. The heat released is in turn stored in the heat storage. A sufficiently high temperature level for the oxidation reaction can be obtained in the entire plant by cyclic switching of the lean gas stream between the tempered heat storages. With this method an autothermal operation is already possible from a concentration of 2 g CH_4/m^3 on. In contrast to the catalytic oxidation the process is insensitive to H_2S. A commercial process based on this principle is available under the brand name VOCSIDIZER©.

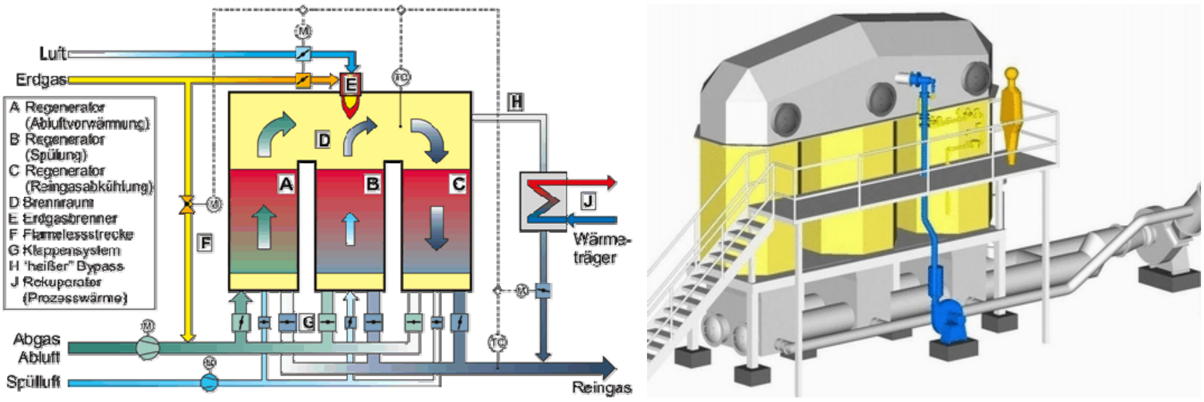

Figure 5: Functional diagram of the regenerative thermal oxidation of combustible gases and virtual representation of a RTO-facility (Source: TU Clausthal, Aersystem Abluftreinigungs- und Wärmetechnik GmbH)

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