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Combined use of coal mine gases for efficient energy generation

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Abstract There are two basic types of coal mine gases: gas from demethanation of coal deposits, and ventilation gas; containing combustible ingredients (mainly methane, CH_4). Effective use of these gases is an important technical and ecological issue (greenhouse gas emissions), mainly due to the presence of methane in these gases. Serious difficulties in this area (e.g. using them as the fuel for internal combustion (IC) engine) occur mainly in relation to the ventilation gas, whereas the gas from demethanation of coal deposits can be used directly as the fuel for internal combustion engines. The proposed solution of this problem shows that the simple mixing of these two gases (without supplying of oxygen from ambient air) is the effective way to producing the gaseous combustible mixture, which can be used for the fueling of internal combustion gas engines. To evaluate the energy usefulness of this way produced combustible mixture the process indicator has been proposed, which expresses the share of the chemical energy supplied with the ventilation gas, in the whole chemical energy of the produced fuel combustible mixture. It was also established how (e.g., by appropriate choice of the mixed gas streams) can be achieved significantly higher values of the characteristic process indicator, while retaining full energy usefulness of the gained gaseous mixture to power combustion engines.

Keywords: Mine firedamp gases; Preparing of flammable mixture; Fuelling of IC engines

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1 Introduction – general characteristics of the issue

In areas belonging to coal mines remain at the disposal two main process gases (containing combustible ingredients – mainly methane, CH_4; next other components: nitrogen, N_2, and oxygen, O_2, in proportion as in the air [1–3]):

- gas from demethanation of coal deposits (with the methane content about $CH_{4,p} \approx 50\%$, at dry gas state, which often constitutes a serious fire hazard in the mine),
- ventilation gas (methane content $CH_{4,w} \leq 1.0\%$, at dry gas state, most commonly lead out through ventilation shafts into the environment).

Effective and reasonable use of these gases is an important technical and ecological issue (greenhouse gas emissions), mainly due to the presence of methane in these gases [4,5]. Serious difficulties in this area (e.g. using them as the fuel for internal combustion (IC) engine) occur mainly in relation to the ventilation gas, whereas the gas from demethanation of coal deposits can be used directly as the fuel for IC engines [6–8].

By analyzing the chemical composition of the mine gases in terms of the basic stoichiometric conditions of the combustion process – it can be stated, that in the typical ventilation gas the amount of oxidant (air, oxygen O_2) is present in large excess (or deficient of appropriate combustible components, mainly methane in relation to stoichiometric needs. A different situation is characterized by utilization of the gas from demethanation of coal deposits; the main combustible component methane occurs in relative stoichiometric excess, which means that for the full and complete combustion of this gas an additional amount of oxidant (air, oxygen O_2) should be supplied into the combustion chamber [2,9]. In view of the above it was noted, that it is possible to prepare the good gas combustible mixture (mainly in the aspect of the appropriate oxygen excess ratio, λ [7,8]) – by adequate mixing of the ventilation gas stream with the gas stream from demethanation of coal deposits.

The analysis presented in the paper refers to desirability of the implementation of a properly organized mixing process of the gas stream from demethanation of coal deposits with the adequate stream of the ventilation gas; and of course all without downloading additional air (oxygen O_2) from the environment.

For assessment of the energy usefulness of the specific produced gas fuel mixture special process indicator, Ω, is defined, which value expresses the share of the chemical energy supplied with the ventilation gas, $E_{ch,w}$, in the whole chemical energy, $E_{ch,m}$ of the produced gas fuel combustible mixture. An complex analysis of the values thus defined process indicator was done, and on this way successfully confirmed its practical usefulness in the complex investigation of the whole issue.

2 Basic stoichiometric conditions for the flammable gas mixture

Any portion of the mine gas (ventilation, as well as demethanation gas) may be treated in general as a mixture of the methane, CH_4, and air (main components: oxygen, O_2, and nitrogen, N_2).

The combustion of the main combustible component (methane of the mine gas takes place according to the scheme

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \; , \tag{1}$$

which means that the specific minimum oxygen demand for the methane is

$$n_{ox,\min} = 2\,\mathrm{kmol}_{O_2}/\mathrm{kmol}_{CH_4} \; , \tag{2}$$

while the specific minimum demand of the air, respectively

$$n'_{a,\min} = 2/0.21\,\mathrm{kmol}_{\mathrm{air}}/\mathrm{kmol}_{CH_4} = 9.524\,\mathrm{kmol}_{\mathrm{air}}/\mathrm{kmol}_{CH_4} \; . \tag{3}$$

The real combustion process takes place at a certain excess of the air (so also the oxygen O_2), which is expressed by the air excess ratio $\lambda \geq 1$ [6,7]. Therefore, the actual specific amount of air supplied is

$$n'_a = \lambda\, n'_{a,\min}, \quad \text{so also the oxygen} \quad n'_{ox} = \lambda\, n_{ox,\min} \, . \tag{4}$$

The real content of the methane in the prepared flammable gas mixture equals

$$z_M = \frac{1}{(1 + \lambda\, n'_{a,\min})} \; , \tag{5}$$

and because n'$_{a,\min}$ = 9,524 kmol$_{air}$/kmol$_{CH_4}$ can be rewritten as

$$z_M = \frac{1}{(1 + 9.524\,\lambda)} \; . \tag{6}$$

Interdependence of stoichiometric parameters (z_M, $\lambda \geq 1$) conditioning the correctness of the combustion process, and resulting directly from formulas (5) and (6) are illustrated in Fig. 1.

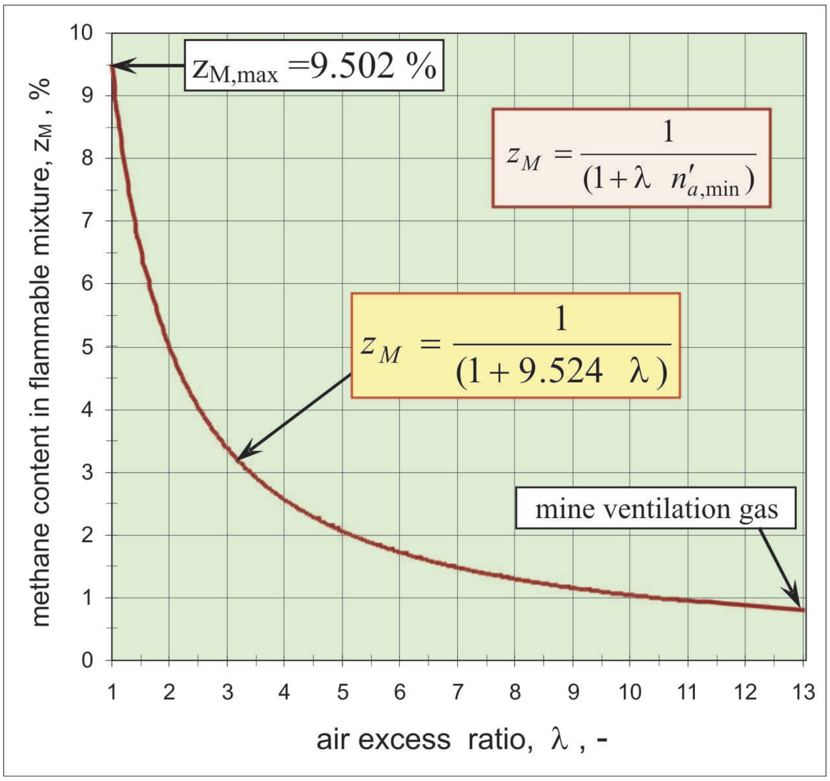

Figure 1: Stoichiometric parameters of the methane combustion mixture.

The maximum value of the methane content in the flammable mixture, $z_{M,\max}$, is obtained for $\lambda = 1$, and next after using Eq. (6) the standard value is obtained: $z_{M,\max} = z_{M,\lambda=1} = 9.502\%$. From this follows a significant limitation $z_M \leq z_{M,\max}$, whereby the maximum value $z_{M,\max}$ is obtained for the so-called stoichiometric mixture (at the value: $\lambda = 1$).

The above observation indicates that the methane content, z_M, in real, good prepared (in the aspect of the oxygen excess ratio, λ) flammable mixtures does not exceed the predetermined value $z_{M,\max} = 9.502\%$, because otherwise the combustion would be deficient (the presence of carbon monoxide, CO, in the exhaust gas), and even incomplete (the soot appears in combustion products).

The gas air-methane mixture with a slightly higher content of methane CH_4, it means at $z_M > z_{M,\max}$ can also be ignited (it is also usually a serious mine explosion hazard); however, a combustible mixture by more than stoichiometric participation of methane should not be directly used [7,8] for fueling of different energy plants (e.g., boilers, gas turbines, internal combustion engines).

3 Preparation and use of the mine gas combustible mixture

Basic mine gases differ in chemical composition (especially in the methane content), so consequently in the calorific value and its energy usefulness [7]. The typical ranges of the methane content are [6,9]: $z_{M,w} = 0.5$–1.2% – in the ventilation gas; $z_{M,p} = 40$–60% – gas from demethanation of coal deposits. As average values (typical for the Silesian Mining Region, in Poland) used next for presented exemplary calculations are taken: $z_{M,w} = 0.8\%$ and $z_{M,p} = 50\%$.

By analyzing the chemical composition of the mine gases in terms of the basic stoichiometric conditions of the combustion process it can be stated, that in the case of typical ventilation gas the amount of oxidant (air, oxygen) is present in large excess (or deficient of combustible component, methane) in relation to stoichiometric needs. Meanwhile by utilization of the gas from demethanation of coal deposits the main combustible component methane occurs in relative excess (because usually the methane content $z_{M,p} > z_{M,max}$), which means that for the full and complete combustion of this gas an additional specific amount of oxidant (air, oxygen) should be supplied into the combustion chamber. Therefore should be noted, that it is possible to prepare the good gas combustible mixture (mainly in the aspect of the oxygen excess ratio $\lambda \geq 1$), by adequate mixing of the ventilation gas stream with the gas stream from demethanation of coal deposits; and of course all without downloading additional air (oxygen) from the environment.

The base system for preparing of the flammable mixture using the gas stream from demethanation of coal deposits and adequate stream of the ventilation gas is shown in Fig. 2.

Combustible mixture prepared on this way (by mixing of the ventilation gas with the gas from demethanation of coal deposits) can be next effectively used for fueling of the combustion engines.

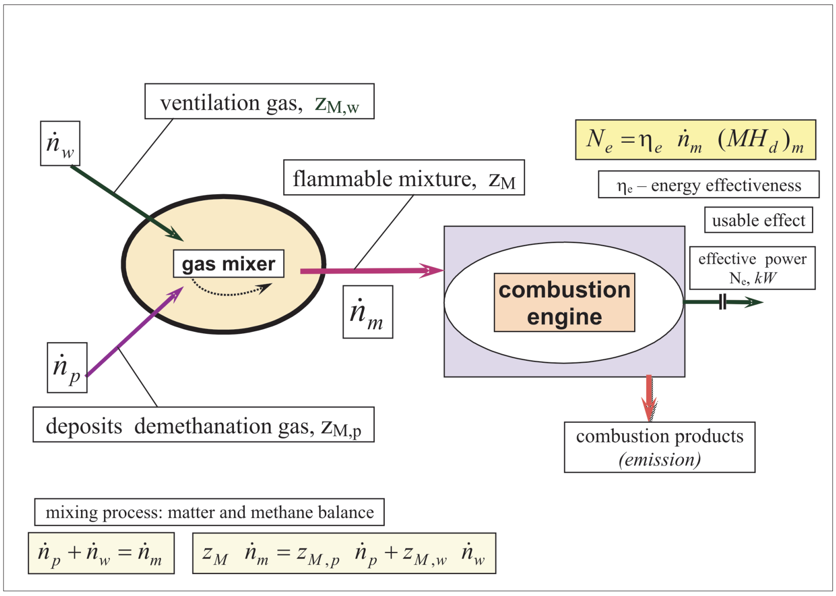

Figure 2: Preparing of the mine gas combustible mixture with fueling of IC engine.

Internal combustion engines (both spark and compression ignition) are fuelled mostly with classic liquid fuels (petrol – for spark ignition (SI), diesel oil – for compression ignition (CI)) [3,7]. The classic system of the spark ignition combustion engine is presented in the Fig. 3. In case of spark ignition engines, in which the ignition of the earlier prepared vaporised fuel-air mixture is realised by the spark energy source, the liquid fuel (petrol) can be totally replaced by the gas fuels practically without additional troubles. This possibility is essentially restricted in case of compression ignition engines, because ignitability of the gaseous fuels is mostly not so good as ignitability of the diesel oil.

Self-ignition of the gas fuels appears only at considerable higher temperatures in comparison to self-ignition of classical diesel oil. Adequate solution, if this problem can be practically achieved by using of the dual fuelling system is illustrated in Fig. 4.

The diesel engine will be basically filled out with the gas fuel, but for ignition of the prepared fuel gas-air mixture a specified, minimal amount of the liquid fuel (diesel oil) should be at first additionally injected into the combustion chamber [7,8].

The lower heating value of the pure methane equals $(MH_d)_M = 802.32$

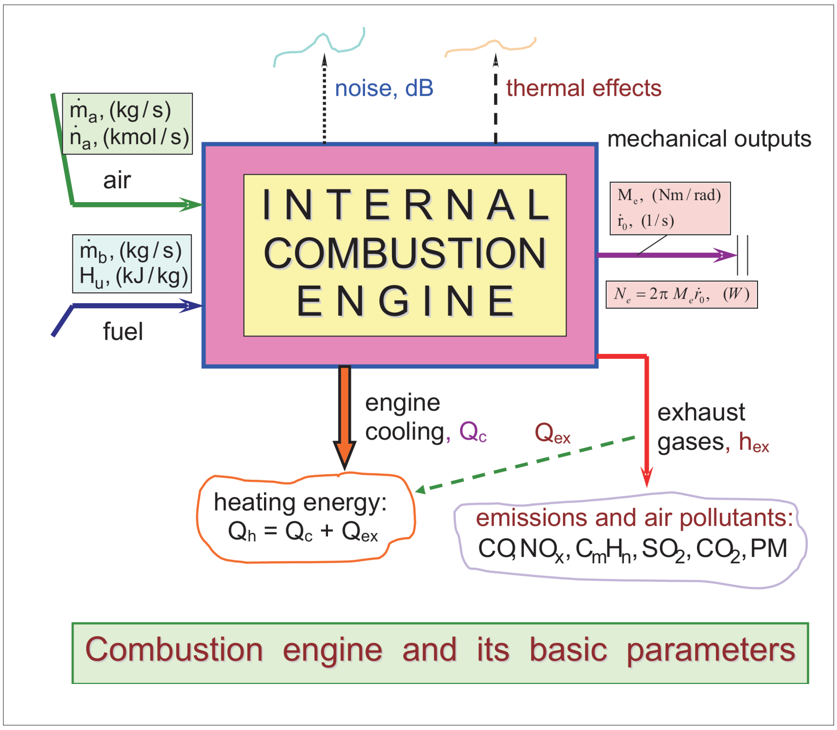

Figure 3: Classic system of the spark ignition (SI) combustion engine.

MJ/kmol$_{\mathrm{CH_4}}$, and therefore adequate $(MH_d)_w \approx 8.826$ MJ/kmol$_{gas}$ $\approx$ 394.02 kJ/m^3_n for the ventilation gas, and for the gas from demethanation of coal deposits: $((MH_d)_p \approx 381.10$ MJ/kmol$_{gas}$ ≈ 17013.39 kJ/m^3_n.

As regards to the methane stoichiometric mixture ($\lambda = 1$), for which the value of methane content $z_M = z_{M,\max} = 9.502\%$, its caloric value equals $(MH_d)_{\mathrm{mix},\lambda=1} = 76.24$ MJ/kmol$\approx$ 3403.41 kJ/m$^3_{n\mathrm{mix}}$.

This specific indicator is particularly relevant to the possibility and the efficiency use of this fuel for effective powering [8] of IC engines.

4 Basic dependences and balance ralations

The basic stream of the produced flammable mixture $\dot{n}_m$ is the sum of two basic gas streams ($\dot{n}_p$, $\dot{n}_w$) flowing into the system, (Fig. 2)

$$\dot{n}_m = \dot{n}_p + \dot{n}_w \,. \tag{7}$$

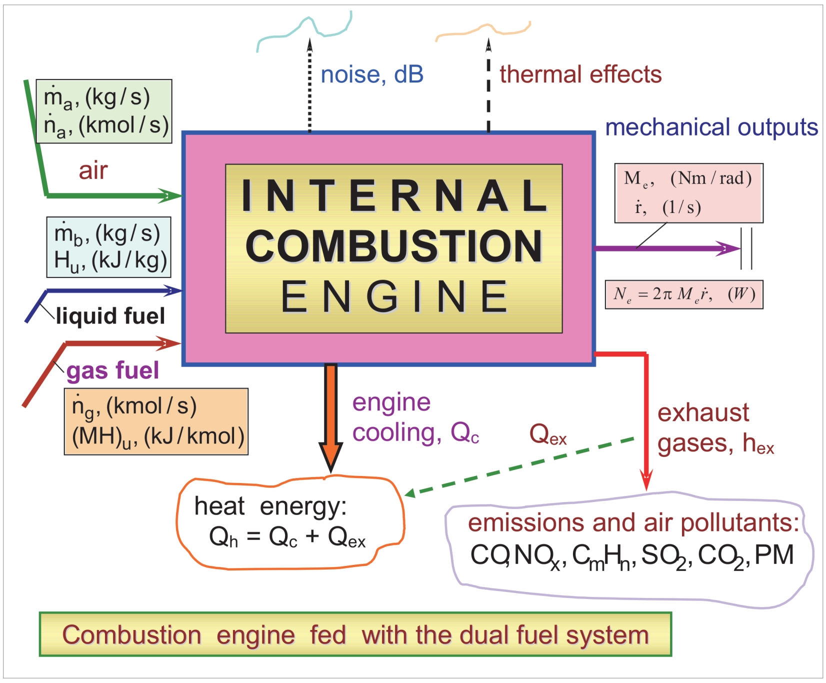

Figure 4: Compression ignition (CI) combustion engine with a dual fuel supply system.

The substance balance of the methane for the mixing process obtains the relationship

$$z_{M,p}\,\dot{n}_p + z_{M,w}\,\dot{n}_w = z_{M,m}\,\dot{n}_m\,, \tag{8}$$

where: $z_{M,m}$, – content of the methane in the produced flammable mixture, $z_{M,w}$, – methane content in the ventilation gas, $z_{M,p}$, – content of the methane in the gas from demethanation of coal deposits.

Connecting the balance relations (7) and (8) the content of the methane in the produced combustible mixture takes the form

$$z_{M,m} = \frac{1}{\dot{n}_p + \dot{n}_w}\left(z_{M,p}\,\dot{n}_p + z_{M,w}\,\dot{n}_w\right), \tag{9}$$

and finally

$$z_{M,m} = \frac{1}{1+\left(\frac{\dot{n}_p}{\dot{n}_w}\right)}\left[z_{M,w} + z_{M,p}\left(\frac{\dot{n}_p}{\dot{n}_w}\right)\right] \tag{10}$$

From relation (10) can be concluded, that by increase of the relative amount of the gas from demethanation of coal deposits $(\dot{n}_p/\dot{n}_w)\uparrow$, increases the share of the methane $z_M \uparrow$ in the flammable mixture, up to the limit value $z_{M,\max} = z_{M,\lambda=1} \approx 9.502\%$. This relation is illustrated in Fig. 5.

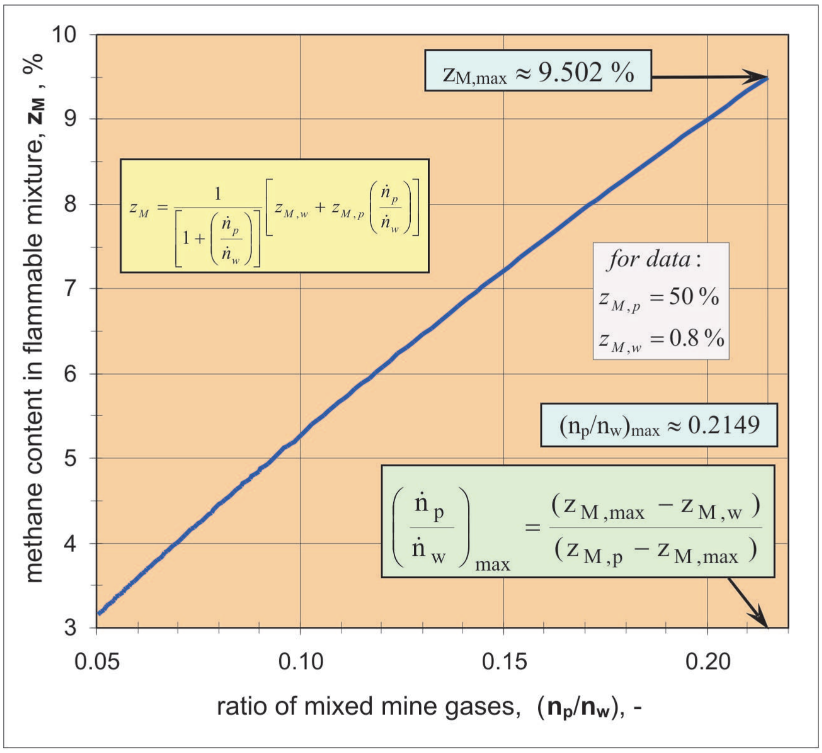

Figure 5: Influence of mine gases relative amount on the methane share in the combustion mixture.

The limitation (6) should be taken into account, which together with relation (10) enables to determine the maximum value of the relative mine gas amount

$$\left(\frac{\dot{n}_p}{\dot{n}_w}\right)_{\max} = \frac{z_{M,\max} - z_{M,w}}{z_{M,p} - z_{M,\max}}, \tag{11}$$

whereby the value $z_{M,max} = z_{M,\lambda=1} \approx 9.502\%$, whence it follows also $(n_p/n_w)_{max} \approx 0.2149$.

Connecting Eqs. (5) and (11) following relationship is obtained

$$\lambda = \frac{\left[(1 - z_{M,w}) + (1 - z_{M,p})\left(\frac{\dot{n}_p}{\dot{n}_w}\right)\right]}{n'_{a,\min}\left[z_{M,w} + z_{M,p}\left(\frac{\dot{n}_p}{\dot{n}_w}\right)\right]}, \tag{12}$$

which allows to determine the actual value of the air excess ratio ($\lambda \geq 1$); whereby parameter used $n'_{a,min} \approx 9.524$ kmol$_{air}$/kmol$_{CH_4}$, and the another typical values of representative characteristic parameters can be taken as $z_{M,w} = 0.8\%$ and $z_{M,p} = 50.0\%$.

In order to achieve the assumed value of the air (oxygen) excess ratio $\lambda \geq 1$ should be, using Eq. (12), respectively, choose the quotient of mine gas streams as

$$\left(\frac{\dot{n}_p}{\dot{n}_w}\right) = \frac{1 - z_{M,w}\,(1 + \lambda\, n'_{a,\mathrm{min}})}{z_{M,p}\,(1 + \lambda\, n'_{a,\mathrm{min}}) - 1}, \quad \lambda \geq 1\,, \tag{13}$$

while limiting $(\dot{n}_p/\dot{n}_w) \leq (\dot{n}_p/\dot{n}_w)_{max}$ resulting from Eq. (11).

Basing on Eq. (13) the influence of the assumed value of the air excess ratio $\lambda \geq 1$, on the value of the analyzed relative mine gas streams $(\dot{n}_p/\dot{n}_w) \leq (\dot{n}_p/\dot{n}_w)_{max}$ is depicted in Fig. 6.

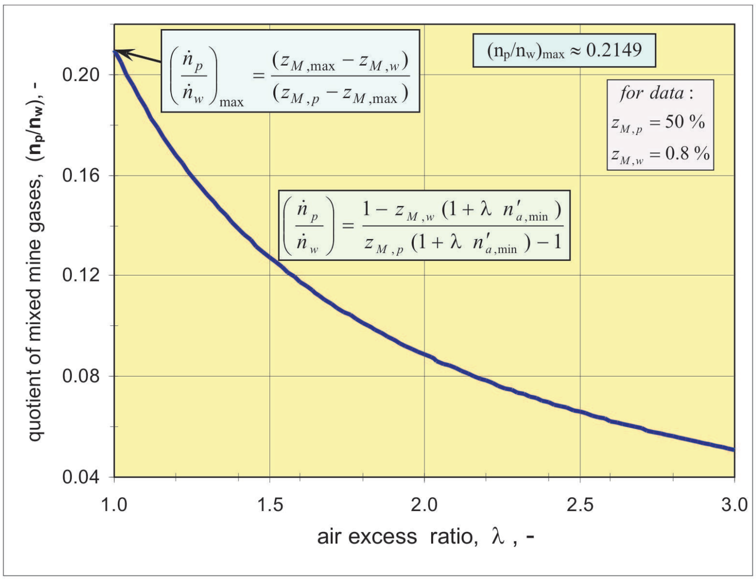

Figure 6: Influence of the air excess ratio on the relative amount of mixed mine gases.

Taking into account the stoichiometric state of the air excess ratio $\lambda = 1$, the maximum value of the demethanation gas relative amount results directly from Eq. (13)

$$\left(\frac{\dot{n}_p}{\dot{n}_w}\right)_{\mathrm{max}} = \frac{1 - z_{M,w}\,(1 + n'_{a,\mathrm{min}})}{z_{M,p}\,(1 + n'_{a,\mathrm{min}}) - 1}\,, \tag{14}$$

which dependence directly corresponds with relation (11).

The air excess ratio ($\lambda_{\max} \geq \lambda \geq 1$) reaches the maximum value at the zero value of the ratio $(\dot{n}_p/\dot{n}_w) \to 0$, and then

$$\lambda_{\max} = \frac{(1 - z_{M,w})}{n'_{a,\min}\, z_{M,w}} \,. \tag{15}$$

whereby $n'_{a,\min} \approx 9.524$ kmol$_{air}$/kmol$_{CH_4}$, and for the value $z_{M,w} = 0.8\%$ $\lambda_{max} = 13.02$ is obtained.

Often also (at $z_{M,w} = 0.8\%$) may appear that the produced gas fuel mixture is outside the flammability. Although allowing higher content of the methane in the ventilation gas (Fig. 1), e.g., for $Z_{M,w} \approx 2\%$ the maximum of the air (oxygen) excess ratio reaches value about $\lambda_{\max} = 5.145$, and it means that in this case the prepared mine gases mixture will burn in principle without any problems.

5 Energy usefulness of formed mine gases mixture

The main quantity determining the energy usefulness of the mine gases prepared mixture is its lower heating value $(MH_d)_m$, which depends basically from the actual methane content, z_M, resulting directly from Eq. (10), because

$$(MH_d)_m = z_M\,(MH_d)_M \ , \quad z_M \leq z_{M,\max} \approx 9.502\% \ , \tag{16}$$

where: $(MH_d)_M = 802.32$ MJ/kmol – lower heating value of the pure methane.

After substituting dependence (10) in relation (16) is achieved

$$(MH_d)_m = \frac{(MH_d)_M}{1 + \left(\frac{\dot{n}_p}{\dot{n}_w}\right)} \left[z_{M,w} + z_{M,p} \left(\frac{\dot{n}_p}{\dot{n}_w}\right) \right] \ , \tag{17}$$

and next the maximum value equals

$$(MH_d)_{m,\max} = z_{M,\max}(MH_d)_M \ , \tag{18}$$

since $z_{M,max} \approx 9.502\%$ therefore finally $(MH_d)_{m,\max} = 0.09502 \times 802.32 = 76.24$ MJ/kmol.

The quotient of the mixed mine gases $(\dot{n}_p/\dot{n}_w)$ is limited: $(\dot{n}_p/\dot{n}_w) \leq (\dot{n}_p/\dot{n}_w)_{max}$, which recognizes from formula (14), and therefore principally indicates the maximum value of the relative amounts of the gas from demethanation of coal deposits.

Finally the relative value of the lower heating value, $(MH_d)_m$, of the formed mine gas mixture in relation to lower heating value, $(MH_d)_M$, of pure methane presents the formula

$$\frac{(MH_d)_m}{(MH_d)_M} = \frac{1}{\left[1 + \left(\frac{\dot{n}_p}{\dot{n}_w}\right)\right]} \left[z_{M,w} + z_{M,p}\left(\frac{\dot{n}_p}{\dot{n}_w}\right)\right], \tag{19}$$

which informs, that the analyzed relative lower heating value $(MH_d)_m/(MH_d)_M$ grows with increase of the technology gases quotient $(\dot{n}_p/\dot{n}_w)$. This dependence, resulting from Eq. (17), is illustrated in Fig. 7.

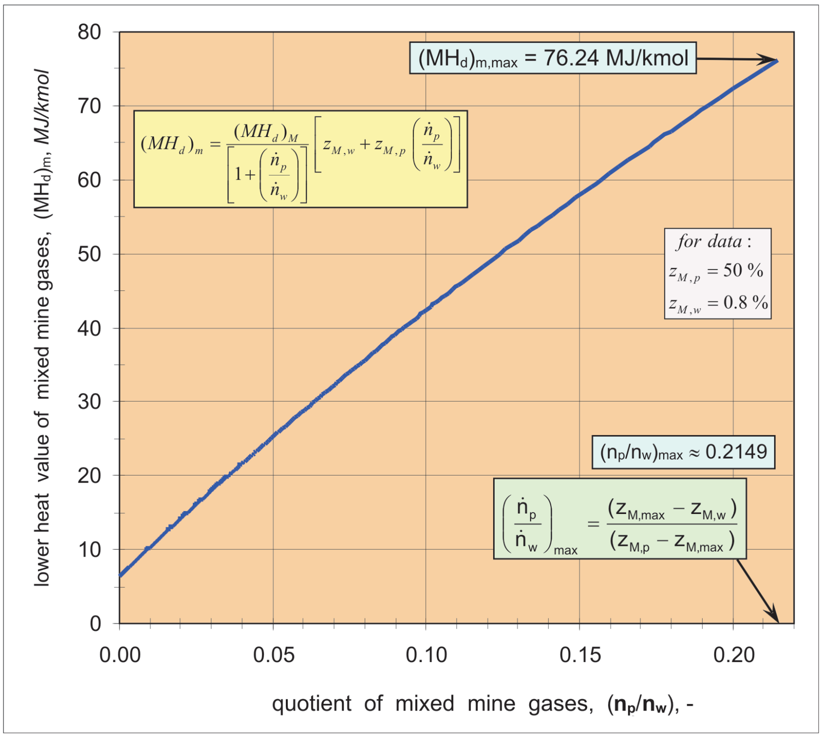

Figure 7: Influence of mine gases relative amount on the lower heat value $(MH_d)_m$ of flammable mixture.

Bearing in mind the objective of application it should consider how does the share of chemical energy supplied with ventilation gas, $E_{ch,w}$, in the entirely stream of chemical energy, $E_{ch,m}$, of produced combustion mixture; this expresses the process indicator defined as

$$\Omega \stackrel{df}{=} \frac{\dot{E}_{ch,w}}{\dot{E}_{ch,m}} = \left(\frac{z_{M,w}}{z_{M,m}}\right)\left(\frac{\dot{n}_w}{\dot{n}_m}\right) . \tag{20}$$

The quotient of gas flows equals:

$$\frac{\dot{n}_w}{\dot{n}_m} = \frac{1}{1 + \left(\frac{\dot{n}_p}{\dot{n}_w}\right)} , \tag{21}$$

then according to definition (20) the process indicator results

$$\Omega = \frac{z_{M,w}}{z_{M,m}} \frac{1}{1 + \left(\frac{\dot{n}_p}{\dot{n}_w}\right)} . \tag{22}$$

In turn, after inserting Eq. (10) into (22) is obtained

$$\Omega = \frac{z_{M,w}}{z_{M,w} + z_{M,p}\left(\frac{\dot{n}_p}{\dot{n}_w}\right)} . \tag{23}$$

Influence of the relative amounts of mixed gases, $(\dot{n}_p/\dot{n}_w)$, on the achieved values of characteristic process indicator is illustrated in Fig. 8.

The process indicator minimal value, Ω_{min}, is to be achieved at the air excess ratio $\lambda = 1$; it can be deduced due to relation (14), so after taking into account Eqs. (14) and (23) is obtained

$$\Omega_{\min} = \frac{z_{M,w}}{z_{M,w} + z_{M,p}\left[\frac{1 - z_{M,w}\,(1 + n'_{a,\min})}{z_{M,p}\,(1 + n'_{a,\min}) - 1}\right]} , \tag{24}$$

where: $n'_{a,min} \approx 9.524\ \mathrm{kmol}_{air}/\mathrm{kmol}_{CH_4}$.

For the values $z_{M,w} = 0.8\%$ and $z_{M,p} = 50.0\%$ is obtained the basic minimal value $\Omega_{\min} = 6.9304\%$. The values of the process indicator systematically increase $(\Omega > \Omega_{\min} \approx 6.9304\%)$ with the dropping the quotient of mixed mine gases amount $(\dot{n}_p/\dot{n}_w) < (\dot{n}_p/\dot{n}_w)_{\max}$, what should be emphasized in terms of the energy utilization efficiency of the mine gases used.

In the general case, using relation (13), according to which

$$\left(\frac{\dot{n}_p}{\dot{n}_w}\right) = \frac{1 - z_{M,w}\,(1 + \lambda\, n'_{a,\min})}{z_{M,p}\,(1 + \lambda\, n'_{a,\min}) - 1} \quad \text{at} \quad \lambda \geq 1 \tag{25}$$

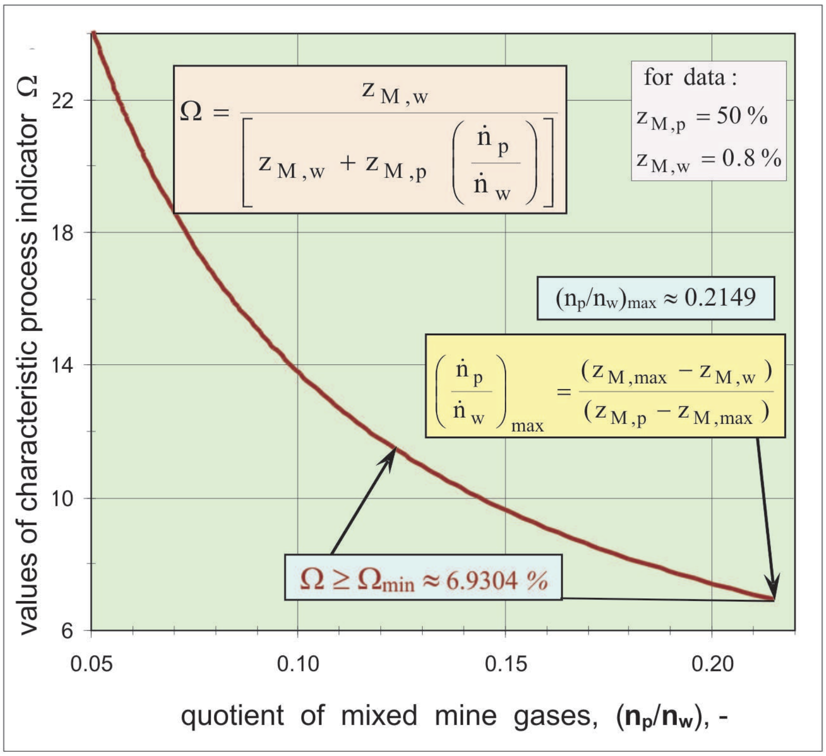

Figure 8: Influence of the mixed gases relative amount on the values of process indicator.

the analyzed dependence (23) takes the form

$$\Omega \;=\; \frac{z_{M,w}}{z_{M,w} + z_{M,p}\,\frac{1-z_{M,w}\,(1+\lambda\, n'_{a,\min})}{z_{M,p}\,(1+\lambda\, n'_{a,\min})-1}}\;, \tag{26}$$

with which is possible to analyze the effect of the air (oxygen) excess ratio $\lambda \geq 1$ on the values of the process indicator. The achieved solution of the analyzed problem is illustrated in the Fig. 9.

With the increase of the air excess ratio (at $\lambda > 1$) simultaneously grows the process indicator ($\Omega > \Omega_{\min} \approx$ 6.9304%), and it is worth emphasizing in terms of the system energy utilization efficiency.

Results of the several experimental investigations [7,8] confirm that for powering of the internal combustion gas engines is preferable to use the so-called over-stoichiometric flammable mixtures, i.e., those which are characterized by a slightly higher values ($1.5 > \lambda > 1.0$) of the air (oxygen)

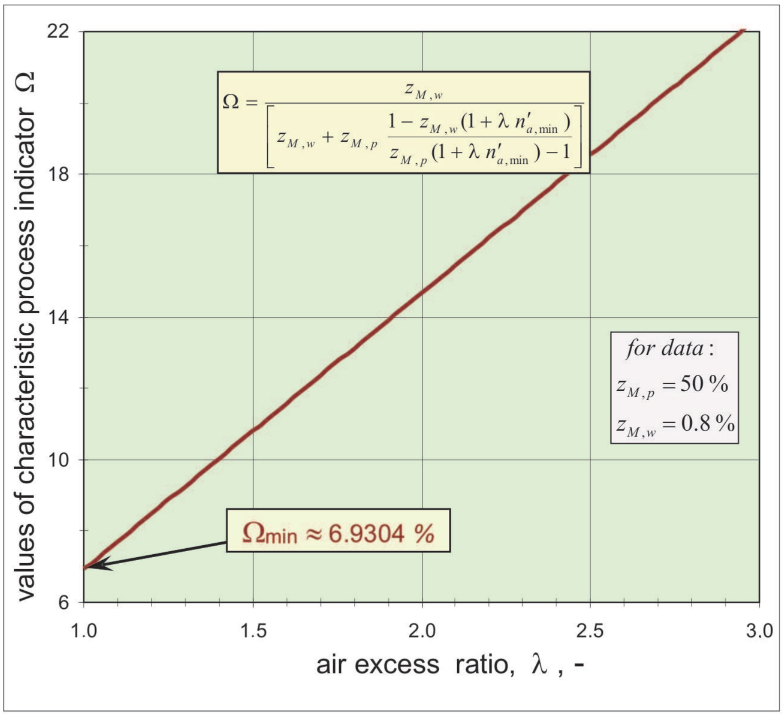

Figure 9: Influence of the air (oxygen) excess ratio on the values of process indicator.

excess ratio. This procedure, by applying the over-stoichiometric air excess ($1.5 > \lambda > 1.0$) allows for achieving of higher values of effective energy efficiency of the internal combustion gas engine. In this situation appears also the possibility of achieving much higher values of the efficiency process indicator, which determines the chemical energy supplied with ventilation gas in relation to the entirely stream of chemical energy of the produced flammable gas mixture (Figs. 8 and 9).

The above indicated positive effect confirms the desirability of the analyzed process, based on the adequate mixing of the ventilation gas stream with the gas stream from demethanation of coal deposits; and all without downloading additional air (oxygen) from the environment. In this way there is the possibility of preparing the good combustible mixture, using available mine gases (the ventilation gas and the gas from demethanation of coal deposits), which can be effectively used for powering of combustion engines; alike the spark ignition, as well as self ignition engines.

6 Summary and conclusions

In areas belonging to coal mines remain at the disposal two basic types of mine gases; namely gas from demethanation of coal deposits, and - ventilation gas; containing combustible ingredients (mainly methane). Effective use of these gases is an important technical and ecological issue (greenhouse gas emissions), mainly due to the presence of methane in these gases.

The paper pointed out to the desirability of implementation of appropriately selected mixing process of the ventilation gas with the gas from demethanation of coal deposits; and all without downloading additional air (oxygen) from the environment. For the assessment of the energy usefulness of so origin produced combustible mixture has been proposed system indicator, determining amount of the chemical energy supplied with ventilation gas in relation to the entire stream of chemical energy of the produced gas mixture.

The minimal value of the defined system indicator equals to about 6.9304%, and can be achieved for the stoichiometric (at the air excess ratio $\lambda = 1$) gas mixture, what should be emphasized in terms of the energy utilization efficiency of the mine gases used. The performance procedure, by applying the over-stoichiometric air excess ($1.5 > \lambda > 1.0$) allows for achieving of higher values of effective energy efficiency of the internal combustion gas engine.

In the study was also indicated how can be achieved much higher values of the characteristic indicator; with the increase of the air excess ratio (at $\lambda > 1$) simultaneously grows (Fig. 9) the system indicator, $\Omega > \Omega_{\min}$), and it is worth emphasizing in terms of the system energy utilization efficiency.

Finally has been demonstrated that the technology for preparing of the good quality combustible mixture, using available mine gases, can be effectively used for powering internal combustion engines (spark ignition, self-ignition engines), e.g., as driving elements of the cogeneration systems.

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References

[1] *Assessment of the Worldwide Market Potential for Oxidizing Coal Ventilation Air Methane.* U.S. Environmental Protection Agency, EPA 430-R-03-002. USEPA, 2003.

[2] Beard J.T.: *Mine Gases and Ventilation: Theory and Practical Ventilation, 2nd Edn.* Mc.Graw-Hill Book Company. London 1920.

[3] Bibbler C., Carothers P.: *Overview of coal mine gas use technologies*. Second Int. Methane Mitigation Conf., Novosibirsk 2000.

[4] *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990 - 2020. Office of Atmospheric Programs Climate Change Division*. U.S. Environmental Protection Agency, Washington 2006.

[5] McPherson M.J.: *Subsurface Ventilation and Environmental Engineering with Ventilation Planning.* Chapman State & State Hall, New York 1993.

[6] Nawrat S., Gatnar K.: *Estimate of condition and capabilities of VAM utilization from underground coal mines*. Polityka energetyczna **11**(2008), 2, 69–83 (in Polish).

[7] Postrzednik S., Żmudka Z., Przybyła G.: *Main conditions and effectiveness of gas fuel use for powering of dual fuel IC self-ignition engine*. Transp Prob. **10**(2015), 3, 99-111.

[8] Przybyła G., Postrzednik S., Żmudka Z.: *The combustion process analysis of SI engine fuelled with lean air-gas mixture*. Sci. Mag. Combus. Eng. **154**(2013), 3, SC-038 (in Polish).

[9] Somers J.M., Schultz H.L.: *Thermal oxidation of coal mine ventilation air methane.* 12th U.S. North American Mine Ventilation Symp. 2008, 301–306.