Fuel Flow Simulation and Fuel Characteristic Analysis in the Combustion System Using Statistical Method

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Abstract

One of the goals of the engineering curricula is to convey an understanding of engineering methods such as analysis and computation, modeling, design and experimental verification. Another goal is to have students gain experience in applying these methods to realistic engineering problems and processes [1]. Many students in the industrial engineering department have participated in the ongoing projects at the laboratories of Center for Avanced Energy Systems & Environmental Control Technologies (CAESECT). These students took some courses (ex. Thermodynamics, design & analysis of energy systems, the advanced instrumentation technology) and then they conducted experiments using advanced instrumentation (ex. Laser based PDPA system and PIV system). This paper shows how the students improved their skills of designing the experiment and analyze the data using statistical method.

Introduction

The research results are focused on the solids-flow monitoring and measurement in the combustion system. The laser based phase Doppler particle analyzer (PDPA) system and particle image velocimetry (PIV) were used to explore solid-particle flow and their characteristics.

The phase Doppler method is based upon the principles of light scattering interferometry. Measurements are made at a small, non-intrusive optical probe volume defined by the intersection of two laser beams. The intersection of the two beams creates a fringe pattern within the probe volume. As a particle passes through the probe volume, it scatters light from the beams and projects the fringe pattern. A receiving lens strategically located at an off-axis collection angle projects a portion of this fringe pattern onto several detectors. Each detector produces a Doppler burst signal with a frequency proportional to the particle velocity. The phase shift between the Doppler burst signals from two different detectors is proportional to the size of the spherical particles [2,3].

PIV is an optical imaging technique to measure fluid or particulate velocity vectors at many points in a flow field simultaneously. PIV is able to measure particle flow without disturbing the flow, therefore the data collected is useful [3].

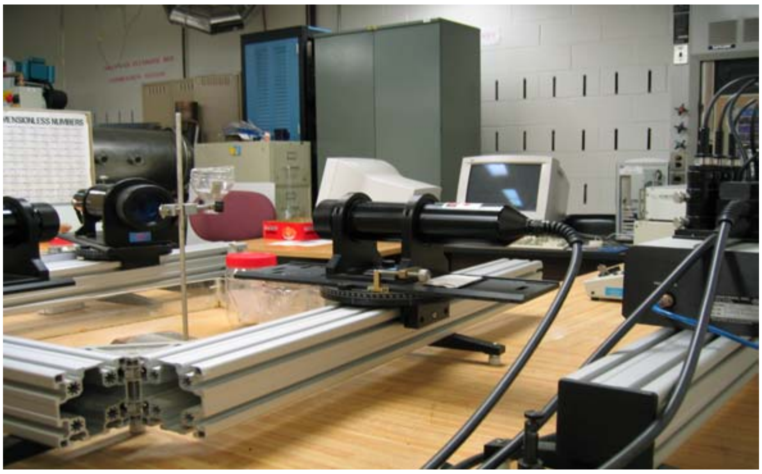

Figure 1. Pictorial View of PDPA Instrumentation System

Figure 2. Pictorial View of Laser-based PIV Experimental Set up and Instrumentation

Figure 1 and 2 show the pictorial views of PDPA system and PIV system respectively. Figure 1 shows the set up of PDPA system inclusing electronic signal processor, optical transmitter, and optical receiver. Figure 2 shows the set up of laser based PIV system including charge-coupled camera (CCD), laser power supply, 2 Yag lasers, a laser pulse synchronizer and a computer monitoring system.

Comparison of experimental design skill

The advanced instrumentation techniques class was offered in industrial engineering department. In the beginning of the class, the theory of laser based phase Doppler particle analyzer (PDPA) and particle image velocimetry (PIV) [4,5,6] were introduced to the students. After the lab manager introduced the operating procedure of the systems, the students were asked to conduct the experiment by themselves. When the class was first taught, most of the students did not have the background knowledge about statistics and experimental design. So the experiment was simply conducted. For the PDPA system, different types of nozzle were used at different distance. The experiment reports were prepared individually. Since they had no background about statistics, the collected data were analyzed using microsoft excel. Although they could observe the different result for each case, they could not tell if the difference is significant or not.

The next semester, the same group of students took the advanced instrumentation techniques class before participating in the research. By this time, they already took statistics and experimental design classes. Before starting the research, the lab manager introduced the objective of the project to the students. The students were also taught what parameters might affect the performance of the combustion system. When they started the research, they had an idea of using different particles to design the experiment. They conducted the experiment under the different conditions even when using the same particles. They used organic particles and humid particles. The reason the student select organic particles is that it could be used to simulate the coal particle flow in the combustion system. For the humid particles, they selected it because they learned that the air velocity has some effect on the particle flow.

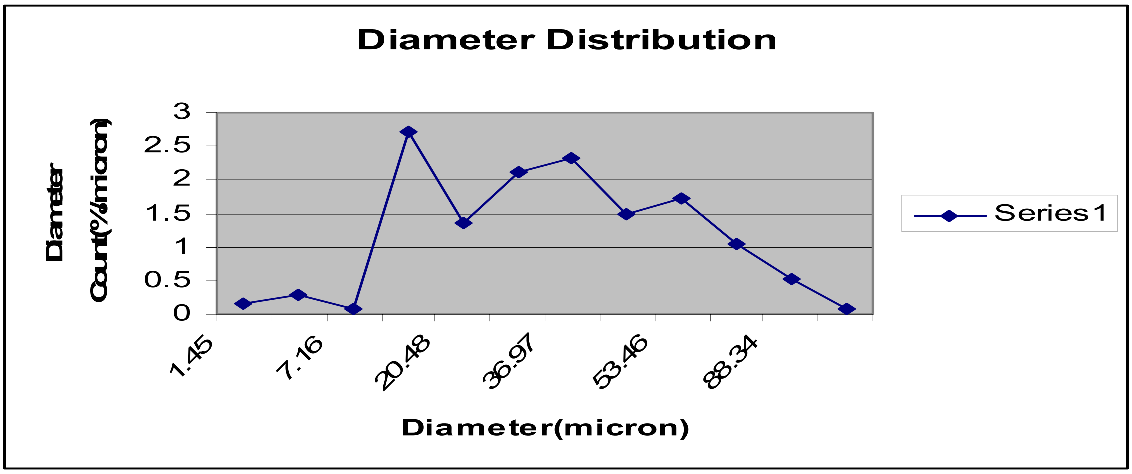

Figure 3. Water Particle Size Distribution Test

Figure 3 shows the PDPA test result of water test. From the graph, the result shows that the particle size range is 0-125 micron. At the diameter 16.44micron, there are the most particles.

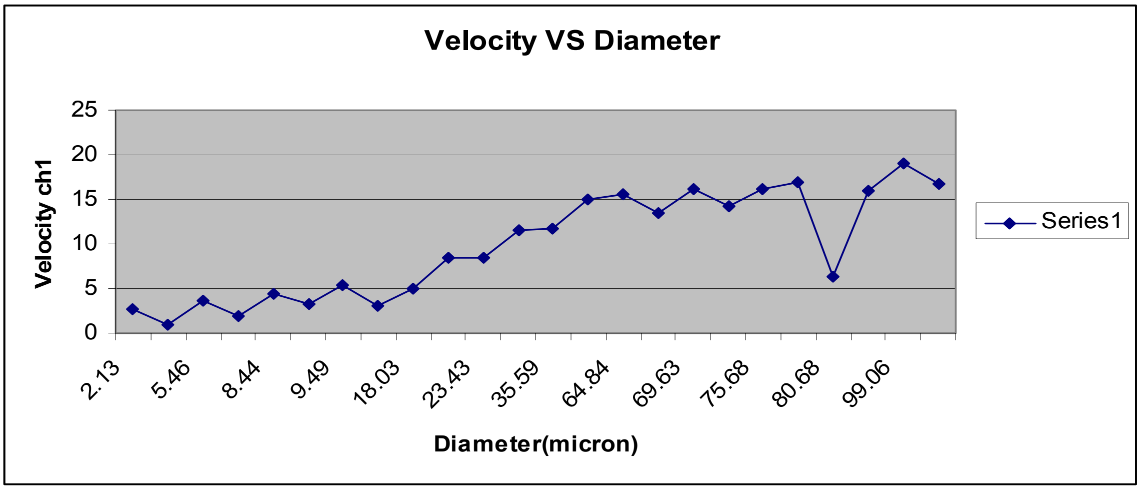

Figure 4. Water Particle Velocity Distribution Test

Figure 4 shows the PDPA test result of particle velocity distribution. From the graph, the result shows that from 2.13 micron to 79.89 micron, the velocity of the particles increases gradually. At the diameter 80.68 micron, the velocity decreases rapidly and increase. At the diameter 99.06 micron, the velocity reaches the maximum.

These are only the example of test result, which was observed and analyzed by the students before they participated in the research. Because they lacked knowledge about statistics, they could only compare the result from different figures they got.

When the experiment was conducted, the students used humid particles to conduct the PDPA experiment. They changed the air velocity of the blower to see how this affects the particle size and velocity. They were trying to figure out how the air velocity in the combustion system affects the size and velocity of the coal particles. They set the air velocity as the parameter and conducted hypothesis test.

Flow Rate	Observations (No.s)			
	1	2	3	4
Low	6.39 (microns)	6.73	6.35	6.26
High	6.67	6.96	7.06	7.01

Table 1.The Analysis of Mean Diameter of Humid Particles

Table 1 shows the mean diameter of the humid particles when the humid particle flow rate is high and low.

Table 2. Analysis of Humidifier Strength Effect on Particle Mean Diameter

Source of Variance	Sum of Square	Degree of Freedom	Mean Square	F_o
Flow Rate	0.351525	1	0.351525	9.649548
Error	0.218575	6	0.036429	
Total	0.5701	7		

Table 2 shows the analysis result of the humid particle flow rate effect on the mean diameter of the humid particles. When the α equals to 0.1, the value of $F_{0.1,1,6}$ is 3.78 which is less than the value of F_o .So the humid particle flow rate has a significant affect on the mean diameter of the particle size.

Flow Rate	Observations (No.s)			
	1	2	3	4
Low	1.37 (m/sec)	1.39	1.50	1.53
High	1.59	1.72	1.73	1.77

Table 3. The Analysis of Mean Velocity of Humid Particles

Table 3 shows the mean velocity of the humid particles when the humid particle flow rate is high and low.

Table 4. Analysis of Humidifier Strength Effect on Particle Mean Velocity

Source of Variance	Sum of Square	Degree of Freedom	Mean Square	F_o
Flow Rate	0.13005	1	0.13005	21.0039
Error	0.03715	6	0.0061917	
Total	0.1672	7		

Table 4 shows the analysis result of the humid particle flow rate effect on the mean diameter of the humid particles. When the α equals to 0.1, the value of $F_{0.1,1,6}$ is 3.78 which is less than the value of F_o . So the humid particle flow rate has a significant affect on the mean velocity of the particle size.

From the test analysis, we can easily see the improvement of the experimental design skill and data analysis skill. And also the accuracy of the data analysis has improved a lot.

For the PIV test, the students selected the organic particles [7] to simulate the coal particle flow. They used different sizes of organic particles to see if particle size affects particle velocity. If the results show that the particle size has any effect on the particle velocity, then this means that the time for the fuel to stay in the combustion system could be changed by adjusting the coal particle size. In addition, they changed the particle flow rate to see if particle flow rate affects particle velocity. If the flow rate has any effect, it means the thermal efficiency can be improved by changing the coal particle flow rate in the combustion system.

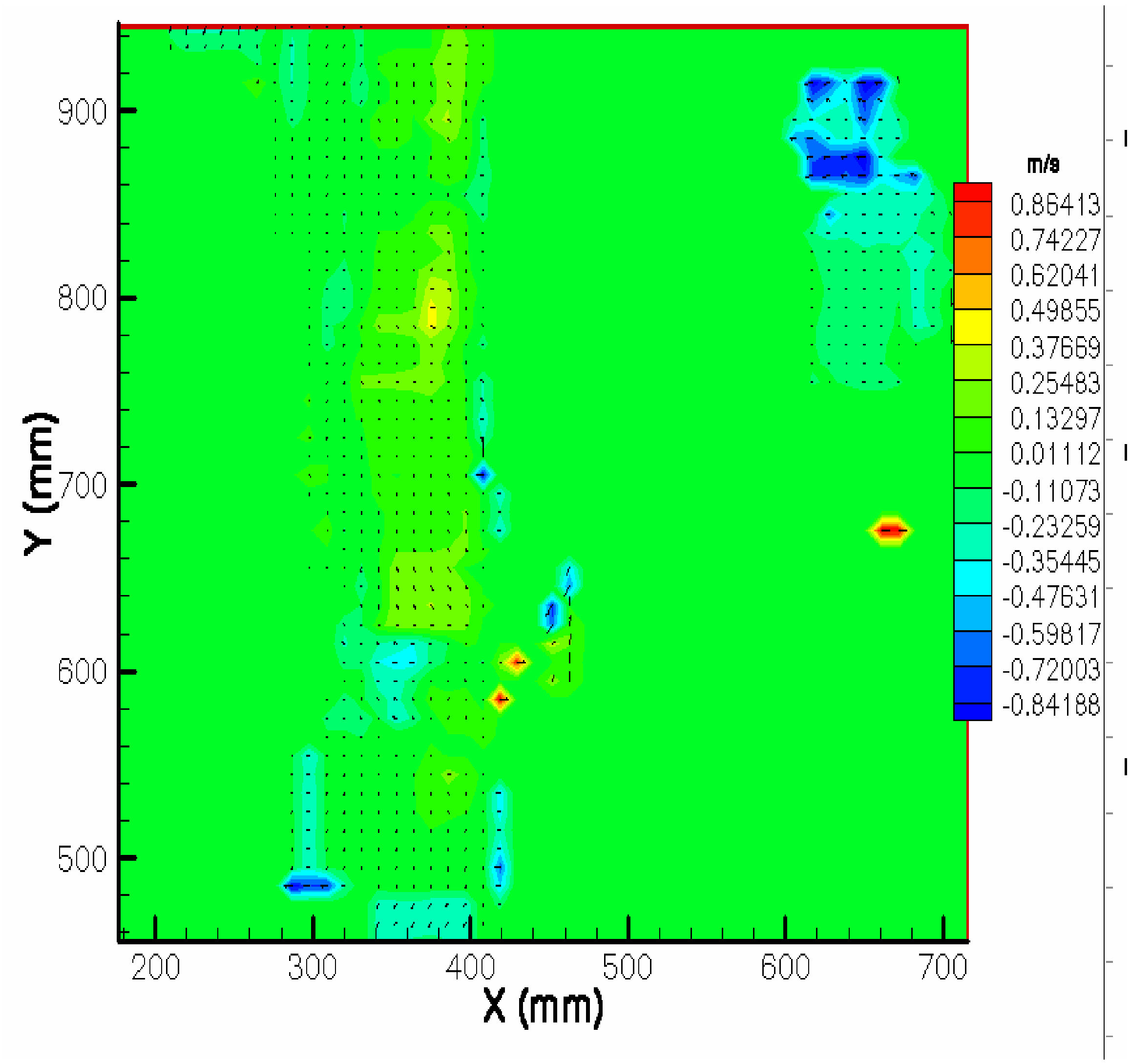

Figure 5. Velocity Profile of Organic Particles(size<150microns)

Figure 5 is one example of PIV system test. From the velocity profile of organic particles with the particle size of less than 150 microns. the students could tell that the range of particle velocity is between 0.25 m/sec to 0.37 m/sec. The highest velocity is 0.86 m/sec and the minimum velocity is -0.84 m/sec. The negative velocity indicates that the organic particles are so small they sometimes just fly in an upward direction while the velocity is measured. Actually the figure was the same from before. But the analysis method was improved.

Table 5. PIV Test Result

Particle Size (microns)	Flow Rate 1/16	Flow Rate 1/8
<150	-0.26	-1.35
150-250	-0.505	-0.49
250-355	-0.505	0.285

Table 1 shows the PIV test result. The students summarized the PIV test result under different conditions. Using these observed data, they created the ANOVA table below.

Table 6. ANOVA Table For PIV Test

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	Fo
Treatment (Particle Size)	0.4852	2	0.2426	0.5435197
Blocks (Flow Rate)	0.0135	1	0.0135	0.0302453
Error	0.8927	2	0.44635	
Total	1.3914	5		

From the ANOVA table, the students got the conclusion that neither particle size nor the particle flow rate does have significant effect on the particle velocity.
Compare with the analysis from before, the analysis became more accurate and logical.

Observation and Discussion

The experiment designed by the students was very simple because the students didn't have any background in statistics and experimental design. Therefore, the parameter they selected was just the nozzle type and distance from the intersection of the laser beam which is the very basic instrumentation using PDPA system. The experimental result was very simple and the effect of the parameters was not analyzed in statistical way.

By the time the students were enrolled in the research, their skills of designing the experiment had been improved noticeably. They used different types of particles and chose particle flow rate as the changing parameters. They didn't pick them blindly. It was related to the real case of the project. They selected different parameters and conducted the experiment to see how these affect the test results. The test results were also analyzed statistically and this has improved the accuracy of the analysis.

Conclusion

The improved performance of the students shows that the background knowledge of the students is closely related to the students' way of thinking. When the students do not have any idea or don't realize how the knowledge they learn is applied in the real life, they will just conduct the experiment blindly. However, when they have the knowledge about the research and the objective of the class they are taking, they will have a better idea of what needs to be done and how it needs to be done. Hence, when the instrumentation class is taught, it's better to connect to the real project so that the students will design the experiment with purpose. The students need to take some courses like statistics, thermodynamics, experimental design etc. so that they can analyze the observed data in a more accurate way.

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