DOE/PC/90310--T11

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QUARTERLY PROGRESS REPORT #10

TITLE: COMBUSTION OF DENSE STREAMS OF COAL PARTICLES

GRANT NO: De-FG-22-90PC90310

REPORT PERIOD: November 29, 1992 to February 28, 1993

PRINCIPAL INVESTIGATOR: Kalyan Annamalai
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GRADUATE STUDENTS: C. Gopalakrishnan
X.Y. Du
E.Kharbat

SUBMITTED TO: Pittsburgh Energy Tech. Center
US Department of Energy
P.O. Box 10940
Pittsburgh, PA 15236

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Tasks For November 29, 1992 to February 28, 1993

1. Continue the parametric experiments on stream combustion: i) cloud denseness, ii) particle size, iii) gas temperature, iv) residence time, and v) oxygen concentration.
2. Mr. Gopalakrishnan is expected to defend his MS Thesis by May 1993. The MS Thesis of Mr. Gopalakrishnan and a part of the Ph.D Thesis of Mr. Du and Dr. William Ryan will constitute the final report on the project.

Activities During November 29, 1992 to February 28, 1993

1. Attempts have been made on direct measurement of the velocity of particles using imaging technology (Appendix A). The status of the tasks is given in Table 1 (Appendix B). The effects of cloud denseness (A:F ratio in the stream) and residence time (zone height) on the burnt fraction are given in Figures 1 and 2 (Appendix B). The A:F ratio of 1:1 is equivalent to 7×10^9 particle per m^3 or $l/a = 16$. Detailed video-images have been obtained which are expected to yield the luminosity contours and stream diameters. However, analyses of the images have not yet been completed.
2. The computer code for combustion of spherical clouds has been used to model the combustion of a large porous coal particle because of the strong analogy between the combustion of clouds and a porous coal particle. The model was first used for generating results on heterogeneous and homogeneous ignition of coal particles assuming uniform particle temperature. The transient results indicate heterogeneous ignition first followed by homogeneous ignition and combustion at later times. Large particle starts with homogeneous ignition. Further transient results differ from quasi-steady results of Wall, et al of Australia.

Vast amounts of experimental and theoretical data have been generated during the course of the grant. Because of preoccupation with Part II of the review on interactive combustion processes of coal and char particles and the revision of Part II, the submission of following articles are still pending:

1. Digital Imaging Studies on Arrays of Particles, to be submitted to C&F
2. Interactive Array Combustion- Transient Effects
3. Group Combustion of Coal- Double Flames, to be submitted to CST
4. Transient Ignition of Single Particles, in preparation
5. Combustion of Streams of Particles, in preparation

A part of the results on #2 and #3 were already reported in Part II of the review paper.

Tasks For February 29, 1992 to May 31, 1993

Finish all remaining tasks and submit the final report.

11/28/92 to 2/28/93

APPENDIX A: COAL STREAM COMBUSTION

INTRODUCTION:

The objective of the project is to run coal combustion experiments for various particle sizes under different operating conditions. Report #8 explains the experimental set-up and operating procedures along with the analysis of the preliminary results. This report provides a methodology for the measurement for flowing particle velocity and also analysis for the first set of experiments. See Table 1 for the tasks proposed originally in the proposal and status on each task.

METHODOLOGY FOR VELOCITY MEASUREMENT:

As the coal particles flow steadily into the vitiated atmosphere, they heat up due to the high temperature provided by the methane flame of the flat flame burner, release volatile, fixed carbon gets burned and eventually the burnt particles collected at the particle collection system. The proximate analyses of the collected samples reveal the degree of combustion and/or gasification.

Once volatiles in the stream are ignited, it is difficult to visualize the central coal stream hidden in the coal flame. If the coal flow is steady, there will be a darker region just above the fuel injector before ignition followed by the dark central region surrounded by luminous flame. Since the phenomena is three-dimensional while the camera picture is 2-D, then the flame may obscure the observation of the central dark region. An ideal camera with a depth of focus considerably smaller than the stream diameter, can focus on the mid-plane, and distinguish the flame from the coal stream. Since depth of field depends upon the aperture, the wide open aperture

The whole combustion process when captured through a digital video camera can be viewed through a monitor frame by frame. The time gap between two successive frames is 33ms with the pixel clock rate of 10MHz (532*635*100ns). If a steady stream combustion is captured, then all the frames may have identical flame shapes with the same operating environment showing an initial coal stream, its ignition and a group flame. It will be more useful to capture the initial coal stream development process to calculate the rate at which the coal stream progresses. Then the successive frames will show the growth of the coal stream from the coal injector tip of the burner. The pixel location of the coal stream tip can be tracked through the frames and, with the known time gap, the stream velocity can be calculated.

As has been mentioned in the previous reports, each flame image is represented by 512*512 pixel. Each pixel has a brightness value depending on the intensity of the incident luminosity. The maximum value is 255 while the lowest is 0. In the combustion experiments, the flame will have a value of 255 while the coal stream will have around '0.' These pixel values are helpful in tracking the stream across the frames. In addition to this, false color manipulation feature of the 4MEG VIDEO image processing package helps to assign

color according to the brightness value. For example, pixels having a brightness value above 220 can be given high red and green color to get a final yellow color to represent flame, while lower pixel values can be given darker green and blue colors to denote coal stream. The cold coal stream development can be seen through these false colors very clearly.

MODEL VELOCITY CALCULATION:

Coal stream images are captured with a time gap of 33 ms. The color images are false color manipulated to identify the coal stream in two successive frames. The pixel locations for the end of the stream in the first and the second frames are noted. The real distance between these two is calculated using an image scale provided by the software. The pixel clock rate of 100ns (10MHz) is used to calculate the time gap between these pixels. The stream velocity is calculated using both this time gap and distance.

pixel location

first X:221 Y:359
second X:221 Y:249

Distance travelled:

$$\begin{aligned}
 & \text{Velocity :} \quad \text{I} \quad 18 \text{ mm} \\
 & \quad \text{total pixels:} \quad 635 * 532 = 337820 \\
 & \quad \text{pixels sub :} \quad 635 * 358 + 221 + 4 = 227555 \\
 & \quad \text{pixels:} \quad = 110265 \\
 & \quad \text{II} \\
 & \quad \text{pixels} \quad 635 * 248 + 221 + 4 = 157705 \\
 & \quad \text{total} \quad = 267970 \\
 & \quad \text{time} \quad = 267970 * 100 * 1e-9 \\
 & \quad \quad = 0.026797 \text{ s} \\
 & \quad \quad = 26.797 \text{ ms} \\
 & \quad \text{Velocity} = 18 / 26.797 \\
 & \quad \quad = 0.672 \text{ m/s.}
 \end{aligned}$$

It is to be noted that the particle velocity approaches the gas velocity of 0.15 m/s as it travels up.

The consequent flame images of various experiments are being false color manipulated to find the stream velocity.

APPENDIX B: PROPOSED TASKS, STATUS ON TASKS AND EXPERIMENTS

PROPOSED TASKS (as outlined in the proposal)

TASK 1:

Develop and modify the group combustion model to include the cylindrical geometry.

STATUS: Done (Mr. Du and Dr. Ryan)

TASK 2a:

Modify the existing laminar flow reactor/flat flame burner facility for measuring the burnt fraction as a function of residence time.

STATUS: Construction of facility completed (MS thesis of Gopalakrishnan).

TASK 2b:

Conduct a detailed set of experiments and investigate the effects of particle size, gas temperature and cloud denseness.

CURRENT STATUS ON TASK 2b:

#	PARTICLE SIZE	GAS TEMP	OXY CONCENT, THEORY (measured)	ZONE HEIGHT	A:F	STATUS
1a	64	1200K	11 % (6-7%)	4 cm	0.775	done
1b					1.46	done
1c					1.91	done
2a				5cm	0.44	done
2b					1.198	done
2c					2.51	done
3a				6cm	0.81	done
3b					1.30	done
3c					2.41	done
4		1000 ~ K	7% (2-3%)			in progress

Figs. 1 and 2 show the results for the burnt fraction vs coal denseness (A:F ratio in the stream). It is apparent that the dense clouds (low A:F ratio) results in lower burnt fraction. However, after 2:1, the interactions do not appear to be severe due to the mixing of surrounding oxygen rich gases with the stream. If the stream diameter is large, then interactions may persist even for A:F of 2 due to increased time required for exposing the core particles with oxygen rich gases. A coal injector with larger diameter will be used to verify the hypothesis (however this task was not originally included in the proposal). The video-images are being analyzed for obtaining the flame profiles and estimating the stream diameter.

TASK 2c:

Compare the experimental data with predictions.

STATUS: in progress

TASK 2d:

Relate the results to spray combustion modeling.

STATUS: in progress

Gasification Eff Vs A:F Ratio

@4 cm height

Fig. 2

**DATE
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