FEASIBILITY STUDY OF COALMINE VENTILATION AIR METHANE UTILIZATION

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ABSTRACT

During underground coal mining some dangerous and explosive gases are released. Due to safety reasons the underground mines should be intensively ventilated. Much of the released gas at coal mining is methane. Released gases are vented to surroundings with ventilation air and therefore the methane is not profitably used. One of the potentialy beneficial utilization of methane in ventilation air is the utilization as a combustion air in a power plant. This paper analyzes the possibility of using the ventilation air from the Velenje Coal Mine in the Power Plant Šoštanj Unit 5. The analysis shows that this utilization would have a positive effect in the environmental and energy aspect.

POVZETEK

Pri izkopavanju premoga se sproščajo razni plini, ki so nevarni in eksplozivni. Premogovnike je zato potrebno intenzivno prezračevati. Velik del sproščenih plinov pri izkopu premoga predstavlja metan, ki se s prezračevalnim zrakom neizkoriščen odvaja v okolico. Ena izmed možnosti koristne izrabe metana v prezračevalnem zraku je, da se ta zrak uporabi kot zgorevalni zrak za veliko kurilno napravo. V članku so analizirane možnosti izrabe prezračevalnega zraka iz Premogovnika Velenje v parnem kotlu bloka 5 Termoelektrarne Šoštanj. Izvedena analiza pokaže, da bi imela takšna izraba prezračevalnega zraka koristne okoljske in energijske učinke.

1. INTRODUCTION

In the coal mines, various gases are released during the mining extraction. Methane and carbon dioxide are the most common ones. The amount of gases, released during the extraction from the ruined coal seams – i.e. gob, has unique characteristics with each coal mine. Some of the mines are very gassy while others are not. The most coal mine gases are produced at the extraction of younger types of coal, which are lignite and brown coals, while the least gases are released during the extraction of hard coals.

The coal mine Velenje is among more gassy mines. With the extraction of one ton of lignite 6 m^3 to 10 m^3 of methane and from 10 m^3 to 16 m^3 of carbon dioxide is released. In concentrations from 5 % to 15 % in air methane is explosive and therefore dangerous. Methane acts as a greenhouse gas in the atmosphere. Its contribution in the global greenhouse effect is 18 %. The greenhouse effect caused by methane is 24 times stronger than the greenhouse effect caused by carbon dioxide. The reduction of methane emissions into surroundings has positive effects in a view of the global greenhouse effect. Methane utilization for energy production can further reduce the consumption of other fossil fuels.

Numerous researches are being conducted over the world on how to reduce methane greenhouse effects and utilize the methane from mining extraction. We can find quite a few methods for oxidation or combustion for methane mitigation and utilization Technologies are divided into two main groups according to the methane concentration in the gas mixture. The utilization of gas mixture with relatively high methane concentration above 20 vol. % is not problematic. It can be used as an additional fuel with low calorific value. This kind of gas methane mixture can be produced by direct degassing of coal seams before the extraction. This article does not deal with these technologies. The utilization of *Ventilation Air Methane* –VAM with low concentrations of methane below 1 vol. % is far more complicated. One of the possible and relatively undemanding methods of VAM utilization is its employment as a combustion air in large furnaces, for example thermal power plants (steam boiler, gas turbine).

2. SAFETY AND RELIABILITY

The mixture of air and methane is explosive and has caused many accidents [2]. Due to the potential hazard connected to employment of this mixture, many measures and regulations have been brought into effect in order to prevent accidents. The explosive limits of the air-methane mixture have been experimentally measured many times. Data in the literature states 5 vol. % as the lower explosive limit and 15 vol. % as the higher explosive limit. The minimum ignition energy is required at the concentration of 8 vol. %, which is just below the stoichiometric ratio [3]. There are multiple scientific publications dealing with the reduction of methane emissions from mines and increasing the working safety. Mostly they include three technologies [1, 2, 4]:

- Degassing of coal seams before extraction and capturing of gases with high methane content (above 30 vol. %)
- VAM utilization with low methane content (up to 2 vol. %)
- Gob (ruined seams) degassing after the extraction

The use of mine methane in various forms is discussed in some review articles, which quite specifically present the mentioned field [1, 2, 4]. The use of VAM with low content of methane as a combustion air in the large steam boiler fired with pulverized coal is stated in [1, 2, 5, 6, 7]. As a matter of fact the co-combustion of methane in the pulverized coal furnaces also decreases the emissions of nitrous oxides NO_x [1, 5, 6, 8].

According to the literature the main reason why VAM is not used as combustion air in large steam boilers and gas turbines more often is the absence of a vast combustion air user (like thermal power plant) located in the close vicinity of the mine. In this particular case we have an ideal situation since the mine's VAM exhaust is located in the backyard of power plant Šoštanj.

3. EMISSIONS FROM VELENJE LIGNITE EXTRACTION

Values measured thus far show that with the extraction of Velenje lignite 10-16 m^3 of carbon dioxide and 6-10 m^3 of methane are released per ton of lignite. In mass terms 20-32 kg of carbon dioxide and 4.3-7.2 kg of methane is released per ton of extracted lignite. In energy terms it corresponds to 1.5-3.3% of energy obtained from the extracted lignite if lower calorific values of 10 MJ/kg for lignite and 50 MJ/kg for methane are assumed.
The total average greenhouse effect (GWP – Global Warming Potential), caused by the combustion of 1 ton of Velenje lignite expressed as a CO_2 equivalent is:

- 1000 kg of CO_2 from the combustion of lignite
- 26 kg of CO_2 is released during the extraction
- 144 kg of CO_2 equivalent represents methane released from the coal, on average ~6 kg of methane * 24 GWP = 144 kg CO_2 equivalent

Total average GWP therefore adds up to 1170 kg of CO_2 equivalent per 1000 kg of lignite.
Since the greenhouse effect of methane is 24 times larger than the effect of carbon dioxide, the greenhouse effect would decrease with the methane combustion and CO_2 formation. If the released methane would be captured and burnt into CO_2 the total average greenhouse effect from 1 ton of Velenje lignite would decrease to 1042.5 kg of CO_2 equivalent, which is ≈11 % decrease from the present situation.

4. POSSIBLE UTILIZATION OF VAM IN POWER PLANT ŠOŠTANJ

The idea of using VAM from the Velenje mine originates from the fact, that the ventilation station of the coal mine is located directly in the power plant Šoštanj (PPŠ) backyard. The concentration of methane in the ventilation air in normal conditions does not exceed 0.2 vol. % [9]. VAM also contains particles of coal dust and volatile substances of coal and therefore has a specific scent. This is disturbing for the nearby urban area.

Potential use of VAM as combustion air for boiler of unit 5 in PPŠ would have several favorable effects. Methane emissions would significantly decrease along with coal dust and smell. Additional energy would also be supplied to the boiler of unit 5.

The data from PPŠ shows that the air consumption at maximal generator power of 345 MW is about 380 kg/s (296 m^3/s at 0°C and 1,013 bar). At minimal generator power of about

170 MW the consumption of air is about 180 kg/s (140 m^3/s at 0°C and 1,013 bar). These quantities are consistent with the coal mine ventilation station capacity.

Coal mine ventilation station is located in the northern part of PPŠ area. There are two horizontal axial ventilators installed in parallel formation in the ventilation station. Due to safety reasons the ventilators operate alternately. During the studied period the average mass flow of VAM was 238 kg/s(203 m^3/s or 12781 m^3/min at 0°C and 1,013 bar).

4.1 Connection of VAM mineshaft and steam boiler

Forced-draft fan operating point

The length of the VAM duct connecting the ventilation station and the boiler would be 350 to 400 m. 350 m long duct configuration consisting of 8 sharp and 4 medium-sharp knees and 15 m/s air velocity was considered for estimation of pressure losses. The calculated pressure losses at maximum VAM flow add up to about ~5 mbar. In this assessment of the pressure losses, line losses present 30 %, while local losses present 70 %. Pressure losses have been determined using the classic method listed in [11, 12].

We also had to determine if the existing forced draft fans are able to cover the additional pressure losses caused by VAM duct. Due to presently unknown and unconsidered conditions and resulting eventual additional pressure losses range of 5 mbar to 10 mbar was taken into account. Fig. 1 shows range of expected operating points of the forced draft fan (red color). There have been some operating points measured in the past which are approximated by a green hatched line. It is evident that the draft fan is oversized and has enough capacity to cover the additional pressure losses caused by VAM duct.

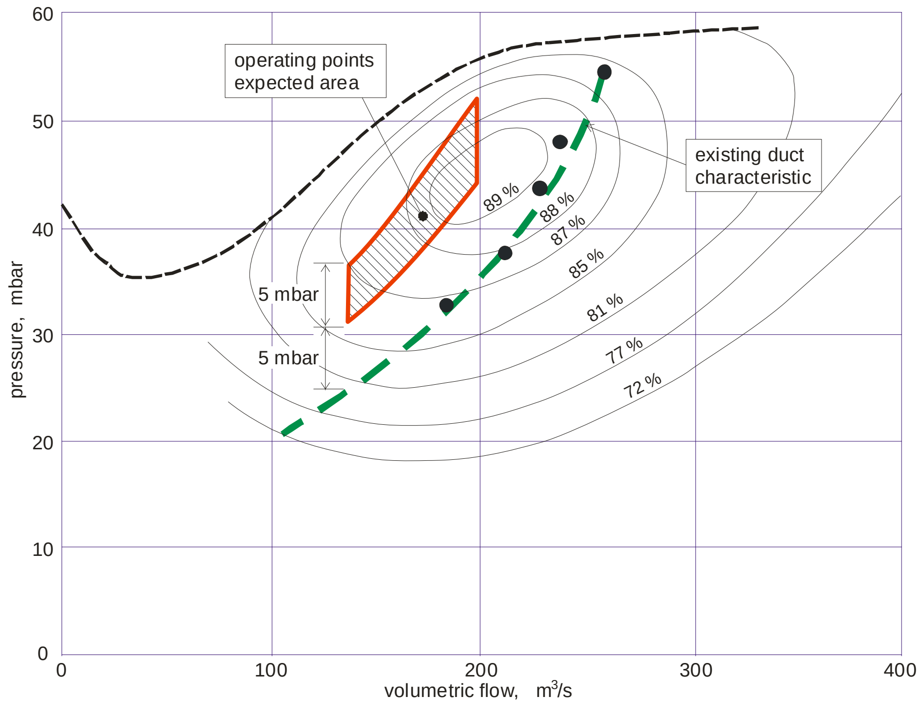

Figure 1: Forced draft fan characteristics

The amount of combustion air for the unit 5 was reduced in the past years due to the following measures:

- installation of low-NO_x burners and over-fire-air control resulting in reduced air ratio
- installation of cold-flue-gas recirculation,
- improved furnace-pressure control,
- improved air-heater sealing
- reduced uncontrolled air leakage into boiler and its components,…

The predicted realization

The connection between the mine ventilation station and the boiler should be carried out in a way that the mine safety and boiler operation are not compromised. The mine ventilation system must continue to operate normally in a case of unexpected boiler stoppage. Furthermore the operation of the boiler should not be disturbed due to discontinued VAM supply from ventilation station. Fig. 2 shows an existing VAM extraction above the exhaust ventilation station diffusers [13] and duct leading to VAM consumer.

Figure 1: Realized open VAM connection, Australia [13]

In the PPŠ the VAM duct could be carried out similarly to the example in Fig. 3.

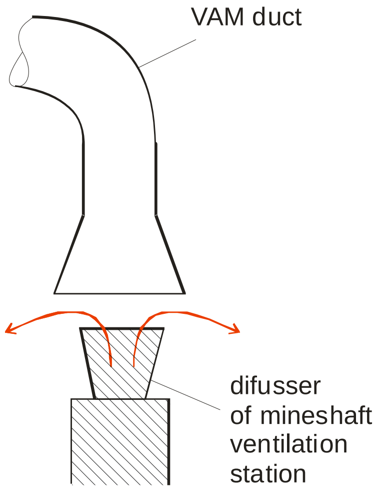

Figure 3: VAM-duct connection to the mine's ventilation station

In the case of the boiler stoppage or in the case of low VAM demand the presented VAM connection enables releasing the excessive VAM through the clearance. The weakness of such design is an ejector effect due to which VAM is diluting with ambient air. Considering that the boiler 5 consumes more air than released from the mine the mentioned ejector effect is not very disturbing.

5. VAM ENERGY SUPPLY AND MASS BALANCE

Combustion of pulverised coal with VAM is modelled with software package IPSE [14]. The simplified model is shown in the Fig. 4. The combustion of pure methane from VAM is simulated in the separate combustor. The total volume flow of pure methane and total volume flow of pure ventilation air (without methane) equals the average flow of VAM. The volume flow ratio between pure methane and fresh air is VAM equivalent.

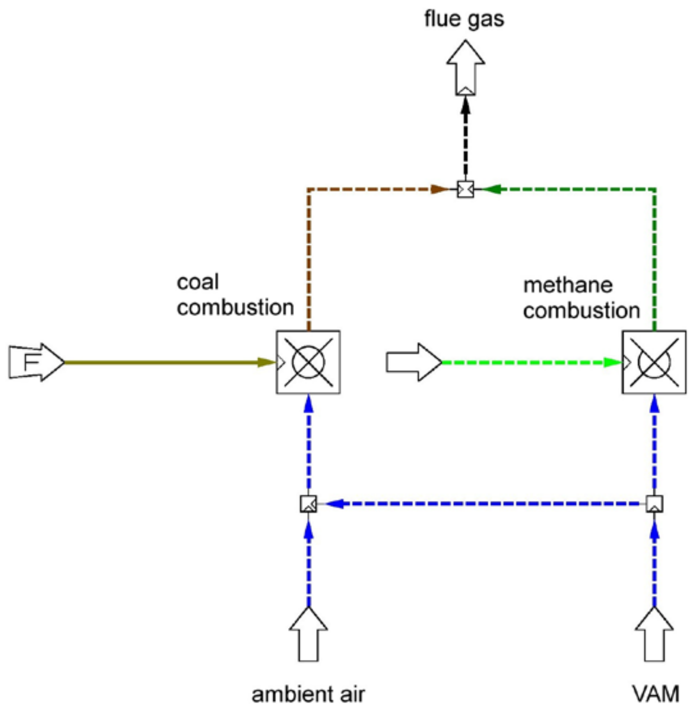

Figure 2: Simplified model of coal and VAM combustion

5.1 Results and discussion

Several operating states and combinations were simulated. Some main conclusions are presented here.

The methane heat supply from VAM would equal 6.9 MW at lowest boiler load (not all VAM is utilized) and 9.2 MW if all VAM is utilized. At minimum load the boiler requires only 75 % of available VAM, while the rest of VAM is discarded into ambient. According to the average load of unit 5 most of the time all of VAM would be utilized.

Due to VAM utilization the consumption of warm air sucked from below the ceiling of the boiler house would be reduced. To prevent the raise of temperature in the boiler house additional ventilation should be introduced. Consequently boiler losses due to convection and radiation would be increased. According to the results of the simulation these losses would amount to 2.4 MW at minimum and 3.1 MW at maximum boiler load.

The average temperature of warm air from beneath the boiler house's ceiling entering the air heater is between 30 °C and 50 °C. The average temperature of VAM is around 18.5 °C. If relatively cold VAM was used instead of warm air the temperature of the flue gas exiting the air heater would also decrease resulting in lower flue-gas loss. The decrease of loss is estimated to be about 1 MW regardless of boiler load. The estimation was made in accordance with standard procedure for boiler's efficiency determination, EU standard EN 12952 [15].
VAM energy balance resulting from the simulation is presented in Table 1.

Table 1: VAM energy balance (+energy gain, – energy loss)

	Max. power	Average power	Min. power
	MW	MW	MW
Methane heat supply	+9,2	+9,2	+6,9
Additional radiation and convection losses	–3,1	–3,1	–2,4
Decrease in flue gas loss	+1,0	+1,0	+1,0
Power increase of force draft fan (heat equiv.)	–1,0	–0,8	–0,7
Total gain	**+6,0**	**+6,3**	**+4,9**

6. CONCLUSIONS

Paper deals with potential Ventilation Air Methane (VAM) utilization. VAM would originate from coal mine Velenje and would be utilized in Power plant Šoštanj – Unit 5 as combustion air. Ventilation air contains methane, coal dust and disturbing smells. If VAM was used as a combustion air all of the combustible substances of VAM were oxidized to CO_2 and H_2O and disturbing smell of would vanish. In the vicinity of Power plant Šoštanj the imission of dust particles PM 10 and PM 2.5 would be reduced. Co-combustion of methane in the furnace can also lead to NO_x emission reduction. Methane (greenhouse effect) emissions from the coalmine would be significantly reduced.

Lower explosion limit of methane-air mixture is 5 vol. %. According to several years of mining data records the highest measured concentration of methane in the ventilation air was only 36 % of the lower explosion limit. Usually the concentration of methane in the ventilation air is less than 0.2 vol. % (i.e. 4% of the lower explosion limit). So there is no direct explosion hazard. The reason that the literature indicates why the VAM from the mines is not used "often" as combustion air is the absence of large combustion plants in the vicinity of VAM exhaust. Alleging that the ventilation air is unsafe to use as combustion air due to potential explosion hazard is not correct.

According to current VAM release from coal-mine Velenje most of the time all of VAM could be utilized in the boiler of unit 5 in Power Plant Šoštanj. Energy supply by methane from VAM would be 6.9 MW to 9.2 MW. The simulation results and analysis indicate that the energy balance of VAM utilization would be positive at all boiler loads.

7. REFERENCES

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