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DESIGN OF LABORATORY CYCLONE SEPARATOR FOR BIOGAS PURIFICATION

Marián Fodora, Ján Gaduš, Jan Mareček, Tomáš Vítěz, Viera Kažimírová

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Abstract

FODORA MARIÁN, GADUŠ JÁN, MAREČEK JAN, VÍTĚZ TOMÁŠ, KAŽIMÍROVÁ VIERA: *Design of laboratory cyclone separator for biogas purification.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 3, pp. 631–635

This article deals with calculation of a cyclone separator for biogas purification using physical and chemical methods. There is presented a methodology for determination of operating dimensions of the cyclone separator and description of principal features of the cyclone separator model. Calculations have been performed for the diameter of the cylindrical part of cyclone separator 175 mm and for the biogas volume flow rate $6.9 \cdot 10^{-5}$ $m^3 \cdot s^{-1}$. The calculations can be used in practice for the design of cyclone separator depending on the flow rate of biogas, size of the biogas plants respectively. The developed cyclone separator has been used for the cleaning of biogas in operating conditions at the biogas plant in Kolinany (Slovakia). The presented method of biogas purification has been used for the removing of hydrogen sulphide, particulate matter and carbon dioxide from the raw biogas at the biogas plant. Removal of these undesirable impurities from the biogas is an important step in the production of a fully valued fuel, biomethane.

biogas purification, physical-chemical method, construction design of cycloneseparator

Trends in the development of methods for purification and conversion of raw biogas to the efficient fuel, biomethane, which may, according to its properties, fully replaced natural gas are mainly influenced by the growth in fossil fuel prices and their gradual decline (Janíček *et al.*, 2007; Deublein and Steinhauser, 2008). The difference between biogas and natural gas is mainly in its composition. The biogas contains lower proportion of methane and higher proportion of H_2S, up to a limit of 1% (10000 ppm) according to the natural gas (Kohl and Nielsen, 1997; Coulson and Richardson, 2002). The production of biomethane depends on quality of purification and conversion of biogas, so the methane content in the treated gas - biomethane would be about 95 % CH_4 (Straka *et al.*, 2007; Coulson and Richardson, 2002).

For the biogas purification and conversion different methods based on the adsorption, absorption, chemical and biological principle are used at the biogas stations. The most commonly method used for the biogas purification based on physical principle is a technology of water scrubber, which uses the absorption of CO_2 and H_2S to the liquid medium – water at a pressure of 1000 kPa (Ryckebosch *et al.*, 2011).

The chemical absorption methods include amine (MEA – monoethanolamine, DEA – diethanolamine and MDEA – methyldiethanolamine) and glycolic wash gas (Kohl and Nielsen, 1997). The biogas cleaning, mainly from H_2S impurities by solid adsorbents can be done by the physical and chemical principle (Fodora *et al.*, 2012; Kohl and Nielsen, 1997). Well known methods of purification are the methods of adsorption during the pressure change (Pressure swing adsorption), the temperature change (Temperature swing adsorption) and at the vacuum (Vacuum swing adsorption). The less known method for incremenent of the methane content in the biogas is membrane and cryogenic separation and biological methods (Coulson and Richardson, 2002; Kohl and Nielsen, 1997).

Based on a critical review of published information's about biogas purification technology, it was decided to use cost-effective alternative of adding oxygen to ensure biogas desulphurisation for experiments. Desulphurisation has been conducted by using microorganisms which have been used, as a source of energy for their metabolism needs, hydrogen sulphide while producing elementar sulphur and sulphate (Fodora *et al.*, 2012). For the microorganisms needs it is necessary to dose the fermentor with air (oxygen) in an amount generally from 6% to 12% of volume flow of the biogas (Urban *et al.*, 2009). The necessary amount of oxygen is determined by stoichiometric reaction equation of the existing amount of hydrogen sulphide.

Range of methane explosibility with the air is commonly referred to the value 5–15% vol. of CH_4 (Straka *et al.*, 2007). The great advantage of the biogas is a fact, that carbon dioxide (CO_2) decreases in it the limits of the explosibility. The aim of our work was to design a filter device in the shape of a cyclone, which will ensure a perfect blend of biogas and atmospheric oxygen mixture, where the chemical reaction has been run. After the reaction of hydrogen sulphide with oxygen, incurred elemental sulphur has been settled in the conical part of the cyclone separator, which was caused by vertical flow in the cyclone separator. For the testing at the site (biogas station Kolinany) the cyclone separator has been inoculated by bacteria of genus *Thiobacillus*, respectively naturally settled cultures of bacteria brought in by the flow of raw biogas has been used.

Simple design and related low cost of operation and maintenance, and high reliability is the reason that cyclone separators are very often used in pneumatic transport facilities and for the separation of the solid particles. The most common and simplest configuration of the cyclone separator is a tangential cyclone with slotted inlet, where the gas flows tangentially on the outside through the slot (Vavro and Hodúr, 1996). Technically better and more affordable solution is the cyclone separator with spiral inlet. Another option is an axial inlet, where the gas axially entering the cyclone separator is regulated through the use of deflector plate to the desired rotation. The upper part of cyclone separator space is cylindrical, the lower portion is generally conical and other parts are also cylindrical (Hillers, 2009).

MATERIALS AND METHODS

The next section describes the calculation of the basic parameters and dimensions of the cyclone separator with tangential inlet and axial outlet through an overflow cylindrical pipe (Vavro and Hodúr, 1996). The basic geometrical dimensions of the cyclone separator has been diameter of the cylindrical part, which was $D_c = 175$ mm.

The shape of the cyclone can be determined by the values of simplex:

$$\frac{D_c}{D_p} = 2 \; till \; 4 \Rightarrow D_p = \frac{175}{4} = 43.75 \; mm \qquad (1)$$

$$\frac{D_k}{D_p} = 0.2 \; till \; 1.1 \Rightarrow D_k = D_p \times 1.1 = 43.5 \times 1.1 = 48.13 \; mm \qquad (2)$$

The height of cylindrical H_v and conical H_k of separating space can by calculated:

$$\frac{H_v}{D_c} = 0.5 \; till \; 2 \Rightarrow H_v = 175 \times 2 = 350 \; mm \qquad (3)$$

$$\frac{H_k}{D_c} = 2 \; till \; 4 \Rightarrow H_k = 175 \times 2 = 350 \; mm\,. \qquad (4)$$

The total height of the cyclone separator can by calculated:

$$H_c = H_k + H_v = 350 + 350 = 700 \; mm \qquad (5)$$

$$H_c = 2.5 \; till \; 6 \Rightarrow H_c = 4 \times D_c = 4 \times 175 = 700 \; mm\,. \qquad (6)$$

Overflow pipe insertion depth into the cylindrical part of cyclone separator can be calculated:

$$\frac{H_p}{D_p} = 1.5 \; till \; 3 \Rightarrow H_p = 3 \times D_p = 3 \times 43.75 = 131.25 \; mm \qquad (7)$$

The cone angle κ_k can be calculated:

$$\kappa_k = 2 \times arctg \cdot \left(\frac{(D_c - D_k)}{D_p} \right) =$$

$$= 2 \times arctg \cdot \left(\frac{175 - 48.125}{2 \times 350} \right) = 20°32'\,. \qquad (8)$$

For the axial distance h_0, based on the fulfilment of the condition $D_k > D_p$, the following equation may be used:

$$h_0 = H_v - H_p + H_k = 350 - 131.25 + 350 = 568.75 \; mm\,. \qquad (9)$$

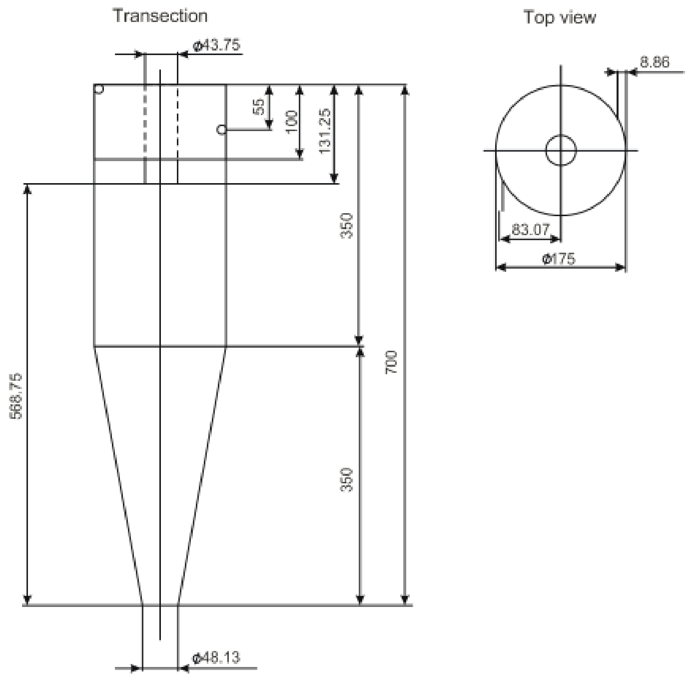
Surface area of the inlet pipe for tangential cyclone separator can be calculated as a surface area of a rectangle:

$$A_e = B_e \times H_e = 8.8622 \times 8.8622 = 78.54 \; mm^2\,. \qquad (10)$$

For the circular inlet diameter of D_e is counted in the calculation with equivalent square (rectangular) cross-section of the inlet, equivalence will be according to the flow area:

$$B_e = H_e = D_e \times \frac{\sqrt{\pi}}{2} = 10 \times \frac{\sqrt{\pi}}{2} = 8.86 \; mm\,. \qquad (11)$$

Drawing of cyclone separator with marked dimensions calculated is shown in Fig. 1.



1: *The computational model of the cyclone separator*

According to the Vavra and Hodúr (1996), an important operating parameter is the value of tangential input velocity component of the mixture to the separating space of the cyclone u_e, which is defined by the proportion values:

$$u_e = \frac{\dot{V}_e}{A_e} = \frac{6.94\times10^{-5}}{7.85\times10^{-5}} = 0.8841\, m\cdot s^{-1}, \tag{12}$$

where:
V_e .....volumetric flow rate of the mixture, [$m^3 \cdot s^{-1}$]
A_e .....surface area of the inlet pipe for tangential cyclone separator, [m^2].

We do expect supply of the biogas to the system at a volume flow of $6.9\cdot10^{-5}$ $m^3\cdot s^{-1}$.

Hillers (2009) describes the basic methods of flow in a cyclone separator.

For the flow rate is valid:

$$\dot{V} = 2\times\pi\times r\times h\times v_r =$$

$$= 2\times3.14\times0.0875\times0.350\times0.000361 = 6.94\times10^{-5}\ m^3\cdot s^{-1} \tag{13}$$

Alternatively for the radial velocity:

$$v_r(r) = \frac{\dot{V}}{2\times\pi\times r\times h} =$$

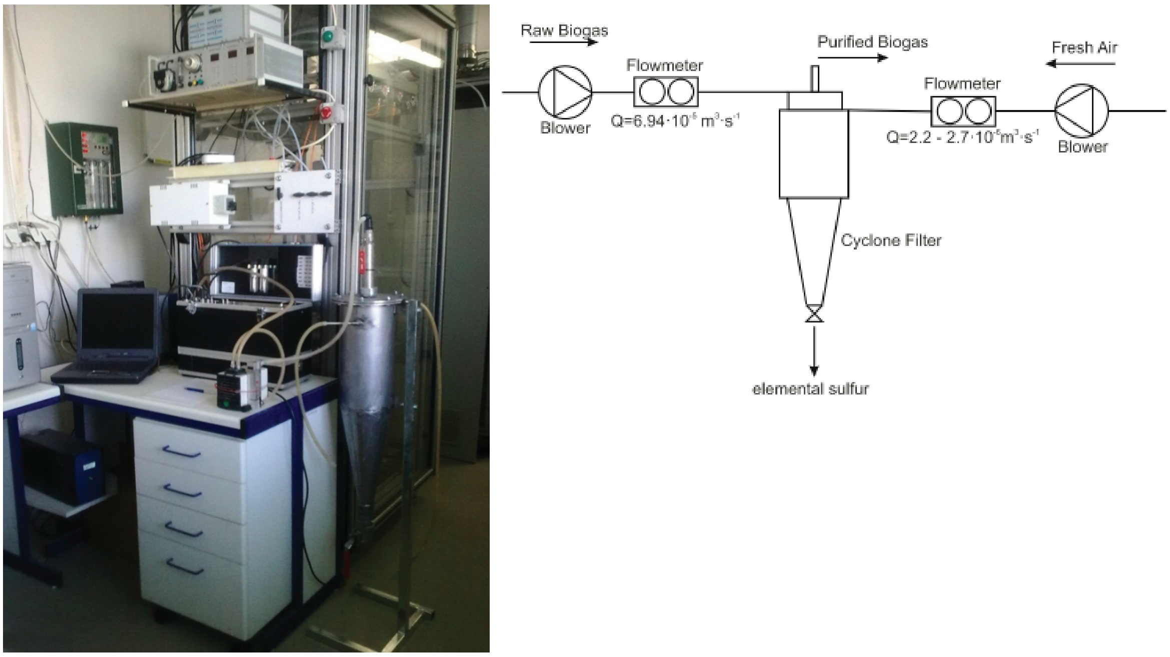
$$= \frac{6.944\times10^{-5}}{2\times3.14\times0.0875\times0.350} = 0.000361\, m\cdot s^{-1}, \tag{14}$$

where:
$v_r(r)$ ..radial flow rate depending on the radius, [$m\cdot s^{-1}$]
r........radius of the cylindrical part, [m]
h.......height of the cylindrical part (cylinder), [m]
V.......flow rate, [$m^3\cdot s^{-1}$].

The experimental cyclone separator has been installed at the biogas plant Kolinany (Slovakia), Fig. 2. Series of test measurements in operating conditions are in progress at the moment.

Biogas analyzer Shmack SSM 6000 with the measurement range CH_4 0–100%, H_2S 0 ppm – 5000 ppm, CO_2 0–100%, O_2 0–25% has been used for the quality measurement of raw biogas, which was pumped into the system by using the compressor KNF N035 STE. Flowmeter with flow regulator was supply the biogas at flow volume of Q = $6.9\cdot10^{-5}$ $m^3\cdot s^{-1}$ with subsequent flow into the cyclone separator.

To control the flow of biogas to the system KOBOLD KDG1232RV000 flow meter with operating parameters ($6.9\cdot10^{-5}$ $m^3\cdot s^{-1}$, 0.12 MPa, 20 °C) and a flow regulator BRONKHORST Hi-Tec type E-7100-AAA have been used. From the opposite side, the clean air as a source of oxygen needed at Q_{max} = $2.2\cdot10^{-6}$ $m^3\cdot s^{-1}$ – $2.7\cdot10^{-6}$ $m^3\cdot s^{-1}$, corresponding to 4% vol. – 6% vol. of flow volume of biogas has been pumped in. Analyzer MADUR GA-21 plus has been used to determine and monitor the quality of biogas (CH_4, CO_2, H_2S, O_2). The quality of purified biogas has been recorded and compared with the quality of raw biogas, by which will the effect of this experimental biogas purification device has been verified.



2: *Cyclone separator and measuring devices in operation at the biogas station Kolinany*

RESULTS AND DISCUSSION

The proposed device operating on the principle of cyclone filter meets all the requirements for the operation at the biogas plant. Cyclone separator design provides the perfect mixture of both gaseous phase (biogas and atmospheric oxygen). The rotary motion of the gaseous components in the separator allows the perfect mixture of gases and consequently there is a more complete chemical reaction of hydrogen sulphide with oxygen, while the degradation of hydrogen sulphide to elemental sulphur. First results obtained by using of experimental device, cyclone separator, at the biogas plant in Kolinany indicated that the device is ready for operating and the geometric dimensions for the quantity and composition of the biogas have been selected correctly. This was proved by results of removal hydrogen sulphide, particulate matter and carbon dioxide from the raw biogas at the biogas plant.

SUMMARY

The authors of the article deal with the design of cyclone separator for purification of the biogas based on physical and chemical methods. In the article there is presented the methodology for calculating of cyclone separator dimensions and description of the principle features of the model cyclone separator. The authors dealt with the design of the measuring system and the involvement of filtration device in operating condition at the biogas station Kolinany. This method of purification of biogas has been used to remove hydrogen sulphide, particulate matter and carbon dioxide from the raw biogas at the biogas plant. Separation of these undesirable impurities in the biogas is an important step in the production of a biomethane.

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Address

Ing. Marián Fodora, prof. Ing. Ján Gaduš, Ph.D., Research Centre for Renewable Energy Sources, Ing. Viera Kažimírová, PhD., Department of Production Engineering, Slovak University of Agriculture in Nitra, Trieda A. Hlinku 2, 949 76 Nitra, Slovak Rerpublic, prof. Ing. Jan Mareček, DrSc., Ing. Tomáš Vítěz, Ph.D., Department of Agriculture, Food and Environmental Engineering, Mendel University in Brno, Zemědělská 1, 613 00, Brno, Czech Republic, e-mail: m.fodora@gmail.com, jan.gadus@uniag.sk, marecekj@mendelu.cz, vitez@mendelu.cz, Viera.Kazimirova@uniag.sk