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Review

Techniques for transformation of biogas to biomethane

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ABSTRACT

Biogas from anaerobic digestion and landfills consists primarily of CH_4 and CO_2. Trace components that are often present in biogas are water vapor, hydrogen sulfide, siloxanes, hydrocarbons, ammonia, oxygen, carbon monoxide and nitrogen. In order to transfer biogas into biomethane, two major steps are performed: (1) a cleaning process to remove the trace components and (2) an upgrading process to adjust the calorific value. Upgrading is generally performed in order to meet the standards for use as vehicle fuel or for injection in the natural gas grid.

Different methods for biogas cleaning and upgrading are used. They differ in functioning, the necessary quality conditions of the incoming gas, the efficiency and their operational bottlenecks. Condensation methods (demisters, cyclone separators or moisture traps) and drying methods (adsorption or absorption) are used to remove water in combination with foam and dust.

A number of techniques have been developed to remove H_2S from biogas. Air dosing to the biogas and addition of iron chloride into the digester tank are two procedures that remove H_2S during digestion. Techniques such as adsorption on iron oxide pellets and absorption in liquids remove H_2S after digestion.

Subsequently, trace components like siloxanes, hydrocarbons, ammonia, oxygen, carbon monoxide and nitrogen can require extra removal steps, if not sufficiently removed by other treatment steps.

Finally, CH_4 must be separated from CO_2 using pressure swing adsorption, membrane separation, physical or chemical CO_2-absorption.

1. Introduction

Biogas is generated by micro-organisms in the absence of air by a so called anaerobic metabolism. Industrial biogas is produced at (1) sewage treatment plants (sludge fermentation stage), (2) landfills, (3) sites with industrial processing industry and (4) at digestion plants for agricultural organic waste, both mesophilic (35 °C) and thermophilic (55 °C) [1].

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The nature of the raw materials and the operational conditions used during anaerobic digestion, determine the chemical composition of the biogas [2]. Raw biogas consists mainly of methane (CH_4, 40–75%) and carbon dioxide (CO_2, 15–60%). Trace amounts of other components such as water (H_2O, 5–10%), hydrogen sulfide (H_2S, 0.005–2%), siloxanes (0–0.02%), halogenated hydrocarbons (VOC, < 0.6%), ammonia (NH_3, <1%), oxygen (O_2, 0–1%), carbon monoxide (CO, <0.6%) and nitrogen (N_2, 0–2%) can be present and might be inconvenient when not removed (Table 1) [3–7].

The treatment of biogas generally aims at: (1) a cleaning process, in which the trace components harmful to the natural gas grid, appliances or end-users are removed, (2) an upgrading process, in which CO_2 is removed to adjust the calorific value and relative density in order to meet the specifications of the Wobbe Index. This latter parameter is dependent on both the calorific value and the relative density (Fig. 1) [2,5].

After transformation, the final product is referred to as 'biomethane', typically containing 95–97% CH_4 and 1–3% CO_2. Biomethane can be used as an alternative for natural gas. In general, the type of end use of the biogas sets its quality demands [3]. An overview of the currently available and used biogas transforming techniques, operational conditions, efficiencies and drawbacks, is given below. This overview is structured according to the components that need removal or conversion.

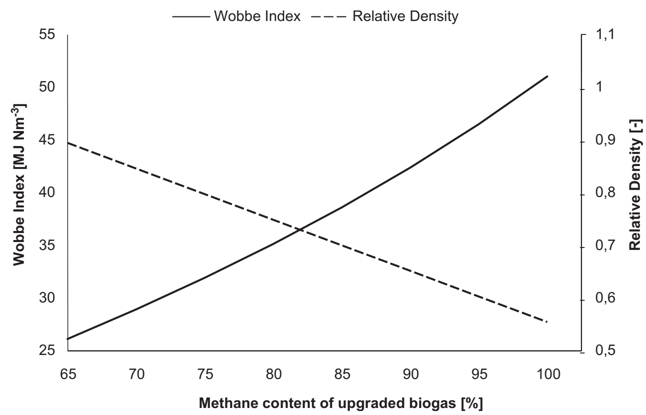

Fig. 1 – Wobbe index and relative density as function of methane content of the upgraded gas [5].

2. Removal of water

Pipeline quality standards require a maximum water content of 100 mg m^{-3} water and compressed natural gas (CNG) vehicle fuel standards require a dew point of at least 10 °C below the 99% winter design temperature for the local geographic area at atmospheric pressure [8]. Untreated or raw biogas is usually saturated with water and the absolute water quantity depends on the temperature. For example, at 35 °C the water content is approximately 5% [2]. The lower the temperature, the lower the water content in the raw biogas. The removal methods for water are generally based on (1) physical separation of condensed water or (2) chemical drying (Table 2).

These methods might simultaneously remove impurities such as foam and dust from the biogas [5,9].

Table 1 – Biogas impurities and their consequences.

Impurity	Possible Impact
Water	Corrosion in compressors, gas storage tanks and engines due to reaction with H_2S, NH_3 and CO_2 to form acids Accumulation of water in pipes Condensation and/or freezing due to high pressure
Dust	Clogging due to deposition in compressors, gas storage tanks
H_2S	Corrosion in compressors, gas storage tanks and engines Toxic concentrations of H_2S (> 5 cm^3 m^{-3}) remain in the biogas SO_2 and SO_3 are formed due to combustion, which are more toxic than H_2S and cause corrosion with water
CO_2	Low calorific value
Siloxanes	Formation of SiO_2 and microcrystalline quartz due to combustion; deposition at spark plugs, valves and cylinder heads abrading the surface
Hydrocarbons	Corrosion in engines due to combustion
NH_3	Corrosion when dissolved in water
O_2/air	Explosive mixtures due to high concentrations of O_2 in biogas
Cl^-	Corrosion in combustion engines
F^-	Corrosion in combustion engines

2.1. *Physical drying methods (condensation)*

The simplest way of removing excess water vapor is through refrigeration. This method can only lower the dewpoint to 0.5 °C due to problems with freezing on the surface of the heat exchanger. To achieve lower dewpoints the gas has to be compressed before cooling and then later expanded to the desired pressure. The lower the dew point, the higher pressure is needed to be applied [2]. The condensed water droplets are entrapped and removed. The physical drying methods prevent water contact with downstream equipment like compressors, pipes, activated carbon beds and other parts of the process. This way, corrosion is prevented.

Techniques using physical separation of condensed water include:

- *demisters* in which liquid particles are separated with a wired mesh (micropores 0.5–2 nm). A dewpoint of 2–20 °C (atmospheric pressure) can be reached;
- *cyclone separators* in which water droplets are separated using centrifugal forces;
- *moisture traps* in which the condensation takes place by expansion, causing a low temperature that condenses the water;
- *water taps in the biogas pipe* from which condensed water can be removed [9].