IOP Conf. Series: Journal of Physics: Conf. Series **822** (2017) 012033 doi:10.1088/1742-6596/822/1/012033

Preliminary investigation on the effects of primary airflow to coal particle distribution in coal-fired boilers

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Abstract. This paper presents an investigation on the effects of primary airflow to coal fineness in coal-fired boilers. In coal fired power plant, coal is pulverized in a pulverizer, and it is then transferred to boiler for combustion. Coal need to be ground to its desired size to obtain maximum combustion efficiency. Coarse coal particle size may lead to many performance problems such as formation of clinker. In this study, the effects of primary airflow to coal particles size and coal flow distribution were investigated by using isokinetic coal sampling and computational fluid dynamic (CFD) modelling. Four different primary airflows were tested and the effects to resulting coal fineness were recorded. Results show that the optimum coal fineness distribution is obtained at design primary airflow. Any reduction or increase of air flow rate results in undesirable coal fineness distribution.

Keywords: *coal fineness, pulverizer, primary airflow, CFD simulation*

1. Introduction

Pulverizers system provides pulverized coal to the boiler. Within the pulverizers, the coal is ground and classified to the proper size. Primary air is used to dry and transport the pulverized coal for burning in the boiler [1]. There are various issues related to pulverizer performance such as poor coal fineness and uneven coal flow distribution. The uneven coal flow distribution in furnace could be caused by many reasons. Coarse coal particle entering the furnace is one of the contributing factors [2]. Continuous research in this area has been carried out by many researchers. Richard [3] describes theoretical information on technique in pulverized coal pipe testing and balancing. Shah et al. [4] performed Computational Fluid Dynamics (CFD) simulation to investigate the effect of classifier vane settings on pulverizer performance. Their results show the optimum classifier vane opening can improve the fineness but need to consider other factors such as uniform coal mass flow rate at PC pipes outlets, desired size fraction and classifier efficiency. Sung et al [5] present the influence of coal particle size on Nitrogen Oxide, emission and burnout characteristic. The results show that the burnout performance increases with an increase in the level of coal fineness. The effectiveness of air staging on the NO reduction and burnout performance is significant in the flames with fine pulverized coal

particles. Nakamura et al [6] studied the effect of equipment geometry on grinding performance of the pulverizer. Their results show that the stator concave angle affects the particle residence time and total number of the particle stator collision. Blondeau et al [7] present a methodology for the on-line monitoring of both coal particle size and flow distribution and investigate the influence of varying the classifier speed on coal particle size and flow distribution. It was demonstrated that the coal flow distribution between burners was improved when the particle size was the smallest.
Many inefficient operations of boilers and pulverizers were reported in coal-fired power plants in the world. One of the common causes of this inefficiency was due to inefficient operation of pulverizers when coarse coal is allowed into boiler furnace for combustion. These coals are transported into boiler furnace by primary air. The flow rate of primary air is crucial in determining the right coal size that exits the pulverizer mill. In this work, coal fineness and coal flow distribution were measured at different primary air flow rate. The study also involved preliminary CFD modelling of coal particles distribution from pulverizer to burner. The research work aims to improve boiler efficiency and the focus is given to the flow characteristic inside pulverizer mill.

2. Methodology

In this research study, isokinetic coal samplings were carried out at pulverizer to determine coal flow distribution in each pulverized coal (PC) pipes. CFD investigations were carried out focusing on flow characteristics of coal particles inside pulverizer. The CFD model used is based on a real vertical bowl mill at coal-fired power plant in Malaysia.
Coal flow distribution were sampled from the vertical straight PC pipes just after the pulverizer by using Dirty air pitot (DAP) and Pulverized Fuel Sampler (PFS) to measure the flow velocity and extract coal samples [8]. To ensure isokinetic sampling, the sampling gas velocity is maintained at the same level as the gas velocity in the PC pipe. The DAP and PFS are inserted through a dustless connection into the PC pipe. Then, coal fineness was determined by sieving following procedure in ASTM D197-87 [9]. The quantity of coal passing each sieve is used to determine coal particle sizing. The fineness was determined by sieving through ASTM 50, 100 and 200 Meshes and plot into Rosin-Rammler distribution. The sampling activities and fineness test to investigate coal flow distribution are shown in Figure 1-3.

Figure 1: PC pipes velocity measurement by using Dirty Air Pitot

Figure 2: Pulverizer Fuel Sampler - extract coal sample

Figure 3: Coal Fineness test

CFD modelling for pulverizer system was developed to investigate the coal particle distribution at the exit of pulverizer when the amount of primary air varies at 60%, 80%, 100% and 120% of design condition. The recommended range of primary air for power plant for this case study is 80 -100 kNm^3/h. For this project, 90 kNm^3/h is chosen as 100% of the amount of primary air. This calculation is done with the assumption of fixed classifier angle. This system includes all the parts and components that exist in the pulverizer.

Figure 4 shows the schematic diagram of pulverizer model for the simulation of flow and coal particle distribution. Generally, the pulverizer consists of the centre chute where raw coals first enter the system. The raw coal will later grinded on the rotating table with three rollers at the bottom part of the mill. At the same time, hot primary air is injected to carry the grinded coal to the pulverizer exit. Prior to the pulverizer exit, the mixture of grinded coal and hot air will pass through the classifier which is located at the top of the pulverizer. Depending on the classifier angle, fine coal will pass through it and flow downstream to series of complex piping system that leads the mixture to the burner and furnace entrance. The classifier is designed to prevent coarse coal particle to pass through it and these coarse will falls and returned to the bottom of the pulverizer where it will be re-grinded on the rotating table. It is important to carefully take into account the classifier in the model for correct determination of coal fineness leaving the system. In order to model the whole pulverizer system accurately, each components that exist in the mill are taken into account and model separately for simplicity. Figure 5 and Figure 6 show the classifier vane and primary air inlet respectively while Figure 7 shows the cross sectional view of the completed assembly of components that make up the pulverizer.

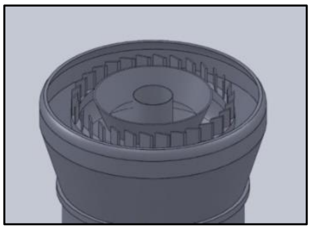

Figure 4: Classifier vane

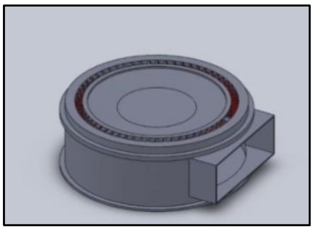

Figure 5: Primary air inlet

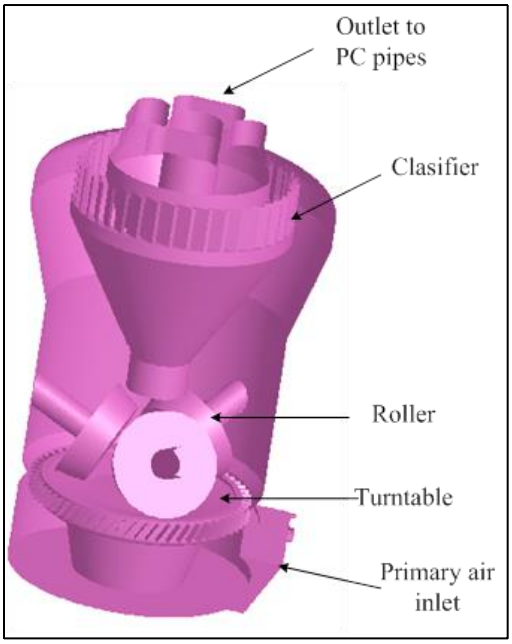

Figure 6: Schematic diagram of pulverizer model

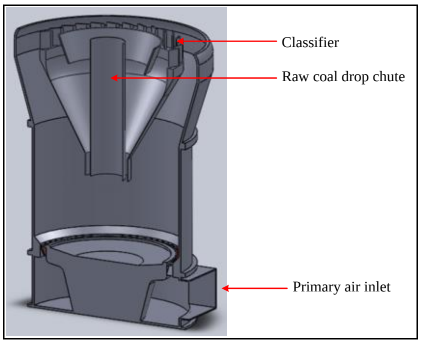

Figure 7: Cross sectional view of pulverizer

3. Results and Discussions

Figure 8 shows the Rosin Rammler chart to represent the sieve test result of coal fineness from the sampled pulverized coal. The x-axis shows the percentage of coal passing through the sieve and the y-axis shows the sieve size in mesh or particle size in µm unit. The ascending line represents the cumulative percentage of coal passing through the sieve. According to plant requirements, more than 70% by weight of the pulverized coal should be smaller than 75µm and less than 1% of the pulverized coal should be larger than 300µm. However, from the coal fineness tests of the sampled pulverized coals, less than 50% were smaller than 75m and more than 10% of the pulverized coal samples were larger than 300µm size. Figure 9 shows the coal flow distribution for the four PC pipes. The figure indicates that there is a significant mal-distribution of coal mass flow in the PC pipes. It shows that the quantity of coal delivered to each burner is not equally distributed. Theoretically, the deviation limit between four PC pipes for each pulverizer is not more than 10% [4].

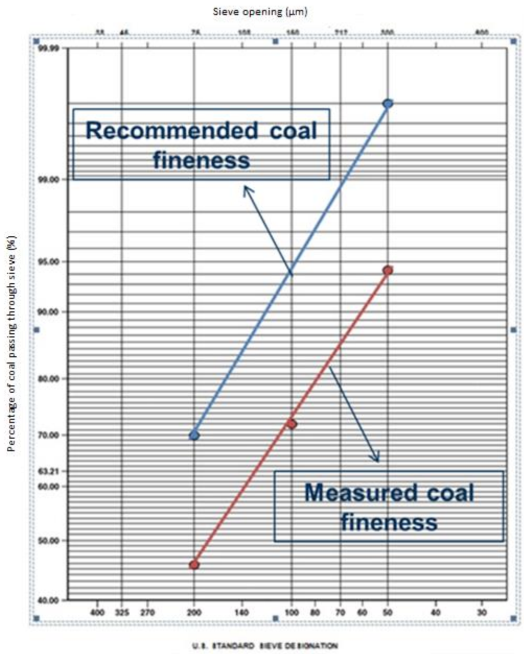

Figure 8: Result of coal fineness

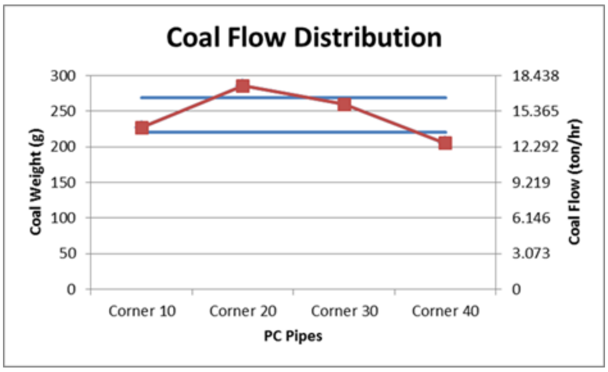

Figure 9: Result of coal flow distribution

The CFD simulation for pulverizer system aims to investigate the coal particle distribution at the exit of pulverizer when the amount of primary air varies at 60%, 80%, 100% and 120% of design condition. This calculation is done with the assumption of fixed classifier angle. Figure 10 shows the prediction of coal particle size distribution at pulverizer exit when the primary air is 60% of the design condition. At this rate, it is predicted that higher percentage of coarse coal passed the classifier and exit the pulverizer. The trend is linear in which fine coal was found to be the lowest. This condition is undesirable in the operation of the pulverizer and explains why it is not practised in actual operation. Similar trend was also found to be true for the case of 80% primary air as illustrated in Figure 11.
However, at 100% primary air the distribution of coal fineness at pulverizer exit changes completely at which most of coal particle group that exits the pulverizer were fine particles. The lowest particle group that escape the classifier was coarse particle as shown in Figure 12. This trend explains why the suggested setting for primary air is at the design condition (100% primary air). Attempt is also made to further increase the amount of primary air to 120% design condition and the resulting coal fineness distribution is shown in Figure 13. It is clear that further increase in primary air is not favourable as the coal fineness distribution falls in the average coal particle size.
To summarize the prediction made on coal fineness distribution at pulverizer exit, comparison is made for all cases and this is shown in Figure 14. It can be concluded that is the supply of primary air is less than the design value, most of the coarse coal particle will escape the pulverizer (with minimum amount of fine coal particle). The optimum setting is given by 100% primary air where it is predicted that with this setting, most of the coal particle that escape the pulverizer is fine particle which is desirable in pulverizer operation. Further increase in primary air does not guarantee continuous supply of fine coal particle as the coal fineness distribution was found to be in a mixture of coarse and fine particle.

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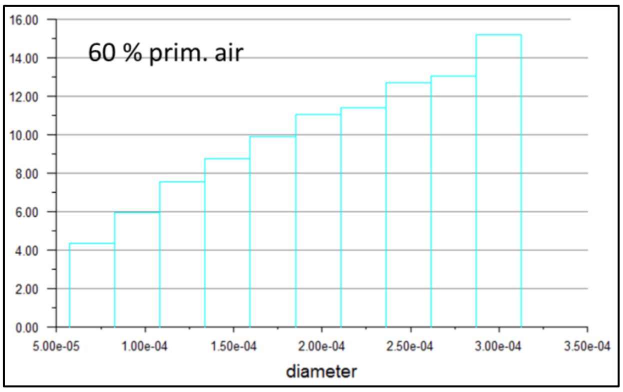

Figure 10: Prediction of particle diameter distribution at pulverizer exit (60% primary air)

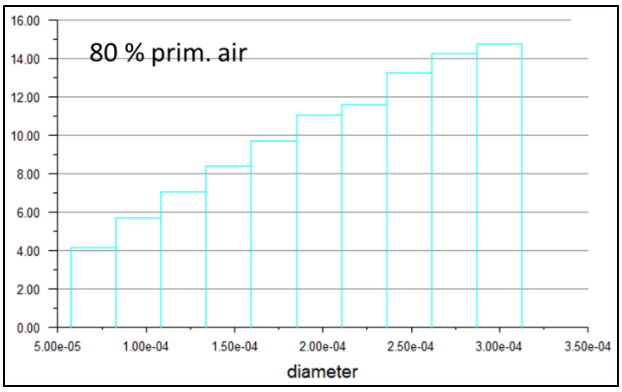

Figure 11: Prediction of particle diameter distribution at pulverizer exit (80% primary air)

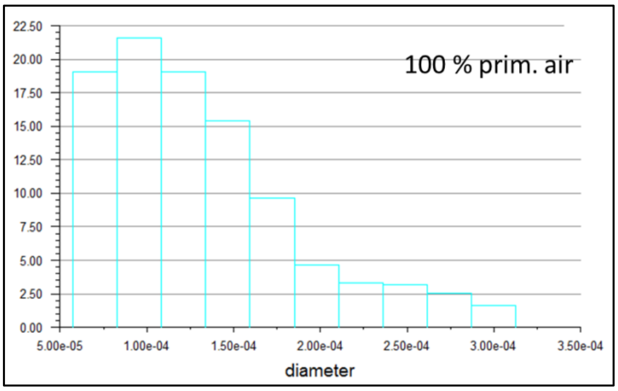

Figure 12: Prediction of particle diameter distribution at pulverizer exit (100% primary air)

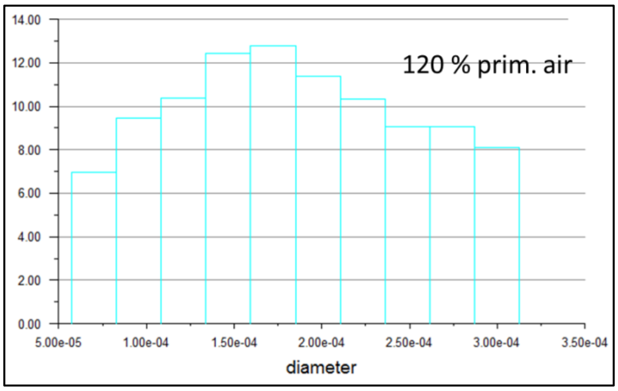

Figure 13: Prediction of particle diameter distribution at pulverizer exit (120% primary air)

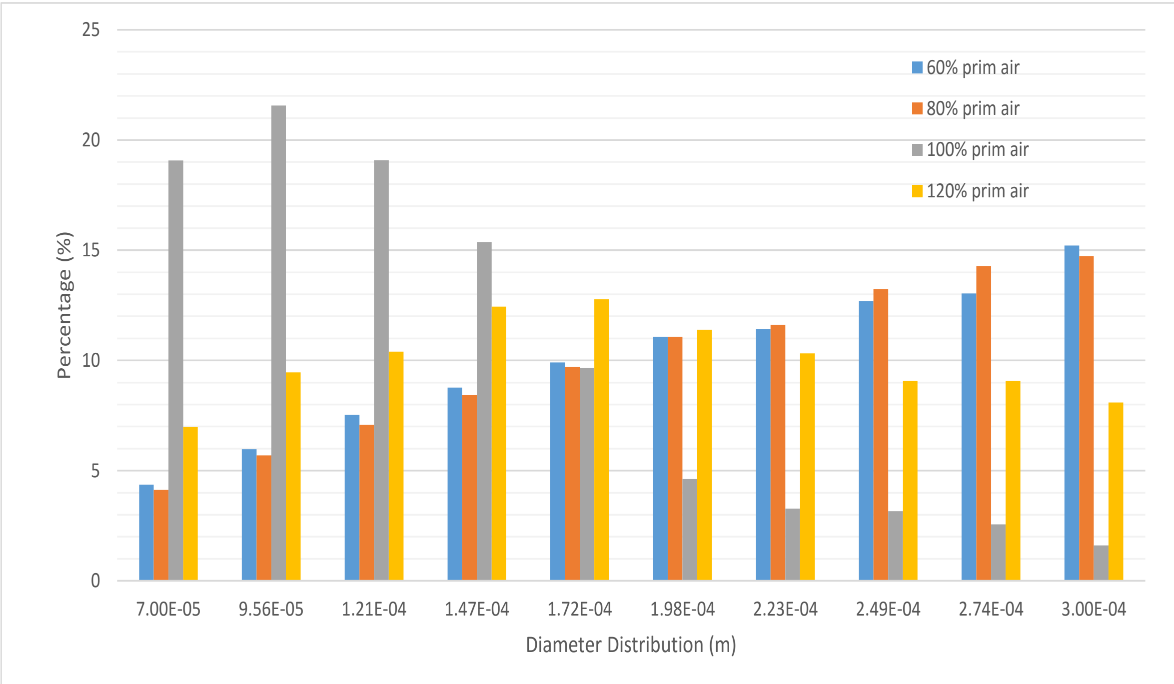

Figure 14: Comparison of particle diameter distribution at pulverizer exit

4. Conclusions

In this work, the effects of different primary air flow on coal flow distribution in coal-fired power plant are simulated using CFD. Isokinetic coal sampling to collect sample for coal fineness analysis were performed. From the measurement, less than 50% pulverized coal were smaller than 75 µm and more than 5% pulverized coal were larger than 300 µm when sampled. To further investigate this problem, CFD simulation was carried out. CFD analysis of coal particle flow and distribution inside pulverizer is carried out. Variation of primary air flow at fixed pulverizer parameters was tested. Based on the simulation, the following conclusions can be withdrawn:

i. Setting of lower primary air (carrier air) results in high percentage of coarse coal particle leaving the pulverizer. Increasing the primary air further will reduce the coarse particle and the trend is valid for air mass less than 100% (design).
ii. At 100% primary air (design), the amount of fine coal particle leaving the pulverizer is the highest.

Based on the prediction made by computational simulation, it is thus recommended that the operation of pulverizer be set at 100% primary air supply. This is to ensure sufficient momentum flux for optimum coal fineness at the pulverizer exit and at the same time avoid pre-mature combustion of coal mixture should the primary air be set lower than design condition.

Acknowledgements

The authors wish to thank Tenaga Nasional Berhad (TNB) for providing the research grant to carry out this project. The financial support received from the Ministry of Education Malaysia via Fundamental Research Grant Scheme (20150210FRGS) is also acknowledged.

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