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Real-time simulator of agricultural biogas plant

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ABSTRACT

This article presents a real-time simulator of an agricultural biogas plant. The project contains biogas and biomass circuits simulation, as well as heating circuit simulation with a complete control system and visualization interface of the whole process. The software tool used to simulate the plant work is CFD (*Computational Fluid Dynamics*), which enables a user to create and test simulation objects based on fundamental physical laws related to fluid circuits and flows. The research work was concentrated on building simulation object reflecting real plant dynamics in the most precise way that can be achieved with the provided simulation tools. Presented simulation creates a possibility to minimize dangerous and undesirable situations on a real plant by manipulating of control parameters and observing simulated object reaction. The simulation results enable to optimize biogas production and operation costs. The simulator is intended to be an operator staff training material and can increase the operators' reliability during plant's operation. It is an important aspect in biogas plant risk management and it may reduce the requirements for safety instrumented system as well as the cost of their implementation.

1. Introduction

The renewable energy source industry becomes very significant on the European Union territory. As a result it can be considered as an alternative to the conventional energy source such as fossil fuels (Igliński et al., 2012). But it is important to integrate its development with resource utilization and environmental protection (Yea et al., 2002). Current technology used during biogas production is controversial from the viewpoint of environmental protection as well as potential environmental and economical loses (Svoboda et al., 2013). Hence the need to develop guidance for the usage of safety management including a proper simulation tools as well as a functional safety technology in the newly designed control and protection systems in objects of this type (Barnert et al., 2009; Barnert, 2011; Śliwiński, 2011).

A biogas plant can be described as a building containing systems constructed to produce biogas from plant biomass, animal excrements, disposal wastes, or even wastewater sediment. A typical biogas plant consists of a biomass system, a heating system and a gas system. Depending on a production technology method, these listed systems may differ if it comes to size, structure and even based functional units. The most rapid technological growth in biogas production through the last ten years is noticed among agricultural plants. These objects base on a modern electronic equipment and automation solutions. In some of those plants advanced process optimizers are installed to minimize heating energy and a gas loss. In an agricultural biogas plant the source of methane is one or more of the following: animal excrements, manure, slurry. In some cases, crops are grown purposely to produce biogas. The most common plants which are grown by this way are: corn, potatoes, sorghum. If it comes to producing biogas using the corn as a source, at first, it needs to be processed (first) to corn silage, which is far more energy-efficient form of corn. The main purpose of building agricultural biogas plants is to produce electrical and heating energy. The agricultural biogas plant simulation model proposed in this paper has been created in software environment called Flownex SE, which is commonly known CFD (*Computational Fluid Dynamics*) system. Flownex is a software used for creating simulation models of applications such as: power plants, compressors, medium distribution systems, heat exchangers etc. Because of an intuitional user's interface and an ability to adopt external programming scripts the software is widely used by the engineers who works with the simulation models. This software can work with both static and dynamic equations. It can be easily used to simulate the applications that requires prediction and dynamic tuning. Variety of optimization tasks can be examined by using Flownex. The software allows to observe the system reaction on changing work parameters of such components like: pumps, compressors, valves, turbines, etc. What is important, the momentum and an energy equation are calculated separately for each element of the system. The simulation's results can be easily presented in graphs, charts, or value vectors. The functionality of

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Flownex enables to understand, examine and optimize variety of the flow-based systems.

The agricultural biogas plant simulation model itself is based on both theoretical and practical knowledge and is described by a set of rules containing relations between physical quantities occurring in the biogas plant. Contemporary agricultural biogas plants often have oversized elements (e.g. diameter of system pipe). During designing the majority of biogas plant control systems optimizing process has been omitted, which can cause some critical situations that result in the process stoppage. The presented simulation provides an opportunity to detect which element's size is incorrect and should be changed. It also prevents from the mentioned oversizing of elements at the planning stage of a new plant construction. Moreover, this simulation project can be used to increase the operator staff qualification, because simulated process time values are almost identical with the real ones.

2. Review of the related works

The biogas plant location and environmental conditions, especially methane fermentation factors have been examined. Some calculations results and sample solutions have been presented (Głaszczka et al., 2010). Another set of examinations has been performed to analyse a biogas plant process, which has 60 tons daily production capacity with fermentation time equals 20 days. Also an innovative plant solution has been described. It is called *combined heat and power system*. It is the biogas system that produces electrical energy not only from biogas itself, but also from unused excess heating energy (Xiaolin et al., 2010). The control unit of a feeding system also has been examined. The system itself is very complicated, complex and uneasy to control because of strong non-linear characteristics of a non-oxygen fermentation process. The examined control method is NMPC (non-linear model predictive control). This type of a system has been installed to optimize dispensing of the essential substrate used in the gas production. The control algorithm has been tested with simulation tools. As a result show some methods to optimize the substrates were proposed (Gaida et al., 2012). The general technology used in biogas plants and an economical aspect of its maintenance have been examined as well (Sanz-Bobi et al., 2012). Focusing on simulation abilities some useful sample simulation solutions have been made. Sample control parameters of the agricultural biogas plant have been collected, examined and described (M-Tech Industrial 2012).

The topic of building the nonlinear model of predictive control for the use of biogas production optimization has been developed in the control engineering market. During the Mediterranean Conference on Control & Automation in Barcelona the presentation focused on NMPC was presented. It has been proved, that optimizing the biogas production process by using a state estimator results in 550 Euro gain per day, in comparison to traditional control methods. It was also noticed, that there is a necessity to examine proper proportions between substrates, as it has the biggest influence on the process effectiveness (Gaida et al., 2012). The control issue is based on a biogas plant mathematical model and an optimization method is described in so called "fitness function". As it was stated, the controlled system is very complex and it demands some period of time to optimize the production process dynamically (the estimated time is around 100 days long).

German researches focused on the significant role of the human in the biogas production control system. It is clearly shown, that the knowledge, experience and conciseness of the operator has huge influence on production effectiveness (Knape et al., 2013). In addition, not all process values can be measured in real time (high sensors costs, toxic environment, etc.) Control system inventors have tried to inject human analysing skills into the control system by using a neural network (system that was created on the base of human brain functionality) and a fuzzy logic-control technique describing an object's behavior in the unclearly, "fuzzy", subjective way. These unconventional control tools can be very useful and effective in situations, where not all object information are provided in real time.

The Swedish energy market pays attention to a biogas plant system that has been designed to be cost effective predicting both energy and substrates costs fluctuations (Amiri et al., 2013). It was deducted, that the CHP system (combined heat and power plant) – the system that can provide both electrical and heat energy can be far more effective economically than the conventional electrical power biogas plants. The plant simulation model was created, so the control system can be tested and the economic results can be checked and analysed. The substrates in Sweden mainly come from food waste and slaughterhouse waste. The process needs more heat energy than usual, because the high temperature is necessary in pre fermentation tank to kill bacteria. The described simulation model is used to optimize cost needed to achieve the demanded amount of energy. The engineer simulation software used here is called Cplex. The simulation enables a user to check differences between the old and the modified production systems if it comes to effectiveness and the total energy production plant ability.

The biogas energy market in Poland is growing year by year. The changes in the Polish energy law made in 2009 established the enterprise of a biogas plant building much easier. Nearly 180 biogas plants constitute a significant part of the environment-friendly energy market in Poland. Nevertheless hardly any of them could exist without a financial support from the government at the stage of building those objects. Most of Polish biogas plants are the property of private companies (e.g. plants in Koczała and Nacław) (Igliński et al., 2012).

Some articles focus on electrical energy. Biogas itself and the heat market is mentioned just to examine the European demand market for biogas plants products (Sanz-Bobi et al., 2012). Some interesting ways of using produced heat are proposed (e.g. heat energy can be sold to an external consumer). In many cases selling biogas can be more economically effective than selling the energy made from it. Sometimes generators cannot use all amount of produced biogas, so the rest can be sold. The fact that biogas plants are very expensive in exploitation has been mentioned. It is a difficult task to make it cost effective. That is why so many optimization models are being designed.

3. Project profile

The described plant is an agricultural biogas system, which can produce electrical energy with power estimated up to 1070 kW and heat energy that can reach 1200 kW simultaneously. This particular biogas plant is called a wet system, which means that total concentration of dry biomass is bigger than 15%. Methane fermentation proceeds in the technology based on mesophilic fermentation, where the temperature in technological chambers reaches the value of 40°C. The agricultural biogas plant working in the "wet technology" uses liquid substrates and solid co-substrates. The contents of the mentioned biogas system is based on the following batch elements:

- Animal excrement coming from a pig farm.
- Substratum consisting of manure slurry (54.6%), oily substances (1.8%) and corn silage (43.5%).

The production efficiency of biogas made from these substrates reaches 113.8 m^3/ton, which means that 113.8 m^3 of product can be made out of 1 ton of substrates. The production efficiency of biogas made only from manure slurry reaches 35 m^3/ton. The