

Assessment of technological simulation of an agricultural biogas installation using integration mechanisms

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RECEIVED 23.09.2023

ACCEPTED 21.11.2023

AVAILABLE ONLINE 31.12.2023

Abstract: The article presents technological and measurement systems and methods for substrate preparation, production and purification of raw biogas, biogas storage, cogeneration, and processing of post-fermentation mass. Based on the existing infrastructure for biogas production from pig slurry, a model system for integrating objects in the AVEVA environment using integration mechanisms was demonstrated. The simulation used an imaging method, and the 3D model was used for technological simulations. The work presents simulation results that allow us to understand the availability of graphic imaging techniques at each stage, define and expand the library of typical errors and requirements for pipeline installations, structures and devices, facilitating the identification of design errors and accelerated introduction of corrections to the installation design.

The article features the use of integration of elements of a pilot biogas production installation in the AVEVA environment – innovative systems for heating the substrate and managing agricultural biogas production were implemented. A node for the production of raw biogas was indicated for the transport system of biogas produced in the fermentation tank, along with devices enabling the conduct, control and regulation of the fermentation process. The visualisation concerned integration of the biogas production technology diagram with the model environment for the created pipelines using integrator mechanisms.

Keywords: AVEVA environment, biogas production, integration, simulation, visualisation

INTRODUCTION

Biogas is a renewable fuel with favourable properties and parameters enabling its wide use in virtually every economic area. Biogas is a fuel produced locally, most often from raw materials sourced nearby, and is an energy carrier that leaves a relatively small carbon footprint (Klimek *et al.*, 2021).

The agricultural industry's interest in small-scale biogas production allowed design companies to develop a prosumer concept for mobile installations, often with a simple container structure, ready to be located in the economic infrastructure. Designing a specific micro-biogas plant is basically done individually for each farm. The biogas plants implemented so far are characterised by great diversity – both in terms of installed equipment and the amount of biogas produced and energy obtained from it.

Technological, measurement systems and methods for substrate preparation, production and purification of raw biogas, biogas storage, cogeneration, and post-fermentation processing are presented – indicating the description of the current state.

Installation for testing turbomachines with a continuous or circulating flow system of the working medium, the pipeline of which is equipped with fittings, accessories, control and measurement equipment, a heat exchanger and one tested unit compressing the working medium, or one tested unit expanding the working medium are additionally characterised by a second expansion unit and a compression unit connected in series with the test unit, the compression unit comprising a drive motor, and the expansion unit comprising a driven generator, the expansion unit and the compression unit having bypass lines (Peszko, 1991).

A method and installation for processing wet fuel, especially biomass, is presented. The installation is integrated with an

energy-generating device comprising a combustion section and an energy-generating section, characterised by a wet fuel dryer equipped with an ambient combustion air supply, a wet fuel supply and a dried fuel discharge, the dryer being connected to the energy-generating device. The energy-generating device is connected via an exhaust gas pipe to a condenser equipped with a condensate drain and connected to the dryer with a heating medium pipe for condensing exhaust gases. (Abyhammar, 1996).

The method and device for odourising a gas installation consists in adding a fragrance substance to the carrier gas, supplying it together with the carrier gas to a buffer tank, and then injecting it into the gas installation, characterised by the liquid fragrance substance which is heated and evaporated before adding it to the carrier gas, the fragrance substance is mixed in gaseous state with a carrier gas and the gas mixture of the fragrance substance and the carrier gas thus obtained is introduced from the buffer tank to the gas installation (Svensson, 1996).

Method of the utilisation of pig, cattle or chicken slurry by methane fermentation to produce biogas and installation for utilisation of slurry by methane fermentation (Kumanowski *et al.*, 2008) is characterised by the fact that the slurry from the fermenter is directed to a classification device, the separated thick suspension is returned to the fermenter, and the liquid is directed to a heat exchanger, fed with hot water heated in a boiler fed with biogas produced in the fermenter, and then the heated liquid is returned to the fermenter.

The waste processing method consists in the waste delivered to the installation being divided at the waste acceptance station into four groups of waste: solid waste, liquid waste, sewage sludge and organic waste. Solid waste is first crushed in a shredder, and then a mineral fraction is detached in a separator, which is directly sent to a mineral waste landfill, and a high-calorie fraction, which is sent to an incinerator, and a third fraction, consisting of biodegradable waste, which is mixed in tanks indirectly with liquid waste along with water from the water tank, the contents of which are supplemented with clear liquid from the tank, and then the pulp thus obtained is sent for thermal hydrolysis in the reactor (Komarowski, 2010).

Method for isolating biomolecules and biomolecule fractions from the fermentation and post-fermentation mass of a biogas plant and installation for this method (Konieczny *et al.*, 2014) lies in the possibility of simultaneous production and use of any agricultural and industrial products in the form of biogas, digestate and selected biomolecules and biomolecule fractions from the fermentation mass of a methane reactor. Thanks to the large surface area of membranes per volume unit, installing membrane modules does not require significant space, which increases the efficiency of the separation process. The separation techniques used do not require the use of high temperatures or chemicals, therefore they do not change the chemical structure or destroy isolated substances, biomolecules and microorganisms.

Method for simultaneous production of hydrogen and biogas and installation for simultaneous production of hydrogen and biogas (Szewczyk and Zamojska-Jaroszewicz, 2011) is characterised by the fact that hydrogen fermentation and methane fermentation proceed simultaneously, in separated reaction spaces, which communicate only through a semi-permeable membrane. Thanks to this, it is possible to independently control both processes and ensure independent conditions for the stable operation of each of them.

A biogas plant with a tunnel digester and an installation for the production and utilisation of biogas is presented. (Fotyga, 2011). The biogas plant is equipped with a biomass tank that has a thermally insulated base and vertical side walls, an installation for wetting the biomass with the process liquid, an installation for recirculation of leachate water, an arched roof covering supported on the vertical side walls of the biomass tank, gas-tight gable walls and a biogas storage facility formed by a double layer of covering foil roof with an inlet to the biogas storage located in the upper part of the fermentation chamber, which is characterised by both layers of foil, the upper and lower, forming the biogas storage, are mounted on opposite sides of the rigid arched supporting structure of the roof covering. The lower foil has gas slots at the base of the arched supporting structure, and a duct fan is connected to the inlet channel, forcing the flow of biogas to the biogas storage facility. The diaphragmless heat and mass exchanger has a fixed bed with a high thermal capacity, through which seepage water is passed in a countercurrent to the exhaust gases supplied to the bed through the flue from the cogeneration system.

Method of purifying biogas to the parameters of transmission gas and installation for biogas purification (Filanowski, Pitula and Rybicki, 2013) according to the invention, includes the removal of carbon dioxide from unpurified biogas, and is characterised by the fact that carbon dioxide is removed by cooling the biogas with liquid nitrogen, leading to phase separation in such a way that the untreated biogas is directed through a pipeline to the compressor in order to raise the pressure to a value higher than 1.5 MPa, and then flows through a heat exchanger for pre-cooling, where the biogas is cooled with the output biogas from the installation, and then, after pre-cooling, the biogas is directed to the pre-cooling column purification to separate water and remove hydrogen sulphide, then the biogas prepared in this way is directed to the heat exchanger, where it is cooled to a temperature in the range between -62 and -72°C using liquid nitrogen, and then, after leaving the heat exchanger, the biogas is directed to the separator to separate carbon dioxide and other pollutants from methane.

The fermentation of decomposable waste fractions is also known from descriptions (Hood, 1987; Dipl, 1988) each time mentioning the use of the resulting biogas as a fuel.

Description by Pallett *et al.* (1990) presents a waste treatment method in which solid waste is fermented and the liquid portion is fermented separately, resulting in a higher degree of fermentation. The fermented liquid contains anaerobic bacteria and is added to ferment solids. Both fermentations take place in towers, and each time the temperature is equalised by heating. Fermentation of solids occurs in a discontinuous manner.

Publications (Coletti and Taverna, 1985; Bouche and Chaussinand, 1992) refer to separation methods in which solids that have settled there are lifted from the bottom of the pool using a pumping device. The separation method applies to material that has already been subjected to composting or another biological decomposition process. Description (Coletti and Taverna, 1985) discloses a device with a settling tank in which a forcing means, e.g. a forcing spiral, is placed to transport the settled material from the bottom to the surface. There are nozzles placed under the forcing spiral and at the upper end above the spiral, from which water sprays onto the transported material. The nozzles are supplied with fresh water at the upper end in order to achieve the desired cleaning effect.

According to Bouche and Chaussinand (1992), relatively large components (size ≥ 50 mm) are separated according to the specific mass. The water supply to the vertical conduit from the bottom of the settling tank, containing a pumping device, is used to push away (keep at a distance) light particles carried downwards from the vertical conduit and to generate an additional current in the settling tank, directed upwards, so that the relatively light particles rise up.

There is also a known method of waste disposal only by anaerobic fermentation, wherein this waste is the sludge from a sewage treatment plant located in a biogas plant (Pieralisi, 2008).

As a result of the analysis of the literature review regarding gas flow conditions – especially agricultural gas produced in the anaerobic fermentation process – the technical and process aspects of biogas technologies were indicated, analysing the technical and technological criteria for producing biogas from pig slurry. The key issue related to the development of the biogas sector is the search for new and more advanced technologies enabling the intensification of the biogas production process, taking into account the hydrodynamic conditions of the anaerobic fermentation process in a skeleton bed reactor using structural module modelling techniques through commercial software.

MATERIALS AND METHODS

At the Institute of Technology and Life Sciences – National Research Institute, Poznań branch, a mobile pilot installation of an agricultural biogas plant with an active fermenter capacity of 15 m^3 was developed and located on a farm (Fig. 1) having 1,100 pigs kept in a slatted system (Wałowski, 2019).

The raw biogas production node is a transport system for biogas produced in the fermentation tank (Fig. 2) together with the equipment that enables the fermentation process to be carried out, controlled and regulated.

The fermenter, the cylindrical part of which is located vertically, is filled with vertical pipes (1) with a rough surface made of plastic. In the upper part of the fermenter, there is a common connector (2) through which fresh substrate in the form of slurry and fermenting mass are supplied. Next to it, there is a biogas outlet port (3), which is connected with a pipe, via a blower (4), a biogas drainage valve (5), and a biogas inlet port (6) with a bubbler (7). The bubbler is located horizontally near the bottom of the fermenter. Vertical pipes (1), which increase the active surface for the fermentation bacteria flora, are located inside the heating spiral (8). The heating spiral is connected to the water pump (9) and the heat exchanger (10), creating a closed water circuit fed periodically from the outside. In the lower part of the fermenter, there is an outlet port (11) for the fermenting mass, which is connected via the fermenting mass pump (12) to a common port (2) supplying fresh substrate in the form of slurry and fermenting mass to the fermenter. The outer walls of the fermenter are covered with a layer of thermal insulation (13). The fermenter is equipped with a safety valve (14), a main digestate outlet port (15) connected to the digestate pump (16) and a biogas outlet port (17), through which the biogas is discharged for further use.

The fermenter is filled with slurry through connector (2), preferably in an automatic cycle, ensuring the vertical movement of the bioferment fraction through the entire tank. The digestate mixed with slurry also flows periodically through this connector. Part of the biogas contained in the gas space of the fermenter is moved to the bubbler and then travels upwards in the form of bubbles, mixing the suspension. The fermenter operates at a temperature of $35\text{--}40^\circ\text{C}$. The heating medium is warm water



Fig. 1. Mobile pilot installation, example of the location of an agricultural biogas plant on a farm; 1 = livestock building, 2 = manhole to the well, the so-called “pre-tank for pig slurry”, 3 = digester, 4 = container with the installation, 5 = digestate tank the so-called “lagoon”; source: own elaboration

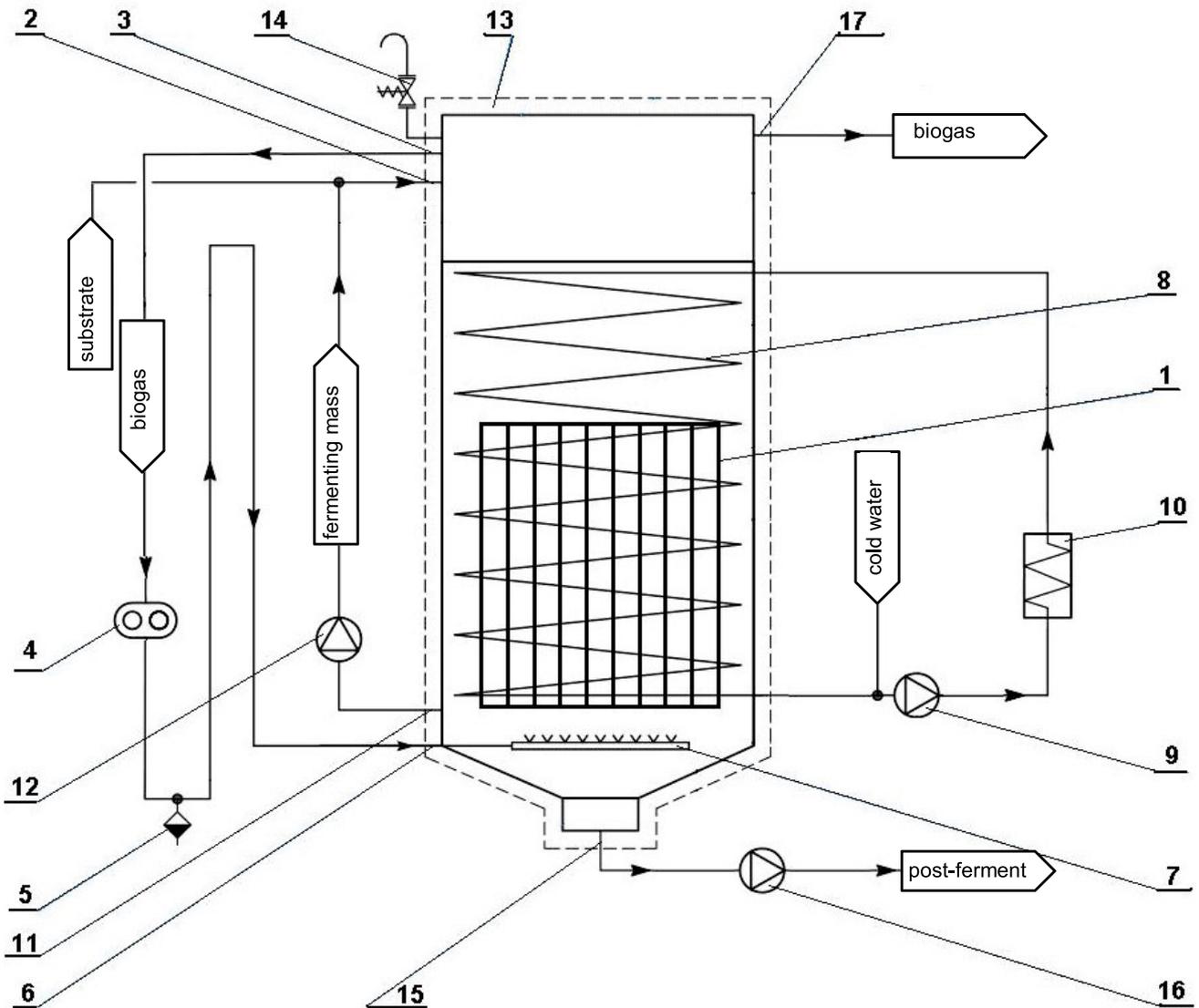


Fig. 2. Diagram of the fermenter: 1 = pipe, 2 = connector, 3 = biogas outlet connector, 4 = blower, 5 = biogas drainage valve, 6 = biogas outlet connector, 7 = bubbler, 8 = heating coil, 9 = water pump, 10 = heat exchanger, 11 = fermenting mass outlet port, 12 = fermenting mass pump, 13 = thermal insulation, 14 = safety valve, 15 = main digestate outlet port, 16 = digestate pump, 17 = biogas outlet port; source: Myczko *et al.*, 2018.

flowing through the heating coil. The digestate is drained 2–3 times a day through the main digestate outlet port. When emptying, the fermenter is not filled. Then the digester is filled with slurry in the same volume as the digestate was removed. The filling level of the fermenter is controlled in an automatic cycle. During filling, the pressure equalises after the biogas spontaneously flows through the outlet port (17) to the next part of the installation, which is described in detail in the work (Wałowski, 2021; Wałowski, 2022).

As part of my own work, I used the possibilities of the environment related to the creation of engineering diagrams, a three-dimensional model and documentary drawings. The aim of the work was to prepare engineering diagrams of the planned test installation and then, based on them and using inter-industry integration and data exchange mechanisms, to create a 3D model. Based on the 3D model, it was then possible to create base documentation drawings.

RESULTS AND DISCUSSION

Time pressure significantly affects the risk of making mistakes during the analyses and preparation of results, and this risk applies to every aspect of scientific work and research, including analyses and design work preceding the implementation of a new type of installation. To avoid or minimise the mentioned risk, it is necessary to use the best available methods and tools to support scientific work.

Such tools include AVEVA's highly integrated design environment. It provides tools for preparing, processing and keeping up-to-date such project components as engineering lists, technological diagrams or three-dimensional models, including documentation drawings, reports and specifications prepared on their basis.

The next components are tools enabling the maintenance of the installation in operation through access not only to documents strictly related to the design process but also to all

other documents and information related to the transfer of the created installation and keeping it in operation, including access to data on the operation of the installation in real time and predicting and preventing failures, ultimately up to the closure and dismantling of the entire installation.

AVEVA Everything3D™ (AVEVA E3D™) is the most technologically advanced solution for the 3D design of industrial objects and installations. It offers class-leading performance and functionality while remaining compatible with all other solutions of AVEVA Engineering & Design.

AVEVA E3D™ meets three important requirements:

- 1) clash-free, multi-discipline 3D design, accurate and fast drawing, and report generation to meet tight project schedules;
- 2) reduction of costs, time and risk associated with investment projects, both new and modernised facilities; support for the long-term development of users in effective design methods consistent with lean construction;
- 3) it provides best-in-class project execution capabilities and the ability to collaborate with a global community of solution users AVEVA.

The product contains the following main modules:

- MODEL – interactive, multi-discipline 3D design, data consistency control and material lists;
- DRAW – making scaled drawings from the model 3D;
- ISODRAFT – generating isometric drawings of pipelines from a model 3D.

Each of them delivers best-in-class performance.

AVEVA E3D™ can be quickly configured to meet specific company or project requirements, including:

- data structures;
- access rights;
- control of the status of designed facilities;
- principles of consistency control;
- reporting and drawing formats.

Configurations can be introduced at the project level, which allows you to meet the requirements of different customers for individual, simultaneously implemented projects. Company- or project-specific processes and information flows can be easily tailored to individual user needs and rigorously enforced.

The built-in internal Programmable Macro Language (PML) programming language along with the network-based application programming interface (NET API) provide almost unlimited freedom in creating your own functions that automate work, increase efficiency and gather valuable resources of expert knowledge.

AVEVA E3D™ sets a new standard for rendering 3D models (Fig. 3).

User-configurable edge definitions, shading, transparency, and highlights make complex 3D models easier to understand – Figure 4 shows more intuitive placement of objects in the model, reducing the number of necessary adjustments.

This advanced technology offers huge efficiency gains in both types of projects: new investments and modernisation of existing ones. When modifying existing facilities, newly designed installation fragments can be precisely adjusted to the reference points, and collisions between new and existing installation or structure fragments can be eliminated.

Laser scans of selected objects, parts of installations or the current condition of the construction site can be quickly attached to the project and compared with the 3D model. Inconsistencies can be eliminated to ensure the investment schedule, while the 3D design can be constantly updated to reflect the actual condition of the facility being implemented (as-built).

This means significant benefits for the technical project by adapting it to changes at every stage of investment implementation and for the investor by providing a reliable 3D model (Fig. 5) for resource management purposes.

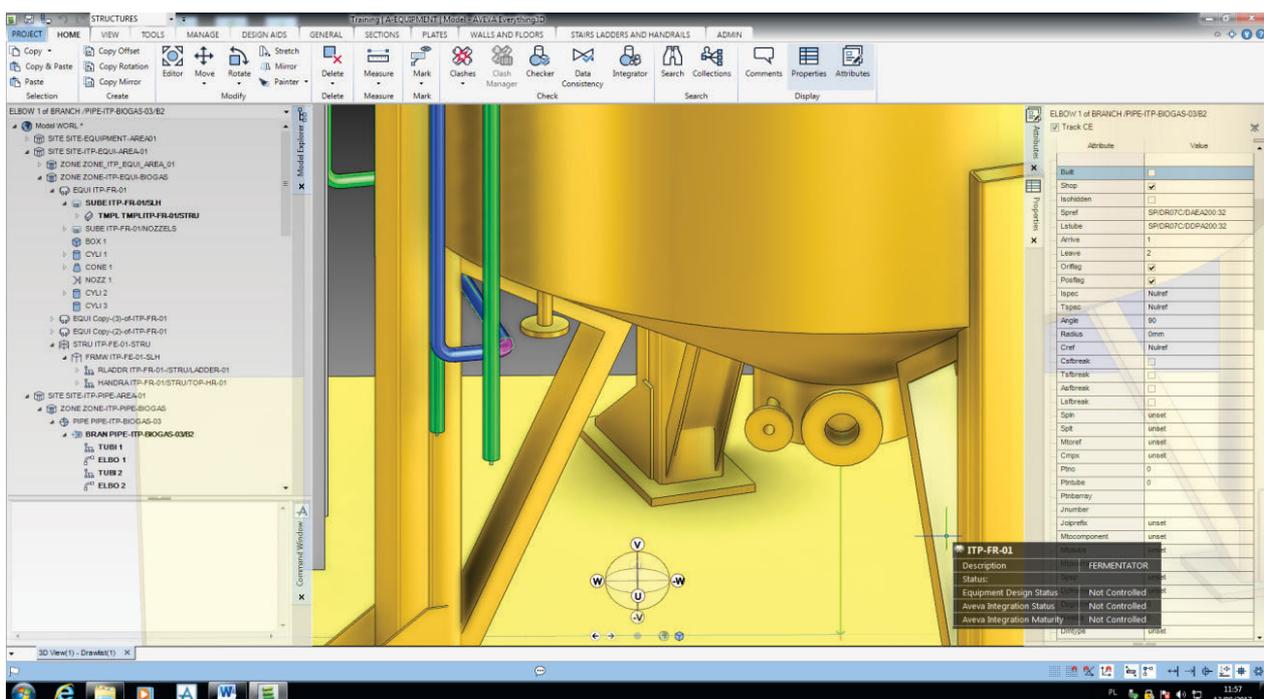


Fig. 3. Visualisation – AVEVA 3D Integrator – fragment of the bottom of the fermenter, P&ID diagram and 3D model; source: own study using AVEVA (2020)

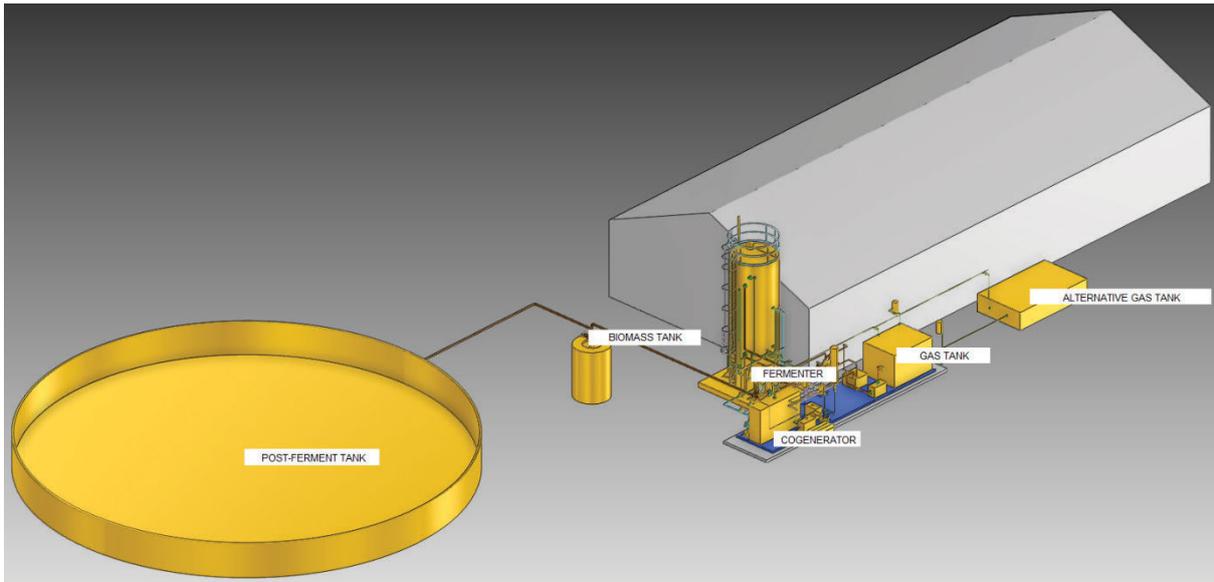


Fig. 4. Visualisation – AVEVA 3D Integrator – biogas production installation, integration of the diagram with the model environment and creation of pipelines using Integrator mechanisms; source: own study based on AVEVA (2020)

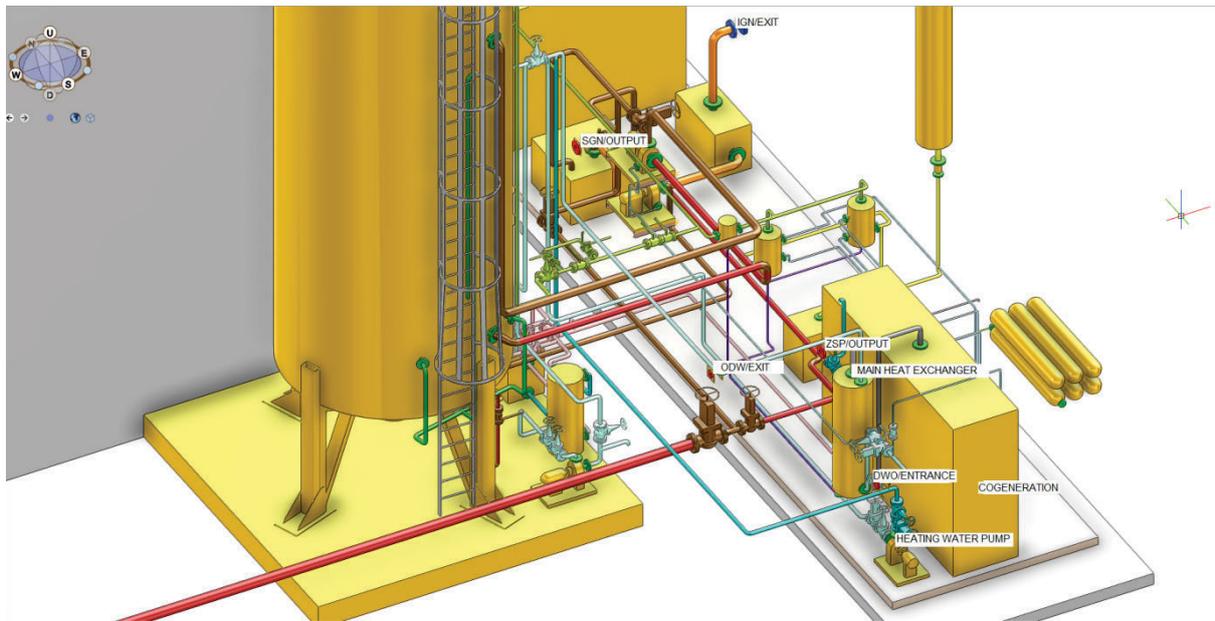


Fig. 5. Visualisation – AVEVA 3D Integrator – fragment of the biogas production installation, integration of the diagram with the model environment and creation of pipelines using Integrator mechanisms; red = substrate flow, IGN/EXIT = digestate outlet, SGN/OUTPUT = digestate inlet, ZSP/OUTPUT = hot water outlet, ODW/EXIT = substrate outlet, DWO/ENTRANCE = water inlet to be heated; source: own study based on AVEVA (2020)

AVEVA E3D™ can work with point clouds from any scanner, including FARO, Leica Geosystems HDS, Riegl, Trimble Dimensions and Z+F. Laser scan support in AVEVA E3D™ is based on Light Form Modeler (LFM) technology and works with prepared LFM Server™ data sets.

Introduction of new and unique technology HyperBubble™ allows users to work in an environment that includes a 3D model and a 3D HyperBubble view. AVEVA E3D™ allows you to remove fragments of point clouds. When working together with software LFM Server™, supporting work processes, the function of removing cloud fragments and adding updated scans allows you to work in an always up-to-date, trusted environment. Users can

treat it as their 3D world for design purposes, knowing they have the most up-to-date information.

It is also possible to model a technological installation using SolidWorks software, which uses 3D as an approach to the design process. When designing a part, from the initial sketch to the final result, we create a 3D model. From this model, we can create 2D drawings or add component constraints consisting of parts or subassemblies to create 3D assemblies. You can also create two-dimensional drawings of three-dimensional assemblies. When designing a model using SolidWorks software, we can make a three-dimensional visualisation of the appearance of the model after its production (Dassault Systèmes, 2016).

SolidWorks is a computer-aided design (CAD) computer program created and distributed by SolidWorks Corporation, which is part of Dassault Systèmes. It is a program based on the Parasolid kernel that generates the spatial geometry of the designed detail (DPS Software, 2023). Based on the 3D model of the part, it is possible to create assembly models, technical drawings, motion and load simulations, animations and much more. SolidWorks was designed to work with assemblies of several thousand elements. It is most often used for simple projects such as workplace equipment, auxiliary devices for production and others. Advanced design based on surface modelling is also possible, which has been significantly improved in newer versions of the program. Many companies use SolidWorks for the advanced design of tools such as injection moulds, stamping dies, and cutting dies. It integrates very well with CAM programs.

SolidWorks was first presented in 1995 as a competitor to such CAD programs as Pro/ENGINEER, Unigraphics, I-DEAS, CATIA and AutoCAD Mechanical. In 2007, it was one of the main CAD design programs on the market, and its main competitor was Autodesk Inventor and Solid Edge.

The program is characterised by an intuitive interface, relatively large design possibilities, rich libraries of ready-made elements and a quite attractive price. Its disadvantage is the hardware requirements – on the same computer and with the same model (opened, for example, from an STP file) it runs significantly slower compared to programs such as CATIA or AVEVA.

The pilot plant installation and operation simulation concept promotes innovative, efficient and cost-effective solutions that support the EU's energy efficiency policy through the optimal integration of appropriate module systems used in the AVEVA environment. The project develops, integrates and demonstrates easy-to-install and highly energy-efficient solutions for the production of agricultural biogas implemented on an agricultural and livestock farm.

CONCLUSIONS

Thanks to the basing of the entire design environment on standards/norms and material classes, available for every field, from lists through diagrams to models and documentation, the created project is not just a geometry model, it offers the possibility of automatic or semi-automatic building of a model based on a diagram or automatic completion and updating information in the model with information from lists and schemas. Ensuring compliance with standards significantly reduces potential problems with the implementation itself, from the purchase of parts to the creation of structures and setting up of installations.

ACKNOWLEDGEMENTS

The study was carried out in the context of the National Centre for Research and Development realised in the BIOSTRATEG programme, contract No. BIOSTRATEG1/269056/5/NCBR/2015 of 11.08.2015.

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