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Pretreatment techniques used in biogas production from grass

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ABSTRACT

Grass is being considered as a potential feedstock for biogas production, due to its low water consumption compared to other crops, and the fact that it can be cultivated in non-arable lands, avoiding the direct competition with food crops. However, biogas production is limited by the characteristics of the feedstock; in particular its complex lignocellulosic structure. Hence, different pretreatment methods are being investigated for grass structure disruption before undergoing the anaerobic digestion process. The aim of this paper is to review current knowledge on pretreatment techniques used for grassland biomass. Pretreatment techniques were categorized into mechanical, microwave, thermal, chemical and biological groups. The effect of the application of each studied methods on the biogas yield and on the energy balance is discussed. A further comparison between the covered techniques was revealed.

Contents

1. Introduction

Grasslands play an important role in global agriculture, covering around the 26% of world's total land area (2009) and the 78% of the Scotland's agricultural area (2013). Grasses are the main plant species in verges along roads, railways and on river dikes, for that reason the hectares of grassland available are difficult to quantify. Besides its role as basic nutrient for herbivores and ruminants, grassland has a key role in the prevention of erosion, the immobilisation of leaching minerals and as carbon storage, helps in the regularization of water regimes and in the purification of pesticides and fertilizers. Also serve to furnish a habitat for wildlife, both flora and fauna and contribute to the attractiveness of the landscape [1–4].

In recent years considerations on grassland use for bioenergy have increased considerably, mainly for biogas production and as solid fuel for combustion [5]. A well as for biogas production,

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grasses can be used in future for the production of lignocellulosic bioethanol, synthetic natural gas or synthetic biofuels. The main benefits of using grass for bioenergy production are its lower water consumption for growth than other crops and the fact that it can be cultivated in non-arable lands, without competing with food crops [6–8].

Over the past thirty years in Scotland, the grass over five years old increased in more than 48% due to the abandonment of farmland and grazing produced in turn by the decrease in animal husbandry; the same process is occurring in most developed countries. For that reason, grass should be considered as biomass feedstock for bioenergy production, and in particular for biogas production. At present there is no anaerobic digestion plant in Scotland using grass as feedstock, very different is the situation in Northern Ireland where all the nine existing AD plants use grass for co-digestion alongside with other substrates, usually animal manures. In Germany, already 30–40% of the biogas plants operate with grass or grass silage as co-substrate, with an average of 8% by weight of grass silage in the total substrate, reaching in some case 50% [9,10]. A useful tool in cases of biomass utilization plants and biomass to biofuel projects is the quantification of biomass potential; Christoforou et al. (2015) document the existing plant-derived biomass potential quantification methods and deliver a framework for the definition of biomass resources [11].

In crop production, energy is required for tillage, crop seedlings, fertilising, herbicides application, harvest and transport. Furthermore, considerable energy is required for the production of herbicides, fertilisers and pesticides. On average, fertiliser production represents about 50% of total energy requirement, the 22% are required for machinery, about 15% for transport fuel and 13% for pesticides [12]. Due to the fact that grass is not cultivated but it grows naturally, the higher energy demanding processes (fertilizer and pesticide production and application) are not necessary, therefore the energy balance is presumed more advantageous although biogas yields are not as high as in other crop species.

2. Biogas production from grass

Anaerobic digestion is a microbial fermentation in the absence of oxygen resulting in a mixture of gases (mainly methane and carbon dioxide), known as "biogas" and an aqueous slurry or "mud" containing the microorganisms responsible for the degradation of organic matter [13]. The raw material subjected to this treatment is preferably any residual biomass that has high moisture content, such as food scraps, leftover leaves and herbs from garden or orchard cleaning, livestock waste, domestic and industrial wastewater, sludge from water treatment plants and urban waste. The main product of anaerobic digestion, the biogas, is a mixture of methane (50–70%) and carbon dioxide (30–50%), with small proportions of other components (nitrogen, oxygen, hydrogen, hydrogen sulphide), whose composition depends on the raw material and the process parameters such as HRT or temperature [5,14–16]. Considering methane has a higher heating value (HHV) of ca. 37.8 MJ/m^3 and carbon dioxide has no energy associated with it, biogas has an energy content of between 19 and 26 MJ/m^3 and it can replace natural gas in combined heat and power plants (CHPP) undergoing previously a purification process to reduce the CO_2 content and eliminate contaminants as sulphides [17–20]. At the end of the anaerobic digestion, the nutrients remain largely contained in the digestate, thus, a nutrient-rich digester residue remains and it can be used as fertilizer. Legal requirements such as laws governing fertilizer, hygiene and solid waste must always be observed in the further use of the digestate as fertilizer.

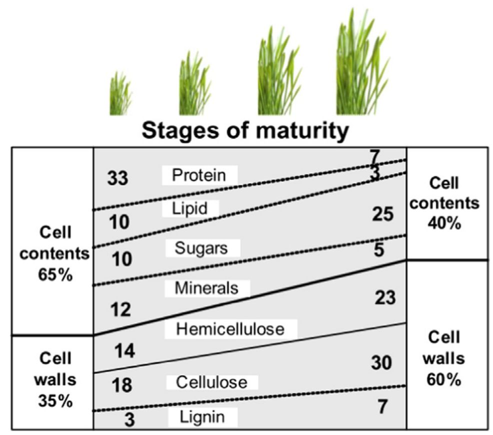

Fig. 1. Values of grass components through maturity stages [31].

The grass composition, the harvesting time, the chopping size and the use of ensiling agents are important factors that influence the feedstock quality [10]. The results of fermentation tests indicate that the optimal cutting time of grass for anaerobic digestion should be around three or four days after that the grass used for dairy cattle feeding [21]. The percentage of cell wall components (cellulose, hemicellulose and lignin) increases with increasing maturity of the grass, whereas the percentage of cell contents (protein, lipid, sugars) decreases (Fig. 1) [22]. To achieve high methane yields, crop substrates need a low lignin content as well as a high content of easily degradable components such as carbohydrates and soluble cell components [23,24]. Two key parameters in the biogas production from grassland: sugar and fibre content, can be optimized by selecting the suitable harvesting time [10]. Grass can be harvested once or twice per year with conventional haying equipment. Harvesting once a year has the economic advantage of being cheaper than cutting twice and fewer nutrients will be removed from the soil. In autumn the harvesting time is preferable at least one month after the first heavy frost as nitrogen and some potassium will move into the root system and the cutting height should be 6 to 8 inches. The cutting height when harvested during spring should be 8 to 10 inches, at this stage, sufficient carbohydrate reserves have been built up and allow for rapid regrowth [6,25,26]. Switchgrass harvested in spring has lower mineral (potassium and chlorine) concentrations than switchgrass harvested in autumn. Meadow foxtail grassland harvested monthly from June to March in northeast Germany resulted in specific biogas yields decreasing throughout the season from 547 l/kgVS in June to 299 l/kgVS in February, the methane yields showed a parallel pattern from 298 l/kgVS in June to 155 l/kgVS in February whereas the methane percentage stays constant in a mean value of 52 over the year [27].

Growth rates of plants are regulated by the photosynthetic ability and a multitude of environmental factors. Grasses are classified into C3 and C4 species based on their photosynthetic pathway. Anatomical differences in leaf and bundle sheath cells occur between C3 and C4 grasses [28,29]. Typically, the optimum light intensity for C4 species is twice that for C3 species, for that reason C4 grasses are common in tropical regions while C3 grasses are more abundant in European countries. Grasses are classified into annual species, which include many cereals, and perennial species, which include many forage grasses. Tropical grasses grow faster than trees and produce higher biomass in a shorter period. [30].

The type of grass used is another factor that affects the biogas production, depending on the grass specie, its composition vary, therefore the substrates available for anaerobic digestion are different for each grass type. Fig. 2 shows the most common grass varieties for anaerobic digestion. The most important grass specie in Europe is

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