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COMBUSTION CHARACTERIZATION OF COAL FINES RECOVERED FROM THE HANDLING PLANT

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ABSTRACT

The main goal of this research project is to evaluate the combustion characteristics of the slurry fuels prepared from the recovered coal fines and plant coal fines. A specific study will include the combustion behavior, flame stability, ash behavior and emissions of SO_x , NO_x and particulate in a well insulated laboratory scale furnace in which the residence time and temperature history of the burning particles are similar to that of utility boiler furnace at 750,000 Btu/hr input and 20% excess air. The slurry fuel will be prepared at 60% solid to match the generic slurry properties, i.e., viscosity less than 500 cp, 100% of particles passing through 100 mesh and 80-90% of solid particles passing through 200 mesh. The coal blend is prepared using a mix of 15% effluent recovered coal and 85% plant fines. Combustion characteristics of the slurry fuels is determined at three different firing rates 750K, 625K, 500K Btu/hr. Finally a comparison of the results is made to determine the advantages of coal water slurry fuel over the plant coal blended form.

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OBJECTIVES

The main objective of this project is to determine the combustion characteristics of coal-water slurry fuel prepared from the recovered coal fines and plant coal fine fractions.

The specific goals of this project are:

- Preparation of a stable coal water fuel and evaluation of its rheological properties
- Determination of the flame stability properties of the resultant fuel as a function of burner settings and the firing rates
- Determination of the combustion efficiency for the coal water slurry fuel as a function of residence time in the furnace and the firing rates.
- Evaluation of the fuel's fouling potential at each firing rate
- Examination of emissions of SO_2 , NO_x , CO , CO_2 and O_2 .

INTRODUCTION

During this period Dr. S. N. Dwivedi, a project consultant, & PSDI (Productivity Systems Design Inc) have discussed, planned and organized project experiments with EERC (Environmental & Energy Research center) at North Dakota University. Which will be conducted in near future.

EERC combustion test facility will be used to complete this experimental work. The Experimental work is divided into two steps. The first step involves the Preparation of the coal-water slurry fuel and the evaluation of its rheological properties. The second step involves combustion testing of coal water slurry fuel. the combustion test includes nine separate tests of three different burner settings each at three firing rates. In addition, the fuels fouling properties will be assessed at each firing rate.

STEP 1: Preparation of Coal Water Slurry Fuel

Coal water slurry fuel will be prepared by blending the recovered coal fines with water using a slurry preparation system. The slurry preparation system consists of 500 gallons storage tank, two metering pumps and a hp mixer assembly. An attrition mill will be used to ensure that the mean diameter size

of the solid particle ranges from 40 to 50 μm . the fuel viscosity of less than 500cp will be determined by rheological evaluation of the slurry. No additives will be necessary to stabilize the slurry fuel before combustion. EERC will analyze the received fuel fines in order to determine their proximate, ultimate and heating value analysis.

STEP 2: Combustion Testing of Coal Water Slurry Fuel

The coal water slurry fuel will be fired over a nine test period to determine the flame stability characteristics and combustion efficiency dependent on the burner settings and firing rates. During the 5.25hr test period of each firing rate, a limited evaluation of the ash-fouling characteristics will be performed. These tests will be completed using a pilot scale combustion system which consists of a combustor that will fire natural gas to preheat the system to the necessary operating conditions. The tests will be conducted over a 3 day period, firing at a different rate each day.

An international flame research foundation type secondary air swirl generator designed to achieve secondary air swirl numbers between 0 to 1.9 will be used during the testing.

On day 1 the coal water slurry will be fired at 750 KBtu/hr in order to provide a furnace exit gas temperature above 2200°F with an excess air level near 20%. Burner settings will be adjusted to find the point of flame instability. Stable conditions will also be determined by defining the flame as fully contained within the burner quarl. A constant swirl setting will also be used so that the performance may be correlated between each load test.

Data recorded will include a gas analysis, the ratio of primary to secondary air, flame temperature at a single point in the furnace and a measurement of the furnace wall heat flux for each burner setting. The flame temperature and the heat flux are measured by a high velocity thermocouple and a water-cooled probe, respectively. The measurements indicate flame shape and intensity. A visual record of the flame will be provided at each burner setting. A small cyclone will be used to collect fly ash samples to assess its carbon content to determine the effect of burner settings and load.

The burner will be set at a constant swirl rate and deposition probes will be inserted into the flue gas duct work, in which the surface temperature of the probe will be maintained at 1000°F. Ash-fouling deposits will be collected and particulate will be extracted from the furnace at three heights and analyzed for its carbon content. A portable gas analyzer will provide the flue gas concentrations of O₂, CO, NO_x, and SO₂. The fouling deposits will be collected weighed and analyzed at the end of the test period. An electrostatic precipitator will be used to collect bulk fly ash samples and analyze its carbon content, size distribution, and elemental oxide composition using X-ray fluorescence.

On the second and third day of testing the firing rates will be 625 K Btu/hr and 500 K Btu/hr respectively. The same protocol will be used for each testing day.

The cost of the above experiment as defined by the EERC is \$30,000 payable upon completion of the experimental work. (Appendix A).

PROJECT STATUS

During this period, an effort was made to train and familiarize two recently appointed research assistants (one graduate and one undergraduate student).

1. Tamar C. Holley, (Undergraduate research assistant),
studied various test methods and procedures to assess CWM's combustibility, transportation capacity, stability, environmental protection and rheological properties.

Tamar also studied the viscosity, coal beneficiation and use of coal fines extracted and prepared at a washing plant.

Her studies are given in appendix B.

2. Omeir Mohannad, (Graduate Research Assistant),
Studied the flame stability aspect of the project and a summary of his work is presented in appendix C.

CONCLUSIONS

The work performed during this period included the preparation of experimental work by the Environmental and Energy Research center at North Dakota University. The work of the research team involved the literature review and the study of experimental procedures to assess future execution of this research project.

Appendix A

Budget removed
at

Appendix B

TEST PROCEDURES USING COAL WATER MIXTURE

using 33 MW Himeji No. 1 Boiler

The test procedures that follows were developed to find the effect various brands of coal has on the environment and its handling techniques as a power generation fuel. The test procedures were divided into a series of tests including the Basic Test, the Combustion Test, and the Components Test.

BASIC TEST

The basic test assesses the ease of manufacture and the combustibility of the coal water mixture.

CWM TRANSPORTATION AND PIPELINE PERFORMANCE TESTS

The cwm was prepared prior to transportation which was some distance away from the power station. The cwm was transported by tank lorries and transferred to the onsite tanks at the power station via a cwm loading pump. This test assessed the dynamic behavior of the cwm for handling.

PIPELINE PRESSURE LOSS TEST

This test uses two diameter pipes (3in and 5in) for supply and return. For various flow rates and the pressure losses were measured. The experimental and theoretical values of the fluid flow equations did agree in this test.

LINE RESPONSE TEST

This test determines the pressure propagation velocities and flow rate velocities difference upon changing the supply rate of the cwm. For various boiler loads, the flow rate demand signal was changed and the responses to the flow rate and inlet pressure were measured. The results were well within the range allowed for boiler operation.

PUMP RESTART-UP TEST

Effects of the boiler shut-down time were assessed due to the amount of force it takes to start the flow of the cwm. This procedure includes restarting the pump with the cwm held in the supply and return lines in terms of cwm flow characteristics and line pressure losses. CWM will not present any problems for boiler shut down times of as long as one week.

LONG TERM CONTINUOUS PIPELINE TRANSPORTATION TEST

This test assessed the future long-range pipeline transportation of cwm. This test was conducted with the same cwm fuel pump through the supply and return lines. The cwm pump revolution speed and supply rate of the cwm remained stable throughout the 75 day examination. There were decreases in the viscosity and the change in pump delivery pressure.

COMBUSTION TEST

COMBUSTIBILITY

Stable combustion of a coal with a high fuel ratio was controlled by adjusting the burner vanes finely and by keeping the furnace atmospheric temperature high. The low fuel ratio burned with ease and its combustibility was rated as well as pulverized coal. The burner, which is compatible for both oil and coal, achieved stable combustion with both. Also, the conversion to either was performed smoothly.

OPERABILITY

Fossil power stations have to be flexible enough to adjust to various power demands. Thus, minimum operation loads and cyclic operation practices will have to also be exercised by coal firing stations as well.

Load changing test

This test confirms that the performance of cwm firing is the same as oil firing under the Automatic Boiler Control mode. The boiler was operated at a load changing rate of 3.3% per min from 16.5 MW to 33 MW. CWM firing are about the same as oil firing, and better than pulverized coal. The deviation was kept to within the allowed control limits ($\pm 1.8K$) both for load turn-up and load turn-down.

Lowest load confirmation test

The power output was gradually decreased from 33 MW to 10 MW at intermediate loads. The boiler was stable on four burners and with no assistant fuel. This value is very comparable to that of oil firing and lower than pulverized coal. This minimum load was imposed by that of a turbine and not by combustion.

Start-up and shut-down test

The system was brought to full load smoothly by cwm firing. Although some oil was used to increase the gas temperature in which fuel gas could be forced into the de nitrification plant. The start up time for cwm was shorter than that of pulverized coal and was very comparable to that of oil.

COMPONENTS DURABILITY TESTS

BURNERS

Visual inspection of the interior and exterior of burner guns proved no abnormal wearing or deposits of coal from the cwm. Thus, the design of the burners were adequate for the services of cwm.

PUMPS

The pump performance did degradate at approximately 22%. Further improvement to the wear resistance of the base material and its surface treatment is needed.

VALVES AND LINE PIPES

No wearing nor deposits of coal from coal water were found in the fully open or closed valves. Although, the partially closed valves did show signs of clogging and deposits.

STRAINERS

No anomalies

ELECTROMAGNETIC FLOW METERS

No anomalies

It is expected that the CWM fired boiler will meet the demands of newest coal fired boilers.

TEST PROCEDURES WITH COAL WATER MIXTURE using a 60 t/h oil fired industrial boiler

Since 1984, 1200 cumulative hours of operation and 4500 tons of coal water have been consumed using the 60 t/h boiler. The combustion efficiency was approximately 97% with 83% boiler thermal efficiency. What follows are the various situations of combustion tests and findings on the 60 t/h boiler.

The boiler has a convection superheater, economizer, and air preheater, and six burners mounted in the front wall. It must be noted that radiation from the walls causes quick igniting of the cwf sprays from the atomizers.

divergent angle, axial swirling	120°
velocity, primary air	5-15 m/s
velocity, secondary air	30-45 m/s
swirling intensity	7.3

The purpose of this series of tests is to assess among other things, the combustion condition, the suitability of axial swirling, and the function of the precombustion chamber.

OPERATION TESTS

The CWF flame length and fullness within the combustion chamber were all excellent. The flame temperature was constant over 1350°C without fuel oil support. With the boiler operating solely on CWM, the temperature of the superheat steam does not fluctuate but the temperature in the combustion chamber and the top flue gas decreased. The steam pressure and steam temperature were maintained at 24-25 kg/cm² and 370-380°C, respectfully.

COMBUSTION TEST

The temperature of the combustion chamber approached 600-800°, in which at that time fuel switching occurred. The CWF flame was red and steadily changed into apricot yellow as the temperature increased from 900° - 1350°. With boiler load increasing, the flame becomes brighter and more stable. The temperature increased with boiler load increase from 900° to 1350°C and the flame became more stable.

Low load operation tests were conducted in two ways. CWF pressure was reduced and the air flowrate adjusted to achieve stable combustion at a 60% load. The second way to conduct the low load operation test was to stop part of the burners, adjust CWF pressure, air flowrate, and the ratio of primary air to secondary air to achieve stable combustion at 40%. This test has concluded that cwf fired boilers has advantages by comparison with pulverized coal fired boilers of load turndown.

The CWF combustion process may be divided into three stages:

Evaporation of Water

De volatilization and Volatile Combustion

Combustion of Coke

8% of total combustion time is spent on evaporating the water in the coal water mixture. To provide rapid ignition of the CWF spray, the evaporation time of the water must be reduced as much as possible. Methods to reduce the evaporation time include: recirculating flowrate of high temperature gas, installing a front combustion chamber, etc. ..

The temperature of the CWF flame is 1000° lower than oil, but the exhaust gas rate is larger than that of oil. In conducted studies, the temperature of the superheated steam of the 60t/h boiler consistently remained in the range from 370-380°, which is 20-30°C lower than the theoretical value.

CWF is a low pollution fuel, its Nox emission is less than pulverized coal, due to the fact that the CWF flame temperature is relatively low. The Nox emission was approximately 73 to 211 ppm, which is also lower than that of pulverized PC.

CONCLUSION

The tests conclude that application of the coal water mixture in a modified oil designed boiler is feasible, the combustion of the cwm is stable, and operation is simple and reliable. The combustion is intensified and carbon conversion efficiency is increased by registering axial swirl in front precombustion chambers. The Nox emission and the SO₂ emission were lower than that of the State Standard.

CHARACTERIZATION, STABILITY AND RHEOLOGY OF COAL WATER MIXTURES

TEST SAMPLE PREPARATIONS

The test slurries used in the experiments were composed of an Illinois No. 6 coal that was pulverized using a dry rotary pulverizer. The pulverized coal was mixed with distilled water and normally no additives were added to the slurries. In changing the pH of the slurry, additives were added, and the concentration was adjusted by removal or addition of supernatant, as appropriate.

SEDIMENTATION OF CWM

With the initial concentration of the slurry at a fixed pH and as a function of the pH at a fixed concentration, results on the gravity settling of the coal water mixture were found through experiment. Increasing the pH from 2.3 to 10.0 retards the settling of the coal water mixture as well as an increase in concentration at a fixed pH because of increased particle interactions (Turian, pg. 78).

CWM YIELD STRESS/CONCENTRATION DEPENDENCE

The yield stress/concentration dependence of CWM was measured using the vane apparatus. For pH increasing from 2.6 progressively to 3.0, 3.5, 7.1 resulted in progressive decay in the yield stress (Turian, pg. 78).

SHEAR STRESS SHEAR RATE/CONCENTRATION DEPENDENCE OF CWM:

The shear stress/shear rate dependence of coal water mixture for a pH of 2.6 was measured as a function of solids concentration using Brookfield rotational viscometers and a capillary rheometer (Turian, pg. 79). The behavior of the coal water mixture is power-law shear-thinning over the lower shear rate range and attains a high-shear Newtonian limit.

EXPERIMENTAL PROCEDURE

The rotational viscosity data using standard methods and the capillary tube rheometer data is analyzed using established standards. The vane method is also analyzed. The vane element consists of four thin rectangular blades attached at right angles to each other. The torque heads on Brookfield viscometers were used to drive the vane elements. The experimental procedure included immersing the vane elements into the slurry, and setting the rotational speed to a sufficiently low value. A torque vs. time trace will start with a rise of the torque to a maximum value.

MEASUREMENT OF VISCOSITY

Atomization, or the reduction of particles to a fine spray, of coal water fuel is an important factor in determining the combustion efficiency of the fuel. Through various studies, it was established that the droplet size distribution of the CWF spray is controlled by the viscosity of CWF at high shear rate. The capillary tube viscometer has been extended and modified to measure the viscosity of the fluid at shear rates up to $2 \times 10^5 \text{ sec}^{-1}$ (Yu, pg. 85). A viscometer measures the frictional pressure drop of laminar flow of a fluid at a given flow rate through a smooth cylinder tube of known dimensions.

COAL BENEFICIATION

COAL BENEFICIATION OBJECTIVES

The advantages that beneficiation, or the filtering process in order to improve the properties, of removing sulfur and mineral matter from the coal prior to the preparation of the coal water mixture are extensively known. The adverse effect include ash slagging and fouling, increased production costs and poor atomization and carbon burnout during combustion. The interaction of initial coal properties, the effects of beneficiation, and chemical additives is highly complex. A in depth understanding the this interaction is needed in the design of the overall CWF manufacturing processes and methods to produce the CWF with the required parameters.

Most of the coal beneficiation research and development is targeted at the removal of sulfur and gross mineral in order to reduce the SO_x emissions, the total particulate emissions, and waste ash production from the coal. Other objectives of the coal beneficiation include reducing the moisture level, improving grindability, preserving combustible volatiles, improving the carbon burnout characteristics, reducing selected mineral components, and improving the CWF rheology. Many of this objectives are conflicting each other. The altered additive formulations required following beneficiation may result in high additive costs and adverse effects on CWF rheology, atomization, and combustion (Walters, pg. 223).

COAL BENEFICIATION EFFECTS ON CWF FORMULATION

The least expensive substances that promotes the formation and stabilization of the CWF are anionics such as ammonium lignosulfonates. Its effectiveness depends on coal surface hydrophilicity, pH, and ionic strength.

More expensive nonionic substances that promote the formation and stabilization of CWF with adverse impacts on CWF atomization and storage properties are needed to disperse coals beneficiated by hydrophobic coal cleaning techniques. Nonionic dispersants also perform well for coal mixtures subject to pH drift and multivalent cation concentrations.

Less expensive anionic dispersants perform well at atomization and storage temperatures but do not work well with coal beneficiated with hydrophobic techniques.

FINE COAL WASTE

There is a concerted effort to find ways to reduce the cost of coal water mixture preparations. The cost of the coal itself is 50% of the product price. Using the cheapest coal quantities with the required qualities is the most feasible method. One possibility is to use fine coal slurries produced in coal washing plants. The use of the fine coal would ease the difficulty of processing and become of economic value, it makes for a reduced level of investment using existing infrastructures and personnel, the coal type is well defined and offers the possibility of optimizing the type of thinning and stabilizing.

A negative effect of using fine coal waste is that it has a very high ash content. It is not possible to reduce the mineral matter whereas the product can be utilized in retrofitted combustion plants designed to burn fuel oil. Thus, the product can only be used in new combustion plants whose characteristics will be similar to that of pulverized coal combustors. Another drawback is that the operating conditions of a washing plant are optimized for producing washed coals, thus important variations in the by products must be expected.

FINE COAL CHARACTERIZATION

A study was conducted in the Freyming-Merlebach washing plant to assess the slurry obtained from a cut of the volatile bituminous coal at approximately .5 mm was concentrated at the washery and then sent to a processing station. The slurry was dewatered and thermally dried in ovens. The dried coal was reduced to the appropriate size consist and burnt as pulverized coal in the boiler. The daily average concentration was relatively stable (Brunello, pg. 227). The size consist was also quite stable. The ash content was the most stable characteristic. In this study the fine fractions (particle size) retained a high ash content whereas, the coarse fractions were relatively clean (Brunello, pg. 228).

BENEFICIATION

To reduce the ash content by up to 25% in the product, to a level of acceptability from the heat content, transport cost and side effects view points. Due to the fact that the product includes fine and coarse fractions, a two step beneficiation process of mechanical separation of the low ash coarse fraction and cleaning of the fine fraction is suggested. Two methods, sieve bend and high frequency vibrating screen, are used to separate the ash content from the coarse fraction of the slurry.

Through tests performed, it has been established that by sieve bend the accuracy of separation is a bit less than high frequency vibrating screen but the treatment capacity is much greater (Brunello, pg. 229). In cleaning the fine fraction, laboratory flotation tests in 5 liter cells,

demonstrated the necessity of treating fresh slurries and highlighted the detrimental effects of flocculants in the feed (Brunello, pg. 230). Preliminary tests with a selective agglomeration process were performed in which results produced only 4.3% of ash with a 91% Btu recovery (Brunello, pg. 230). This process is not yet available to the public.

FORMULATION OF COAL WATER MIXTURES

The coal type, size consist, and the type and quality of additives used are important parameters in the formulation of coal water mixtures. Getting the best for each parameter have opposing and conflicting results and may not correspond. For example, the most favorable composition from a solid-content standpoint is a staggered distribution of large size particles and very fine particles, but from a combustibility point of view, it is just the opposite. The research and tests performed in the Freyming plant has resulted in (Brunello, pg. 230):

- Selection of 2 additives which have certain performance-price advantages and are compatible with the reagents introduced upstream.
- Adopting a system comprising of two mills: the first receiving half of the flow and regulated to produce large quantities of fine, the second is supplied with a mixture comprising of raw feed and the product from the first mill.

Under these conditions, a solids content may reach 70% of acceptable viscosity. It is indeed feasible to prepare quality coal water mixtures using fine coal slurries from washing plants. The economic results suggests that CWM produced in washing plants should be competitive with oil or gas.

FUNDAMENTALS OF COAL-WATER FUEL COMBUSTION

Modifying an oil-fired boiler to burn Coal-Water Fuels poses several challenging situations. Ignition delay times, burnout rates, and the potential erosion of convective tube banks are aspects to retrofitting design which are affected by the droplet size, coal type, and combustion conditions.

Experiments were carried out in a laminar flow reactor to study the behavior of combustion in a controlled environment. Samples of agglomerated CWF particles are reinjected into the Laminar Flow Reactor to determine their combustion histories and provide information on the fragmentation and burnout kinetics. A new CWF droplet generator was developed to ensure the same results of in-situ generated particles.

The combustion process consists of the agglomeration of the coal particles within a droplet upon drying, pyrolysis and volatile combustion in an envelope flame around the particle.

EXPERIMENTAL

Two methods, the In-situ CWF Droplet Generation and the CWF Agglomerate Injection, were used to introduce CWF droplets/particles into the Laminar Flow Reactor.

In-situ CWF Droplet Generation

The twin fluid, internally mixed, single exit orifice atomizer was developed and used to generate a wide stream of CWF droplets in the size range of 5-500 microns and at feed rates less than 3 mg/s (Srinivasachar, pg. 331). A wide angle CWF spray is discharged into the cylinder of the skimmer, consisting of a 10 cm diameter cylinder with 16 holes 2 cm in diameter enclosed in a 25 cm diameter Plexiglas tank, a base plate and three cones with different opening diameters in the range of .25-.75 cm (Srinivasachar, pg. 331). The spray was passed through the cones to chop most of the spray. The narrow stream of CWF droplets produced by this process was fed directly to the LFR.

CWF Agglomerate Injection

A water quench probe withdrawn from the centerline of the CWF diffusion flames in were analyzed for their volatile matter and total ash. The structure and form (morphology) of the CWF was assessed by scanning electron microscopy. Combustion experiments on the CWF particles, at atmospheric pressure, were conducted in a laminar flow furnace. The particles are injected into the hot zone of the reactor through a water cooled feeder probe. The particles are then heated rapidly to ignition by conduction from the gas and radiation from the walls (Srinivasachar, pg. 331).

Ignition

After injection of the droplet into the furnace, the water quickly evaporates, leaving the coal particles adhered to the surface. The particles are exposed to the heat and become plastic and fuse on the outer perimeter of the agglomerate. Thus, ignition occurs initially at one corner of the agglomerate and is followed by the spread of ignition to the whole surface.

Volatile Combustion

If oxygen can be displaced from the particle surface by volatile evolution an flame forms around the particle. Cracking of the hydrocarbons species (soot) in the high temperature zone near the flame front fuel causes radiation to form. The char agglomerates are heated by the energy fed back to the surface by the envelope flame.

Only one particle at a time is measured for radiation at a time due to the field of view, which helps provide information about the different aspects of the combustion process. The duration of the volatile flame ranged from 5 ms at 100% O₂ to 8 ms at 70% O₂ and 11.9 ms at 50% O₂ for a mean agglomerate size of 83 microns and a gas temperature of 1200 K (Srinivasachar, pg. 332). There was good correspondence in the volatile combustion between the in-situ and re-injected flame agglomerate.

Particle Rotation

A major fraction of the volatiles is evolved in the form of jets from the agglomerate. The particle is rotated due to the centrifugal forces generated from the momentum. A rotation frequency of 1000 cps of a 50 micron diameter particle generates centrifugal forces at the particle surface of 100g (Srinivasachar, pg. 332). Separation of adhering coal particles, fine ash particles, and fragments from char can be achieved with this rotation frequency.

Ignition of char

When the volatile evolution decreases, the flame front recedes and the particle is extinguished. The char agglomerate is solely heated by the gas until the oxidation reaction is quick enough to reignite the particle. This ignition delay is a function of the gas temperature and the oxygen mole fraction. It varies from about 7 ms at 21% O₂ mole fraction to 1 ms at 70% O₂ for a mean agglomerate size of 83 microns at a gas temperature of 1200 K (Srinivasachar, pg. 332).

Char Burnout

The burnout times for char can be achieved from photomultiplier signals or high speed movie photographs. The burnout time for a 75-90 mm agglomerate is 36.3 ms at 50% O₂ and 20 ms at 70% O₂ for a gas temperature of 1200 K. The char burnout times of both the in-situ and re-injected particles are in agreement.

Fragmentation

Fragmentation of the agglomerate occurs during the devolatilization and char burnout. During devolatilization, the fragmentation is bulk phenomenon, whereas during char oxidation it is in both a percolative and bulk phenomenon mode. The particle time-temperature history is

important in determining the extent of fragmentation. From the viscosity-temperature relationship it is seen that at higher heating rates, the period of plasticity of bituminous coals become narrower and also occurs at higher temperatures (Srinivasachar, pg. 333). Increasing the extent of fragmentation is useful because it will reduce the time required for burnout and decrease the fly-ash particle size due to their origin from finer parent fragments.

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Appendix C

FLAME STABILITY

What Is Flame?

Flame is combustion reaction accompanied by light, the specific property of which is self-propagation within a suitable combustible medium.

In general, any flame can be classified into four categories. The first category is the state of the flame, whether it is stationary or it moves with respect of a reference plane. the second category is the existence, or absence, of any fuel and oxidizer agent before entering the reaction zone. The third category, is the nature of the gas-flow through the flame zone. The fourth category, is the initial physical state of the fuel: liquid (heterogeneous flame), solid (heterogeneous flame).

The More Important Flame Manifestations

The most important flame manifestations are the radiation, temperature and velocity of propagation. The flame radiation is partly thermal and partly chemiluminescent. The thermal radiation comes from the spectral bands of some chemically stable products of the flame such as H_2O , CO_2 , CO , etc. The strongest spectral bands in the infrared range are due to the main products of the combustion, the carbon dioxide and water vapor.

The second flame manifestation is the temperature. Temperature is the parameter characteristic of a system at equilibrium. But flame is a non-equilibrium system. We can speak of flame temperature only if we assume the existence of a volume of gas of small dimension compared with that of local temperature measurement.

The third manifestation of the flame is the velocity of propagation. Flame velocity depends on the initial state of the system. The higher the velocity, the smaller the part played by the time factor in the degradation of the energy given off by the combustion process.

Flame As Applied To Industrial Processes(Industrial Flame)

There are two main fields for industrial flame :

- (i)The flame produced by burning solid fuel on a fire gate.
- (ii)The burner flame.

Burner flames are stationary with respect to the burner nozzle taken as a reference point.

Industrial flames, including the combustion processes developed in internal combustion engines, cover the following fields:

- (i)Steam boiler furnaces.
- (ii)Industrial furnaces for metals and ceramic material heating.
- (iii)The combustion chamber.

The flame of pulverised-fuel has wide industrial application, the flame produced by the combustion of the upon grate-bars, on a fluidised bed, and the cyclone flame.[1]

Stability And Stabilization Of The Flame(Combustion)

Ensuring the flame stability in the different operating condition is one of the most important problems of industrial combustion plants.

Flame stability and stabilizing is divided into two ranges: the burner flame and the combustion of solid fuel in a bed.

The stability and stabilizing of the burner flame is divided into four parts:

- (i)Stability and stabilizing the premixed gas flame.
- (ii)Stability conditions of the diffusion flame.
- (iii)Methods of stabilizing the diffusion flame; the flame of the liquid fuel spray, and the flame of the pulverized coal jet.
- (iv)Details relative to obtaining the stabilization of the turbulent diffusion flames.

In the case of solid file combustion in a bed, if the combustion process has been stabilized, the ignition front is localized in the bed over a certain surface, whose shape and dimension depend on the feeding of the bed with fuel and air.[1]

Factors that Affect the Flame Stability

Fuel quality has an important influence on the flame stability y performance of coals burned as pulverized fuel. The main quality is coal volatile matter content. The higher the volatile content of the coal, the more easy it is to stabilize the flames.

There are some other factors that affect the flame stability like ash. Ash has two effects on flame stability. The first is thermal burden, and the second factor of ash, is its additional particle surface area ash for heat transfer out of the flame by radiation.

Another factor is particle size distribution. Flame stability performance is improved by finer grinding. Radiation temperature increases as coal grind becomes coarser. One more factor is the excess air. Radiation temperature increases linearly with excess air factor. At low excess air, less char needs to be burned in the flame for flame stability, because of the small thermal burden[2].

REFERENCES:

- 1: Stambuleanu, Adtian. Flame Combustion Processes in Industry. Abacus press, 1976.
- 2 :L. Smoot, L. Douglas and Philip J. Smith. Coal Combustion and Gasification. Plenum Press.