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Evaluation of Efficiency CHP Systems for Electric Energy Production

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Abstract: The main idea of exploitation combined heat and energy production is to reduce usage of primary fuels and with that connected reducing of pollutions due to the integration of renewable energy sources and with regard to the natural environment. Presented work is analysis of CHP system producing electricity and compare to conventional systems.

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1 Introduction

Integration of renewable energy and cogeneration systems for heat and electric energy are becoming very important for future energy production. Main idea of installing cogeneration unit and renewable energy sources is to reduce energy prices, decreasing pollutions and increasing efficiency integration into the energy production. A combined heat and power (CHP) system is proposed to minimize the production cost and to maximize the revenue from power. Since 2007, the EU has targeted several serious climate change and energy related issues which means 20% CO_2 emissions reduction comparing to 1990, 20% improvement in energy efficiency, 20% share of renewable energy sources in the end use, which is called 20–20–20 goals, should be acquired by 2020.

CHP is considered a sustainable and economic technology to fulfill those abovementioned goals for its significant performance in primary fuel consumption reduction, pollutions reduction and independency on fossil fuel.

2 Combined heat and power

A combined heat and power (CHP) system is proposed to minimize the production cost and to maximize the revenue from power. Combined heat and power (CHP) is technology which simultaneously produces heat and power by recovering heat that would otherwise be wasted in conventional condensing generation of electric power. For small scale CHP units is under consideration to replace conventional boilers in home installations with the production of electricity simultaneously with the generation of heat give an economic benefit for the consumer. Also, the fossil fuel consumption and CO2 emissions are effectively lowered. The thermal and electrical efficiency depend on the operating hours, unit capacity and installed type of technology. The economic benefits of CHP systems depend on the specific conditions under different operation strategies. When all the thermal energy of a CHP system can be utilized, it can reach much higher efficiency than conventional separate heat and power production.

3 Conventional Generation vs. CHP: Overall Efficiency

The average efficiency of fossil-fueled power plants in the Europe is around 36%.

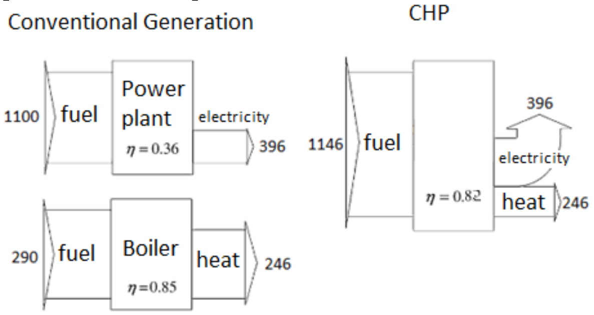

Figure 1 conventional generation vs. CHP

On the figure 1 is shown an example of a typical CHP system comparison to conventional power generation. To produce 369MW of electricity and 246MW of useful thermal energy, the conventional system uses 1100 + 290 units of fuel inputs. However, the CHP system needs only 1146 units of energy inputs to produce the same amount of output electricity and useful thermal energy, resulting in a total efficiency around 82%. By producing electricity onsite, CHP also avoids transmission and distribution losses that occur when electricity travels over power lines and heat transferred by pipes.

4 Term Cogeneration

The term cogeneration is one of the CHP systems based on fuel combusting engine which usually supplies an asynchronous generator. This work is focused on describing the installed natural gas cogeneration unit operating on the diesel principle generating electricity and heat.
This cogeneration system has been designed optimally according to economic and energy requirements with respect to environmental criteria and is automatically managed
by microprocessors and the current energy needs.
The main idea for installing a cogeneration unit is to reduce energy costs, reduce pollution and increase efficiency by integrating renewable energy sources, such as biogas and cogeneration. Several existing installed systems have shown that there is excess heat in summer and therefore accumulation is needed.

Average fuel consumption in year 2017 is around 81500 m^3 of natural gas. Monthly fuel consumption is shown in figure 2.

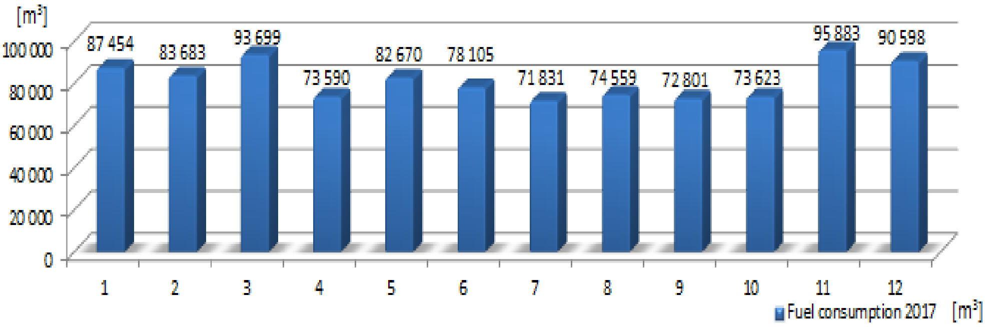

Figure 2 Monthly natural gas consumption in 2017

The electrical efficiency of cogeneration unit is around 39%. To the quantity of consumed fuel, we add calorific value which is around 10,761kWh.m^{-3} and we get theoretical energy included in that amount of fuel. By summing each electric energy and thermal energy and dividing it by theoretical energy included in fuel we get % effectivity of cogeneration unit. Graphics values show that cogeneration unit in summer season is very ineffective. In winter season efficiency of cogeneration unit is around 82 to 87%. From the point of view of the generation of heat, for the final customer the advantage of the central heat supply compared to other forms are relatively low prices for heat in connection with the increase of the usage cogeneration.

4.1 *Cogeneration unit efficiency*

Monitored value of produced electricity and heat is shown in figure 3. Total average effectivity of monitored cogeneration unit is around 87%. Priority on the production of cogeneration unit is in thermal energy as shown in the figures. Overall power of cogeneration unit was not recorded, the only recorded values are shown at figures.

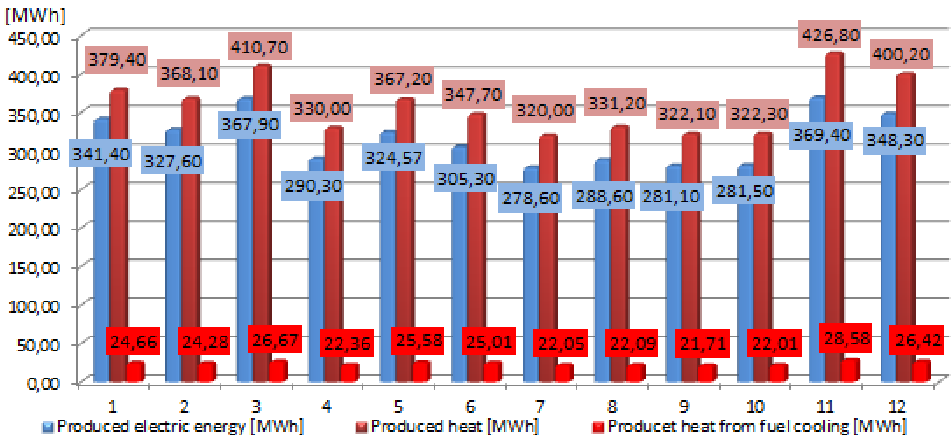

Figure 3 Produced electricity and heat 2017

The theoretical and measured values lead to knowledge which you can read above that allows understanding the cogeneration unit effectivity and describes the effectivity. Measured values show that there are not big differences in produced electricity. The largest differences in percentage are in produced energy is in heat from cooling fuel. Efficiency of electricity production is shown in figure 4. Average electricity efficiency in 2017 is around 38,88%. Compared to steam backpressure turbine which efficiency is around 10-30%, Steam turbine condensing with vapour collection 30-35%, combustion turbine 20-40%. Since natural gas is the dominant fuel for the production of heat, greater emphasis need to be placed on combined energy production methods and directly connected to cogeneration and electricity production.

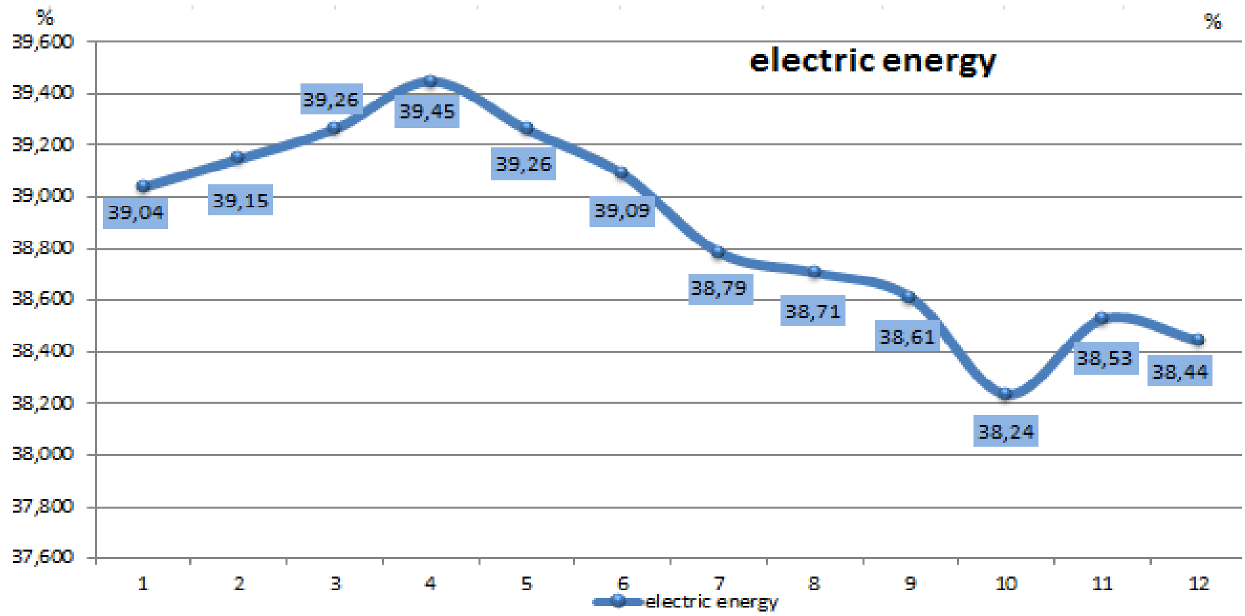

Figure 4 Monthly electric energy produced in 2017

As shown in figures, there is a direct correlation between the generated electricity and the heat in combined heat and energy production. Figures confirm problems with non-economical usage of cogeneration unit and shows that whole system is ineffective in summer season.

5 Conclusions

Compared to conventional thermal energy and electric energy production cogeneration is effective but there are still many others systems that could be more effectively. Due to the distribution of heat and electricity production where fossil fuels are predominantly used, it would be better to eliminate the use of this type of fuel. Cogeneration itself permits a new approach to the production of heat and electricity in the industrial sphere, where heat and electricity can be used to heat office and production areas and to engage in industrial production. An important role in this case is the appropriate annual distribution of heat and electricity demand which is negative in the overall economic balance of cogeneration units. Therefore, this technology is not yet fully implementable in decentralized systems.

6 The reference list

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Aspects of Determination of Convective Coefficients

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Abstract: The paper deals with selected aspects in the determination of convective coefficients and the formation of air convection models on solid surfaces. The goal is to assess the suitability of individual approaches for application in specific situations, considering that convective heat transfer coefficients have a significant impact on the resulting accuracy of the facilities/process design. Convection is a dynamic phenomenon, its exact physical description is complex, convection coefficients cannot be measured directly. Correct determination of convective coefficients is therefore very important in various areas where thermal energy is transmitted in this way. The paper gives an overview of selected aspects of various methods for determining convective heat transfer parameters.

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1 Introduction

Convective heat transfer as a phenomenon means thermal energy transfer between solid surface and surrounding fluid environment. This process is difficult to describe precisely because of many parameters that influence it. The convective coefficient which characterizes the convective heat transfer, is a function of several variables. Even for steady convection excluding phase changes the convective coefficient h_k can be described as follows [1]:

$$h_k = f(w, t_s, t_\infty, \lambda, c_p, \rho, \eta, \beta, \Phi, \tau, L_1, L_2, L_3 \dots) \quad (1)$$

where w – flow rate (m.s^{-1})
t_s – solid body surface temperature (K)
t_∞ – non-affected fluid temperature (K)
λ – thermal conductivity coefficient (Wm^{-1}K^{-1})
c_p – specific heat capacity at constant pressure (J.kg^{-1}K^{-1})
ρ – density (kg.m^{-3})
η – dynamic viscosity coefficient (Pa·s)
β – thermal expansion coefficient (K^{-1})
τ – time (s)
Φ – parameters describing solid body shape
L_1, L_2, L_3 – solid body dimensions (m).

2 Methods of convective coefficient determination

Obviously, it is not possible to construct a convection model that would perfectly fit all flow patterns encountered in solving technical problems. However, based on the available knowledge, we can find a model that will accurately describe the given situation.

One of the early methods that was developed for applications in internal (indoor) environment was Alamdari and Hammond method [2]. The formulas are applicable for buoyant flow caused by the temperature difference between the fixed surface and the air surrounding the surface. Relations are not applicable if the flow is generated by the heat source such as heating system, etc.

Data for determination of formulas were originally intended for the so-called free surfaces. Although some authors find this approach inappropriate [3], experimental evidence confirms sufficient precision of relations for convection modeling in confined spaces [2].

Calculation parameters implemented in this model include:

- ΔT – absolute value of temperature difference between solid surface - air (K)
- H – height of vertical surfaces (m)

- D_h – hydraulic diameter (m)
- h_k – convective coefficient ($Wm^{-2}K^{-1}$).

There are three basic formulas within this method according to particular purpose.

For vertical surfaces:

$$h_k = \left\{ \left[1.5 \cdot \left(\frac{\Delta T}{H} \right)^{1/4} \right]^6 + \left(1.23 \cdot \Delta T^{1/3} \right)^6 \right\}^{1/6} \tag{2}$$

For horizontal surfaces with buoyant flow:

$$h_k = \left\{ \left[1.5 \cdot \left(\frac{\Delta T}{H} \right)^{1/4} \right]^6 + \left(1.63 \cdot \Delta T^{1/3} \right)^6 \right\}^{1/6} \tag{3}$$

For horizontal surfaces with stratified layers:

$$h_k = 0.6 \cdot \left(\frac{\Delta T}{D_h^2} \right)^{1/5} \tag{4}$$

Another series of experiments were carried out by Awbi and Hatton [4] with a focus on natural convection occurring on heating surfaces. Accordingly, the resulting formulas are relevant for heating applications. Two formulas follows from the research:

For wall heating:

$$h_k = \frac{1.823 \cdot \Delta T^{0.293}}{D_h^{0.121}} \tag{5}$$

For floor heating:

$$h_k = \frac{2.175 \cdot \Delta T^{0.308}}{D_h^{0.076}} \tag{6}$$

As it is shown, the formulas implement hydraulic diameter D_h and temperature difference ΔT as input parameters. Hydraulic diameter:

$$D_h = \frac{4S}{P} \quad \text{(m)} \tag{7}$$

where S is the area of the given surface (m^2), P (m) is perimeter of the surface.

Another set of experiments were carried out by Khalifa [5]. Khalifa conducted experiments to determine convection models in buildings. The tests were repeated many times under different conditions to achieve a set of convective modes for different heating systems. The work resulted in 36 equations for the determination of convective modes, the set was further reduced to the 10 equations. Derived coefficients refer to the temperature difference ΔT (K) between the surface and the ambient air. Khalifa's equations are considered to be models with a tendency to give results somewhat higher than reality [6], whilst the error of the results increasing with the temperature difference.

Table 1 Determination of convective coefficient according to Khalifa [4]

SURFACE	*APPLICATION*	h_k ($Wm^{-2}K^{-1}$)
Walls	• rooms with radiator heating • radiator is not located under the window • valid for surfaces near radiator	$1.98 \cdot \Delta T^{0.32}$ (8)
Walls	• rooms with radiator heating • radiator is located under the window • rooms with wall heating • not valid for heated wall itself	$2.30 \cdot \Delta T^{0.24}$ (9)
Walls	• rooms with convector heating • valid for surfaces opposing fan	$2.92 \cdot \Delta T^{0.25}$ (10)
Walls	• rooms with convector heating • valid for surfaces that are not opposing fan • rooms with floor heating • rooms with radiator heating • radiator is not located under the window • valid for surfaces which are not located near radiator	$2.07 \cdot \Delta T^{0.23}$ (11)
Windows	• rooms with radiator heating • radiator is located under the window	$8.07 \cdot \Delta T^{0.11}$ (12)
Windows	• rooms with radiator heating • radiator is not located under the window	$7.61 \cdot \Delta T^{0.06}$ (13)
Ceilings	• rooms with radiator heating • radiator is located under the window • rooms with wall heating	$3.10 \cdot \Delta T^{0.17}$ (14)

Khalifa's method together with Awbi and Hatton results provide integrated set of equations for convective coefficients determination for all kinds of surfaces in confined heated spaces (closed rooms). The formulas are valid for natural occurring convection.

Experiments aimed on investigation of forced convection in air conditioned indoor spaces were conducted by Fisher [7]. The aim of the research was determination of convective coefficient in such conditions. He studied forced convection modes for typical airflows and typical room geometry. For the research, two types of diffusers were used, namely ceiling radial diffuser and wall horizontal diffuser. As a result, correlations have been obtained for three types of flow: for ceiling diffusers in an isothermal room, for ceiling diffusers in a non-isothermal room, and free horizontal diffusers in an isothermal room.

Following are formulas for convective coefficient h_k obtained by Fisher [7].
Ceiling diffusers in isothermal room for:

- Walls $\quad 0.19 \cdot n^{0.8}$ (15)

- Floor $0.13 \cdot n^{0.8}$ (16)
- Ceiling $0.49 \cdot n^{0.8}$ (17)

Free horizontal diffusers in an isothermal room:

- Walls $-0.110 + 0.132 \cdot n^{0.8}$ (18)
- Floor $0.704 + 0.168 \cdot n^{0.8}$ (19)
- Ceiling $0.064 + 0.00444 \cdot \frac{n^{2,8}}{\Delta T}$ (20)

The ranges of typical values of convective coefficients h_k ($Wm^{-2}K^{-1}$) for various types of convective flows are large.

Typical values [1]:

- Free convection
  - gases 2 – 25
  - liquids 50 –100
- Forced convection
  - gases 25 –250
  - liquids 50 – 20,000

Conclusions

Correct determination of the convective coefficient model is essential for creation of a heated space model that would use the thermal domain connection with the flow domain. Convection studies consistently represent a non-trivial problem in environmental engineering, convective coefficients themselves are often considered to be certain constants in simple applications, but they are too simplified: coefficients of convection heat transfer are in fact the functions of many variables as seen from the research and experimental works mentioned in this paper. [8] The research of convective processes itself is relatively labor-intensive, many of these experiments were carried out in real-size rooms and with real inputs. Multiple series of measurements under different conditions were often performed to obtain applicable results.

It can be said that the results of these research papers provide an opportunity to use the simulation model of the indoor environment to predict the temperatures and the energy and mass flows in the built environment, and when properly used, such a model can provide a sufficiently precise output.

It is clear that each model is always a certain simplification of reality, but this is not only a disadvantage. A theoretical model, which would copy reality accurately, would probably be very difficult to manage (imagine a map at 1:1). The model should provide usable results that help design energy saving systems while providing thermal comfort and good indoor air quality in buildings.

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Combustion Cleaning Methods in Dangerous Waste Incineration Houses

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Abstract : Two (dry and semi-dry) methods of cleaning the combustion products from the dangerous waste incineration process are discussed in terms of the environmental (emission limits, waste and emission volumes, etc.) and economic criteria (material balances) as well as the plant service life and operation. The dry combustion product cleaning method as a BAT technology is recommended as the most suitable one.

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1 Introduction

Waste incineration produces pollutants, i.e., solid, liquid, and gaseous substances which directly or after a chemical or physical change in the air, or in combination with another substance, have adverse effects upon the air, thus being dangerous and having harmful effects upon human health and/or other organisms, deteriorate the environment and/or inflict damages to property [1].

It is mainly the following products that are generated by waste incineration:

- solid pollutants
- sulphur oxide
- nitrogen oxides
- heavy metals (mercury, thallium, cadmium, arsenic, nickel, chromium, cobalt, lead, copper, manganese)
- hydrocarbons
- halogenated hydrocarbon derivatives
- other substances, such as dioxins.

2 Waste incineration process

Waste incineration represents a special area in the field of fuel combustion, characterized by specific properties compared to the conventional solid, liquid and gaseous fuels. The waste incineration process consists of several stages, including drying, heat accumulation, pyrolysis, ignition, flame burning, und after-combustion. The combustion scheme is given in Figure 1.

While conventional fuel combustion is more or less simple and the perfect combustion is significantly conditined by a sufficient supply of air, waste contains components the incineration of which may cause irreversible damages in the case of unprofessional attendance. They mainly include fluorine and chlorine compounds which - through the incineration house combustion products - may endanger the environment. By implication, the following four conditions must be observed for any incineration process:

- sufficient amount of burning air,
- sufficient amount of heat,
- sufficient combustion temperature,
- keeping combustion products in the high-temperature range.

The principle of a sufficient amount of burning air follows the fuel combustion conditions requiring the sufficient amount of oxygen. The amount of burning air supplied is 1.5 to 2 times higher than the desired value because the waste composition may vary significantly. Therefore, an excessive oxygen volume must be ensured for any condituions. It should be, however, noted that excessive air reduces the combustion temperature. Hence, it is necessary for an operator to maintain these two values in balance.

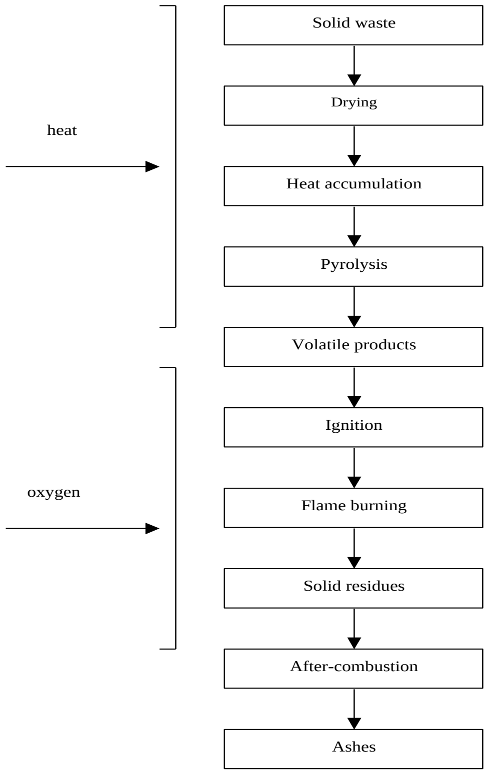


Figure 1 Waste combustion process scheme

The sufficient amount of heat is required for the rapid warming up of waste to the ignition point. Slow waste warm-up is accompanied with the risk that a considerable amount of pollutants do not burn down. Instead, they can evaporate and escape to air during the warm-up process. The sufficient amount of heat is reached by means of an appropriate fireplace design, its insulation and by additive fuel combustion. This amount of heat is closely related to the sufficient waste combustion temperature. Given the ignition temperature of carbon black is 700-750ºC, the combustion product temperature in the fireplace area may not drop below 800°C. This guarantees the perfect burning of those waste components which remained after the release of volatile conbustible from the burning waste. Consequently, any industrial waste incineration house must be provided with an after-combustion chamber with the temperature 900 or 1200°C, depending on the waste type. All combustion products leaving an incineration house must reach this temperature.

Like any other chemical reaction, the combustion of substances does not take place immediately. A sufficient time is required for the combustion process. The combustion time ranges from 0.1 to 1 s. Therefore, any combustion products must remain in the after-combustion chamber for 1-2 seconds. Moveover, the perfect mixing of all combustion products is a must.

Table 1 Operation conditions for the combustion of dangerous waste according to Act No. 137/2010 of the Digest [3]

O_2 content in combustion product	11 %
Temperature behind the combustion chamber	min. 850ºC
Temperature behind the after-combustion reactor	min. 1150ºC
Combustion product delay	min. 2 s
O_2 content at the combustion product outlet	min. 6 %

2.1 Emission limits for dangerous waste incineration houses

The dangerous waste incineration house operators must observe all emission limits. An emission limit is the maximum allowable quantity released to the air from the pollution source, expressed as a mass pollutant concentration in waste gases or a mass pollutant flow per unit of time or a mass pollutant quantity relative to the unit of production, or the air pollution level caused by the respective source. The following emission limits (in Table 2) apply to the incineration of special and dangerous waste types [3].

Table 2 Emission limits for the pollutants according to Decree of the Ministry of Environment No. 410/2012 of the Digest [4]

	Emission limits /mg.m^{-3}/ (daily average)
Total solid pollutants	**10**
Organic pollutants in the form of gases and vapours, expressed as a total organic carbon	**10**
Heavy metals (limits as average value) Sb + As + Pb + Cr + Co + Cu + Mn + Ni +V Hg+ Cd + Tl	**Total: 0,5** **Total: 0,05** **Total: 0,05**
Gaseous compounds of chlorine, expressed as HCl	**10**
Carbon monoxide CO	**50**
Sulphur oxide SO_2	**50**
Nitrogen oxides such as NO_2	**200 (400)[1]**
Gaseous compounds of fluorine, expressed as HF	**1**
PCDD + PCDF	**0,1 ngTEQ/m^3**

([1] applies to existing plants with a capacity of up to 6 tons per hour)

3 Combustion product dry cleaning method

This technological process, introduced by Solvey Co., Belgium, is designed for the cleaning of combustion products resulting mainly from chemical compounds of sulfur, chlorine, fluorine, and from separation of ash which binds heavy metals. The combustion product cleaning is based on the principle of selective adsorption, with the subsequent mechanical cleaning of combustion products in a cloth filter. This technique employs the sodium hydrogen carbonate powder which is decomposed to sodium carbonate at the temperature of 140°C. Reactions of acid components and adsorption of other pollutants (heavy metals) take place on a large surface of the carbonate.

The following chemical reaction takes place in this process:

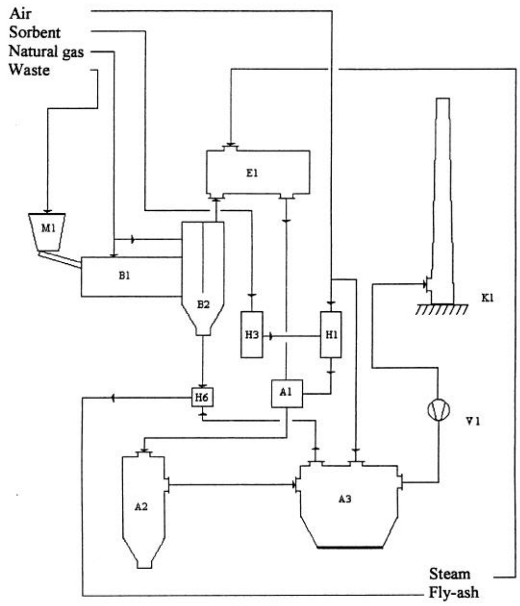
$$2\ NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

The sodium hydrogen carbonate powder is added to combustion products following the after-combustion thermal reactor. The latter is used for perfect thermal and oxidation destruction of dangerous substances in the combustion products. The method works with temperatures from 140 to 250°C. The contact period is at least 2 seconds. After their reaction, the combustion products are filtered in a cloth filter in order to separate ashes, including heavy metals and waste sorbent. The advantages of this method include:

- Meeting the strictest emission limits
- No liquid is used
- No liquid waste is generated

An important advantage of this method is the possibility of recycling the used sorbents; as a result, the quantity of waste sorbent may be reduced to 2-3 kg/ton combusted waste. The operation of an incinerator based on the dry cleaning method is illustrated in Figure 2.

The solid and paste-like waste types are homogenized in a mixer and transported by conveyers to the M1 container and then to the B1 incinerator. Here, the first combustion phase takes place at temperatures from 800 to 900°C. Waste is set to fire and combustion is stabilized by a natural gas torch. The delay time and thus the thermal decomposition may be regulated by furnace and/or grate inclination. The amount of gas is regulated according to the incinerator temperature. The incinerator is connected to the B2 after-combustion chamber which is fitted with another torch. Combustion products burn at the temperatures ranging from 900 to 1350°C. Combustion products remain here for 2 seconds minimum. The combustion products pass from the thermal reactor to a fire cyclone. The latter arrests solid pollutants and ashes which are collected in the H6 container. Combustion products pass from the thermal reactor to the E1 boiler to transfer its heat to water, thus producing warm water or steam. Combustion products cooled down to the temperature of about 180°C pass to the cleaning subassembly. Sodium hydrogen carbonate is added to the combustion products in the A1 mixer. Then they pass through the A2 contactor and the A3 cloth filter to arrest solid pollutants and ashes which subsequently fall into the H6 container.



Legend: A1 mixer, H1 sorbent dosing, A2 contactor, H3 sorbent container, A3 cloth filter, H6 ashes container, B1 rotary combustion furnace, K1 chimney, B2 thermal reactor, M1 waste dosing, E1 boiler, V1 combustion product fan

Figure 2 An incinerator for the dry cleaning of combustion products

4 Combustion product semi-dry cleaning method

This method of combustion product cleaning is based on a chemical reaction of acid compounds, contained in combustion products, with lime hydrate, and on the separation of ashes, including heavy metals. Combustion products are cleaned after the after-combustion reactor used for a perfect thermal and oxidation destruction of dangerous substances. First, sorbent is prepared by mixing lime powder and water in a mixing tank, the filtration of lime hydrate, and its discharging to a tank. From the tank, the sorbent is transported by jets to a combustion product washer where a chemical reaction between sorbent and acid gases from combustion products, and subsequent drying the suspension. Combustion products are then filtered by means of a cloth filter in order to separate solid pollutants with heavy metals and the residual dry sorbent. The following chemical reactions take place during the cleaning of combustion products:

$2\ HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2\ H_2O$

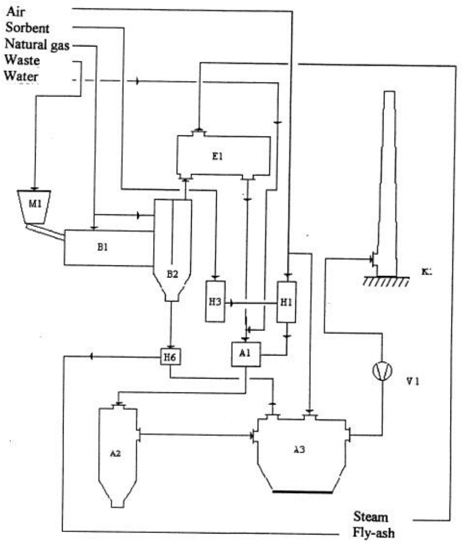
$2\ HF + Ca(OH)_2 \rightarrow CaF_2 + 2\ H_2O$

$SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O$

$2\ SO_2 + 2\ Ca(OH)_2 + O_2 \rightarrow 2\ CaSO_4 + 2\ H_2O$

The waste resulting from the cleaning process is classified in the Catalogue of Wastes as components from gas cleaning. It is a mixture composed of salts of lime acids, non-reacted lime hydrate, ashes, dust, and carbon black, including the pollutants. This waste is disposed of by dumping.

The operation of an incinerator based on the semi-dry cleaning method is illustrated in Figure 3.



Legend: A1 mixer, H1 sorbent dosing, A2 contactor, H3 sorbent container, A3 cloth filter, H6 ashes container, B1 rotary combustion furnace, K1 chimney, B2 thermal reactor, M1 waste dosing, E1 boiler,V1 combustion product fan

Figure 3 An incinerator for the semi-dry cleaning of combustion products

The processes of waste incineration and combustion product cleaning are similar to those applied in dry cleaning. Waste is dosed to the M1 doser and transported to the B1 furnace. Waste is set to fire and combustion is stabilized by natural gas. The incinerator is connected to the B2 thermal reactor ensuring perfect burning of combustion products at the temperatures ranging from 900 to 1350°C. Combustion products pass to the E1 boiler to transfer their heat to water, thus producing warm water or steam. Combustion products are cooled down to the temperature of about 180°C. The combustion product cleaning operation itself takes place after the heat-exchanger. Lime powder is mixed with water in the A1 mixer. The A2 combustion product washer is designed for a chemical reaction between and acid gases from combustion products sorbent and from drying the suspension. Combustion products are filtered by a cloth filter and exhausted to the air through a chimney. Solid pollutants and ashes from the combustion product washer and the cloth filter are arrested in the H6 container. The advantages of this method include:

- No waste water resulting from the process.
- Meeting the emission limits.

The disadvantages include:

- A more demanding operation compared to the dry cleaning method.
- The cleaning efficiency for high pollutant content is ensured by greater excess of sorbent, which increases the volume of the waste produced.
- Since water is used in the process, the equipment service life is shorter due to the influence of corrosion.

5 Results of measurements and discussion

The following emission values characterize the both methods developed for special and dangerous waste incineration processes (see Table 3 and Table 4).

The dry method uses sodium hydrogen carbonate which is neutral, non-toxic and non-irritating and does not cause the corrosion. It has no harmful effects upon the environment. This method consumes about 15 kg sodium bicarbonate per 1 ton incinerated waste and produces about 10 kg combustion product waste per 1 ton incinerated waste. This solid waste is classified as dangerous waste in the Catalogue of Waste [2]. It is trapped in containers and transported to a dump. Its manipulation is simple. The waste is transported to a dump of construction class III (dump for the dangerous waste).

For the dry method, sorbent is dosed by pressurized air. The equipment service life is about 5 years. Emission value are significantly influenced by a filter. Its service life for the dry method is about 12-18 mounths of continous operation.

The semidry method uses lime hydrate (calcium hydroxide solution) as a sorbent. Unprotected exposure to $Ca(OH)_2$ can cause severe skin irritation, chemical burns, blindness and lung damage. This substance is liquid and therefore has adverse effects upon the environment. This method consumes from 60 to 10 kg lime hydrate per 1 ton incinerated waste. The waste is transported to a dump of construction class III (dump for the dangerous waste) [2].

Table 3 Measurement of emissions in the dangerous waste incinerators

Emission component	Average value [mg.m^{-3}] Dry*	Semidry**
Solid pollutants	**23,1**	**7,0**
CO	**7**	**15**
SO_2	**16**	**8**
NO_x	**121**	**106**
Total organic carbon (TOC)	**13,2**	**1,0**
HCl	**1,9**	**0,2**
HF	**0,13**	**1,0**
Σ Hg + Tl + Cd	**0,147**	**0,2**
Σ As + Ni + Cr + Co	**0,069**	**1,0**
Σ Pb + Cu + Mn	**1,133**	**0,5**
Legend: *dangerous waste incinerator house **hospital waste incinerator house		

It follows from the table that all methods of combustion product cleaning meets the emission limit value specifications.

Table 4 Measurement of PCDD and PCDF emissions

Method of determination	Dry* EN 1948	Semidry** VDI 3499
Average value of O_2 in combustion gas [vol%]	**10,25**	**14,4**
Σ PCDD and PCDF (normal state, dry air mass) K_{ss} [ng.m^{-3}]	**6,3**	**31,5**
Σ PCDD and PCDF (0°C, 101,325 kPa, 11% O_2) [ng.m^{-3}]	**5,8**	**29,3**
TEQ (normal state, dry air mass) K_{ss} [ng.m^{-3}]	**0,199**	**0,839**
TEQ - K(0°C, 101,325 kPa, 11% O_2) [ng.m^{-3}]	**0,185**	**0,78**
TEQ – limit accord. Degree of Gov.SR, No.473/2000 of the Digest) [ng.m^{-3}]	**0,1**	
TEQ – limit recommended by EU) [ng.m^{-3}]	**0,1**	
Weight flow Σ PCDD and PCDF [μg.h^{-1}]	**10,4**	**80**
Weight flow TEQ [μg.h^{-1}]	**0,329**	**2,53**

Sorbent is dosed for semidry method by means of dosing jets. Their service life is about one year, which is influenced by the effects of liquid and hogh temperatures. The service life of filters used for semidry method is about6-8 mounths, which is connected with the influence og high humidity.

6 Conclusions

The comparison of the individual methods clearly indicates that the dry method offers the best values of all. While complying with the specifiied emission limits, this method is the simplest of all in terms of equipment and operation, consumes the lowest amount of sorbents, and produces the lowest volume of waste from combustion product cleaning. By implication, the operation is cheap and has the least adverse effects upon the environment and the equipment service life of all the methods compared.

It is labeled as BAT, i.e., the Best Available Technology. In addition to the special and dangerous waste combustion product cleaning it may be applied for he production of ceramics, cement and for tire combustion. Its use has been recommended by the EU contries.

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Assessment of Temperature Ratios During Operation of Pneumatic Artificial Muscles

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Keywords : pneumatic artificial muscle, thermovision, coating temperature

Abstract : The article deals with the description of experimental measurements performed to describe problematic point real-time temperature measurement of PAMs surface. The original measurement method was replaced by an alternative thermovision measurement. Thermal images were created at predefined times of operation of the device and its predefined operating states. Experimental measurements have shown that the temperature range of the PAMs is within the temperature range that limits the safe operation of the device.

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1 Introduction

In the area of manufacturing facilities using manipulators designed to perform monotonous tasks with an increased risk of injury or damage to common types of manipulators or areas where it is necessary to replace or strengthen the human muscular system pneumatic artificial muscles (PAMs) are used. The reason for an increasingly intensive research into the properties of PAMs and their application is their high power-to-weight ratio, with sufficient inherent safety and high strength. Thanks to their clean operation, simple maintenance, low procurement costs, maintenance costs and long service life, they are a possible alternative to replacing conventional drives (hydraulic and electric drives) in the production facilities. Contrary to conventional drives, there is no risk of sparking or electric drive on PAMs, and their operation is cleaner than hydraulic cylinders [1] [2] [3] [4] [5]

In the field of the pneumatic artificial muscles and their implementation into manufacturing facilities, prevailes the research in antagonistic involvement of pneumatic artificial muscles (PAMs).

For the further extension of the use of these drives, it is necessary to master accurate position control. This requires a control system that is capable of responding to changes in device performance characteristics at a sufficient speed. For position control, mathematical and statistical methods are often applied to create a mathematical model of the system with an estimate of optimal controller parameters. However, the control system must in practice control the positioning of the manipulator, which may be very non-linear, for example due to reduced performance of the transition phenomenon due to changes in external load or working media compression problems. When changing the external load, it is not easy to provide high-precision position control. [1] The modeling and design of a precise, stable and robust positioning control system for PAM applications is challenging due to the non-linearity and time variability of the control system due to air compressibility, air flow through the valves, problems with time scatter, compliancy, high hysteresis, etc.. To overcome these drawbacks, a number of new pneumatic actuators have been developed, such as McKibben's Muscle or Braided and Rubber Actuator. [1] Some of the above shortcomings still persist. [6]

In order to overcome some of these deficiencies described above, the Department of Process Engineering (KPT), Faculty of Manufacturing Technologies with a seat in Prešov (FVT), focused on the design of a control system for real-time monitoring and diagnostics of the manipulator with antagonistic

PAMs using a control algorithm modified for the use of hardware and software that enables real-time work.
The functionality and effectiveness of the proposed management algorithm is verified by carrying out a series of experimental measurements on the proposed device. The operational characteristics of the device were described by the experimental measurements executed mainly in for the reason to study the terms of the influence of the individual process variables on the positioning accuracy of the propulsive actuated arm with a drive consisting of two pneumatic muscles in the antagonistic connection in the vertical position. The ambient temperature and the drive temperature were within the operating conditions defined by the manufacturer as safe for the operation of pneumatic artificial muscles, temperature was not taken into account when assessing the experimental measurements. However, this article describes the temperature ratios in the drive from antagonistic engagement of pneumatic artificial muscles during their short and long-term operation.

2 Description of the Experimental Device

The experimental assembly includes the antagonistic engagement of pneumatic artificial muscles mounted on the support structure and the weight loaded on the support arm, as well as equipment for sensing, processing and recording of characteristics,which are changing during operation of the device with the possibility of controlling the real-time interventions.

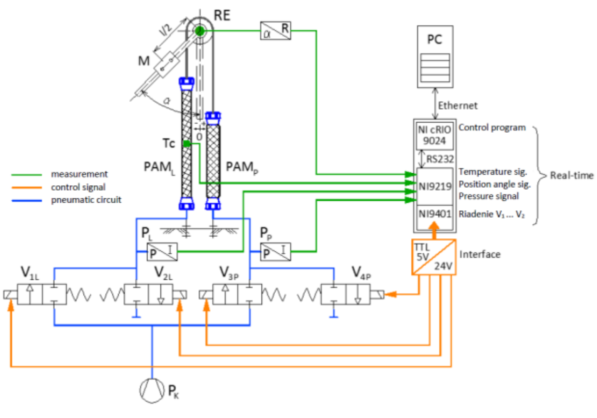

Figure 1 Experimental assembly with PAMs in antagonistic involvement. [4]

Scheme description: PAML – left pneumatic artificial muscle, PAMP – right pneumatic artificial muscle, M - weight, RE – position sensor, α – arm rotation angle, Tc - thermocouple, R – electric resistance, PC – computer (workstation), PL – left pressure sensor, PP – right pressure sensor, P - pressure, I – electric current, V1L, 3P – inflating electropneumatic valve left/right, V2L, 4P - deflating electropneumatic valve left/right, PK – vessel pressure.

In the above scheme are monitored, the constant pressure in PAMs, the size of the carrier arm and the temperature at the left muscle, during the operation of the device.

Experimental facility management is provided by a real-time control system, consisting of NI CompactRIO components, designed for real-time monitoring, diagnostics and control. The control system algorithm itself was designed in the LabVIEW Real Time LabVIEW graphical development environment. The PC provides the user with the ability to monitor the progress of the measured variables while controlling the facility in the user environment of the program.

3 Description of the Experimental Measurements

3.1 Measurement 1 - Left PAM pressure control measurement

In Fig. 2 there are shown measured pressure patterns at ambient temperature of 25.5 °C, regulation without PWM modulation, arm position and left muscle temperature. Under the set initial conditions according to Tab. 12, a no-load measurement for three different pressures in the left artificial muscle was performed.

From the pressure behavior, it can be seen that the 2 bar pressure is maintained on the right PAM with the precision about 0,05 bar. The pressure in the left PAM was changed from 2 bar to 3 bar, 4 bar and 5 bar sequentially. By increasing the left-hand pressure to 3 bar, we observe a relatively linear course at the leading edge of the left-hand pressure curve, given by the permeable capacity of the left-hand intake air valve and the low force of the right PAM. The relative linearity phenomenon can only be observed in the left PAM at low pressure, with a multiple pressure differential on the left charging valve during pressure increase (between the muscle and the compressed air source) and the small reaction (reverse) force of the right muscle. With higher pressure in the left-hand muscle, there is a smaller pressure differential between the left filling valve and the right muscle's reaction force, which increases the stiffness of the entire mechanism, and the linearity of the stroke is lost. With a decreasing angle of inclination of the left pressure curve, there is an increasing amount in muscle filling cycles in time as seen at the curve of the pressure rise to 5 bar. Holding muscle pressure to the desired value is within the tolerance of 0.05 bar defined in the mode of the pressure control program. Any out-of-tolerance pressure is compensated by a short increase or decrease in muscle pressure. The pressure fluctuations are due to the elasticity of the whole experimental device. The vibration damping is formed by the stiffness of the antagonistic engagement, and the friction of the chain transmission has negligible effect. The decreasing curves of the left PAM pressure during pressured air discharging have higher non-linearity and a longer time course compared to the pressure increase due to faster decreasing of the pressure variation on the left emptying valve.

The second graph in Figure 2 shows the valve switching patterns for the left muscle, and the third graph shows the switching patterns of the right muscle valves. The left PAM valve performance exactly matches the time of the filling of the left PAM and the short pulse to adjust the muscle pressure in pressure tolerance. The left muscle deflating valve, with its performance, naturally copies the progress of the decreasing curve of left muscle pressure, and by narrow impulses, it also leverages the left muscle pressure tolerance.

The graphical dependence of the opening and closing of the valves function for operation of the right PAM shows the constant muscle compensation pattern in the right muscle. Constant right PAM pressure is disturbed by left muscle activity and is therefore constantly compensated by valves of the right PAM. Frequent right muscle compensation occurs at times when the left muscle is inflated, less often the right muscular pressure is compensated for the leakage of the left muscle, and at a time when the pressures are maintained at a constant value, there is only a small amount of pulses that compensates for the muscle's compliance or leaks.

With very tight pulses in their top part, despite the regulation without PWM modulation, a constriction can be seen, which may be due to the decimation of data for plotting, and these impulses will be considered rectangular.

Positioning is the resulting load and pressure control function. The course is seen to be very responsive to changes in pressure. During measurements with position control we do not interfered with position because the position is a dependent variable for this measurement.

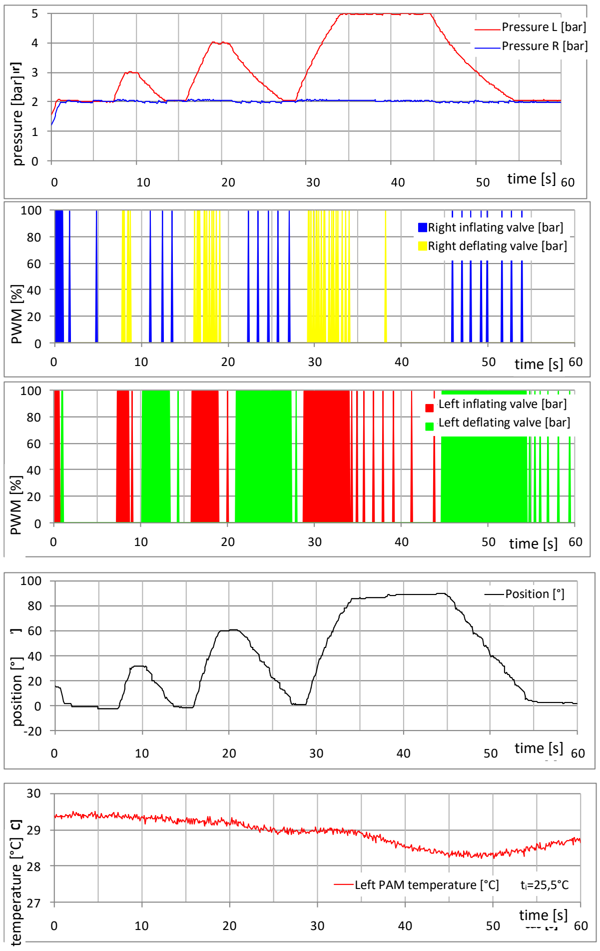

Figure 2 Graphic Dependencies - Measurement 1

The temperature is recorded on the surface of the left muscle and, as seen in connection with increasing pressure in the muscle, tends to rise slightly, and then it is possible to subtract the decrease in the temperature of the compressed air with the muscle. Overall, the average muscle temperature is clearly higher in contrast to the indoor temperature. The temperature flow in the PAMs during their operation corresponds to the work done by the muscles. However, the temperature measurement in this way did not take into account the design of the experimental device, with the placement of the inlet and outlet valves at the bottom of the device. In the vertical placement of PAMs, even though air is mixed inside the PAM, air is mainly discharged from the bottom of the filled PAM volume. At the same time, the mechanical stress at the ends of pneumatic artificial muscles, which could have caused uneven distribution of the temperature field on the PAM surface, was not taken into account. The placement of the thermocouple for measuring the temperature itself was not correct and the selected technical means caused a significant deterioration of the measured data. This means that a more appropriate method has to be used to measure the temperature.

3.2 Measurement 2 - Thermovision Measurement

In order to provide a better overview of the temperature of the surface of both PAMs installed on the experimental device changes, measurement with the use of thermocamera was selected. Measurements with thermocamera were performed during operation after the device was started, in selected operating states of the device, and after several hours of operation of the device. At Fig. 3 is a thermal image of the temperature of the device after the first thirteen minutes of its operation. The highest surface temperature of the PAM was manifested in the right PAM, which is in this case the working muscle, when the support arm is positioned at 75 °. Muscle temperature is highest at the junction of the elastic part of the pneumatic muscle with the nut coupled to the chain drive. The ambient temperature was 23,5 °C and the maximum PAM surface temperature was 26,4 °C. That is the reason that temperature differences were so pronounced.

The following figure shows the temperature of the carrier arm which was positioning to 83°, after approximately one and a half hours of operation. The maximum surface temperature of the muscle was at 32.7 °C.

Fig. 5 shows the temperature of the device after the end of its operation and after it has been restored, including controlled reset of its position and the release of the working medium from the PAMs.

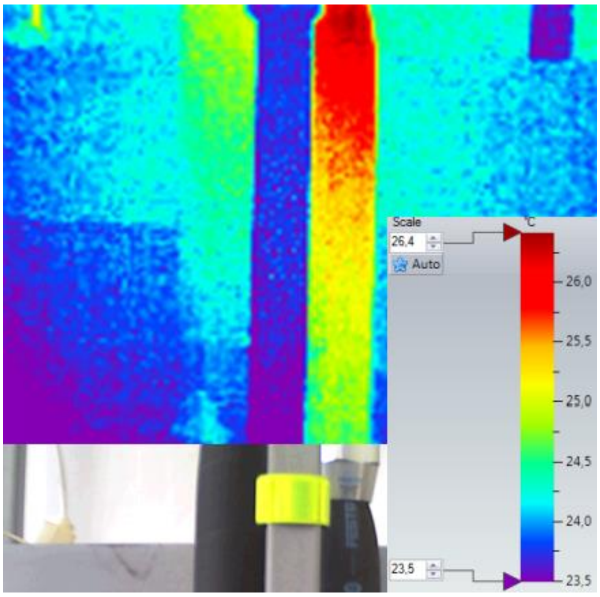

Figure 3 Measurement of PAM surface temperature with a thermal camera after 13 minutes of operation.

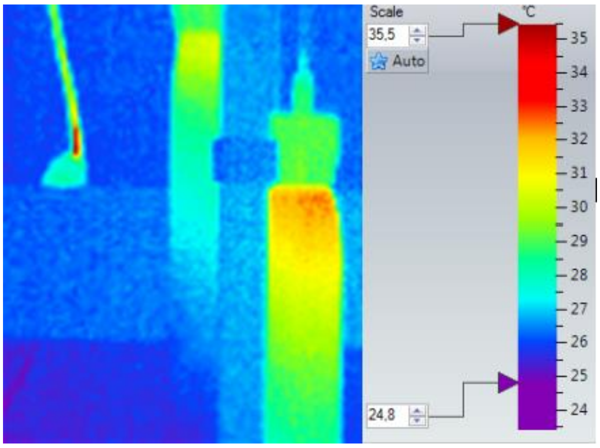

Figure 4 Measurement of PAMs surface temperatures with a thermal camera after 138 minutes of operation.

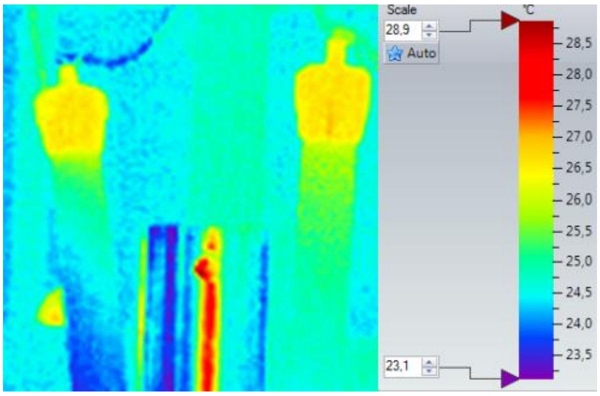

Figure 5 PAMs surface temperature measurement with the thermocamera after 193 minutes of operation of the device and discharge of working medium from PAMs.

The maximum PAM surface temperature during this measurement was 26.1 ° C, which does not correspond to the difference of three degrees to ambient temperature.

Figure 6 shows the operating temperature range to ensure optimum PAM life. It can be seen from the figure that the optimal temperature for the PAM life is in the range of 30 to 60 °C. This means that the operating temperature of the PAMs surface in the experimental device could have been higher, for example due to higher drive load or higher ambient temperature.

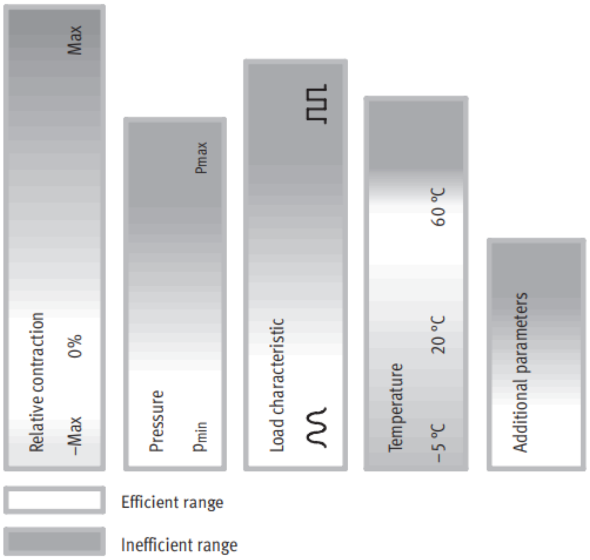

Figure 6 PAM operating temperature range specified by the manufacturer.

4 Conclusions

In terms of operating variables, account must be taken not only of the basic ones, such as working pressure, position of the end member, acceleration, and the like. For a more accurate description of the experimental device operation, it is also necessary to take into account the temperature of the device, which may affect the temperature of the PAM working medium and thus its other operating characteristics. It is not appropriate to monitor the PAM temperature at its surface points, that is to say, at the permanent measurement sites on the PAM surface, except for creating a mathematical model that would allow us to determine the PAM temperature at other points of its surface during work.

Another alternative is to measure the temperature in precisely defined conditions thermographically. Thermography measurement allows to perform PAM surface temperature control and thus control its operation to ensure its longer life.

As mentioned in the introduction to this article, the solution of precise positioning of devices with a drive operating with the antagonistic involvement of pneumatic artificial muscles is a challenging task. However, this article showed that during operation of the PAM, the surface temperature increased up to 6.5 °C, compared to the temperature at the beginning of the measurement. The surface temperature of the device may affect the temperature of the working medium and therefore it is necessary to take into account this operating variable, when developing mathematical models for advanced control of similar devices, and when designing their basic control. Deficiencies removed prior to the introduction of advanced control functions should increase the positioning accuracy.

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Increasing of Utilization Efficiency of the Produced Energy in the Biogas Plant

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Keywords : energy, efficiency, operation, cogeneration, biogas plant.

Abstract : The current trend not only in the world but also in Slovakia is to increase the share of energy obtained from renewable sources. Biogas stations also participate in the share of energy obtained from these sources. Today it is mostly modern and environmentally friendly technical equipment. They process a wide range of materials or waste of organic origin through the anaerobic fermentation process. Its result is biogas, which can be further utilized for the production of heat and electricity. However, the efficiency of the biogas production process is closely related to technical equipment of biogas plant. Also, biogas plant technology must, to the extent necessary, respect the conditions of its safe and reliable operation. The contribution is oriented to the design of a possible solution for increasing the efficiency of utilization of the produced energy in the biogas station.

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1 Introduction

The biogas plant can be characterized as a set of technological equipment for the transformation of organic materials for biogas production [1]. This transformation takes place most often in the form [2] of fermentation of organic biomass with a large percentage of methane gas, i.e., biogas [3]. In the case of the implementation of managed anaerobic fermentation, both from an economic and ecological point of view, it is a prospective way of using biomass for valuable renewable energy sources [4]. The primary product of anaerobic fermentation is biogas [5]. They are also energy-efficient [6] also the by-products of the anaerobic fermentation process such as digestate i.e. the rigid residue after evisceration and fugate i.e. liquid residue after evisceration.

2 Principle of biogas production based on anaerobic fermentation

Biogas is an organic gas that is obtained through a biochemical process. This is a process also called anaerobic fermentation of biomass [7]. Biomass is transformed to biogas in the tanks so called fermentors in the presence of microorganisms. It´s a biochemical process, those the final result is product called biogas i.e. mixture of methane (CH_4), carbon dioxide (CO_2) and by-products [8]. Organic decomposition (fermentation) occurs without access to air in humid environments by the action of anaerobic cultures of microorganisms [9]. Ideal conditions for these anaerobic bacteria are temperatures close to 50 °C. This is a relatively complex chemical process in which biogas usually occurs in its last phase. Anaerobic fermentation takes place in four phases which are referred to as hydrolysis, acidogenesis, acetogenesis a metanogenesis. The diagram in the figure 1 detailed describes the biochemical process of anaerobic fermentation the result of which is biogas (CH_4+CO_2). The time course of the biochemical process of anaerobic fermentation is closely related to many factors [10]. These include, in particular, constant temperature, because in the case of rapid temperature changes, anaerobic bacteria often die. These include, in particular, constant temperature, because in the case of rapid temperature changes, anaerobic bacteria often die. Another important parameter is a suitable pH. For these purposes, it is advisable to maintain a pH range of 6.5 to 7.5. Next to ensure the presence of trace elements such as iron, cobalt, selenium, molybdenum and tungsten. It is also important to keep the required nitrogen, carbon and phosphorus ratios, as well as the total biomass quality in terms of dry matter content. At present, two approaches are applied to biogas production, i.e. wet and dry process of anaerobic fermentation. A wet process of anaerobic fermentation is considered a technology in which a substrate with a water content of 85% or more is processed. Wet anaerobic fermentation is currently the most common method of anaerobic processing of bio-waste in Slovakia. The following figure 2 shows the diagram of wet anaerobic fermentation process.

In the case of a dry fermentation process, a water content of less than 85% is used. For practical reasons, this technology is currently only used in the Slovak Republic at a minimum. However, it is a technology that has a number of benefits in terms of significantly lower energy intensity of operation, lower sensitivity to the quality of input raw materials and lower balances with material handled. The following figure 3 shows the diagram of dry anaerobic fermentation process.

By complying with the appropriate input conditions, has a biogas obtained dry or resp. wet process of anaerobic fermentation a methane content in the range of 55 to 70% with a calorific value in the range of 18 to 26 MJ.m^{-3}.

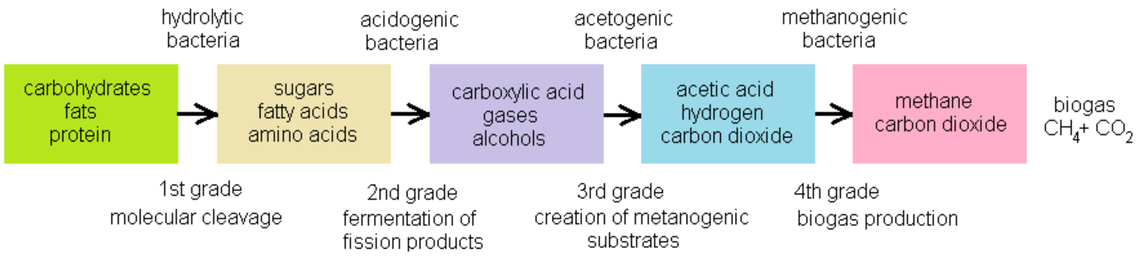

Figure 1 Biochemical process of biogas production through anaerobic fermentation

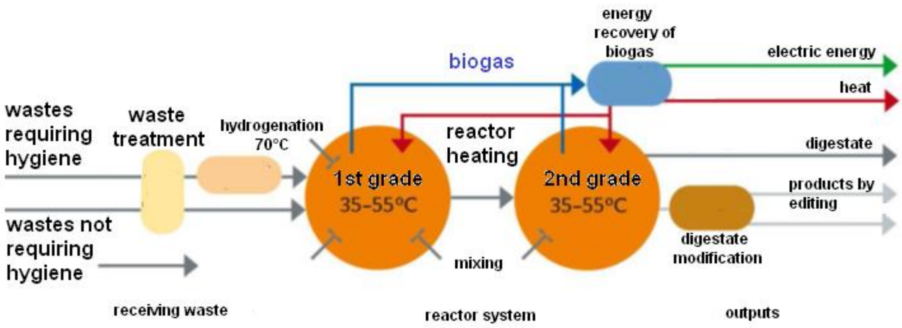

Figure 2 The diagram of the wet anaerobic fermentation process

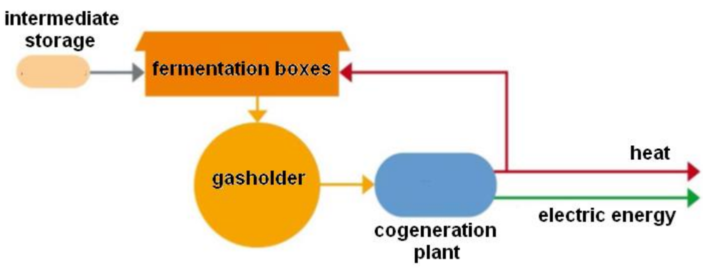

Figure 3 The diagram of the dry anaerobic fermentation process

Table 1 Chemical composition and selected properties of biogas

Chemical composition of biogas								
Biogas component	Methane	Carbon dioxide	Water vapor	Nitrogen	Oxygen	Hydrogen	Ammonia	Hydrogen sulphide
volume %	40 – 75	25 – 55	0 – 10	0 – 5	0 – 2	0 – 1	0 – 1	0 – 1
Selected properties of biogas								
Parameter	Calorific value	Density	Density in relation to air density	Ignition temperature	Range of flammable gas concentration in air		Theoretical need for air	Maximum flame rate in air
Biogas	6 kWh.m^{-3}	1,2 kg.m^{-3}	0,9	700°C	6 – 12%		5,7 m^{3}.m^{-3}	0,25 m.s^{-1}

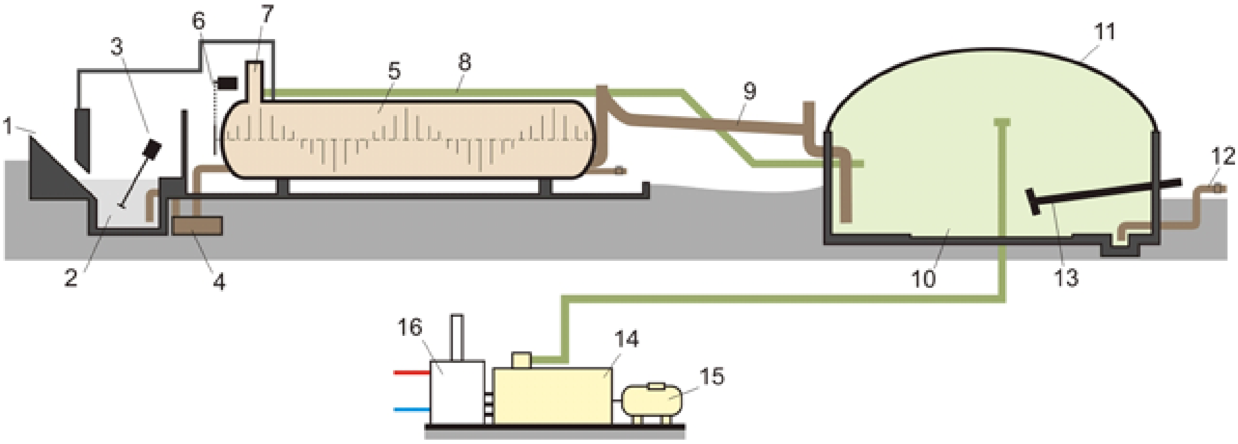

Figure 4 Basic structure of a conventional biogas

1 – hopper; 2 - homogenisation tank; 3 - propeller stirrer; 4 - sludge pump; 5 – fermentor; 6 - mixing fermentor; 7 - gas dome; 8 - gas pipeline; 9 - overflow pipeline; 10 - final storage tank; 11 - membrane gas; 12 - drain pipeline of digestate; 13 - propeller stirrer; 14,15 - cogeneration plant; 16 - heat exchanger.

The table 1 described a chemical composition and selected properties of biogas.
The basic qualitative parameter of biogas is the percentage of methane [11]. The obtained biogas can replace natural gas in practice. It can therefore be used, for example, by means of convection technology equipment for the production of electric or thermal energy [12].

3 Basic technological equipment of biogas plant

For reliable and safe operation of biogas plant technology [13] it is necessary to ensure its quality parts and a suitable monitoring and control system. By using appropriate technical equipment combined with a high-quality monitoring and control system it is possible to achieve its semi-automatic, resp. automatic operation. Current approaches in biogas plant technology are also closely linked to user requirements [14]. Therefore, in addition to safe and reliable operation, the priority is also a long service life. The following figure 4 shows the basic structure of a conventional biogas plant.

The biogas production process begins by dosing the substrate into the dispenser. After adding the required amount of input substrate, it is transferred to the homogenization tank by means of the conveyor. In the homogenization tank, the input substrate is diluted with water. After homogenization to the required density, the substrate is pumped into the fermenter, where the biogas production process begins when the required temperature is reached. In the final phase, the substrate is pumped from the fermenter into the after fermentor and then to the final storage.

4 Weaknesses of current approaches in biogas station technology solutions

In practice it has been observed several deficiencies which concern the biogas plant technological equipment. One of the deficiencies is concerns into the absence of monitoring the density of the substrate in the homogenization tank and the fermentor [15]. Substrate density is one of the important parameter which is associated with the consumption of own electricity produced in a biogas plant. Another major deficiency of current approaches to biogas plant technology solutions is the absence of elements of the monitoring system [16]. It is for example absence of monitoring water flow which is pumped from the collection tank into the homogenisation tank. Water is used to dilute the solid substrate. The amount of water required to dilute the substrate is generally determined only by an estimate of the personnel who must perform the inspection visually. There is often also a missing of monitoring of the amount of liquid residue after fermentation (Fugate). Another problem of the operation of biogas stations is the deficiency of altimeters in fermenters, which serve to monitor the height of the pumped substrate level. During mixing of the substrate in the fermenter, it often happens that the blender throws a piece of substrate over the surface level and the altimeter records it by performing an error message in the monitoring system. A separate group represents a deficiency that is directly related to the energy utilization of the biogas produced [17]. The produced biogas is during a longer shutdown of the cogeneration plant ineffectively burned with a safety burner. In case when the cogeneration plant is shut down and the biogas in the fermenters exceeds the determined fill value then biogas is burned with a safety burner so-called "fakel". This means that biogas is not used and the operator of the process equipment thus loses profit.

5 Designing and implementation changes to eliminate deficiencies in the biogas plant operation

In the event of a complex solution of the above mentioned problems of the biogas station operation it is necessary not only to modernize the technological equipment, but also to innovate the elements of the monitoring and control system. Figure 5 shows innovation proposal of the elements of the monitoring and control system of the biogas plant.

As mentioned above, a separate area of deficiencies in the biogas plant operation is represented deficiencies, which are related to the efficiency of the energy utilization of the produced biogas. These are in particular losses that are caused by the long downtime of the cogeneration plant e.g. turbine generator or power line faults [18]. In this case, the biogas produced is fired by a safety burner due to the safety of the operation of the biogas plant. This burning is necessary to perform in the moment, when the level of the biogas produced in the gas tank above the fermentor is exceeds the limit value. Emergency combustion of biogas has no energy use in that mode and is therefore reported as a loss.

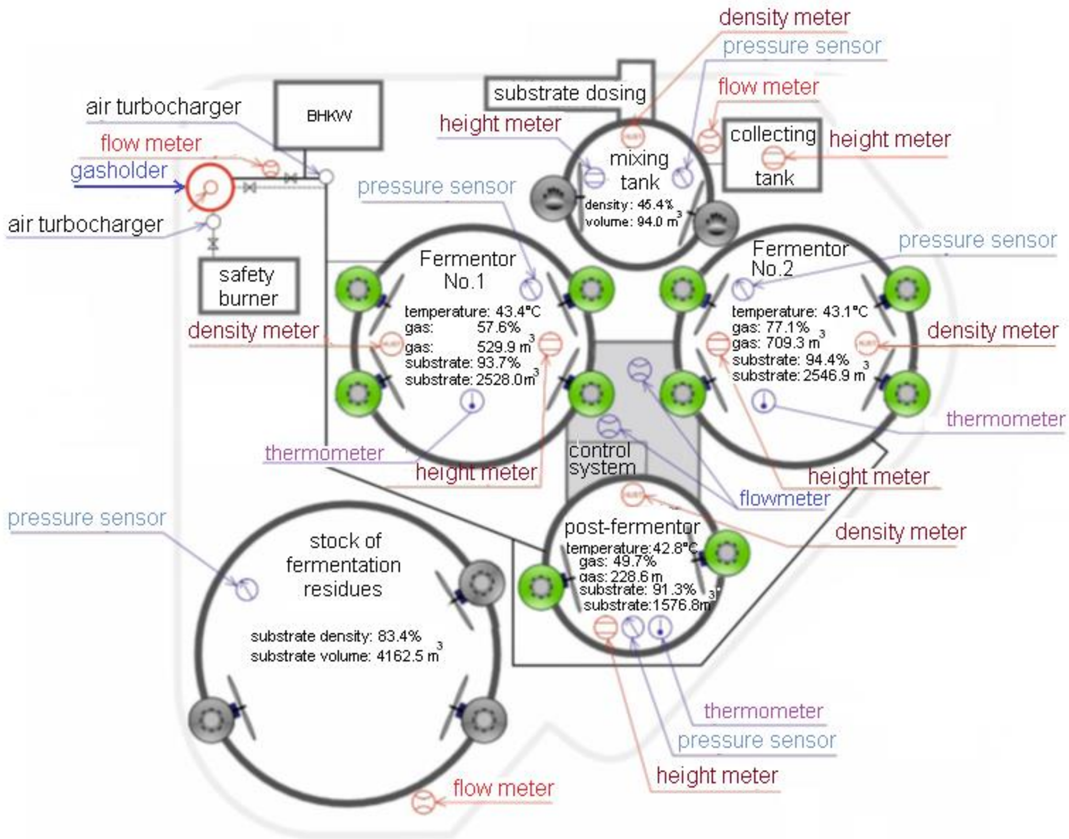

Figure 5 Innovation of the elements of the monitoring and control system of the biogas plant

For eliminate this deficiency must be implemented additional elements of the technological equipment into the system [19]. The main element will be represented by three-membrane gas-holder. The gas pressure in the gas-holder is maintained by air, which is blown between the membranes by the turbocharger. Input air has two functions. The first function maintains a gas overpressure and the second function maintains the permanent shape of the outer membrane, what it creates protection against weathering. The gas-holder size is dependent on the amount of biogas produced in the fermentor per unit time and the time required to cover the downtime of the biogas plant technological equipment intended for the consumption of the biogas produced. The figure 6 shows a three-membrane ball-shape gas-holder.

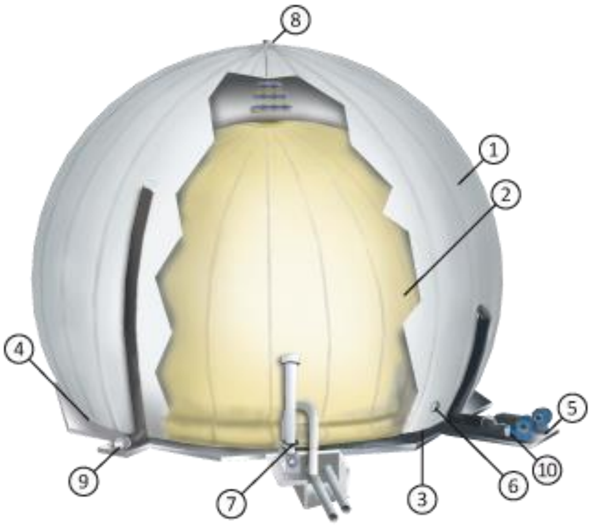

Figure 6 Ball-shape gasholder [21]

1 - outer membrane; 2 - inner membrane; 3 - floor membrane; 4 - anchoring frame; 5 - supporting turbocharger; 6 - peephole; 7 - liquid fuse; 8 - measurement of filling; 9 - regulation valve; 10 - return valve

In the event of a cogeneration plant shutdown, biogas will be transported from the fermentor into the gas-holder using a stainless steel pipeline. The direction of the biogas flow will be controlled by means of a three-way valve. The first branch represents the original solution. The second branch represents an innovative part which will be connected via a turbocharger to a back-up three-membrane gas-holder. In the case of a forced shutdown of the cogeneration plant the control unit sends a signal to the three-way valve to close branch no. 1 and opening of branch no. 2 along with the launch of the turbocharger. Only after the backup gas-holder has been filled and the still persisting shutdowns of the cogeneration plant the biogas will be burned with a safety burner. Figure 7 shows a flowchart which describes the upgrading of the biogas plant operating mode.

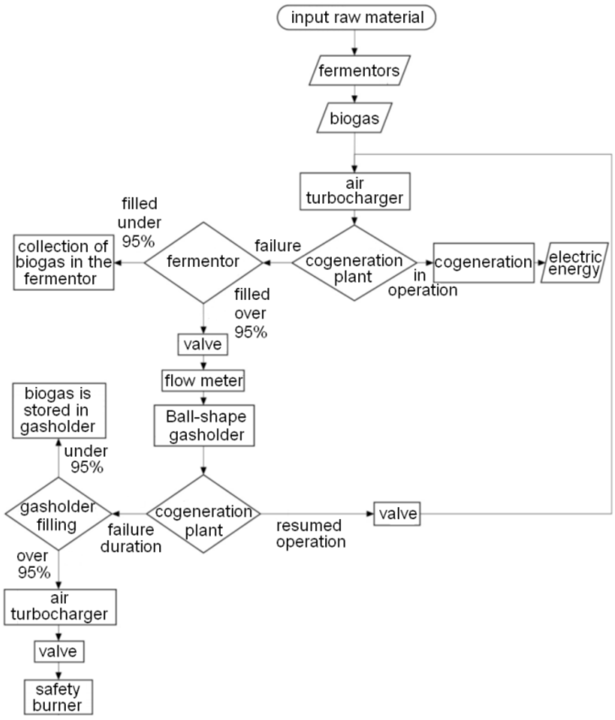

Figure 7 Flowchart proposed of designed innovation of the biogas plant operating mode

After reintegration of the cogeneration plant it is possible the biogas from a backup gas-holder use in case of a lack of biogas production in the fermentor. At the same time, the proposed solution will contribute to higher stability and efficiency of the biogas plant operation.

Conclusions

The aim of the paper was to propose an innovation of the current approach in the technical solution of the technological equipment configuration of the biogas plant in order to increase the economic efficiency of their operation. Innovation also involves the design of suitable sensors necessary for monitoring and control of the upgraded biogas station operating mode. Implementation of the proposed technical solution in practice can reduce losses which arise as a result of the cogeneration plant failure. The proposed solution also allows for the continuous operation of the cogeneration plant even in case of a failure or maintenance fermentor. With these innovations, an operator of a biogas plant can reduce its losses in case of failure on a cogeneration plant or a fermentor and also increase the amount of electricity and heat produced. In case of innovation the monitoring and control system of the biogas plant, almost unattended operation can also be achieved, which also contributes to a significant improvement in economic indicators.

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