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QUARTERLY PROGRESS REPORT #11

TITLE: COMBUSTION OF DENSE STREAMS OF COAL PARTICLES

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Tasks for Feb. 29, 1993 to May 28, 1993

Finish all remaining tasks and write final report.

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

1. Extension was obtained to Aug. 31, 1993.
2. The part II of the review article is being revised in order to incorporate the comments.
3. In order to study the effect of O₂ concentration on burnt fraction pure oxygen was mixed with air. Parametric studies on the effects of residence time, oxygen concentration and air:fuel ratio of cloud on burnt fraction were conducted (Figs.5). Two dimensional digital images were obtained for the flame structure (Figs.6). See the enclosed report.
4. Theoretical analyses on combustion of cylindrical cloud were conducted. A paper summarizing the results is submitted for an ASME International Conference. The paper is under review.

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.

Introduction:

This report analyses the results obtained from the experiments conducted on a dense stream of particles injected vertically upwards into vitiated air. It is divided into two major sections: gasification efficiency and image analysis. In the first part, the effects of residence time and air fuel ratio over gasification efficiency are presented while the second part provides results on flame structure obtained using image analysis.

Overview of the experiments conducted:

A high volatile coal, PSOC 1336 is used for analysis. The proximate analysis on dry basis of this coal is presented below. Three particle sizes 39, 64 and 90 microns are selected with 64 micron size as the base case for our studies. The oxygen concentration in the vitiated

coal	%ash	%volatile	%fixed carbon
PSOC 1336	14.23	33.09	52.68

products is varied from 6.5% to 12% with 10% [O₂] as the base case. The gas temperature is varied from 1200 K to 1400K. Different residence times are achieved by positioning the particle collection system at various distances from the burner. Typically, a distance of 4,5 and 6 cm is kept to get different residence times. The air fuel ratio of the dense stream is varied between 1 and 2 which is generally the case in pf fired plants. In all the cases, the burnt sample is collected in a glass beaker after a set period of time which is typically 2-3 min after the coal flow started. The burnt samples are subsequently analyzed for the ash content. Ash percentage difference in the raw coal and burnt coal provides a quantitative measure of the extent of

gasification of the particles. The following table provides a list of various operating parameters.

coal	Particle Size in microns	Gas Temp in K	[O ₂]	A:F ratio in the stream	Reaction zone height
PSOC 1336	39	1200	6.5%	< 1	4 cm
	64	1400	10%	~ 1	5 cm
	90		12%	> 1	6 cm

The coal injector is of 2.03 mm diameter. If the relative velocity between stream and hot gas is negligible, coal stream is expected to provide a cylindrical cloud of coal particles with the cloud diameter being 2.03mm. On the other extreme, the cloud is of cylindrical geometry at very high velocity due to insufficient time for mixing[Fig.1]. Typically, the coal particles because of high carrier air flow travels with a higher velocity than the surrounding gas velocity. Direct flow calculation gives coal velocity sometimes as high as 33 m/s while cold gas velocity is approximately 0.15 m/s. The coal jet transfers its momentum to the surrounding gases and later reaches the gas velocity. During the process of momentum transfer, the stream entrains the surrounding gases and starts to diverge. Hence it is difficult to get the anticipated cylindrical cloud throughout the combustion period. Since the gas flow is through a sintered porous plug in the flat flame burner, the gas velocity is limited to about 0.6 m/s under hot conditions. Higher velocity can not be achieved since the flat flame will be lifted up. Due to the particle terminal velocity considerations, the stream velocity cannot be brought down below the predetermined velocity. Hence the stream divergence is unavoidable but can be minimized by operating near terminal velocity. Fig.2 shows the stream divergence. It is to be noted that the stream diverges

partly due to the presence of the particle collection system when placed closed to the burner. It is seen from the color flame images as the reaction zone height is increased from 4 cm to 6 cm, the divergent cone angle decreases.

Operating conditions:

The oxygen concentration and the gas temperature are the two most important parameters. The increase in O₂ concentration is achieved by introducing pure O₂ in the line along with air. The gas temperature is measured at the burner centerline at different heights. The measurements are done at different flow rates. The variations are presented in Fig.3. The oxygen concentrations are measured at the standard height of 4 cm above the burner. For a specific methane flow, 100% excess air is expected to have 10% oxygen concentration in the products if complete combustion is assumed, but the measured value is always slightly less than the calculated value. Another important parameter is A:F ratio. This A:F ratio in the cloud is determined from the mass flow rate and the carrier air flow rates. The feeder weight reading is registered every 15 sec in the computer. The coal flow is generally allowed for 2 - 3 min. The mass flow fluctuations during the flow is shown in Fig 4. the fluctuations are about $\pm 10\%$ of average value. The mass flow can be altered by adjusting the dilution flow. As the dilution rate is increased, coal flow rate decreases and A:F ratio increases.

Ash tracer Technique:

One may calculate the gasification efficiency based on the ash tracer method. The ash percentage of the coal sample is determined using proximate analysis before and after the experiments. If the coal is completely gasified, only ash will remain resulting in 100% ash in the burnt sample and 100% gasification. Generally, the coal gets gasified partially only, leading

to less than 100% ash percentage. The gasification efficiency is calculated by the following formula.

$$\eta_g = \frac{100 (A - A_o)}{A (100 - A_o)}$$

where A_o is the ash percentage in the unburnt sample while A is the ash percentage in the burnt sample.

Results:

The effects of A:F ratio and reaction zone height on gasification efficiency are reported. Other experiments are in progress.

High volatile coal of 64 micron was used for different reaction zone height starting from 4 to 6 cm. The experiments are then repeated for different air:fuel ratios in the coal cloud. As the air fuel ratio is increased, the inter particle spacing is increased, less competition for heat and oxygen and thus it will lead to increased gasification. As the reaction zone height is increased, the particles are exposed to increased residence time. The gasification efficiency increases as the residence time increases. These two theoretical predictions are anticipated in the experimental results. The Figs 5 present results for 64 micron high volatile particles at a fixed gas temperature of 1200K and $[O_2]$ 6.5%. In all the three different reaction zone height setting, the gasification efficiency generally increases with A:F ratio of the cylindrical cloud. As this height is increased, the gasification efficiency increases due to increased residence time. The maximum gasification efficiency is only 0.20 due to limited residence time.

Image study:

The color flame images obtained with digital imaging system are obtained for each height

setting are given in Figs 6a, 6b and 6c. As the color change indicates, the ignition of the coal particles begins at the stream periphery leading to the speculation of homogeneous ignition. Once ignited, the flame propagates towards the core and as well outside. It is not clear whether the divergence of the outer flame is due to stream diverging for the reasons as explained before or due to the volatile liberation and formation of external group flame as predicted in the model. In order to locate the flame pixel contours were obtained and pixel analysis is in progress.

Fig 1 High velocity cylindrical stream of coal particles

Fig 2 Combustion of Coal stream

Gas Temperatures Vs Height

for various flows

Fig 3 Uncorrected gas temperature

Fig 4 Typical coal mass flow rate

Fig 5a Gasification efficiency Vs A:F ratio (Reaction zone height 4 cm)

Fig 5b Gasification efficiency Vs A:F ratio (Reaction zone height 5 cm)

Fig 5c Gasification efficiency Vs A:F ratio (Reaction zone height 6 cm)

COAL STREAM FLAME

Reaction Zone Height 4 cm.

Coal type	:PSOC 1336
d_p	:64 μ m
$Y_{O_2,\infty}$	:0.065
A:F ratio	:0.5
T_{gas}	:1200K

Fig 6a Image of coal stream flame(Reaction zone height: 4 cm)

COAL STREAM FLAME Reaction Zone Height 5 cm.

Coal type	:PSOC 1336
d_p	:64 μ m
$Y_{O_2,\infty}$	:0.065
A:F ratio	:0.53
T_{gas}	:1200K

Fig 6b Image of coal stream flame(Reaction zone height: 5 cm)

240.188
225.375
210.563
195.75
180.938
166.125
151.313
136.5
121.988
106.875
92.0625
77.25
62.4375
47.625
32.8125

COAL STREAM FLAME Reaction Zone Height 6 cm.

Coal type :PSOC 1336
 d_p :64 μ m
 $Y_{O_2,\infty}$:0.065
A:F ratio :0.42
 T_{gas} :1200K

Fig 6c Image of coal stream flame(Reaction zone height: 6 cm)

END

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