Applied Thermal Engineering 98 (2016) 449–454

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Online monitoring of coal particle size and flow distribution in coal-fired power plants: Dynamic effects of a varying mill classifier speed

J. Blondeau [a,*], R. Kock [b], J. Mertens [a], A.J. Eley [c], L. Holub [c]

[a] Laborelec (ENGIE), Rodestraat 125, 1630 Linkebeek, Belgium
[b] EUtech Scientific Engineering, Dennewartstrasse 25-27, 52068 Aachen, Germany
[c] Gheco-One (ENGIE), Map Ta Phut Industrial Estate, I-5 Road 11, 21150 Rayong, Thailand

HIGHLIGHTS

- The effect of a coal mill classifier speed was measured online in a 660 MWe plant.
- The coal particle fineness and the coal flow distribution were monitored.
- The amount of particles <75 µm varied between 66 and 74%.
- The maximum coal flow deviation was reduced from 14% to 9%.

ARTICLE INFO

Article history:
Received 23 February 2015
Accepted 24 December 2015
Available online 6 January 2016

Keywords:
Coal
Mill
Classifier
Particle size distribution
Coal flow distribution

ABSTRACT

The fineness of the coal powder and the uniformity of the coal flow sent to the burners are crucial parameters to achieve an effective combustion in coal-fired power plants. This study presents a methodology for the online monitoring of the (i) coal particle size distribution and (ii) coal flow distribution between burners at the outlet of a roller mill installed in 660 MWe coal-fired power plant. The effect of a varying centrifugal classifier speed on these two properties was investigated. To the best knowledge of the authors, it is the first time that such an effect is monitored online in a large scale utility boiler. For a classifier speed between 73 and 99 rpm, the mass fraction of particles smaller than 75 µm varied between 66 and 74%. The coal flow distribution between burners was strongly improved when the particle size was the smallest: the maximum deviation from the average flow rate was reduced from 14% at 73 rpm to 9% at 99 rpm.

1. Introduction

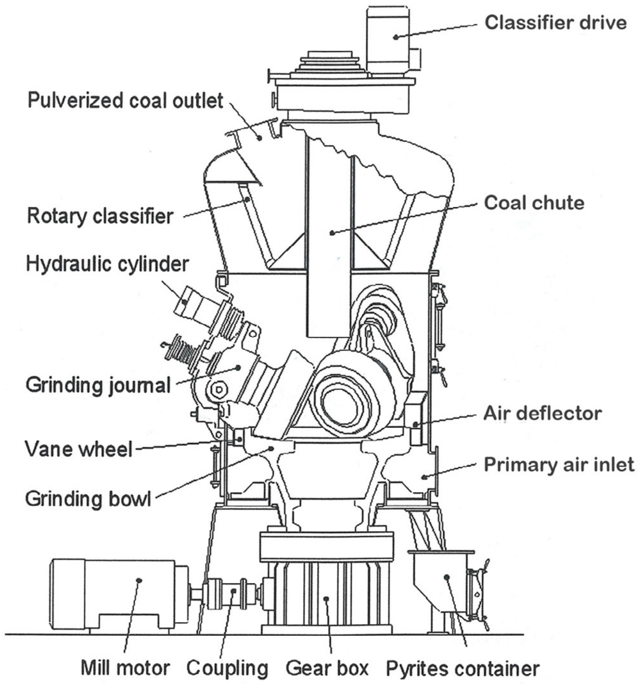
The share of coal as a primary energy source used for electricity generation in the world is about 40% [1,2]. While the technological maturity of Circulation Fluidised Bed (CFB) boilers is continuously increasing, the vast majority of coal-fired utility boilers around the world are still of the Pulverised-Fuel (PF) type, with the traditional drum-type configuration, or the state-of-the-art Super Critical (SC) and Ultra Super Critical (USC) steam cycles.

In PF-boilers, coal is pulverised in a mill (or pulveriser) before being entrained by primary combustion air to burners, to form a high temperature flame in the furnace of the boiler (1000–1600 °C) [2]. The fineness of the coal powder, as well as the uniformity of the coal flow sent to each burner fed by the same mill, are crucial parameters to achieve an effective combustion [3]. The finer the particles, the better the mixing between the fuel and the combustion air, which ensures a complete combustion (low Loss of Ignition, LOI), low CO emissions and a more effective control of NO_X emissions [4–6]. Coarse particles also foster agglomeration and deposition of slag, and they can poison the catalyst of a Selective Catalytic Reduction (SCR) systems installed for NO_X reduction [5]. In addition, an increase of the Unburned Carbon (UBC) content of the fly ash can disqualify it for further commercial use [5]. An uneven distribution of the coal flow between burners essentially results in the same effects, as the fuel-to-air ratio becomes too high in some burners, and too low in some others.

This work is carried out on one specific type of pulveriser: the applied-force mills, better known as bowl mills, or roller mills [2]. In such pulverisers, the coal lies in a bed which is passed over by two or three grinding rollers. The coarse particles are crushed by pressure. The produced fine particles are entrained by the hot primary air flow to the top of the mill, where a classifier separates the fine particles, which is sent to the burner, from the coarse particles returned to the mill. The classifier can be either static, or centrifugal. In the case of a static classifier, the maximum size of the particles flowing through it is determined by the geometry of

* Corresponding author. Tel.: +32 2 382 04 13; fax: +32 2 382 02 41
E-mail address: julien.blondeau@laborelec.com (J. Blondeau).

http://dx.doi.org/10.1016/j.applthermaleng.2015.12.113
1359-4311/



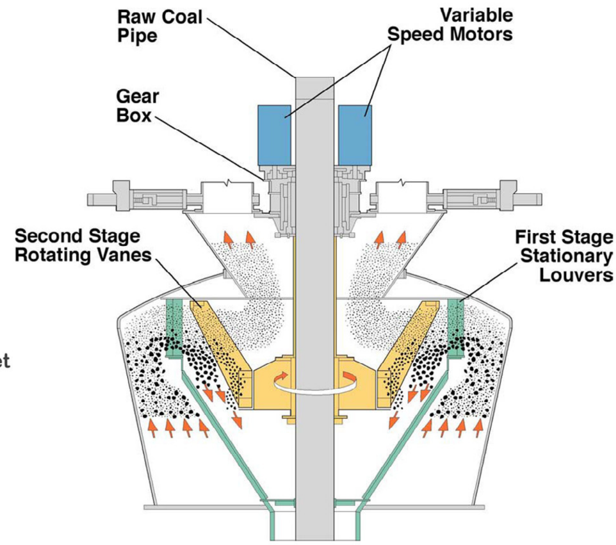


Fig. 1. A typical roller mill (left) [2] and a typical centrifugal classifier (right) [7].

its vanes [3]. The vane angle of a static classifier can generally be modified manually. In case it is a centrifugal classifier, it rotates at a constant speed to increase its selectivity. The classifier speed is then one of the key parameters in the control of the coal Particle Size Distribution (PSD), together with the other parameters ruling the operation of the mill, such as the primary air flow and temperature, and the grinding pressure. A typical roller mill with a centrifugal classifier and the principle of a centrifugal classifier are illustrated in Fig. 1.

During commissioning and operation of a large-scale roller mill, the standard method for the measurement of the PSD is based on a manual sampling of the particles at the outlet of the mill, and the sieving of the collected sample in a laboratory. Based on these measurements, the operating parameters of the pulveriser are adjusted: primary air flow and temperature, grinding pressures and classifier speed, among others. In general, such samples are regularly taken from each mill during operation for follow-up purposes.

As far as the individual coal flow rates sent to the burners are concerned, they are generally only measured during commissioning, for fine adjustment, by performing several local, iso-kinetic samplings of the coal particles in the cross-sections of the coal feed pipes. Based on those measurements, the coal flow distribution to the burners is tuned by a manual adjustment of the diaphragms installed at the outlet of the mills. They aim at compensating the pressure drop differences between the coal feed lines. In some cases though, the coal flow distribution is only assessed based on measurements of the clean primary air flows (in the absence of coal particles). This procedure was applied for the mill considered in this study. It relies on the assumption that the coal flow distribution will strictly follow the air flow distribution, which is only valid in case of an excellent particle fineness.

Those standard measurements of the PSD and the coal flow distribution do not allow for a real time monitoring of the performances of pulverisers, and the online adjustment of the operating parameters of the mill is therefore impossible.

In this study, we will show the results of a measurement campaign performed on the utility boiler of the Gheco-One power plant (ENGIE, Thailand, 660 MWe) with innovative, non-standard equipment installed at the outlet of one mill: a laser probe for the online monitoring of the PSD, and microwave sensors for the online assessment of the coal flow distribution. The objectives of this study are to:

i. present a methodology for the on-line monitoring of both coal PSD and flow distribution,
ii. investigate the influence of varying the classifier speed on coal PSD and flow distribution.

To the best knowledge of the authors, it is the first time that the effect of the classifier speed on those two parameters is measured online in a utility boiler. The performed measurements allow for a straightforward adjustment procedure during the commissioning of pulverisers or during the testing of new fuels or fuel blends.

2. Materials and methods

2.1. Mill operation

The mills installed at the Gheco-One power plant were designed by Loesche Energy Systems Ltd and are of the LM28.3D type. The internal diameter of the coal feed pipes downstream to the mill is 539.8 mm. The mills are equipped with dynamic classifiers of the type LSKS39. They are generally operated with a classifier speed around 80 rpm.

The measurements were performed on one of the six mills producing the pulverised coal particles injected in the furnace (mill D). It was put under manual control during the entire test campaign, with a coal flow set point of 16.4 kg/s. Measurements were done for classifier speeds of 73, 81, 89, 94 and 99 rpm. This was considered as the largest acceptable speed range during commercial

Table 1
Main properties of the coal fed to mill D during the tests.

Hardgrove Grindability Index [–]	46
Total moisture, as received [%w]	20.1
Ash content, as received [%w]	4.4
Volatile content, as received [%w]	36.1

operation. Lower speeds would have led to combustion degradation, while higher speeds would have resulted in excessive vibration, increased electrical consumption, increased pressure drops, and possibly to a limitation of the produced pulverised coal flow. The measured classifier speeds were retrieved from the plant Distributed Control System (DCS).

The main properties of the coal fed to mill D during the test are given in Table 1.

2.2. Online particle size distribution measurements

The PSD of coal at the outlet of the pulveriser was measured using a laser probe, inserted in one of the five burner feed pipes connected to the considered mill. The probe was inserted with 426 mm in one coal feed pipe, perpendicularly to the flow, in a straight vertical section running along the boiler wall, in a location sufficiently away from upstream and downstream elbows (>5 m) to avoid the effect of flow disturbance. The EUcoalsizer laser probe developed by EUtech, already presented in detail elsewhere [8–10], was used. The main principle of the device is illustrated in Fig. 2: each individual particle flowing in the measurement volume is detected by a stream of parallel laser beams. The velocity and the size of each particle are then deduced from the frequency and the duration of the laser signals. The range of detection of the EUcoalsizer probe is 20 µm–4 mm. For a single PSD measurement, the total amount of particles detected before the sample is considered representative is 10^5. For a continuous measurement, as was the case in this study, the sequence of detection of 10^5 particles is constantly repeated, resulting in one measurement point after each sequence. About 5 seconds were needed to perform each measurement.

The estimated error on particle size measurement itself is less than 3%. The precision (repeatability) of the measurements was assessed on a test bench, by quantifying the standard deviation of a series of measurements. It was lower than 1.5%. On site, as for any other measurement device, other factors such as measuring position on the feed line or measuring depth inside the pipe can influence the system accuracy. In this study, as indicated above, care was taken to avoid any flow disturbance, and the position of the probe was kept constant during the whole duration of the test.

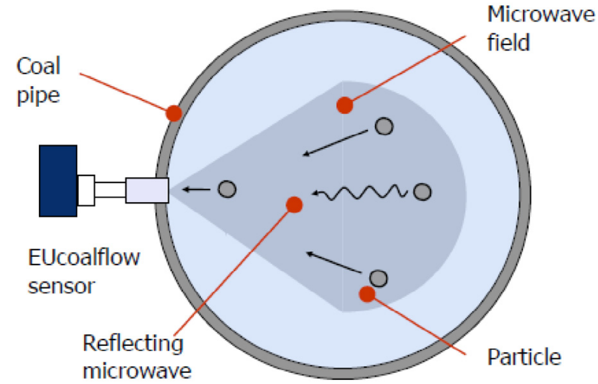


Fig. 3. Principle of the EUcoalflow microwave sensor [11].

2.3. Online coal flow distribution measurement

The coal flow distribution between the 5 burners fed by the considered mill was assessed using the EUcoalflow microwave sensors developed by EUtech, and described in Reference 11. The measurement is based on the detection of the microwaves reflected on the moving particles inside the pipe (see Fig. 3). The detected signal is a linear function of the particle mass flow rate. Relating these measurements to the total coal mass flow rate pulverised in the mill, the collected data give an access to the individual mass flow rates sent to each burner.

In order to cover the whole cross section, 3 sensors were installed per coal feed line (3 × 120°). The sensors were installed in straight horizontal sections, in a location sufficiently away from upstream and downstream elbows (>5 m) to avoid the effect of flow disturbance.

The sensors were calibrated on site under steady state conditions: constant mill operations at various loads were used to deduce the linear relationship between the microwave signals and the coal flow rate in the feed pipes. The estimated error in steady state phases (feeder flow rate vs. EUcoalflow total flow rate) is less than 4%. The precision (repeatability) of the measurements was assessed on a test bench, by quantifying the standard deviation of a series of measurements. It was lower than 2%. On site, the measuring position

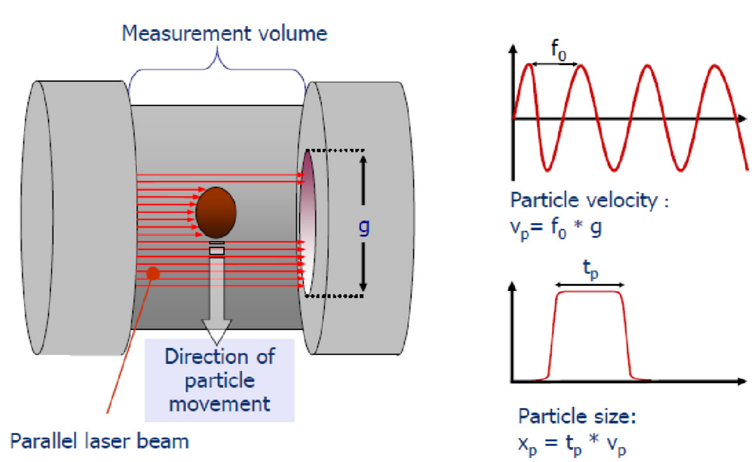


Fig. 2. Principle of the EUcoalsizer laser probe [8].

on the feed line can influence the system accuracy. In this study, as indicated above, care was taken to avoid any flow disturbance.

3. Results and discussion

3.1. Particle size distribution

The PSD measured with the EUCoalSizer probe is reported under the form of 4 curves: mass percentages of particles smaller than 75 μm, between 75 and 150 μm, between 150 and 300 μm and larger than 300 μm (see Fig. 4).

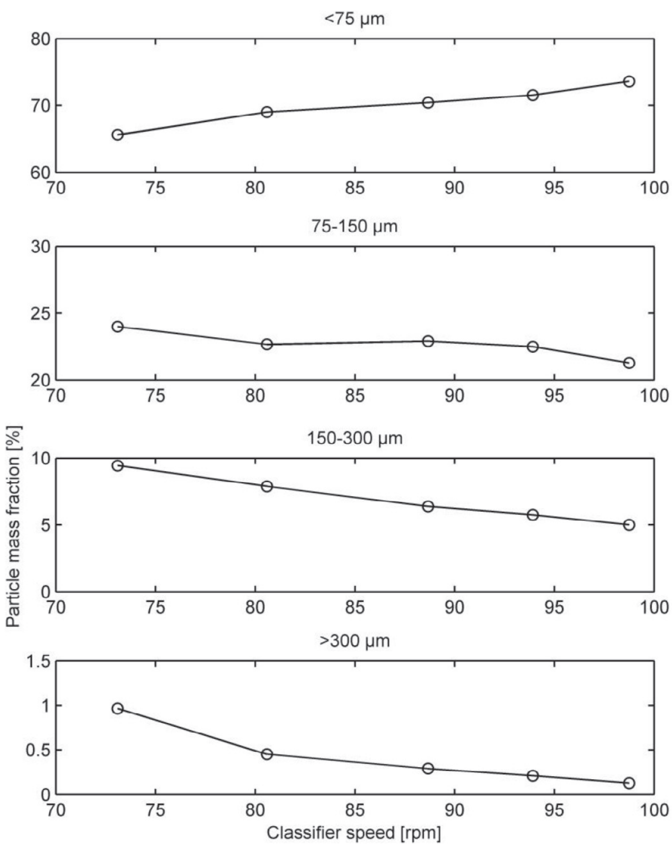


Fig. 4. Particle size distribution vs. classifier speed. From top to bottom: mass fraction of particles <75 μm, 75–150 μm, 150–300 μm and >300 μm.

It is of course expected that higher classifier speeds will result in finer particles, with an increased proportion of small particles, compensated by a decrease of the larger particle mass fractions. What is not straightforward is the extent of this increase and the related compensation for each particle size range.

The tendency observed for particles <75 μm in Fig. 4 is clear and easily explained: the higher the classifier speed, the higher the proportion of small particles is being sent to the burners. Particles in that size range are the more numerous. While they account for 69% of the mass flow in the initial configuration (80 rpm), their mass fraction is decreased by 3% at 73 rpm, and increased by 5% at 99 rpm. Between those extremities, the progression is constant, and almost linear.

As far as the intermediate size ranges are concerned (75–150 and 150–300 μm), they both compensate the higher small particle mass fractions by exhibiting lower mass fractions for an increasing classifier speed. The mass fraction of particles in the range 75–150 μm exhibits an absolute decrease of 3% between 73 and 99 rpm, with a noticeable flattening of the curve between 81 and 89 rpm. For the particles in the range 150–300 μm, even though they represent a smaller mass fraction, the decrease is more pronounced, resulting in an absolute decrease of 4% on the whole speed range, and a relative decrease of almost 50%.

The relative mass fraction decrease of particles >300 μm is even larger: –87% between 73 and 99 rpm, which corresponds to an absolute decrease of 0.8%.

3.2. Coal flow distribution

When the classifier speed was modified online, two effects were observed on the measured coal flow rates: a transient discrepancy between the flow rate fed to the mill by the coal feeder and the total flow rate sent to the burners, and a modification of the coal flow distribution between the burners.

When the classifier speed is increased, more particles are suddenly recycled back into the mill, and the coal flow rate to the burners decreases. The amount of coal trapped in the mill therefore increases. When the classifier speed is decreased, its selectivity is suddenly reduced, and larger particles flow to the burners: the measured total coal flow increases and the amount of coal trapped in the mill decreases. The maximum transient flow discrepancy between the inlet and the outlet of the mill was –14% when the highest classifier speed was tested (99 rpm).

Fig. 5 illustrates the variation of the coal flow distribution: the maximum and the standard deviations from the average flow rate to the burners are depicted as a function of the classifier speed. While

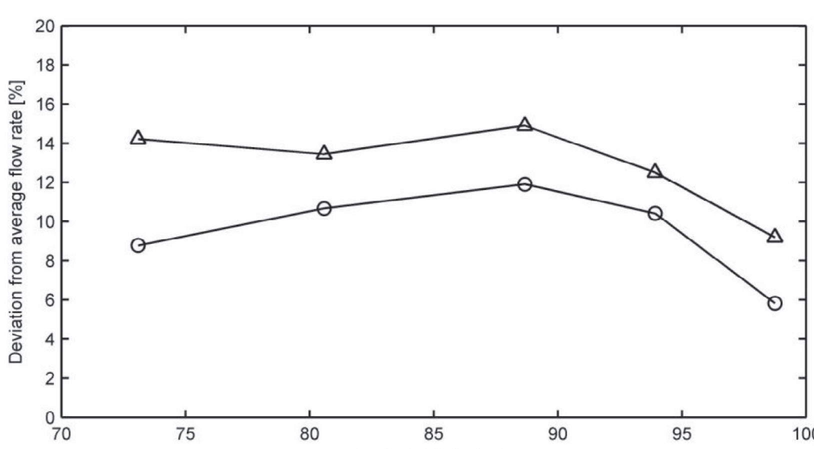


Fig. 5. Coal flow distribution to burners vs. classifier speed: maximum (triangles) and standard (circles) deviations from the average flow rate.

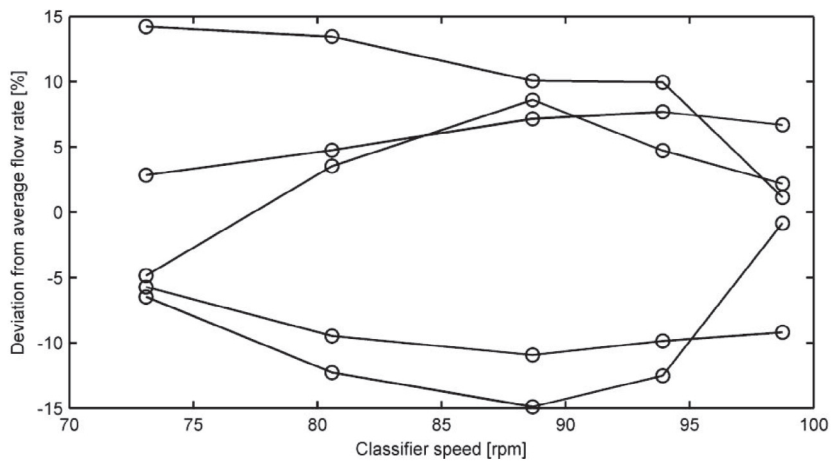


Fig. 6. Coal flow distribution to burners vs. classifier speed: deviations from the average flow rate for the 5 burner feed lines.

the maximum deviation is around the significant values of 14 to 15% for usual classifier speeds (between 73 and 89 rpm), it is strongly decreased when higher coal fineness is reached, i.e. for higher classifier speeds: 12 and 9% for 93 and 99 rpm, respectively. Finer particles tend to be more evenly distributed among the feed lines, as they follow the primary air streams more easily.

More surprisingly, the standard deviation decreases for both high and low classifier speeds. The shape of this curve is explained by the detailed flow rate deviations for the 5 burner feed lines illustrated in Fig. 6. It shows that 3 feed lines can be considered as preferential ways for large particles in the range 80–95 rpm, resulting in a high standard deviation >10%. This pattern is modified for the finest PSD (at 99 rpm), where both the maximum and standard deviation are decreased, and for the coarsest PSD (at 73 rpm), where one feed line moves from a positive deviation to a negative deviation, resulting in a decreased standard deviation, while the maximum deviation remains high, see Fig. 5.

As a reminder, the diaphragms installed on each coal feed line of the considered mill were adjusted based on measurements of clean primary air flows only (in the absence of particles). These results show that this procedure is not suitable for the coal fineness considered here. Reasonable standard and maximum deviations (close to 5% and < 10%, respectively) are only obtained for the highest acceptable classifier speed (99 rpm), which is not always achievable due to other operating constraints on the mill, such as vibration, electrical consumption, grinding pressure or capacity. Coal mass flow rate measurements should always be considered during commissioning instead of clean air flow rates, ideally with online monitoring tools such as those used in this study.

4. Conclusions

The particle size distribution and the flow rate distribution to the burners were monitored in a large scale coal-fired power plant (660 MWe), at the outlet of a roller mill equipped with a dynamic classifier.

In this study:

i. A methodology for the on-line monitoring of both coal PSD and flow distribution was presented, which can be used for commissioning or fine tuning of large scale mills;
ii. The influence of varying the classifier speed on coal PSD and flow distribution was investigated. To the best knowledge of the authors, it is the first time that these effects are measured online in a utility boiler.

The higher the classifier speed, the higher the proportion of small particles. Within a speed range of 73–99 rpm, the share of particles smaller than 75 μm varied respectively between 66 and 74%. The loss in the small particle size range must be compensated by an increase of the number of larger particles. The range 150–300 μm exhibited the largest absolute compensation (−4%), while the largest size range (>300%) exhibited the largest relative compensation (−87%).

The mill acted as a buffer when the classifier speed varied, leading to a transient discrepancy between the feeder flow rate and the total flow rate sent to the burners. The maximum flow discrepancy between the inlet and the outlet of the mill was −14% when the highest classifier speed was tested (99 rpm).

The distribution of coal particles to the burners is strongly impacted by the coal fineness. When the particle size was the smallest, the maximum deviation from the average flow rate was reduced from 14% to 9%, and the standard deviation was reduced from 12 to 6%.

The diaphragms installed on each coal feed line of the considered mill were adjusted during commissioning based on measurements of clean primary air flows only (in the absence of particles). These results show that this procedure is not suitable for the coal fineness considered here. Reasonable standard and maximum deviations (close to 5% and < 10%, respectively) are only obtained for the highest acceptable classifier speed (99 rpm), which is not always achievable due to other operating constraints on the mill, such as vibration, electrical consumption, grinding pressure or capacity. Coal mass flow rate measurements should always be considered during commissioning instead of clean air flow rates, ideally with online monitoring tools such as those used in this study.

For the studied case, future works imply corrective actions on the mill diaphragms to balance the coal flow rates to the burners, followed by an assessment of the impact of such improvements on the boiler operation. This assessment could be supported by Computation Fluid Dynamic (CFD) simulations, in order to get an insight in the details of the combustion process inside the furnace. The gathered data on the fuel flow unbalances could also be used as input in the frame of current researches on uncertainty quantifications in the field of CFD.

References

[1] IEA, Key World Energy Statistics, International Energy Agency, Paris, 2012.
[2] H. Spliethoff, Power Generation from Solid Fuels, Springer, London, 2010.

[3] K.V. Shah, R. Vuthaluru, H.B. Vuthaluru, CFD based investigations into optimization of coal pulverizer performance: effect of classifier vane settings, Fuel Process. Technol. 90 (2009) 1135–1141.
[4] H.H. Liakos, et al., Pulverized coal char combustion: the effect of particle size on burner performances, Appl. Therm. Eng. 18 (1998) 981–989.
[5] R.E. Sommerlad, K.L. Dugdale, Dynamic classifiers improve pulverizer performance and more, Power 7 (2007) 52–55.
[6] S. Belosevic, et al., Numerical prediction of processes for clean and efficient combustion of pulverized coal in power plants, Appl. Therm. Eng. 74 (2015) 102–110.
[7] J. Sanchez, D. Broske, Pulverizer operational and performance upgrades: update on market offerings and current practices. EPRI, Palo Alto, CA, 2006, 1012633.
[8] M. Starke, H.-J. Schulpin, M. Haug, M. Schreiber, Measuring coal particles in the pipe, Power Eng. 111 (2007) 45–48.
[9] M. Schreiber, M. Haug, M. Starke, R. Kock, F. Turoni, Online measurement of coal fineness and air-fuel ratio inside the coal pipe, PowerGen International, 2008, December 2-4, 2008, Orlando, FL, USA.
[10] F. Turoni, R. Kock, Online fineness measurement system for controlling a biomass fired unit, Power Gen Europe, 2012, June 12-14, 2012, Cologne, Germany.
[11] M. Starke, R. Kock, M. Haug, M. Schreiber, F. Turoni, Continuous measurement of coal flow and air-fuel ratio inside coal pipes for closed-loop control, Power Gen Europe 2010, June 8-10, Amsterdam, The Netherlands.