A study on drag reduction scheme of 200MW DACCU bag filter

Yu kun Lyu, Jiaxi Yang and Jiawen Wang
North China Electric Power University, Baoding, China

Abstract. The DACCU bag filter is the main equipment of pollution control in power plant. The resistance is closely related to its structure. Based on the original structure size and field measured operation parameters of bag filter, the CFD was used for numerical simulation analysis to find out the area with the largest resistance in the original model, thereby meeting the actual demand of the overall resistance reduction and flue gas uniform distribution of the bag filter. Accordingly, three successive improvement schemes were designed from three aspects of flue gas inflow direction, flue gas distribution plate's angle and the number of distribution plates. The numerical simulation method was used to optimize to the minimum resistance to ensure the safe and stable operation of the unit. It provides a reference for relevant engineering design.

1. Introduction
In the combustion process of pulverized coal, it is inevitable to produce dust and toxic gases [1-3]. Researching and developing ultra-low emission technology, which has a great significance to promote the development of energy conservation and emission reduction industry, has become an important issue in China and even in the world. As the main equipment of dust emission control in thermal power industry, bag filter is widely used for its character of large amount of flue gas treatment, obvious dust removal effect, and strong applicability [4-8].

Guo Fengnian [9] put forward the applicable occasions for several different types of bag filters in 1982. Zhao Jiangxiang et al. [10] cooperated with Japanese enterprises to design a large pulse bag filter in 1995, which improved its dust removal efficiency to a certain extent. Jin Yiyung et al. [11] added active carbon to the bag filter in 2003, which effectively absorbed dioxin in the flue gas. Zhu Yongchao et al. [12] designed a new type of electrostatic bag filter in 2011. Zhou Hao et al. [13] added orifice plates inside the bag filter to make the flue gas flow more uniform. David Leith et al. [14] analyzed that the proportion of dust removal by blowing pulse of bag filter is directly proportional to the reverse pressure drop during spraying in 1980, which provides a reference for practical application. Morcos [15] studied the relationship between dust particle size and dust removal efficiency and obtained more test data in 1996. Koch et al. [16] studied the dust particle size and dust removal effect in 2016. And then they obtained the research results that the pressure loss of dust remover in removing the uniform particle size dust more than non-uniform. Although many researches have been done on the soot blowing mode and filtration performance of the bag filter, the structure of the bag filter, the uniform distribution of flue gas and the drag reduction still need to be further studied. Therefore, the SolidWorks and CFD software were used to establish the main body model of bag filter and gradually optimize the drag reduction and flue gas distribution in this study.
2. Analysis of working principle and operation status of bag filter

2.1. Working principle of bag filter
The working principle of bag filter is: when the dust passes through the filter element, the functions of inertia, adhesion, diffusion and static electricity are used to capture and collect the dust in the air, so as to achieve the effect of dust removal. When the dust passes through the filter bag, it is captured due to shielding or inertia force; when the dust particle is lower than 0.2 μm, the dust particles are separated from the airflow by collision and contact with the fibers because the fiber spacing is smaller than the free path of the Brown molecules of the gas molecules; when the dust particle size is 1 μm and the filtering speed is low, the electrostatic effect plays a main filtering role.

2.2. Analysis of the current status of a unit operation
A self-contained power plant in Tongliao City of Inner Mongolia, has a total installed capacity of 2 × 200MW in the first phase. It is equipped with two sets of bag filter arranged symmetrically with DACCU. The appearance is shown in Figure 1. The design value of internal filtering wind speed is 0.8 m/min, but the actual filtering wind speed is 0.90 m/min, and the design value of inlet and outlet pressure difference is not more than 1700pa. However, during the start-up process, it is very close to the maximum allowable value of 1700 Pa. Despite many times of technical innovation, the pressure difference between the inlet and outlet of the dust remover can't be effectively reduced, resulting the boiler not be put into full load, which seriously affects the safe and stable operation of the unit.

3. Establishment and verification of the original model
The structural resistance of the bag filter generally accounts for 20% - 40% of the total. In order to reduce the overall resistance, the flow field analysis was only performed on the bulk structure and the inlet pipe without considering other factors.

The SolidWorks was used to build the body model and the inlet and outlet pipe model of bag filter according to the proportion of 1:1. As shown in Figure 2, "bell mouth" was set at the inlet of the lower air inlet type bag filter, and the pressure measuring point A was installed inside. Pressure measuring point B was set at the upper part of the body. The flue gas flows entered the body of the filter through the Z-shaped air inlet pipe. The bag filter body was divided into four chambers which are 1st, 2nd, 3rd, 4th dust chambers in turn from the inlet. The CFD was introduced to simulate the original structure of bag filter. According to the Reynolds number formula (1), the inside of the bag filter was in laminar flow when u is equal to 0.8-0.9 m/min. At the same time, the laminar model was used according to the mass conservation equation (2) and momentum conservation equation (3-5); the number of grids was about 4.5 million, and the design flow speed were at the BMCR, full load and half load. The actual measured results and simulation results on site were shown in Table 1.

According to the statistical results in Table 1, it can be seen that the relative error of simulated resistance between the point AB and the inlet and outlet was less than 10%; although the error between the simulated result of point AB and the actual measured value was slightly larger at half load, the error of other cases was less than 5%. It proved the rationality of model construction and CFD simulation.
\[
R e = \frac{UL}{V}
\]

\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0
\]

\[
\frac{\partial (\rho u)}{\partial t} + \frac{\partial (\rho u u)}{\partial x} + \frac{\partial (\rho u v)}{\partial y} + \frac{\partial (\rho u w)}{\partial z} = \frac{\partial}{\partial x} \left( \mu \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left( \mu \frac{\partial u}{\partial y} \right) + \frac{\partial}{\partial z} \left( \mu \frac{\partial u}{\partial z} \right) - \frac{\partial p}{\partial x}
\]

\[
\frac{\partial (\rho v)}{\partial t} + \frac{\partial (\rho v u)}{\partial x} + \frac{\partial (\rho v v)}{\partial y} + \frac{\partial (\rho v w)}{\partial z} = \frac{\partial}{\partial x} \left( \mu \frac{\partial v}{\partial x} \right) + \frac{\partial}{\partial y} \left( \mu \frac{\partial v}{\partial y} \right) + \frac{\partial}{\partial z} \left( \mu \frac{\partial v}{\partial z} \right) - \frac{\partial p}{\partial y}
\]

\[
\frac{\partial (\rho w)}{\partial t} + \frac{\partial (\rho w u)}{\partial x} + \frac{\partial (\rho w v)}{\partial y} + \frac{\partial (\rho w w)}{\partial z} = \frac{\partial}{\partial x} \left( \mu \frac{\partial w}{\partial x} \right) + \frac{\partial}{\partial y} \left( \mu \frac{\partial w}{\partial y} \right) + \frac{\partial}{\partial z} \left( \mu \frac{\partial w}{\partial z} \right) - \frac{\partial p}{\partial z}
\]

Table 1. Statistics of actual measured values and simulated values.

| Measurement AB inlet and outlet | Measurement Simulation(AB inlet and outlet) | Measurement Simulation(AB inlet and outlet) | Simulation error |
|--------------------------------|---------------------------------------------|---------------------------------------------|-----------------|
| BMCR 700                      | 720.9                                      | 950                                        | 958.94          | -2.89% -0.93% |
| Rate load 550                 | 558.56                                     | 600                                        | 628.69          | -1.53% -4.56% |
| Half load 200                 | 220                                        | 250                                        | 242.4           | -9.09% 3.14%  |

Table 2. Pressure difference statistics of different schemes.

| Improvement scheme | Location       | Pressure difference | Differential pressure variation |
|--------------------|----------------|---------------------|--------------------------------|
| Scheme B1          | AB             | 696                 | -24                            |
|                    | Import-Export  | 1059                | 100                            |
|                    | AB             | 749                 | 28                             |
| Scheme B2          | Import-Export  | 1107                | 148                            |
| Scheme B3          | AB             | 838                 | 118                            |
|                    | Import-Export  | 1192                | 233                            |

When in the BMCR, the velocity and static pressure cloud chart of the middle longitudinal section of the precipitator were shown in Figure 2. It could be clearly seen from Figure 3 that the flow velocity was increasing at the inlet of the bag filter. And the flue gas flowed through the Z-shaped pipe into the interior of the precipitator, directly impacting the 1st and 2nd dust chambers, which was directly lead to the generation of secondary dust. Meanwhile, the flue gas mainly flowed out from the middle of the 3rd chamber and the upper part of the 4th chamber, making the flow field distribution uniformity lower. On the other hand, it can also be seen from the static pressure cloud chart that the local resistance loss increased and the pressure loss increased due to the blocking effect to the flue gas of Z-shaped pipe inlet. And because the flue gas directly impacts the second chamber of the dust remover, the ash hopper with narrow lower flow channel also produced a large pressure loss.

Figure 3(a). Velocity cloud of the original bag filter.  
Figure 3(b). Static pressure cloud of the original bag filter.
4. Scheme of resistance reduction and flue gas uniform distribution of bag filter

4.1. Scheme A: resistance reduction of dust remover

In order to alleviate the excessive resistance caused by the process of flue gas entering the flue, the bag filter was changed from the lower air inlet to the side air inlet to remove the "bell mouth" of the inlet section, and the Z-shaped inlet flue was still used. Remaining other conditions unchanged, the internal flow field of the bag filter bag filter of the scheme A was numerically simulated when in the BMCR, and the velocity and static pressure cloud chart were as shown in Figure 4.

It could be seen from Figure 4 (b) that the flow velocity of Z-shaped air inlet pipe of bag filter was similar to the original one. But after the flue gas flowing through the side air inlet pipe, the situation of direct impact on the first two chambers of the filter was improved due to the diversion effect of the pipe. At this time, the flue gas mainly impacted the first chamber of the precipitator, part of it impacted the second chamber of the precipitator, and a small amount of it impacted the connection of the second and third chambers of the precipitator. Moreover, the flue gas flow velocity in the middle and upper parts of the first and second chambers of the precipitator was increased obviously, the flue gas flow velocity in the middle and upper parts of the third and fourth chambers was decreased, and the overall flow velocity inside the baghouse was more uniform than the original situation.

Since the DACCU system is mainly based on the constant adjustment of the boiler load, the pressure difference of bag filter under the BMCR load, full load and half load was simulated respectively. Figure 5 was obtained by comparing the actual measurement data.

It could be seen from Figure 5 that the pressure difference between the inlet and outlet of the precipitator and between the pressure measuring points AB was reduced after changing to the side air inlet. When the unit was in BMCR, the effect of reducing the pressure difference at point AB was the most obvious, and the maximum pressure drop was 35.5%. Even when the half load pressure drop was the minimum, the drag could be reduced by about 130.9Pa. Therefore, the effect of reducing the pressure difference of the side air inlet bag filter was obvious, but the impact of flue gas on the first and second chambers of the filter was still large.
4.2. Scheme B: Uniform distribution of dust remover

The impact of flue gas on the first and second chambers of the dust remover was still large. In order to solve this problem, the connection between the end of Z-shaped pipe and the side air inlet pipe was proposed to be equipped with flue gas distribution plate. Due to the limited technical conditions during the actual installation, the straight plate was selected as the flue gas distribution plate. The following four flue gas distribution schemes are selected:

- **Scheme B1**: two uniform distribution plates installed at the connection between the end of Z-shaped inlet flue gas and the inlet of side inlet flue gas trapezoid pipe, and the angle was selected to be 0° from the horizontal direction.
- **Scheme B2**: the same number of uniform distribution plates installed in the same position of the Scheme B1, and the angle was selected to be 30° from the horizontal direction.
- **Scheme B3**: The same number of uniform distribution plates installed in the same position of the Scheme B1, and the angle was selected to be 45° from the horizontal direction.

Keeping the other conditions unchanged, the simulation of three scheme was carried out in the BMCR, and the velocity cloud map with the uniform distribution of the flue gas at different installation angles was obtained (Figure 6).

![Figure 6(a). Velocity cloud of 0°.](image)

![Figure 6(b). Velocity cloud of 30°.](image)

![Figure 6(c). Velocity cloud of 45°.](image)

The flue gas distribution boards of the three schemes were compared and analyzed. The flue gas in the Scheme B3 was divided into three layers. Due to the influence of gravity and inertia, the impact on the first and second chambers of the precipitator was still large, and the overall pressure difference of the dust removal system was increased. In particular, the pressure difference at point AB was rose, which is mainly because the flue gas distribution plate plays a certain role in blocking the flue gas.

Adjusting the flue gas uniform distribution plate to 30°, that is, when the Scheme B2 was used, it could be seen that the influence of the flue gas on the third chamber and the fourth chamber was enhanced in addition to the direct impact on the first and second chambers of the precipitator. However, the overall flow field inside the bag filter was not as good as that of the Scheme B3, and the pressure difference was not obvious.

Adjusting the flue gas uniform distribution plate to 0°, that is to say, when the Scheme B1 was used, the flue gas distribution was more uniform in the trapezoidal pipe than the Scheme A. The impact on the 1st and 2nd chamber was slowed down and the impact on the 3rd and 4th chambers was increased. The increase was more obvious for the overall smoke distribution. At the same time, the velocity of flue gas in each ash hopper was significantly reduced, which had a good inhibition effect on the secondary dust. Table 2 can be obtained by calculating the pressure difference of the precipitator under three different schemes.

It could be seen from Table 2 that the resistance would be increased for the installation of flue gas distribution plate. Considering the flow field distribution and pressure drop, the Scheme B1 (two side inlet bag filters with 0° angle flue gas distribution plate were installed at the connection between the end of Z-shaped inlet flue and the inlet of side inlet flue gas trapezoid pipe) was selected.
4.3. Scheme C: Secondary resistance reduction after uniform distribution of flue gas
In order to ensure that the flue gas is evenly distributed and the resistance of bag filter body in the Scheme B1 continues to be reduced, only one uniform plate was used and a baffle plate was installed at the upper corner of Z-shaped flue (scheme C1). The simulation results were shown in Figure 7 with the remaining conditions unchanged.

It could be seen from Figure 7 that the impact of flue gas on the four dust chambers inside the precipitator was more uniform than before, and the pressure drop of trapezoidal pipeline was more. The simulation result of pressure difference at the point AB was 443pa, which was about 26.3% lower than that of the previous two plates. At the same time, the flue gas velocity in the four ash hoppers of the precipitator was lower than other models, and the effect of restraining the secondary dust was more obvious.

Therefore, scheme C (side inlet flue gas, single 0° flue gas distribution plate and corner baffle plate) can be used to minimize the overall resistance of bag filter.

5. Conclusions
Basing on the actual structure size and operation parameters, a 220 MW unit bag filter was gradually improved by numerical simulation. The following conclusions were obtained:

(1) In the Scheme A, it is found that the bag filter was changed from the lower inlet air to the side inlet flue gas, which could reduce the point AB by about 35.5% under the BMCR.

(2) The effect of flue gas distribution was achieved best in the Scheme B1 (side inlet bag filter with two 0° angle flue gas distribution plate).

(3) The demand of flue gas uniform distribution and drag reduction at the same time can be meet in the Scheme C.

References
[1] Menghao Zhao 2018 Experimental study on airflow distribution and pressure characteristics of porous plate in electrostatic precipitator [D] Zhejiang University
[2] Jiaxi Yang, Wenhua Liang 2019 Technical transformation of thermal insulation in liquid ammonia area of a power plant in winter [J] Energy saving (05) 36-38
[3] Wentao Liu 2018 Research on Ultra-low Emission Reconstruction Plan of Thermal Power Unit Electrostatic Precipitator [J] Value Engineering 37(29) 167-169
[4] Wei Luo 2015 Analysis of the Reasons for the Decreasing Operation Reliability of the Pulverized Coal Oven Bag bag filter [J] Environmental Engineering 33(S1) 1030-1032+1050
[5] Kuixu Chen 2018 Calculation and experimental study on resistance of electric bag composite bag filter [J] Proceedings of the CSEE 38(05) 1511-1517
[6] Zhigang Wang, Yuan Gao, Jian Yan 2010 Numerical simulation of three-dimensional flow field
of industrial bag filter [J] Petrochemical Equipment 39(05) 22-26

[7] Liancun Luo 2015 Discussion on prolonging the service life of boiler bag filter bag [J] Soda Industry 04 20-21

[8] Jingfen Li 2009 Practice of reducing the filter pressure difference of blower dust removal system [J] Tianjin Metallurgy 06 24-26+63

[9] Fengnian Guo 1982 Selection of Bag Filter [J] Chongqing Environmental Protection 02 3-11

[10] Jiangxiang Zhao, Feiwei Yu 1995 Design of Large Pulse Bag Dust Collector [J] Environmental Engineering 05 26-29

[11] Yiyong Jin, Yongfeng Nie, Honghai Tian, Hao Quan, Huimin Yin, Ying Hai 2003 Removal effect of bag filter and activated carbon filter cloth on dioxins in flue gas [J] Environmental science 02 143-146

[12] Yongchao Zhu, Jian Li, Peng Xu 2011 Study on the performance of a new type of electrostatic fabric composite precipitator [J] Journal of environmental engineering 5(09) 2091-2094

[13] Hao Zhou, Menghao Zhao, Kai Zhao, Weichen Ma 2019 Experimental study on the combination scheme of porous plates in the large expansion angle electric bag composite precipitator [J] Journal of power engineering 39(02) 142-147

[14] David Leith, Michael J 1980 Ellenbeckera. Theory for pressure drop in a pulse-jet cleaned fabric filter[J]. Atmospheric Environment 14(07) 845-852

[15] V H 1996 Morcos.Performance analysis of industrial bag filters to control particulate emissions[J] Enqry 21(01) 9-14

[16] Koch Michael, Krammer, Gernot 2016 Filter performance with non-uniformly distributed concentration of dust-evidence from experiments and models [J] Powder Technology 149-15