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QUARTERLY PROGRESS REPORT #12

TITLE: COMBUSTION OF DENSE STREAMS OF COAL PARTICLES

GRANT NO: DE-FG-22-90PC90310

REPORT PERIOD: May 29, 1992 to Aug. 28, 1993

PRINCIPAL INVESTIGATOR: Kalyan Annamalai
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GRADUATE STUDENTS: C. Gopalakrishnan
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SUBMITTED TO: Pittsburgh Energy Tech. Center
US Department of Energy
P.O. Box 10940
Pittsburgh, PA 15236

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Sep.20, 1993

Dr. Goldberg
Program Manager
DOE-Pittsburgh
P.O. Box 10940
Pittsburgh, Pennsylvania 15236

SUBJECT: Grant # DE-FG22-90PC90310 - Quarterly Progress Report #12

Dear Dr. Goldberg:

Enclosed please find Quarterly Progress Report #12 for the period of May 29, 1993 to Aug.28, 1993.

Sincerely yours,

Kalyan Annamalai
Professor

KA/

Encl: Report

xc: Marilyn Keane, DOE/PETC
John R. Columbia, DOE/PETC
Kay Downey, Office of Tech. Transfer
Janelle Tucker, Research Foundation

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DISCLAIMER

Tasks for May 29, 1992 to Aug. 29, 1993

1. Conduct cold air flow study through fuel injector(without coal) surrounded by secondary stream of air flowing through porous plug in order to detect the divergence of the stream due to mixing.
2. Inject Coal:air stream through the injector with surrounding air flowing through the porous plug.
3. Inject Coal:air stream into the vitiated air with 0% O₂ concentration.
4. Inject Coal:N₂ stream into the vitiated air with 0% O₂ concentration.
5. Study the effect of O₂ concentration on gasification efficiency.

Activities during May 29,1993 to Aug. 28,1993

1. A cold air flow study has been conducted by injecting cold air through fuel injector(with traces of coal for the purpose of imaging) which is surrounded by the cold secondary stream of air flowing through the porous plug in order to detect the divergence of the stream due to mixing (Fig.6a).
2. Then dense stream of coal was injected through the same fuel injector which is surrounded by cold air jet (Fig.6b). It is apparent that coal jet remains cylindrical due to high injection velocity.
3. The coal:air stream was injected into the vitiated air with 0.6% O₂ concentration (Fig.7a).
4. The air in the fuel injector was replaced with N₂ into the vitiated air with 0.6% O₂ concentration in the presence of water cooled sampling system (Fig.7b) and in the absence of water cooled sampling system (Fig. 8) .
5. The effect of O₂ concentration on gasification efficiency was studied for various cases. Details are given in the enclosed report.
6. The article " Interactive Transport Processes during Gasification and Combustion, Part II : Isolated Carbon/ Coal and Porous Char Particle," is in press. A copy has been forwarded to the Dr.Goldberg, PETC. The revision on part III will be done sometime during Dec.93 and submitted for publication in Jan. 94.
7. 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 combustion of clouds and a porous coal particle. The model was first used for generating results on heterogeneous and homogeneous ignition of coal particle 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. A paper summarizing the results is under review.

Tasks for Aug. 29, 1992 to Nov. 28, 1993

Finish all remaining tasks and submit the final report.

COAL STREAM COMBUSTION

This report presents the results obtained from the gasification efficiency experiments by varying the i) air fuel ratio of the coal cloud ii) reaction zone height (residence time) and iii) oxygen concentration. A brief discussion on the divergence of coal stream is presented.

1. Effect of Oxygen concentration for Different Mass loading and Residence Times

The experimental set up and operating procedures have already been discussed in our earlier reports. The arrangements for temperature and O_2 concentration measurements are shown in Fig.1. The oxygen concentration is measured at a height of 4 cm above the burner at the center in all the cases. Measurements were made with Lancom 6500 portable analyzer. The measured oxygen concentration values are very close to the theoretical predictions assuming complete combustion. Fig.2 presents both these results. The detailed calculations are presented in the Appendix 1. The cloud A:F ratio is calculated based on the instantaneous digital balance reading and the carrier air flow values. Though the air flow can be maintained constant, coal flow does fluctuate. Hence, the A:F ratio fluctuates throughout the experiments and results presented will have an error bar for A:F ratio. The data point in Fig. 3 represent the average A:F ratio. Table 2 presents results of all the experiments. Figs. 3 to 5 show the effect of A:F ratio, the reaction zone height and then the oxygen concentration on gasification efficiency. The gasification efficiency so obtained is an average over the period of collection of burnt samples obtained with fluctuating flows. The plots of gasification efficiency vs average A:F ratio are given in Figs. 6a, 6b and 6c. A second order polynomial curve fit was used in fitting the data.

The experiments were performed to study the effect of A:F ratio, Oxygen Concentration and residence time over gasification efficiency. The coal type PSOC 1336 (high volatile) of particle size 64 micron was selected because of its easy grindability and flowability. Table 1 provides information about the experiments conducted. During the final phase of project, experiments will be repeated for coal particles of different sizes.

Initially, the particles heat up due to the high temperature provided by vitiated gases of methane flame. Coal particles pyrolyze, ignite and then combust and then the burnt particles are collected in the particle collection system. The extent of combustion depends on various parameters viz gas temperature, O_2 concentration, reaction zone height, denseness of coal air mixture and the stream velocity.

As the air:fuel ratio in the stream is increased, the inter particle spacing is increased, there is less competition for heat and oxygen and as such it will lead to increased gasification. However at heights of 4 cm (Fig.6a,6b and 6c), the gasification efficiency has a peak at an A:F ratio of about 1.5. Though the experimental data points are limited, the trend is clear in all three plots. Beyond certain A:F ratio, the gasification efficiency falls down since the cloud is so dilute that air acts as a heat sink and as such heat up time of the particle is increased. This is consistent with minimum in ignition time observed in ignition experiments.

As the reaction zone height is increased, the particles are subjected to increased residence time and hence the gasification efficiency is expected to increase (Figs.6). The increase in $[O_2]$ concentration should also have the same effect. As mentioned earlier, the air fuel ratio does not

remain constant throughout the experiment and hence an error bar for A:F ratio is indicated.

At shorter reaction zone height (ie at lower residence time), the dilute stream ends with lower gasification efficiency which is contrary to expected trend. This is shown in Fig. 3. for reaction zone height 4 cm. It may be due to very cold stream and very short residence time. The stream needs more time to get heated up. If the reaction zone height is increased for the same air fuel ratio, it results in higher gasification efficiency (Figs. 3,4,and 5)

2. Analysis of the flame images

Strong theoretical evidence prevails for homogeneous ignition in dense cloud and heterogeneous ignition for dilute cloud. Group combustion study on cylindrical cloud of coal particles predicts that once the cloud is ignited (outside the cloud for dense streams), the flame moves towards the cloud, reaches the cloud surface and then bifurcates into two flames called inner and outer flames with the inner flame moving into the cloud while the outer one travelling away from the cloud. Generally a stream tends to gain air entrainment from the surrounding atmosphere to which it is injected. This makes a stream to diverge like a jet. Most of flame images obtained so far reveal the divergence of flame. Is this due to coal stream divergence or due to volatile burning outside the cloud? A simple experiment is carried out to investigate this divergence effect.

Cold air jet surrounded by cold air: To begin with, just cold air is sent through the coal injector (V_{in} : 29.2m/s, V_{out} : 0.32m/s). In order to get the visual image of the jet, trace amount of particles are added by tapping coal feeder. The image is presented in Fig. 7a. The jet diameter increases to 6 times its original diameter at 6 cm height (Fig. 7a).

Cold Coal Stream jet in Cold Air: Then the coal feed rate is increased to get an air fuel ratio of 6. In both the cases, the surrounding flow conditions were kept the same and shape of the stream was captured using the digital camera. Same behavior as in Fig. 7a is repeated in when the air fuel ratio is increased to 6 but the central coal stream does not diverge very much as compared to the air stream (Fig. 7b). Stream maintains its cylindrical shape due to inertia of solid particles.

Coal:air Stream in Hot Vitiated Gases : When such a stream is introduced into a hot ambience, a diverging flame was observed. We have seen before that the cold coal jet maintains its cylindrical shape. The high volatile coal used releases volatile and ignition starts homogeneously and the flame follows the volatile and results in a diverging jet shape. The color change seem to indicate that the flame travels in the two opposite directions: inner and outer. The same phenomenon is expected in other experiments.

Coal:air Jet in hot Vitiated Gases of negligible O₂ Concentration: In order to just study the stream behavior, the experiment was repeated with 0.6 % O₂ concentration (Fig. 8a). Coal flame resulted in contrary to the expectation (Fig. 8a). This is attributed to the presence of O₂ in the carrier gases.

Coal: N₂ Jet in Hot Vitiated Gases of negligible O₂ Concentration (with water cooled collection System): For the same identical conditions, carrier air was with N₂. Fig. 8b shows the results. Combustion apparently still occurs.

Coal: N₂ Jet in Vitiated Gases of negligible O₂ Concentration (in the absence of water cooled collection System): In the experiment done to study the effect of particle collection system on stream divergence, the particle collection system was removed. A cylindrical stream resulted as shown from Fig 9. The combustion is not intensive as in the previous case. The interpretation is still in progress.

Reaction zone height (cm)	A:F ratio	particle size microns	gas temp	oxygen concen	status
4	0.5	64	1200	6.5%	done
5	1			10%	done
				12.5%	done
6	2		1400	6.5%	in progress
				10%	
				12.5%	

table 1

1
Fig. 1. Temperature and Oxygen Concentration Measurement Systems

Oxy conc for various flows

figure 2

Fig 3

Fig 4

Fig 5

Fig. 6a.

Fig. 6b.

Fig. 6c.

V_{in} : 29.2 m/s
 V_{gas} : 0.32 m/s (hot)

Fig 7a. Cold Air Flow

V_{inj}	:29.2 m/s
V_{gas}	: 0.32 m/s (hot)
A:F	: 6
Particle size	: 64 mic
Ox/ conc	: 0.6%(meas)
V_{N2} (shroud)	:0.134 m/s

Fig 8a Coal stream combustion (carrier gas : air)

V_{inj}	: 29.2 m/s
V_{gas}	: 0.32 m/s (hot)
A:F	: 6
Particle size	: 64 mic
Oxy conc	: 0.6% (meas)
V_{N2} (shroud)	: 0.134 m/s

Fig 8b Coal stream combustion (carrier gas : N_2)

V_{inj}	: 29.2 m/s
V_{gas}	: 0.245 m/s (hot)
A:F	: 6
Particle size	: 64 mic
Oxy conc	: 0% (meas)
V_{N_2} (shroud)	: 0.134 m/s

Fig. 9 Coal stream pyrolysis (carrier gas : N_2)

Appendix 1: Calculation of [O₂] concentration

	Observed Value(scfh)	Corrected Value(scfh)
Methane	4.8	5.264
Oxygen	1.0	0.952
	3.5	3.332
	5.5	5.236
Air	66	68

i)

$$Y_{\text{O}_2, \text{dry}} = 4.724 / (5.264 + 4.724 + 53.8)$$

$$= 7.41\%$$

$$\text{Measured Value} = 9.94\%$$

ii)

$$Y_{\text{O}_2, \text{dry}} = 7.104 / (5.264 + 7.104 + 53.8)$$

$$= 10.7\%$$

$$\text{Measured Value} = 10.1\%$$

iii)

$$Y_{\text{O}_2, \text{dry}} = 9.008 / (5.264 + 9.008 + 53.8)$$

$$= 13.2\%$$

$$\text{Measured Value} = 12.2\%$$

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