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Upgrading landfill gas using a high pressure water absorption process

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HIGHLIGHTS

- Technique for small-scale gas upgrading was studied.
- Studied process is capable for upgrading landfill gas to over 88% CH_4 content.
- With water absorption, H_2S removal was over 99%.

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ABSTRACT

The upgrading of landfill gas (methane 54.2 ± 2.0%, carbon dioxide 42.1 ± 2.4% and nitrogen 3.7 ± 1.2%) was studied with a pilot-scale high pressure water absorption system consisting of absorption, desorption and gas drying units. The gas was upgraded in two phases and with two absorption columns operating in sequence in pressures up to 180 bar, and with initial pressures of 8 and 10 bar. This type of high pressure process, where water is used for increasing the gas pressure, does not need a separate compression unit to produce the gas pressure required by gas vehicles. Product gas with a methane contents ranging from 83.0% to 92.1% was achieved with differing process parameters, the carbon dioxide and nitrogen content of the product gas ranged from 4.4% to 6.3% and 2.5% to 7.4%, respectively. Hydrogen sulphide was removed from the raw landfill gas with over 99% efficiency. To conclude the used high pressure gas absorption technique is capable for upgrading landfill gas to 87.9 ± 2.0% methane content.

1. Introduction

Due to global need for sustainable development and also due to concern about climate change, the production of renewable energy from biogas has increased during the past few years in several countries. For heat and electricity a wide range of technologies utilising biogas already exist [1–3]. Interest in the use of biogas as vehicle fuel and in fuel cells has also increased [4]. To be utilised for these purposes a high methane concentration is required, i.e. the raw biogas has to be upgraded. The number of technologies for upgrading biogas has increased rapidly in recent years and knowledge about the use of biogas as vehicle fuel has grown [1,5].

One current globally important source for biogas is landfills. The main components of landfill gas are methane (from 40% to 60%), carbon dioxide (from 35% to 50%), nitrogen (from 0% to 20%) and oxygen (from 0% to 1%). Typically landfill gas also contains hydrogen sulphide (from 50 to 200 ppm) and other reduced sulphur compounds, halogenated compounds and organic silicon compounds [6,7]. Because of its low caloric value and potentially harmful components, biogas has to be upgraded before it can be used as vehicle fuel or in fuel cells. Different countries have different standards and guidelines regarding the use of upgraded biogas (biomethane) for gas grid injection and vehicle fuel. Usually, carbon dioxide, nitrogen, sulphur and halogenated compounds need to be removed from the gas [4]. Although natural gas is commonly used as vehicle fuel, biogas upgrading continues to be done in only a few countries.

Water scrubbing is a commonly used method of upgrading biogas, as carbon dioxide and hydrogen sulphide are more soluble in water than methane. The solubility of gases in water is dependent on several factors such as pressure, temperature, and liquid/gas ratio. According to Henry's law, the solubility of gases increases with increasing pressure; however at higher pressures Henry's law is no longer valid in its simple form [8]. In a high pressure system temperature becomes a limiting factor for gas solubility [9]. To be used as a vehicle fuel, gas needs to be pressurised up to 200 bar. This is usually done in a separate compression unit after upgrading [4]. Water scrubbing in a high pressure system is potentially a process where the product gas, biomethane, is ready for use as vehicle fuel immediately after upgrading. The water wash process is used in only very few landfill gas upgrading plants [e.g. 10–12] and

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knowledge on the upgrading of landfill gas remains limited, despite the fact that upgrading is a full-scale operation in some locations. A major difference between landfill gas and other biogases is that landfill gas can contain nitrogen (0–20%) as a result of air flow in the under pressure gas collection pipes [13].

The objective of this study was to evaluate the feasibility of a high pressure water absorption system for upgrading landfill gas. Experiments were performed on-site using a pilot-scale facility in which two absorption columns were used for continuous upgrading.

2. Materials and methods

2.1. Set-up and operation of the upgrading process

The studied high pressure water wash process, supplied by Metener Ltd. (Finland), located at the Mustankorkea landfill, Jyväskylä, contained two adjacent absorption columns (10 l), a collector column (10 l) and a product gas storage bottle (75 l) (Fig. 1). The raw gas was obtained from the landfill gas pumping station after condensation by cooling (considered dried gas). The two absorption columns were operated alternately to ensure continuous operation. The upgrading facility also included a raw gas storage column (50 l) and two columns for water treatment (500 l each) (Fig. 1). The collector column was filled with the plastic pall-rings to prevent the foaming of water in the column. The gas drying unit was placed between the collector column and the product gas storage bottle. Tap water (0.2–0.45 mmol/l) was used in the process.

First, the raw landfill gas was channelled into the raw gas storage column. The raw gas was then pressurised in the raw gas pressurising unit up to 8 and 10 bar (initial pressure). The initial pressure controlled the water and raw gas flow ratio in the absorption columns, as at the lower initial pressure less raw gas was channelled into the absorption columns and, as the water flow was kept constant more water per gas volume was used for upgrading. The initial pressures of 8 and 10 bar were selected after pre-trials of initial pressures of 10 and 14 bar in which 10 bar was found to produce higher methane enrichment. The pressurised raw gas was then channelled into absorption column 1. After absorption column 1 was filled with gas, the raw gas was then channelled to absorption column 2 and water (ca 16 °C) sprayed into column 1 from the top of the column. The rising water level pressurised the gas in column 1 and absorption was performed at pressures ranging from 50 to 170 bar in all trials. When the pressure in column 1 reached the pressure of the collector column (minimum 100 bar), the gas and the water in column 1 was channelled into the collector column. The upgrading continued in the collector column as the gas from absorption column 1 was channelled into the collector column from the bottom of the collector column and fresh water from the middle of the column. The gas was upgraded to its final purity in the collector column and then channelled into the gas storage bottle. The pressure in the collector column was dependent on the pressure in the gas storage bottle so that when the pressure in the collector column reached the product gas storage pressure, the upgraded gas was channelled into the product gas storage bottle from the collector column. The pressure in the product gas storage bottle was maintained over 100 bar at all times. The pressure in the product gas storage bottle increased during the trial. At the end of the trial the gas was pressurised to about 180 bar. The process continued in absorption column 2 as with column 1. One cycle between columns 1 and 2 lasted 36 s. From 6 to 8 trials were performed for each process conditions and in total the each trial lasted from 1.5 to 3 h (after which sample was taken).

The water used in the absorption and collector columns was channelled into a flash tank from where absorbed methane was released from the water at a pressure of 4 bar and returned to the absorption process. From the flash tank the water was channelled into the regeneration column (−0.3 bar) where the absorbed carbon dioxide was released from the water. After desorption, the

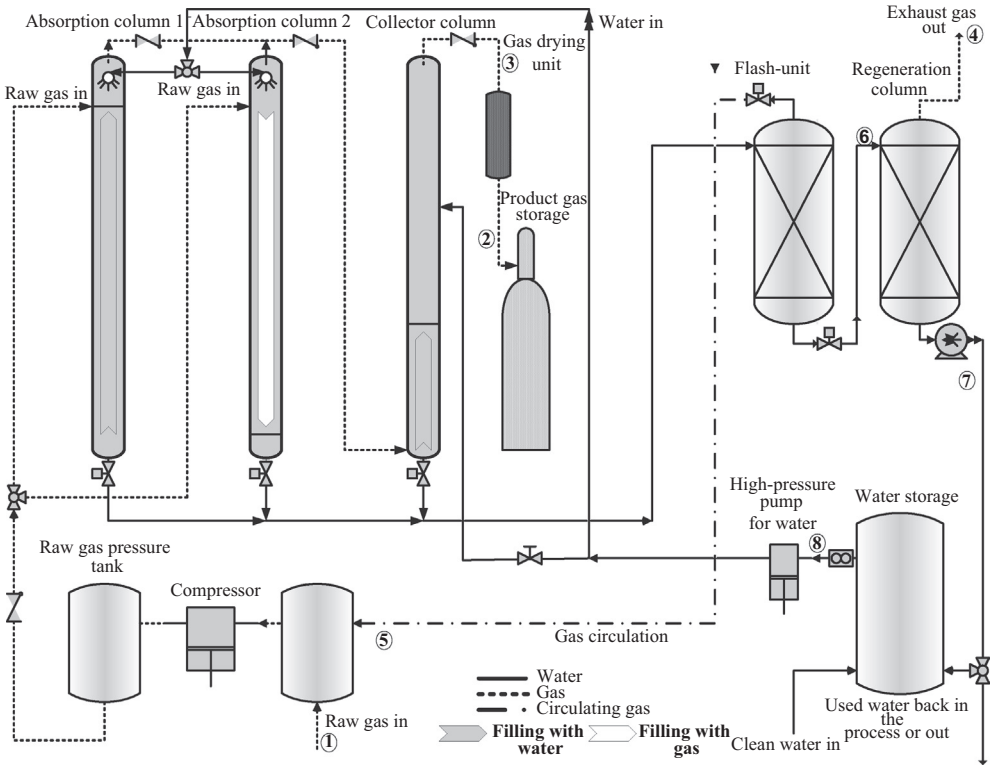

Fig. 1. Simplified figure of the high pressure upgrading process. Sample points: (1) raw gas, (2) product gas after drying, (3) product gas before drying, (4) exhaust gas, (5) gas from flash tank, (6) water before desorption, (7) water after desorption, and (8) water from water storage.