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Measuring particle size distribution and total number in the activation chamber of desulfurization system by PIV

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Abstract: Application of particle image velocity (PIV) techniques for measuring particle size distribution and total number in an activation chamber of desulfurization system is introduced. Watersheld algorithm is used to choose the suitable initial gray level threshold which is used to change the gray level images taken by PIV to black and white ones, then every particle in an image is isolated totally. For every isolating particle, its contour is tracked by the edge enhancement filter function and kept by Freeman's chain code. Based on a set of particle's chin code, its size and size distribution are calculated and sorted. Finally, the experimental data of calcium particles and water drops, separately injected into the activation chamber, and the error analysis of data are given out.

Key words: PIV; image process; desulfurization; particle size distribution

To keep air clean, it is necessary and important to control and reduce the SO_x emission. With the development and gradual sophistication of flue gas desulphurization technology, furnace-sorbent-injection flue-gas-wet-desulphurization technology (FSIFGW), which combines the advantages of furnace sorbent injection technology and flue gas wet desulphurization, is suitable for controling SO_x emissions in middle or small sized power plants and can be widely employed in China[1].

During the furnace sorbent injection and flue-gas-wet in the desulfurization process, there exist many complicated physical and chemical reactions in the activation chamber, which is a typical pattern of the solid-gas-liquid multiphase process. For the sake of the rapid development of FSIFGW, it is urgent to find out the pattern of sorbent particle activities and water drop in the activation chamber. However it is very difficult to use traditional instruments to measure the characteristics the whole flue field.

Recently, with the rapid development of computer technology and photoelectric technology, PIV technology has been widely used to measure the flow parameters. Based on the different ways of dealing with images, PIV can be divided into two kinds — particle image velocity (PIV) and particle tracking velocity (PTV). With regard to every particle cross-correlation, PTV can be applied to get the parameters of particle shape and number in the flow field[2].

In this paper, the principle used to measure particle size distribution and total number in the activation field of desulfurization system by PTV is discussed in detail. The related PTV algorithm and data structure to carry out the algorithm are presented. Finally experimental results and conclusions are given out.

1 Principle and Algorithm

1.1 Principle

The principle of measuring the fluid velocity vector field by PIV is based on the cross-relation information analysis of the series of fluid images. The first step of processing image is to extract all particles from the images taken by PIV continuously and to locate each center of every particle separately. Secondly, every couple of particles with cross-relationship is determined in two series images. And then the distances between every couple are figured out. Based on the distances and the interval time of two series images taken by PIV, the fluid velocity vectors can be computed easily.

According to the above processing descriptions, the particle parameters, such as size and size distribution, etc. can also be obtained in the process of locating the particle centers in the pictures. However, the commercial PIV system is usually used to measure the fluid velocity vectors. Thus, a set of image processing programs has been developed to get the

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particle's characteristics from images taken by PIV.

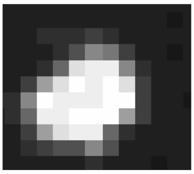

Fig. 1 An enlarged calcium particle's image

Fig. 1 shows a real calcium particle's image which was taken in the Activator Chamber by PIV and has been enlarged 8 times. Some interesting information may be seen from this picture. It is useful to process images in our programs. The first observation is that the shapes of calcium particles injected into fluid are irregular. To consider a calcium particle as a spherical one, it will cause some measurement errors. The second is that there is a gradient variation from the particle gray center (with the maximum gray value) to the particle edge (background). The third is that the gray center of a particle must not be the particle's geometric center. The last one is that the highest gradient magnitude is shown at the edge between the particle and the background.

Based on the preceding characteristics of particle images, it is convenient to approach a particle boundary by recognizing the pixels with high gradient magnitude. Suppose there is only one particle in an image; we can identify the pixel of the highest gradient magnitude as the first boundary point. If several points have the maximum gradient values, then one of them is arbitrarily chosen. At the next step, a 3×3 matrix of the neighborhood centered on the first boundary point is checked and the neighbor with the maximum gray level gradient is taken as the second boundary point. Following such iterative processes, we can determine the particle boundary. As for a group of particles in an image, it is very difficult to search for a proper pixel with high gradient magnitude for every particle, since most of them can have a separate different gray image. Thus, to solve this problem, a good choice is to first isolate every particle in an image by an initial threshold gray level firstly. Then the boundary of every separated particle region will be searched by the above gradient-based method[3].

1.2 Algorithm

Although the images taken by the CCD camera of PIV instrument are recorded digitally, they still include some noise or degradations due to transmission etc. For example, some particles in fluid which are near to the measurement field will be illuminated by the light scattered by particles in the light sheet of the laser, and will be also recorded into the image. On the other hand, because optical lens always has a large or small depth of field, some particle images can be taken by CCD camera, and these particles' images are usually blurred. All these noise can send the tracking temporarily or hopelessly off the boundary. To get a noise-free image, some image processing is applied to improve the image quality and to reduce the noise effects before tracking the particle boundary. In this paper, Wiener filter algorithm is used to remove the noise effects of images, the edge enhancement filter function is applied to enhance the particle edge in the image and the Watersheld algorithm is used for choosing the suitable threshold gray level[4]. The procedure of the algorithm is shown in Fig. 2. Where,

Step 1 Load an image taken by PIV.

Step 2 Remove its noise using Wiener filter algorithm. Enhance the particle edges in the image. Convert it to a black and white image and isolate every particle in it by way of Watersheld threshold algorithm.

Step 3 Determine whether or not to scan all particles or pixels of the image. If scanning is finished, go to step 7.

Step 4 Scan every pixel by line from top to bottom and try to look at the first point with the high gradient magnitude for every isolated particle. This point is taken as the starting point of the particle boundary.

Step 5 From this point, the iterative process of finding the next boundary point will be run till a particle's close boundaries are tracked.

Step 6 Set the gray level of the searched region to the background gray value. Then run step 3 again.

Step 7 End.

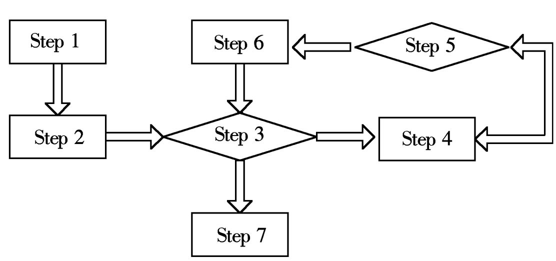

Fig. 2 The schema of algorithm

2 Experimental System

The experimental system is schematically shown in

Fig.3, which is divided into two main sections. One part is built for generating the gas-solid flow in an activate chamfer of desulfurized tower, it consists of two inlets for putting into desulphurization agent (calcium particle) and flue gas separately. By regulating the valve installed into the inlets, the flow mass loading can be changed conveniently. The other part is a PIV system which is made by Dantenc Company. It consists of a streamlined strut containing a mini Nd:YAG Laser, a light-guiding arm, the light-sheet optics and a 1 024 × 1 024 cross correlation camera in a torpedoshaped case. To get clear information about the flow field in the Activation Chamber, the measurement area is designed about 30 cm × 30 cm, of which the relevant image by taken the camera is about 1 000 × 1 000 pixel.

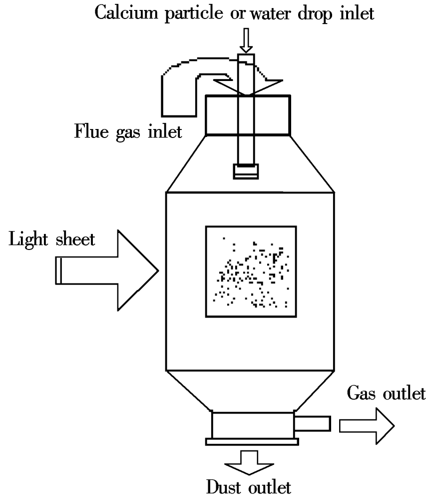

Fig.3 Experimental setup

To promote research on the efficiency of sulphur removal by flue-gas-wet desulphurization and the effect of water drops, it would be ideal to know the flow field characteristics of calcium particles and water drops, respectively. So we compared these characteristics with the parameters of the flow field mixed by water drops and calcium particles. Some interesting results can be shown in this way. The experimental system was used to take the images of calcium particles and water drops in the Activation Chamber respectively. At the beginning of the experiment, nitrogen gas was inserted into the chamber, then the calcium sorbent particle or water drops were added. When flow in the chamber was in a steady state, the flow field was mapped by the PIV system.

3 Experimental Results and Discussion

Fig.4 and Fig.5 are two typical images taken by the PIV, which show the fluid field in the Activation Chamber. Since the size of an image is about 1 000 × 1 000 pixels, it is very difficult to arrange the whole image in the paper so that all particles' images can be recognized clearly. Thus the following two images are parts of the original images and their occupied ration will be noticed in the figures.

Fig.4 and Fig.5 show the images of flue gas fluid with the injected calcium particles and water drops, respectively. The speed of flue gas is about 2 m/s, sorbent (calcium particle) is added about 3 kg/h and water drops about 16 kg/h. From Fig.4 and Fig.5, we know that particles scattered in the image are disorderly and the space distribution of particles is asymmetrical.

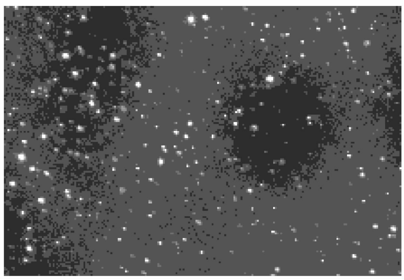

Fig.4 Flue gas with calcium particles (220 × 150 pixel)

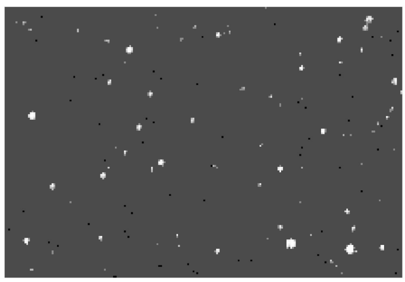

Fig.5 Flue gas with water drops (220 × 150 pixel)

The algorithm described in the previous section is used to determine the particle size and size distribution. Fig.6 and Fig.7 are the results calculated by the algorithm. They show the particle size distribution of the original images (1 000 × 1 000 pixel) of Fig.4 and Fig.5, respectively. The total number of particles in the original images of Fig.4 and Fig.5 are 15 881 and 290, respectively.

Fig.8 shows the number of calcium particles which was measured at every 20 s 3 min. This fluctuant result indicates that the amount of sorbent was injected unsteadily. However the liner fit of the experimental data is very near to a line, which means the fluctant error of measured data can be minimized by the statistical method.

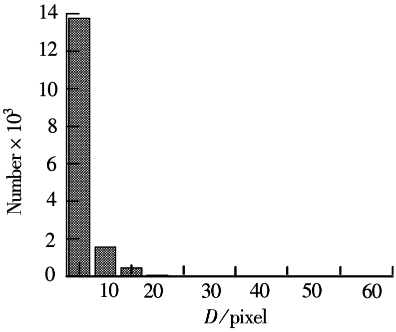

Fig.6 Size distribution of calcium particles

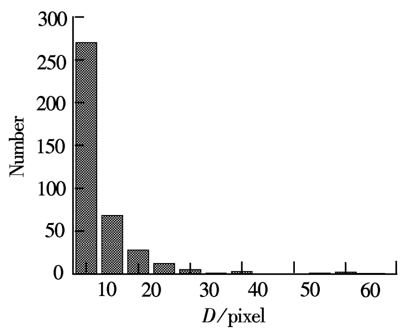

Fig.7 Size distribution of water drops

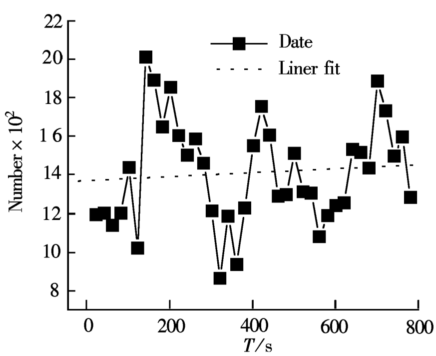

Fig.8 The number of calcium particles

According to Fig.6 and Fig.7, the ration occupied by the particles with smaller size is much more than the other particles with larger size. This is a questionable result. After comparing the experimental images in detail, we find that the size of most particles in the original images taken by PIV ranges from 1 pixel to 5 pixel. Fig.6 and Fig.7 show the same result too. We think the reason for this result is owing to the small optical enlargement coefficient in our experimental setup. Fig.9 is the calibration image for calibrating the optical enlargement coefficient of PIV. It incurs one pixel about 1/195 mm. Thus if the particle size is less than 0.5 μm, its image will not be recorded by our experimental setup. A related experiment will be researched.

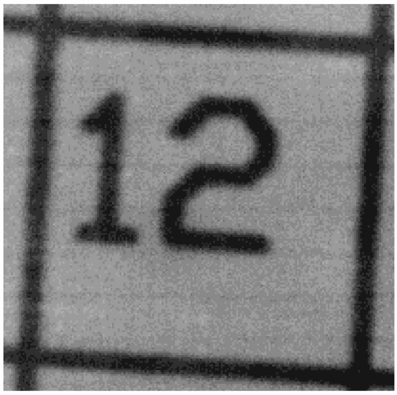

Fig.9 Calibration image

4 Summary

The results gained so far indicate that PIV can be not only used to measure the velocity vector field of multiphase flow, but also used to determine the size and size distribution of particles in the Activation Chamber. PIV will be a powerful tool to research the efficiency of flue-gas-wet-desulphurization.

The presented algorithm consists of the threshold method; therefore how to choose an optimum threshold gray level will be researched thoroughly.

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测量脱硫活化器内颗粒尺寸分布和颗粒数的 PIV 技术

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摘　要　颗粒尺寸分布及颗粒数是研究活化器脱硫效率的 2 个重要参数,本文介绍了一种应用颗粒速度图像仪(PIV 技术)测量脱硫活化器内颗粒尺寸分布和颗粒数的测量方法.为了提高测量的速度,采用 Watersheld 算法计算图像中每个颗粒的灰度域值,应用边缘增强滤波算子搜索每个颗粒图像的边缘,并用 Freeman 链的格式保存搜索结果.基于各个颗粒的 Freeman 链数据,可以计算出流场中颗粒的尺寸分布及颗粒数.最后给出了实际的测量数据及误差分析.研究结果表明 PIV 技术将是研究脱硫效率的一种重要的测试手段.

关键词　PIV 技术; 图像处理; 脱硫; 颗粒尺寸分布

中图分类号　X511