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The use of neural modelling to estimate the methane production from slurry fermentation processes

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ABSTRACT

Slurry constitutes an important substrate, increasingly often forming part of biogas production in biogas plants due to the significant content of methane in biogas produced from slurry. Slurry fermentation leads also to its deodorisation and significantly affects the sanitation process. Biogas production constitutes a microbiological process, one affected by many parameters, both physical and chemical. The complexity of the processes occurring during slurry fermentation means it is difficult to identify the significant parameters of a process. Therefore, the fermentation model is often defined as a "black box" method. Artificial neural networks (ANN) are becoming more frequently recognised as a tool to analyse processes that do not have a formal mathematical description (e.g. in the form of a structural model). Neural models enable one to conduct a comprehensive analysis of an issue, including in the context of forecasting biogas emissions during the slurry fermentation process.

This study aims to develop a neural model that forecasts the level of methane emission during the slurry fermentation process. This study demonstrates that the generated neural predictor constitutes an efficient tool for estimating the amount of methane produced during bovine and porcine slurry fermentation processes.

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1. Introduction

Methane fermentation, named also as anaerobic digestion (AD) is natural, complex process which transforms large amount of organic substances into biogas and post fermented residues called also digestates [1,2]. Biogas contains mainly methane (45–74%) and carbon dioxide (25–54%). The other gases like hydrogen sulphur, ammonia, hydrogen, nitrogen or oxygen do not pass 1–2% of volume content. The compounds which influence on CH_4 content in biogas are mainly fat and proteins (up to 70–72% of CH_4 content), however sugars (including cellulose) can generate biogas with only 50% of methane content. Thus, agricultural biogas produced mainly from plant residues and dedicated crop has average methane content as 50–55% comparing to the biogas produced from urban waste (62–66% of CH_4) and slaughter waste (68–74% of CH_4). Biogas produced from animal excrements (slurry and manure) has medium methane content (60–65%) [3].

Biogas is one of the most known and used Renewable Energy Sources (RES) in the emerging markets [4]. Only in China, there are over 40 million installations (mainly small) working with animal slurry, manure, household and agricultural waste. The biogas produced in Asia or Africa is used mainly for cooking or heating purposes. However, in Europe, the most common direction of exploitation between over 14,500 biogas plants is electric energy production with total capacity of 7857 MW [5]. Only 282 plants across Europe produce purified biomethane (1.375 billion of m^3) [6] estimate that in Europe, at least 25% of electric energy produced from biomass will be obtained from biogas in 2020. The tendency of increasing biogas production is noticed in the whole world because the global electric power of this sector is growing from 14.5 GW in 2012 to 29.5 GW in 2022 [4]. Moreover, it should be underlined that the share of biogas in world RES is only 1.5%, it had the highest growth rate since 1990 (about 15% per year) compared to other biofuels [5].

Slurry is the most popular natural fertiliser produced in Europe. Since the beginning of the development of the biogas market in Europe (also in Asia), slurry has been applied as a basic substrate for biogas production. Currently, slurry constitutes the most important substrate (next to vegetable biomass) used in biogas plants on the most developed biogas markets in Europe (Germany, Denmark, Austria, and the Czech Republic) [2]. However, biogas production is much less efficient in relation to vegetable substrates; therefore use of slurry in biogas systems has often resulted from the need to avoid problems connected with its management (especially from the issue of limitation of odours and the maximum dose of 170 kg N/ha). Slurry has been less frequently applied as a valuable component in biogas production.

However, biogas generation from slurry has many advantages. The methane content in a biogas produced from slurry usually exceeds 60%, which is several percent higher than in the case of silages. Slurry fermentation leads also to its deodorisation and contributes to its sanitation (especially in the case of thermophilic fermentation).

Biogas production is a microbiological process affected by various physical and chemical factors, as well as by the passage of time. There are numerous studies concerning the influence of particular parameters on this process and the mathematical modelling of the process. In the late 1980s and early 1990s, a team of scientists associated with the IWA Task Group for Mathematical Modelling of Anaerobic Digestion Processes developed a mathematic model for the methane fermentation process, known as *Anaerobic Digestion Model No. 1* (ADM1), which was soon regarded as the standard for process modelling [7–9]. The biomass fermentation process described in the ADM1 model is a multistage, multithreaded process, under which biochemical and physicochemical reactions run sequentially and, partially, concurrently. This model considers seven basic groups of bacteria participating in the processing of mainly sugars, amino acids, fats and products of their decomposition, and which are described by 32 reactions. The following factors are considered: rate of microorganism dieback, decomposition and hydrolysis of an organic substance, and impact of ionic and gas–liquid balance on the processes. In the ADM1 model, 35 status variables (gases in the liquid and gas phases) are applied to describe a biomass conversion to biogas (methane + carbon dioxide + hydrogen). Such a high number of variables makes model verification and validation a very difficult task. The model complexity leads also to the situation where some variables present in the model used for simulation calculations must be given with an accuracy exceeding the capacity of applied analytical [10]. However, there is still no full assessment of mutual interactions due to the highly complicated connections between individual process parameters.

In engineering practice, many extended models based on significantly theoretical frameworks are being replaced with simplified models, useful with regard to the modelling process and speed of calculations. Due to the impossibility of making complex and very accurate assessments of the impact of particular parameters on the methane fermentation process, this process may be defined as a black box. It seems that the application of methods based on modelling with use of artificial neural networks (ANN) in the analysis of the impact of particular process parameters on biogas production may provide new opportunities within this scope [11,12]. Artificial neural networks enable one to conduct a comprehensive analysis of an issue, including the context of forecasting biogas emissions in the course of the slurry fermentation process [13].

Artificial neural networks, also known as neural models, constitute an intensively developing area of scientific knowledge with an increasing utilitarian potential. An ANN constitutes a universal approximation system for mapping multidimensional sets of data (including empirical data) [14]. It has the capacity to learn and adjust to changing environmental conditions [15]. In addition, it has the valuable ability of generalising acquired knowledge [16–18]. Contrary to traditional information processing methods provided by cyclical computational devices (computers), which implement a previously written programme, optimisation learning algorithms constitute the basis of ANN development and operation. They enable one to design an adequate ANN topology, and to select optimal parameters for this structure, based on the issue to be resolved.

While viewing ANN from the point of view of the principles of their functioning, both the brain as a biological archetype of ANN and conventional computers perform similar functions: processing, collecting and recovering information. The different way of perceiving an acquired piece of information constitutes a substantial difference. A conventional computer has one (or several) complex processors that operate effectively, if serially, while coded information is stored in specifically located cells of an operating memory [19]. Biological neural networks have billions of neurons that function similarly, each forming very simple processors, while information is stored by synapses that integrate cells with each other in a spatial network. Repetitive stimuli results in the fixing of some neural connections between particular brain centres. Information processing by biological networks occurs in