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"NONEQUILIBRIUM SULFUR CAPTURE & RETENTION IN AN AIR COOLED SLAGGING COAL COMBUSTOR

Second Quarterly Technical Progress Report

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1. SUMMARY

The objective of this 24 month project is to determine the degree of sulfur retention in slag in a full scale cyclone coal combustor. This effort will consist of a series of up to 20 parametric tests in a 20 MMBtu/hr slagging, air cooled, cyclone combustor. During the present reporting period, this combustor was tested for a total of 9 days in February and at the end of March. The tests at the end of March were the first ones in which excellent slagging combustor operation was achieved. This is the key requirement for implementing the test effort in the present project. Therefore, the combustor is now ready for testing under the current project, and initial tests are planned during the next quarterly reporting period, as per the project schedule.

2. PROJECT DESCRIPTION

2.1. Objectives

The primary project objective is to determine the degree of sulfur retention in slag in a full scale cyclone coal combustor. This non-equilibrium process is a key step in the capture and retention of sulfur released during coal combustion by the interaction with calcium based sorbent particles. By encapsulating the sulfur bearing calcium particles in slag, the need for landfilling of this waste is eliminated. This objective will be implemented through a series of up to 20 one day tests carried out in a 20 MMBtu/hr air cooled, slagging combustor-boiler installation located in Philadelphia, PA. The project will consist of two tasks. Task 1 consist of the experiments conducted in the 20 MMBtu/hr combustor, and task 2 will consist of analysis of this data. All the operating procedures for this effort have been developed in the 7 years of operation of this combustor.

2.2. Technical Approach

2.2.1. Overview of the Work

The work of this Phase 3 project will be implemented on Coal Tech's patented, 20 MMBtu/hr, air cooled cyclone coal combustor that is being installed on an oil designed, package boiler at a new facility at the Arsenal Business Center in Philadelphia, PA. This new facility consists of a refurbished and upgraded 20 MMBtu/hr combustor that had been tested at a manufacturing plant in Williamsport, PA from 1987 through 1993. The primary fuel has been, and will remain, coal. Other tests, including combustion of refuse derived fuels and vitrification of fly ash, have been successfully performed. Additional ash injection may be required to achieve high sulfur retention in the slag in the present combustor tests.

The combustor's novel features are air cooling and internal control of SO_2, NO_x, and particulates. Air cooling, which regenerates the heat losses in the combustor, results in a higher efficiency and more compact combustor than similar water cooled combustors. Internal control of pollutants is accomplished by creating a high swirl in the combustor which traps most of the mineral matter injected in the combustor and converts it to a liquid slag that is removed from the floor of the combustor.

SO_2 is controlled by injecting calcium oxide based sorbents into the combustor to react with sulfur emitted during combustion. The spent sorbent is dissolved in the slag and removed with it, thereby encapsulating the sulfur in slag. Part of the sorbent exits the combustor with the combustion products into the boiler where it can react with the sulfur. The primary objective of the present tests is to maximize the degree of sulfur retention in the slag. All spent sorbent not reporting to the slag is either deposits in the boiler or it is removed in the stack particle scrubber.

NO_x is controlled by staged, fuel rich combustion inside the combustor. Additional reductions are achievable by reburning in the boiler or by ammonia injection if the stack gases.

Excellent progress had been made prior to the start of the present project in meeting several of these combustor performance objectives. One of the most important objectives of this technology development effort is to demonstrate very high SO_2 reduction in the combustor. Prior to the start of the present project, the peak SO_2 reduction achieved with sorbent injection in the combustor had been 90%. Of this amount a maximum of 11% of the total coal sulfur was trapped in the slag. Evaluation of this prior data indicated that the low sulfur retention in the slag was due to excessive slag residence time in the combustor. Since the solubility of sulfur in slag is low, long slag residence times (in excess of 5 minutes) can result in substantial sulfur gas re-evolution into the gas phase.

To reduce the slag time in the combustor in the present project tests, the slag mass flow rate will be increased by either using very high ash coals or by injection coal ash with the coal. High ash mass flow rates increase the slag flow rate.

In order to determine the non-equilibrium sulfur-slag chemistry, calcium sulfate (anhydrite) will be injected into the combustor to vary the slag flow rate inside the combustor and to measure the sulfur gas evolution rate independently of the calcium-sulfur heterogeneous capture reaction. This information will then be used to measure the combined sorbent-sulfur capture rate in the gas phase with the sulfur retention rate in the slag inside the combustor.

The 20 tests planned for this project will allow full parametric variation of these sulfur-sorbent capture and sulfur-slag re-evolution reactions.

2.2.2. Task Description

Task 1: Sulfur Chemistry Tests in the Slag of a Cyclone Combustor.

This task will consist of four groups of tests designed to validate the sulfur chemistry in slag under non-equilibrium conditions. The tests are designed to validate the chemical and fluid mechanical processes occurring in the capture and retention of sulfur in slag. These reactions are based on prior analytical and experimental work in coal slags and coal like slags, such as steel blast furnace slags. The plan calls for a total of 20 one day tests. However, due to resource limitations, it is planned to accomplish the project objectives in as few as 15 one day tests. To meet all the parametric test variations, the duration of individual test conditions will be reduced.

In the first group of six tests, anhydrite will be injected into the 20 MMBtu/hr combustor at a rate that duplicates the complete reaction of sulfur from a **2% sulfur** coal with calcined calcium oxide particles. While maintaining this sulfur concentration fixed, the total slag mass flow rate will be increased in three discrete steps, with each step remaining fixed for the entire 6 hour, one day test period. Both fuel rich and fuel lean operation will be tested. The purpose of these tests and the second group of tests is to measure sulfur re-evolution from a sulfur based calcium compound at concentrations that duplicate the maximum amount of sulfur that can be captured in the combustor with calcium oxide sorbents.

In the second group of six tests, anhydrite will be injected into the 20 MMBtu/hr combustor at a rate that duplicates the complete reaction of sulfur from a **4% sulfur** coal with calcined calcium oxide particles. While maintaining this sulfur concentration fixed, the total slag mass flow rate will be increased in three discrete steps, with each step remaining fixed for the entire 6 hour, one day test period.

These two groups of tests will determine the sulfur retention capability of slag as a function of slag residence time in a commercial scale combustor, namely the unit rated at 20 MMBtu/hr. In other words these tests will focus only on the sulfur retention in slag. This type of test was performed briefly in the 20 MMBtu/hr combustor facility and the results indicated that this is an effective method for studying sulfur retention in slagging cyclone combustors.

In the third group of four tests, the entire sulfur capture process will be implemented from the injection of the uncalcined sorbent to its reaction in the combustor and impact and removal with the slag. The slag mass flow rate will be adjusted to duplicate the optimum slag flow rate determined from the group one tests. These fuel rich and fuel lean tests will serve to validate the entire sulfur capture and retention process in the combustor.

In the final group of four one day tests, reacted sorbent collected in the boiler and stack baghouse will be injected into the combustor at the optimum slag mass flow rate determined from the first two groups of tests. The objective of this test series will be to determine the degree of sulfur encapsulation in slag in cases where the magnitude of sulfur capture with injection of sorbent in the combustor is insufficient to meet environmental emission standards.

All the experiments will be conducted in accordance with the procedures developed in the seven years of testing in Williamsport and in the current tests in Philadelphia on the 20 MMBtu/hr combustor.

Task 2: Analysis

The results of the tests in task 2 will be analyzed using two and three dimensional combustion codes for the conditions existing in this combustor, and a code for analyzing slag flow on the walls of the combustor. The results will be compared with prior tests in the present combustor and with laboratory scale data on the sulfur chemistry process in coal and steel slags.

The analytical procedures and bench scale tests on sulfur-slag reactions developed in prior decades will be used for this purpose.

3. PROJECT STATUS

3.1. Effort of the Present Quarter

During the present reporting period, this combustor was tested for a total of 9 days in February and at the end of March. The tests at the end of March were the first ones in which excellent slagging combustor operation was achieved. This is the key requirement for implementing the test effort in the present project. Therefore, the combustor is now ready for testing under the current project, and initial tests are planned during the next quarterly reporting period, as per the project schedule.

The core element of this project is to encapsulate the sulfur released during coal combustion and reacted with the calcium based sorbent in the slag, which consists of a mixture of liquefied coal ash and sulfur bearing sorbent. Due to the low solubility of sulfur in slag, it is essential to limit the slag residence time in the combustor to at most a few minutes. Both good slag flow conditions inside the combustor and in the slag tap are essential for continuous and rapid slag removal from the combustor. Maintaining an open slag tap has been of the important development issues during the period of combustor operation in Williamsport.

For this reason, the test results obtained at the end of March in the present combustor are of considerable significance. In addition to good slagging conditions achieved in the present combustor at a lower thermal input than in the Williamsport combustor, the slag tap operation was excellent. The slag tap contains both a thermal component in that gas heat is used to maintain the tap at a proper operating temperature, and a mechanical component, consisting of a mechanical device to break off frozen slag deposited inside the tap. Both these features operated smoothly in the March tests.

The March test conditions consisted of thermal inputs of up to 13 MMBtu/hr, which equals two-thirds of the rated heat input to the boiler. Of this heat input, over 600 lb/hr was coal, equal to two thirds of the total heat input, with the balance being No.2 oil and a small quantity of propane. Due to the limited coal supply on hand higher fuel feed rates could not be performed in this test.

The important results for the present project that were obtained in the March tests were:

a) The operation of the coal and sorbent feeding system was flawless with no evidence of blockage in any of the feed ports. Eliminating blockage was an area of substantial development in the Williamsport combustor. In the present combustor, the feed system was substantially improved. On a related matter, the pneumatic transport air had been supplied by a compressor in Williamsport. This is very energy inefficient. In the present facility this was replaced by a blower, and until the March tests, there was no conclusive proof that this much lower pressure system would work as effectively. In the event it did and this represents an important milestone for this combustor technology.

b) Excellent slag flow was obtained at a much lower oil fired heat input that in Williamsport. This is also an important result because high oil pre-heat is energy inefficient, and its minimization improves the economics of the technology.

c) A smooth and uniform slag layer was deposited on the entire internal wall of the combustor. This is important because it acts a barrier to slag attack of the combustor wall refractory.

d) Qualitative evidence was obtained that the present combustor has substantially better slag retention that the prior Williamsport unit. In the prior unit, the ash deposited in the boiler furnace and convective tube floors contained considerable amount of coarser ash/char particles. After the recent March tests, the deposits in the boiler floor consisted of only very fine ash which indicates good combustion.

e) The slag tap's gas heaters and mechanical slag breaker, and the slag removal conveyor performed flawlessly. The present system contains an improved design for the heaters and breaker. It also has an improved design for the conveyor for removal of slag from the water filled slag quench tank which is located beneath the slag tap. The combustor tests in the present project require operation at high slag flow rates. Therefore, the proper performance of this sub-system of the combustor is critical.

6 tons of pulverized coal were delivered to the test site in early April, and more extensive coal fired tests are planned in April under the other DOE/PETC project. During these tests, samples of the slag will be analyzed for sulfur content. While these tests will not be performed under the conditions where high sulfur retention in the slag is anticipated, namely high ash throughput rates, they will provide indication of the effectiveness of the present combustor design in retaining sulfur.

It is anticipated that initial combustor tests in the present project will begin in May/June, as per the project's Program Plan. The Test Plan for the first group of tests will be finalized before these tests are undertaken.

Based on the initial results of the shakedown tests in the new combustor facility, it is anticipated that the test effort, analysis, and final report on the present project can be implemented within the scheduled 24 month duration of this project.

4. EFFORT OF THE NEXT QUARTER

Following the completion of the initial shakedown tests on the 20 MMBtu/hr combustor that are being performed under another DOE project in April/May 1996, the tests for the present project will be initiated in May/June 1996, as per the Program Plan. This schedule is based on prior approval by DOE of the Environmental Plan.