

Atomization parameters of coal water paste measured by PIV technique

Lu Yong¹ Lu Ping² Zhang Mingyao¹

(¹Key Laboratory of Clean Coal Power Generation and Combustion Technology of Ministry of Education, Southeast University, Nanjing 210096, China)

(²School of Power Engineering, Nanjing Normal University, Nanjing 210042, China)

Abstract: The particle image velocity (PIV) technique is introduced to measure the atomization angle, particle size and size distribution of the atomization coal water paste (CWP) in a cold state model. Due to high-density atomization spray, wide size distribution and large-scale experimental setup in CWP experiments, a commercial PIV system is updated with a 600-mm-long focal length camera and a convex lens used with a laser beam. This long focal length camera makes the PIV system capable of taking the images of micro particles. The measured minimum diameter is about 15 μm . The convex lens has the benefit of centralising the sector laser beam of the PIV system, so that the measurement window of the high density CWP field sectored by the laser beam is brighter and the images taken by the camera are clearer. The experimental results show that it is a useful and efficient tool for the PIV technique to measure the atomization prosperities of CWP.

Key words: particle image velocity; coal water paste; size distribution

Coal water paste (CWP) is a high density (over 70%) liquid fuel, which is a mixture of coal powder (its particle diameter ranges from micro to millimeters) and water. Owing to its high density, strong stickiness and wide size distribution, it is more difficult for CWP to be atomized than other liquid fuels such as petrol and heavy oil. However, the atomization properties of CWP have a strong effect on CWP's ignition, mixing and combustion in the circulating fluidized bed (CFB) boiler. Thus how to atomize CWP is paid much more attention to than investigating the wet feeding techniques. At present, research into CWP is limited mostly to the combustion characteristics of CWP, while there are a limited number of papers being published for studying the size and size distribution of CWP^[1-3]. It is reported that one set of horizontal experimental devices for measuring CWP's atomization characteristics was built in Kure Laboratory in Japan. On this experimental device, the parameter of drop intensity is introduced to evaluate the atomization quality of CWP. The drop intensity is the ratio of the amount of atomized CWP to the whole injected CWP in the nozzle. Due to limitations of the Japanese experimental device, the size distribution of the atomized CWP was not researched in detail. It is reported that in an experiment in which the CWP was kept injected into the 1 MW pressurized fluidized bed com-

bustion (PFBC) combustor about 48 h was successfully finished^[4]. The experiment shows that the flow of atomized air has a great effect on CWP combustion. When it is not enough to blast the atomized air, the bed temperature of CFB will fluctuate strongly about 200 $^{\circ}\text{C}$. When the flow of atomized air is increased, the bed temperature will fluctuate less and less. It will tend to be steady, and the maximum difference of temperature is only 30 $^{\circ}\text{C}$. This phenomenon is analyzed to show that the better the atomization quality of CWP is, the less the bed temperature fluctuates, which means the CWP is dispersed completely and it is valid for running CFB steadily. Thus, it is necessary to measure the size and size distribution of CWP deeply to investigate the CWP combustion characteristics.

This paper describes a vertical experimental device, which is built based on the CWP characteristics. With the device, the PIV system is applied to take the pictures of the atomized CWP. The average diameter and size distribution of the atomized CWP is gotten by image processing software developed by ourselves.

1 Experimental Device and PIV System

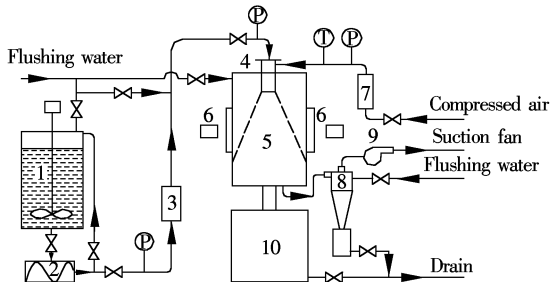
1.1 Experimental device

The experimental CWP atomization system is shown in Fig. 1. It consists of five separate sections, that is the manufacture and transmission part, the atomization air part, the induction dust removal part, the water purge part and the measurement part. The design parameters for this experimental setup are about

Received 2004-11-11.

Biography: Lu Yong (1969—), male, associate professor, ly@seu.edu.cn.

300 to 500 kg/h for flow, less than 1.0 MPa for flow supply pressure, 350 to 600 kPa for atomization air pressure, 0.3 MPa for water purge pressure, and $\phi 1580$ mm for the atomization chamber. In the experimental setup, the screw is applied to seed CWP to Jet, and the electromagnetism flowmeter is used to measure CWP flow. As for atomization air, it is supplied by an air compressor and measured by a float flow meter. In the measurement system shown in Fig. 1, four glass windows of the same size are installed on the chamber wall. The laser beam of the PIV system will sector the CWP atomization field to be a measurement section through one of four windows, and the camera is arranged vertically to take the pictures of the atomization CWP, then the pictures will be transferred to the data storage of the PIV system. Using the software we developed to process the images taken by PIV, we can get the size and size distribution of CWP conveniently.



1—CWP tank; 2—Screw pump; 3—Electromagnetism flow meter; 4—Nozzle; 5—Atomization chamber; 6—Measurement system; 7—Rotameter; 8—Dust catcher; 9—Suction fan; 10—CWP reservoir

Fig. 1 Coal-water-paste atomization system

In the experiment, coal water paste was produced by blending two components of 0 to 0.6 mm fine and 0.6 to 6 mm coarse coal powders with different water contents at three different ratios under agitation. The coal sample was Xuzhou Jiawang soft coal. The three different blending ratios of fine coal powers to coarse coal powders were $m(F) : m(C) = 75 : 25, 60 : 40$ and $40 : 60$, respectively. Among them, the optimal ratio is about 60:40. The detailed parameters about this experimental setup and the construction of the nozzle are shown in Ref. [5].

1.2 PIV measurement system

The measurement system is schematically shown in Fig. 2. This system was made by Dantec Company, the model type is called FlowMap2100, which consists of a streamlined strut containing a 50 micro joule mini Nd: YAG impulse laser, a light-guiding arm, light-sheet optics and a $1\text{ K} \times 1\text{ K}$ pixels cross correlation camera in a torpedo-shaped case.

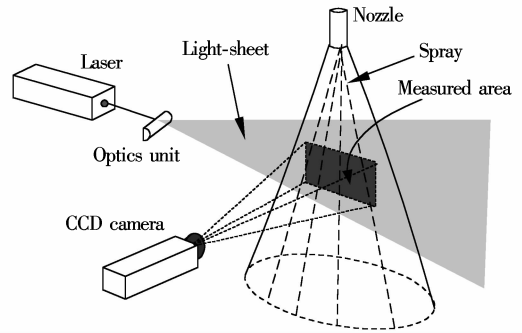


Fig. 2 Diagram of PIV measurement system

At the beginning of the experiment, the prepared CWP is transported into the nozzle, where the CWP is mixed with compressed air, and then it is sprayed into the atomization chamber. When the spray of CWP in the chamber is in a steady state, the flow field is mapped by the PIV system. However, there exist many problems for directly measuring particle size and size distribution using the commercial PIV system (Here, FlowMap2100). First, the size of atomization CWP usually ranges from micro meters to millimeters, the lower limit size is about 150 μm for the Flow-Map2100 with Nikon AF Micro 60 mm 1:2.8 D^[6]. This means that particles whose size is lower than 150 μm will not be mapped by PIV images, then the size and size distribution got from these images will not show the small CWP atomization drops in experiment. Thus for high-density spray, the power of the standard laser source of PIV must be increased by another device. In order to map the smaller micro particles, a camera with TAMRON 60 – 300 mm F/3.8 – 5.4 double focus length ring lens is used in the experiment. Due to the double focus length ring, the larger focus length of this TAMROM is extended to 600 mm. The calibrated image is shown in Fig. 3. In this case, the particle sizes larger than 15 μm can be mapped by PIV, which means 15 μm relates to a pixel of the imaged picture. On the other hand, a convex lens is applied to the laser section beam, and the angle of the laser section beam will be limited to be

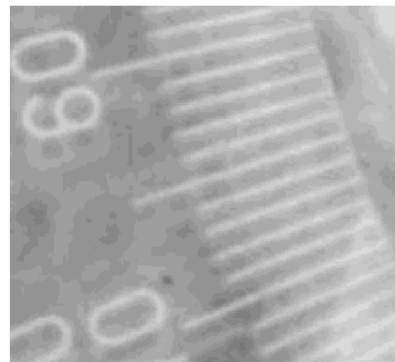


Fig. 3 Calibration image for PIV system

less than 3° . Thus the light density in the measurement section will be brightened, and the section image of high-density atomization spray will be got clearly. As for the particle size processing software, please refer to Ref. [7].

2 Results and Discussion

The images in Fig. 4 and Fig. 5 are typically selected from many pictures in the experiment. The series of Fig. 4 are images taken by the PIV system with a 60 mm focal length, the images are about $150 \text{ mm} \times 150 \text{ mm}$ and show that the atomization angles of CWP nozzle varied about 30° to 35° . At two different distances Z from the nozzle tip, the groups of Fig. 5 are the pictures taken by PIV with 600-mm-long focal length. Fig. 5 is about $15 \text{ mm} \times 15 \text{ mm}$ and shows the part of spray sectored by the laser beam. Comparing Fig. 4 with Fig. 5, Fig. 4 shows the full-scale information of atomization CWP, and Fig. 5 shows the partial atomization of CWP. According to the upper described CCD parameters, a pixel in Fig. 4 is about $150 \mu\text{m}$, and a pixel in Fig. 5 about $15 \mu\text{m}$.

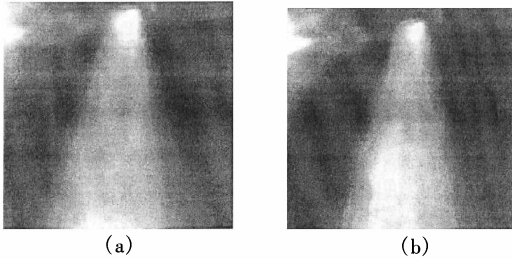


Fig. 4 Atomization angles of CWP with different nozzles

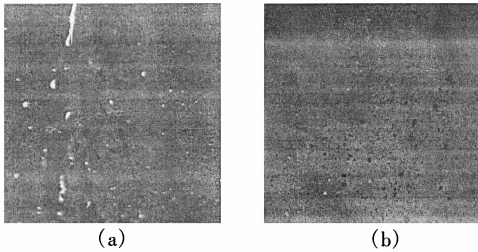


Fig. 5 Section spray with different distances from nozzle tip. (a) $Z = 250 \text{ mm}$; (b) $Z = 500 \text{ mm}$

Both Fig. 6 and Fig. 7 are plotted by data got from processing the images by software we developed. Fig. 6 shows the axial distribution of particle size. Its x -axis represents the axial distance Z away from the nozzle tip, and its y -axis is the mass median diameter (MMD), which denotes the corresponding diameter of 50% mass of the total mass in a particle group (cluster); W_t represents the water ratio in content of CWP. M_g and M_{CWP} stand for the supplied gas flow and the injected CWP flow, respectively. The symbols in Fig. 7 and Fig. 8 are the same as the ones in Fig. 6. According to Fig. 6, it can be seen that

MMD reduces with the increase of the axial distance Z , and the reduction degree of particle size decreases. The atomization effect is very bad when the axial distance Z is less than 250 mm , in which case the particle size cannot be measured; at $Z = 500 \text{ mm}$, the particle size MMD varies slowly, thus this point is regarded as the measurement position for evaluating the atomization quality of CWP.

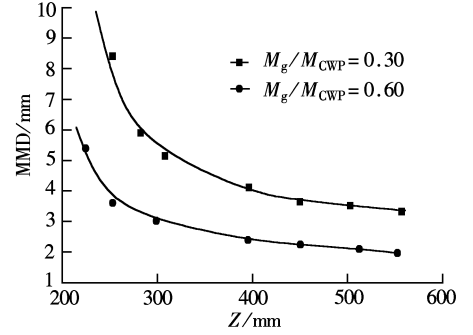


Fig. 6 Atomization particle axial distribution ($m(F):m(C) = 60:40$; $W_t = 27.6\%$)

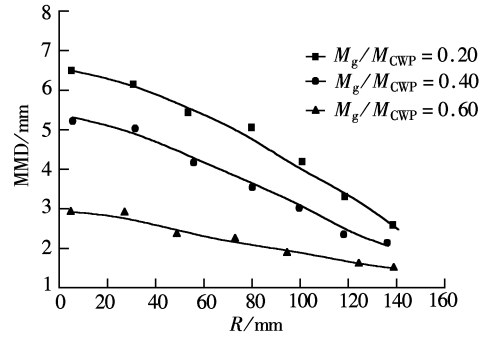


Fig. 7 Atomization particle radial distribution ($Z = 500 \text{ mm}$; $m(F):m(C) = 60:40$; $W_t = 27.6\%$)

Fig. 7 depicts the radial particle size distribution of atomizing CWP. At the same axial distance, the MMD in the middle of the spray is larger than the one at the edge of the spray for any gas to CWP ratio. With the increase of gas to CWP mass ratio, the differences of particle size between the middle and the edge of the spray are decreased. Therefore, the increase of the gas to CWP mass ratio not only makes the droplet small, but also makes the droplet uniform throughout all the spray. This phenomenon occurs for two reasons. One is that a big particle possesses the biggish inertia and small transverse pulse velocity, the particle cannot be dispersed rapidly, the proportion of big atomization particles in the mainstream of spray is much more than other areas; the other is that with the increase of the mass ratio of gas to CWP, the motion of atomization particles increases, the broking ability of injection and the collision effect of particles increase and the uniformity of particles is improved.

Generally coal particle distribution not only af-

fects the viscosity of CWP, but also affects the distribution of CWP atomization particle size distribution directly. According to the CWP atomization and combustion, it is not necessary and impossible to make atomizing particles of CWP very small. Contrarily, the existence of big particle for combustion in PFBC is advantageous as the fly ash can be decreased and the combustion efficiency can be improved. Fig. 8 describes the cumulative distribution of atomized particles of CWP and original coal. It can be seen that the atomized particles have wider range sieving and comparatively more big particles, for the same particle size d_p , the cumulative distribution of atomized particles of CWP is less than for the original coal. With the increase of gas to CWP mass ratio, the range of atomized particle size distribution becomes narrow, and the coarse particle size becomes small. This is the result from the collective effect of the congregative phenomenon of particles and gas to CWP mass ratio. The obvious conclusion is that the influence of gas to CWP mass ratio on the atomizing quality is very huge.

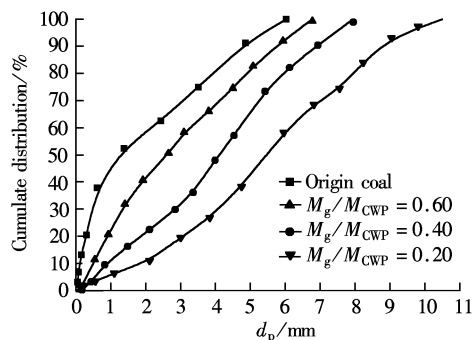


Fig. 8 Cumulative distribution of atomizing particle ($m(F):m(C) = 60:40$; $W_i = 27.6\%$)

3 Conclusion

The CWP atomization angles in the experiment varied in the scope of 30° to 35° . The axial distribution regulation shows that the MMD will decrease and

the uniformity will be improved as the distance away from the nozzle tip increases. The radial distribution regulation is that MMD is the biggest in the middle of the spray, and is relatively smaller in the edge of spray.

The optimization of coal particle size distribution not only decreases the viscosity of CWP, but also increases the uniformity of CWP atomized particles.

References

- [1] Wright S J, Fuirolough R, Booth B. The engineering and operating experience of coal-water slurries to grimehorpe pressurized fluidized-bed combustor [A]. In: *Proceeding of 10th International Conference on FBC* [C]. San Francisco, 1989. 381 – 388.
- [2] Wedel G V, Renz U, Michelfeder S. The pressurized bed combustor at Anchen Technical University [A]. In: *Proceeding of 9th International Conference on FBC* [C]. Boston, Massachusetts, 1987. 250 – 255.
- [3] Takezaki H, Otani Y, Yoshika S, et al. A method of state feeding coal-water paste into pressurized fluidized bed combustor [A]. In: *Proceeding of 12th International Conference on FBC* [C]. San Diego, California, 1993. 397 – 401.
- [4] Liu Q X, Tang C M, Zhang M Y. Experimental investigation of feeding coal-water paste into pressurized fluidized bed [J]. *Combustion Science and Technology*, 1997, 3(4): 385 – 387. (in Chinese)
- [5] Dantec Measurement Technology A/S. Product information [EB/OL]. <http://www.savenhitech.se/products/pdf/Dantec%20FlowMap%203D.pdf>. 1998/2004-10-10.
- [6] Lu Ping, Zhang Mingyao. Study on the resistance properties of coal-water paste in pipes [A]. In: Liu Wei, ed. *Proceedings of International Conference on Energy Conversion and Application* [C]. Wuhan, 2001, 2: 744 – 747.
- [7] Lu Yong, Wang Fengling, Wang Shiming. Measuring particle size distribution and total number in the activation chamber of desulphurization system by PIV [J]. *Journal of Southeast University (English Edition)*, 2003, 19(1): 49 – 53.

测量水煤膏雾化场特性参数的 PIV 技术

陆 勇¹ 卢 平² 章名耀¹

(¹ 东南大学洁净煤发电及燃烧技术教育部重点实验室, 南京 210096)

(² 南京师范大学动力学院, 南京 210042)

摘要: 利用商用 PIV 设备及自我开发的图像处理软件, 针对水煤膏雾化场中粒子浓度高、尺寸分布宽的特点, 采用收缩镜以增强片光源的照度, 使得 PIV 能够拍摄到高浓度雾化场的切片图像; 采用 600 mm 焦距的长焦镜头, 使得所拍粒子尺寸的下限可达 $15\ \mu\text{m}$ 。实验结果表明 PIV 技术是一种高效的水煤膏雾化场雾化角、小粒径及尺寸分布的测量手段, 克服了常规粒子尺寸分析仪器不能用于在线测试大型试验装置中雾化场特性参数的缺点。

关键词: PIV; 水煤膏; 尺寸分布

中图分类号: TQ534.4