

Analysis of potential fire hazards during co-milling of biomass and bituminous coal for the process of their co-combustion

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1. Introduction

Currently at well above 40 energy objects (enterprises) in Poland the biomass co-combustion with conventional fuels (such as bituminous coal or lignite) has been realised. The most popular cofiring (co-combustion and cofiring are used interchangeably throughout this paper) method is a direct combustion at the existing systems of pulverised coal fired boilers and fluidised bed boilers. [1]. Unfortunately, introduction of biomass into the systems of fuel preparation that were designed for coal (furnished with hard coal or lignite pulverisers) at pulverised coal boilers can bring about many operational problems (among others spontaneous ignition of biomass-coal mixtures) [2]. Co-milling (or co-pulverising) of coal mixture with biomass at the same pulveriser can cause other threats than in case of the basic fuel (i.e. coal), which are connected with different biomass properties.

The problems of more frequent ignition of fuels mixture during pulverising process of biomass-coal as compared to coal only that were noted by the installation's operators constituted a prerequisite to undertake the research that would identify source of these spontaneous ignitions. Recognition of the phenomena that increase hazard of the ignitions to occur during co-milling will make it possible to develop technological procedures aimed at improving safety of operation.

The hazards deriving from simultaneous milling (or pulverising) of coal and increased share of biomass in one pulveriser can be classified down to two types of hazards - gas hazards and coal dust hazards. This paper deals with research connected with gas fire hazards.

Because biomass is characterised by lower decomposition temperatures when compared with coal and to the pulverising system the hot air is supplied, which in extreme cases can be as hot as about 300°C, then in the pulveriser processes of pyrolysis or gasification can occur. The result of these processes can be a destruction of solid biomass particles associated with creation of gassy compounds. During these processes combustible gases can be created, among them: carbon oxide (CO), hydrogen (H₂), methane (CH₄), ethane (C₂H₆), ethylene (C₂H₄), propane (C₃H₈), propylene (C₃H₆) and other [3, 4].

One of the building blocks of biomass-hemicellulose, undergoes destruction at temperatures below 300°C [4, 5]. During process of biomass thermal conversion in atmosphere of air with process gases the presence of carbon oxide or methane was noted in process gases in as low temperature as 190°C [6].

Authors investigating torrefaction processes of wood biomass (birch), i.e. thermal destruction in the neutral environment, discovered the presence of combustible gases in the process gases. These authors have noted the CO content at the level of 14% vol. and CH₄ content at the level of 0.1% vol. gas products developed in a torrefaction process at 230°C [7]. Other authors also in a torrefaction process of birch run at 230°C have measured CO content in process gases at the level of 18% vol. and CH₄ content at the level of 0.1% vol. [8]. In both cases the carbon oxide concentration in the products of torrefaction exceeded its Lower Explosive Limit, which is equal to 12.5% vol. in air (Tab. 1).

The gases released in the process of thermal destruction of biomass can create an explosive atmosphere, and in consequence fire hazards. Range of combustible gases concentrations in the air at which the explosion can occur is described by two limits [9]:

- LEL (LFL) - Lower Explosion (or Lower Flammable) Limit. It is the lowest concentration of gas or vapours in air below which the ignition is not possible under influences of the initiating factor and further autogenous propagation of flame at the selected conditions is also not possible (the gas explosive atmosphere cannot be created)
- UEL (UFL) - Upper Explosion (or Upper Flammable) Limit. It is the highest concentration of gas or vapours in air above which the ignition is not possible under influences of the initiating factor and further autogenous propagation of flame is also not possible in the conditions defined by the investigation. The flammability (explosion) limits are the characteristic features of the combustible gas mixtures. Beyond these limits of concentration in air (the oxidising agent) the ignition of the mixture will not occur even when the ignition source would have an infinitive energy. In table 1 are presented Upper and Lower Flammability Limits for the selected gases.

Table 1
Lower and Upper explosive (or flammability) limits and density of the selected gases [10]

Gas name	Chemical formula	„Lower Explosive or Flammable Limit” (LEL/LFL) (% vol.)	„Upper Explosive or Flammable Limit” (UEL/UFL) (% vol.)	Density ¹ , kg/m ³
Carbon oxide	CO	12.5	75	1.250
Hydrogen sulfide	H ₂ S	4.3	45	1.539
Hydrogen	H ₂	4	75.6	0.089
Methane	CH ₄	5	15	0.717
Ethane	C ₂ H ₆	3	15.5	1.356
Ethylene	C ₂ H ₄	2.7	3.4	1.260
Acetylene	C ₂ H ₂	2.4	83	1.170
Propane	C ₃ H ₈	1.2	7.4	2.003
Propylene	C ₃ H ₆	2	11.1	1.915
Butane	C ₄ H ₁₀	1.5	8.5	2.70
Air		-	-	1.292

¹ - density is established in standard conditions

2. Experimental part

Industrial tests were conducted at the in-country CHP plant, this plant has been implementing co-firing of coal and biomass by making use of the existing pulveriser installation. Test was conducted for coal and different mixtures of coal and different types of biomass. The substance that was pulverised was coal and mixtures of coal with 15% weight share of sawdust wood pellets or pellets from sunflower husks. The purpose of these tests was to identify the gaseous combustible constituents that could be released during milling process in a ball pulveriser.

The composition of the gas atmosphere that was created inside of the milling system was established for the following characteristic states of the pulveriser operation:

- Stable operations of the pulveriser system – continuous pulveriser operation with maximum capacity
- Planned switching off/shutdown of the pulveriser according to the CHP's procedures
- Down time of the „empty” pulveriser stopped according to the CHP's procedures
- Start of the pulveriser according to the CHP's procedures
- simulated emergency stop of the pulveriser (through switching off during operations of the pulveriser's fan) with leaving off the fuel inside of the pulveriser
- downtime of the pulveriser with the fuel left behind inside of it.

Switching off the pulveriser in accordance with the procedures in force at the CHP as well as simulated emergency switch off was conducted in two options each: with and without the so-called steaming of the pulveriser.

In figures 1 ÷ 5 the runs are presented of the characteristic pulveriser parameters during conducted tests.

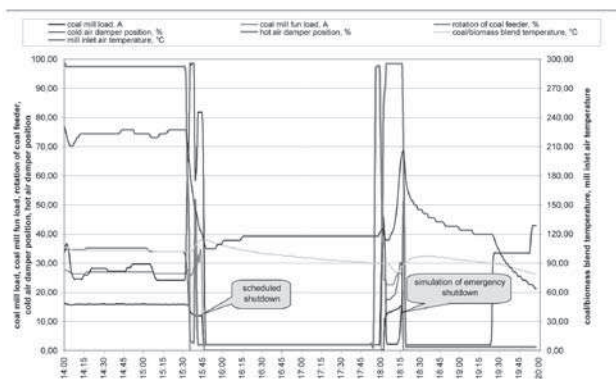


Fig. 1. Parameters runs of the MW2 pulveriser during tests on coal

In figures 1 ÷ 3 pulveriser parameters are presented during its characteristic states without application of steam quenching after it is being stopped. During planned shutdown the coal delivery to the pulveriser has been cut off in order to empty it from milling residues and to cool down its elements. Cooling off the pulveriser was executed by closing the hot air dampers and simultaneous opening of cold air dampers – temperature of air supplied to the pulveriser has been reduced from 220°C to close to 120°C. During switching off (through the simulation of the fan breakdown) the mill (pulveriser) was stopped with the unmilled fuel left inside. Dampers on cold air and hot air were at this time left closed. During this time temperature rise of the coal dust-air mixture was detected, and only after 15 minutes the drop in temperature was detected.

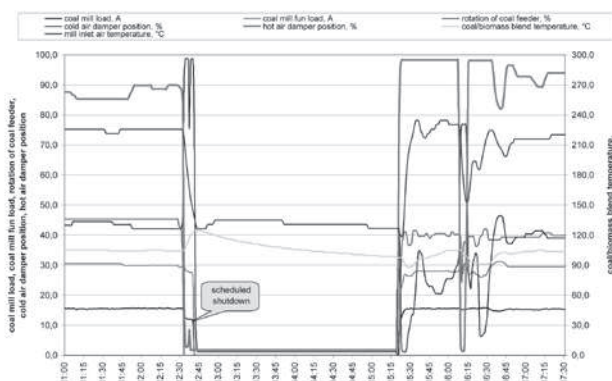


Fig. 2. Parameters run of the MW2 pulveriser during tests on mixture of coal and 15% of pellets from sunflower husks (without using steam quenching installation)

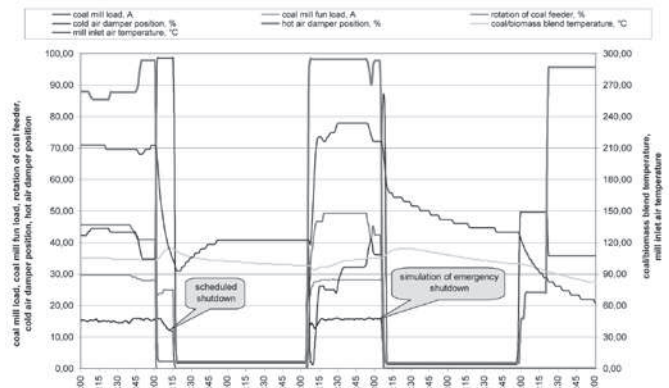


Fig. 3. Parameters run of the MW2 pulveriser during tests on mixture of coal and 15% of pellets from wood sawdust (without using steam quenching installation)

In figures 4 ÷ 5 pulveriser's parameters are presented during characteristic states of operation with using the steam fire quenching installation during it shutdown. These shutdowns were executed as previously described but at the final stage of the planned switching off or after the emergency shutdown steam was supplied to inside of the mill in order to neutralise oxygen atmosphere and to "blow out" the fuel left behind.

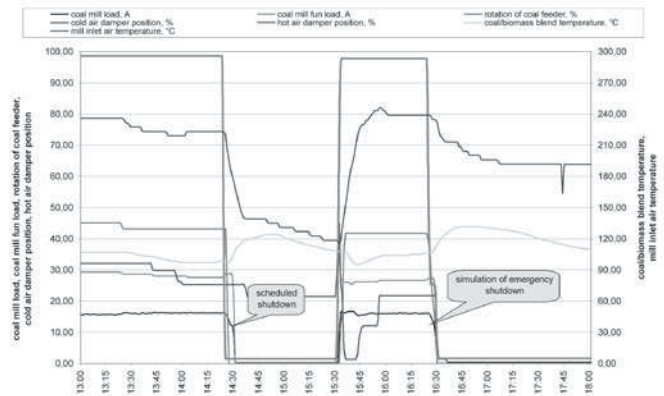


Fig. 4. Parameters runs of the MW2 pulveriser during tests on mixture of coal and 15% of pellets from wood sawdust (with using steam quenching installation)

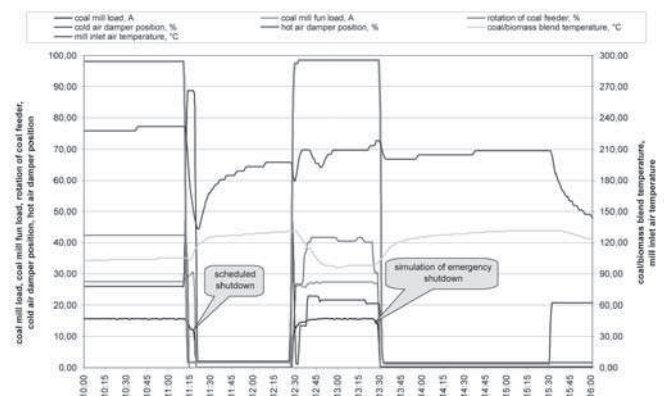


Fig. 5. Parameters run of the MW2 pulveriser during tests on mixture of coal and 15% of pellets from sunflower husks (with using steam quenching installation)

During tests, the samples of gases have been taken at four measuring ports (three were located inside of mill's chamber and one inside of coal dust-air evacuation pipe). Their spacing is shown in Figure 6.

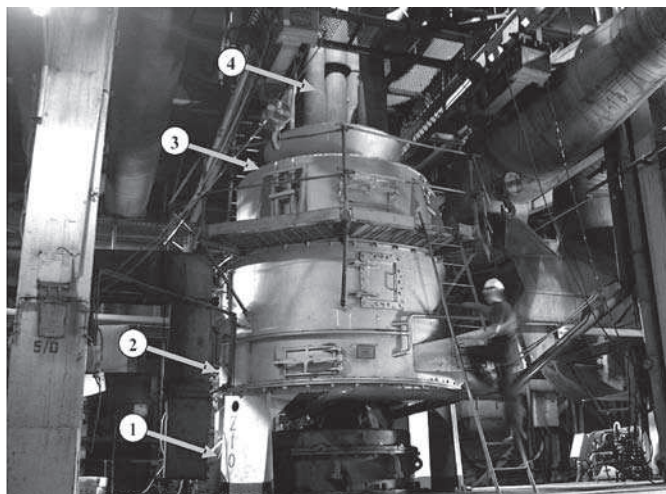


Fig. 6. Spacing of the measuring points in the pulveriser system during tests (1 – pyritic chamber, 2 – space of driving out material , directly below the grinding balls, 3 – upper space, classifier/sieve, 4 – one of four coal dust-air mixture exhaust pipes)

To analyse chemical composition of the sampled gases a technique of gas microchromatography „on-line” (μ GC) was used with mikrochromatograph „Varian GC4900”. Samples have been taken continuously by means of the suction pump but analysis of the chemical composition by the μ GC was conducted at 5 minute intervals consecutively from each point.

3. Discussion of the test results

Below are presented the test results.

3.1. Qualitative and quantitative analysis of gas atmosphere in coal pulveriser – steady state operation of pulveriser

During stable continuous operation of the mill (pulveriser) the gas samples have been taken from all sampling points (Fig. 6). At each of them sample was taken five times. Below in table 2 are presented averaged results of analysis of chemical makeup of the gas for the separate fuel mixtures.

The results acquired by means of the chromatographic analysis indicate that during stable operation of chemical composition of the gas atmosphere, governing in all sample ports, was close to the composition of air.

Table 2

Average chemical composition during stable operations of the pulveriser

Gas composition	Type of fuel / Average concentration of the tested compounds, %vol.																			
	Coal				Coal + sunflower husks ¹				Coal + sunflower husks ²				Coal + sawdust ¹				Coal + sawdust ²			
Measuring point	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
O ₂	20.22	20.26	20.38	20.31	20.81	20.41	20.81	20.13	20.23	20.42	20.18	20.35	20.43	20.13	20.25	20.35	20.41	20.35	20.12	20.16
N ₂	77.21	77.32	77.04	77.09	77.08	77.15	77.64	77.72	77.13	76.88	77.19	77.55	77.24	77.10	77.33	77.24	77.25	77.64	77.43	77.12
CO ₂	0.16	0.18	0.12	0.11	0.13	0.16	0.14	0.17	0.13	0.16	0.14	0.17	0.16	0.18	0.12	0.11	0.16	0.18	0.12	0.11
H ₂								traces ³				traces ³								
CH ₄				traces ³				traces ³				traces ³				traces ³				traces ³

¹ – tests in which the „pairing” of the pulveriser was not used, ² – tests in which the steaming of the pulveriser was used, ³ – concentrations at the level of several dozens of ppm

During tests execution and during stable operation of the pulveriser in cross section of the coal-air mixture evacuation pipe (sampling point nr 4) trace amounts of methane were detected for all tested fuels and of hydrogen (for coal and sunflower husks mixture) concentrations of which were at the level of several dozens ppm.

3.2. Qualitative and quantitative analysis of gas atmosphere in coal pulveriser – Planned shutdown and its standstill

The tests of gas atmosphere in coal pulveriser during its shutdown were conducted at two options. First option was a shutdown of the mill according to internal CHP’s procedures with application of the so-called steam quenching, second option did not comprise steam quenching. Due to quick changes of parameters governing inside of the pulveriser during process of its shutdown, gas for chromatographic analysis was taken only from the port at coal dust – air mixture evacuation pipe (point 4 nr 4, Fig. 6). Because of the air flow through the mill installation the coal dust-air mixture evacuation pipe has been regarded as a representative place at which one can determine the composition of gas leaving the pulveriser. Analysis both qualitative and quantitative of gas samples taken from the cross section of the coal dust-air evacuation pipe during mill’s shutdown has show that in both options this composition was identical with the composition of air.

After the pulveriser was shut down gas was sampled at all sampling ports (Fig. 6) at 20 minutes intervals during a period of about 2 hours. The purpose of this was to check whether the fuel left behind inside of the pulveriser, after earlier drying, undergoes degasification. There exists possibility of fuel to left behind inside of the pulveriser during its shutdown and some of its elements can be heated up to temperature of about 230°C.

In table 3 below results of the chromatographic analysis of gas composition are presented for the separate coal-fuel mixtures.

The results of this analysis have proved that during the pulveriser standstill that was shutdown according to procedures valid in CHP, the combustible gases were not detected. When applying steaming of the pulveriser and without it, the composition of gas atmosphere prevailing at all ports of gas sampling was close to the composition of ambient air.

Table 3

Chemical composition of pulveriser’s atmosphere during its shutdown

Gas composition	Type of fuel / Average concentration of the tested compounds, %vol.																			
	Coal				Coal + sunflower husks ¹				Coal + sunflower husks ²				Coal + sawdust ¹				Coal + sawdust ²			
Measuring point	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
O ₂	20.26	20.38	20.31	20.43	20.13	20.25	19.81	20.13	20.13	20.42	20.38	20.31	20.25	20.13	20.41	20.81	20.25	20.13	20.25	19.81
N ₂	77.32	77.04	77.09	77.24	77.10	77.33	77.64	77.10	76.87	76.7	76.88	77.02	77.33	77.10	77.15	77.64	76.87	76.64	76.89	77.11
CO ₂	0.12	0.11	0.13	0.16	0.11	0.12	0.11	0.13	0.17	0.16	0.13	0.16	0.12	0.16	0.18	0.12	0.11	0.13	0.16	0.14

¹ – tests, in which steaming of pulveriser was not applied, ² – tests, in which steaming of pulveriser was applied

3.3. Qualitative and quantitative analysis of gas atmosphere in coal pulveriser – start-up of the pulveriser system

The pulveriser system was started up in accordance with the internal CHP’s procedures. And because of the limited time and quickly changing pulveriser’s parameters tested was only gas

composition prevailing in cross section of the coal dust-air mixture evacuation pipe (point nr 4, Fig. 6) – per analogy like during the pulveriser's shutdown.

In table 4 below results of the chromatographic analysis of gas composition are presented for the separate coal-fuel mixtures.

Two consecutive gas samplings were made. First, after opening of vane guide of the pulveriser's fan (sample I) in order to enforce insignificant air flow through the pulveriser and to check whether during its standstill the combustible gases haven't accumulated. Second, after a start of the pulveriser's fan (sample II) in order to check if a portion of „fresh“ air will have an impact on the behaviour of the fuel residues (small amount of fuel could be left behind inside of the pulveriser when it was shut down).

Table 4

Chemical composition of pulveriser's atmosphere during its start

Gas composition	Type of fuel / Nr of injection into µGC / concentration of the tested compounds, %vol.									
	Coal		Coal + sunflower husks ¹		Coal + sunflower husks ²		Coal + sawdust ¹		Coal + sawdust ²	
	I	II	I	II	I	II	I	II	I	II
O ₂	20.38	20.81	20.13	20.35	20.32	20.55	20.42	20.52	20.61	20.65
N ₂	77.04	77.64	77.10	77.64	77.64	77.24	77.75	77.05	77.24	77.51
CO ₂	0.10	0.08	0.13	0.06	0.12	0.11	0.14	0.07	0.16	0.08

¹ – tests, in which steaming of pulveriser was not applied, ² – tests, in which steaming of pulveriser was applied

The results of the chromatographic analyses indicated that gas composition inside of the coal dust-air mixture evacuation pipe during mill's start up was close to the composition of ambient air. However certain rule can here be observed. Namely, after the pulveriser's fan is switched on (sample II) which causes supply of large portion of air into the pulveriser, the oxygen content rises insignificantly when compared with atmosphere inside of it when only air dampers on the air channel are open (sample I).

3.4. Qualitative and Quantitative analysis of gas atmosphere in coal pulveriser – emergency shutdown of the pulveriser and its standstill

Similarly as in the previous states of pulveriser's operation (start-up and planned shutdown) during pulveriser's state out of operation the gas samples were taken only from the cross section of the coal dust-air mixture evacuation pipe (point nr 4, Fig. 6). Quantitative and qualitative analyses of the samples taken have proved that in both, when applying steam quenching and without it, the gas composition was identical with that of ambient air.

The shutdown of the pulveriser was simulated by switching off the pulveriser's fan. As a result some fuel was left behind inside of the pulveriser. Similarly, as during the tests of shutting down of the mill according to the CHP's procedure, the samples have been taken at 20 minutes intervals for about 2 hours after the pulveriser has stopped. The samples were taken from all sampling points. The objective of this was to check whether the fuel left inside of the mill undergoes gasification process.

Tests were conducted by steaming the pulveriser during its shutdown and without it.

In table 5 below results of the chromatographic analysis of gas composition are presented for the separate coal-fuel mixtures.

Tabela 5

Average chemical composition of gas during the mill's emergency shutdown

Gas composition	Type of fuel / Average concentration of the tested compounds, %vol.																			
	Coal				Coal + sunflower husks ¹				Coal + sunflower husks ²				Coal + sawdust ¹				Coal + sawdust ²			
Measuring point.	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
O ₂	20.81	20.13	20.43	20.25	20.13	20.25	19.81	20.41	20.41	20.25	19.81	20.13	20.81	20.13	20.25	20.43	20.13	20.42	20.25	20.35
N ₂	77.64	77.72	77.24	77.33	77.10	77.33	74.64	77.24	77.33	76.88	77.02	76.97	77.33	77.10	77.10	77.33	76.87	76.7	77.24	77.10
CO ₂	0.18	0.12	0.12	0.11	0.13	0.16	0.18	0.12	0.13	0.13	0.16	0.11	0.11	0.11	0.13	0.12	0.16	0.18	0.12	0.11

¹ – tests, in which steaming of pulveriser was not applied, ² – tests, in which steaming of pulveriser was applied

The results of the chromatographic analysis indicate that during simulated emergency shutdown of the pulveriser chemical composition of gas at all sampling points did not derive too much from the ambient air composition.

4. Summary

Tests of gas atmosphere prevailing inside of the coal pulveriser and in the coal dust-air mixture evacuation pipe were conducted during characteristic stages of pulveriser's operation such as: stable operation of the mill, during planned shutdown of the mill and during its standstill (out of operation state) (i.e. pulveriser's fan is switched off, closed guide vanes of the fan), during start up and during emergency shutdown of the pulveriser and during enforced start-up of the pulveriser (filled in with fuel).

During tests inside of the pulveriser only gas compounds were detected that are normally present in ambient air (such as: oxygen, nitrogen and carbon dioxide). Also, during stable operation of the pulveriser measurements of the chemical composition in the tested coal-dust-air mixture evacuation pipe proved that mainly air gas compounds were present. However, when mixtures of biomass and coal were used, it were detected negligible (trace) amounts of methane (for wood biomass a coal mixtures) and methane with hydrogen (for coal and sunflower husks mixture) (of the order of several dozens of ppm).

5. Conclusion

The gas hazards derive from presence of combustible gases that can be released under thermal destruction of the fuel, and high enough appropriate concentrations (in air) can cause ignition and as a result explosion.

Hazards deriving from the possibility of gases ignition in case of common pulverising coal mixtures with biomass can occur only in unstable conditions i.e. in emergency shutdowns, planned shutdown and during start-up. Despite the fact that in tests during the above mentioned states/stages of operation any combustible gas constituents inside of the pulveriser system were not detected. As it derives from literature data the biomass left behind on heated up elements of the pulveriser can undergo a destruction with the production of combustible gases [4÷8]. These gases can accumulate in the non-vented spaces of the pulveriser and, as a result a gas mixture can be created with combustible gases concentrations close to the flammability limits (i.e. lower explosion limit – LEL).

Because of that, to secure safe operation of the pulveriser group, one should observe the following guidelines:

Stabler operation of the pulveriser

- When temperature of the mixture raises above 130°C with insignificant gradient, then without hesitation the temperature of the operating pulveriser should be reduced at maintained ventilation and not allowing for the pulveriser shutdown and possible releasing of combustible gases from the fuel stored inside of the pulveriser
- In case of sharp increase of the temperature of the mixture (fire inside of the pulveriser), the steam quenching installation should be started up without hesitation.

Planned shutdown and standstill

- Time of pulverising should be extended at the minimal load of feeders and at the increased ventilation. This activity should be undertaken to blow out from the pulveriser the residues of the fuel that could be left there (especially residues of biomass)
- Prior to shutting down the pulveriser's fan one should switch on the steam quenching system for additional cleaning of inside of the pulveriser elements from the residues of biomass
- Due to possibility of releasing of non significant amounts of combustible gases from the biomass left behind inside of the mill, during standstill the air flow through the pulveriser should be maintained.

Emergency shutdown

- The coal-biomass mixture left behind at the heated up elements of the mill can cause emission of combustible gases creating thus at some concentrations the explosion hazard, as well as it can create another hazard, namely coal dust ignition
- Due to these potential hazards, when the pulveriser is out of operation it is necessary to ventilate it intensively with cold air, the task of which is to remove potentially created combustible gases as well as to cool elements of the pulveriser. During cooling process the steam quenching installation should be switched on in order to mainly increase the moisture content of the fuel left behind in the mill
- In case of fire the air supply to the pulveriser should be cut off, only steam quenching installation should be on, and this installation will create inert atmosphere and will stop accumulation of the created combustible gases to the dangerous flammability levels
- After cooling down of the pulveriser i.e. after temperature of the fuel-air mixture will drop below 80°C one should start to empty the pulveriser from the fuel left behind in it
- In case when ignition of the fuel in the mill will take place, before the emptying from the fuel starts, water should be used in addition in order to totally quench the fire in the fuel residues that can still smoulder, since these residues still pose a hazard of explosion when in contact with the air.

These guidelines are of a general type and observing them can for sure improve conditions of operation of boilers that co-fire biomass with its increased share (above 10% by weight).

However to secure maximum credibility at individual energy systems one should suggest execution of tests/research with the scope as described in this paper and for the most often biomass types burnt and its share in mixture with coal.

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