Project: " DEVELOPMENT & TESTING OF INDUSTRIAL SCALE , COAL FIRED COMBUSTION SYSTEM,PHASE 3"

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ABSTRACT

In the fourth quarter of calendar year 1996, 15 days of combust–boiler tests were performed, including 10 days of tests on a parallel DOE sponsored project on sulfur retention in a slagging combustor. Between tests, modifications and improvements that were indicated by these tests were implemented. This brings the total number of test days to the end of December in the task 5 effort to 57, increased to 65 as of the date of this Report, 1/27/97. This compares with a total of 63 test days needed to complete the task 5 test effort, and it completes the number of tests days required to meet the task 5 project plan. The key project objectives of the areas of combustor performance and environmental performance have been exceeded. With sorbent injection in the combustion gas train, NO_x emissions as low as 0.07 lb/MMBtu and SO_2 emissions as low as 0.2 lb/MMBtu have been measured in tests in this quarter. Work in the next quarter will focus on even greater reductions in environmental emissions. Also tests are planned with coals other than the Eastern US bituminous coals tested in this project. For example, it is planned to tests Indian coals whose ash concentration is in the 40% range.

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1. EXECUTIVE SUMMARY

In the fourth quarter of calendar year 1996, 15 days of combust–boiler tests were performed, including 10 days of tests on a parallel DOE sponsored project on sulfur retention in a slagging combustor. Between tests, modifications and improvements that were indicated by these tests were implemented. This brings the total number of test days to the end of December in the task 5 effort to 57, increased to 65 as of the date of this Report, 1/27/97. This compares with a total of 63 test days needed to complete the task 5 test effort, and it completes the number of tests days required to meet the task 5 project plan. The key objectives of this project in combustor operation and environmental performance have been met. However, to further the commercial potential of this technology further work in the next quarter will focus on even greater reductions in environmental emissions. Also tests are planned with coals other than the Eastern US bituminous coals tested in this project. For example, it is planned to tests Indian coals whose ash concentration is in the 40% range. Work in this area is currently in progress in the first quarter of calendar 1997. Results as of the date of this report are excellent and they will be reported in the next quarterly report.

The tests in the present reporting period continued the excellent slagging combustor performance experienced in the previous two quarters. 10 of the 15 tests days performed in this quarter were on the parallel sulfur control project and the results are reported in that projects quarterly technical report. The 10 tests on the other project focused on high slag flow conditions which are necessary for substantial sulfur retention in slag. The results contributed to the present project because high slag flow occurs in high ash coals of which extensive domestic supplies are available in a number of other countries, such as India. The five tests conducted in the present reporting period focused on several areas. One was to further improve the reliability of the slag tap. The other was to determine the processes by which slag blocking deposits in the exit nozzle of the combustor could be removed. Another was to operate the combustor under identical conditions in consecutive tests in order the evaluate the durability of the combustor internals. Finally, attention was directed toward further reducing the SO2 and NOx emissions in the combustor.

Two very important results were achieved in the area of emissions reduction. For the first time, SO2 stack emissions of 0.2 lb/MMBtu were measured with sorbent injection in a low sulfur, (<2%) coal. This is one of the goals of this Phase 3 project.

A second and even more important result was the observation for the first time that NOx emissions could be dramatically reduced by injection of a sorbent in the combustion gas flow train. In prior work in the 20 MMBtu/hr combustor in Williamsport with staged combustion, average NOx emissions were in the 0.45 lb/MMBtu range. To achieve this level required a combustor stoichiometric ratio{SR1) of 0.65. At this conditions carbon conversion was very poor, being in the range of 80%. In the present combustor, the comparable NOx emissions levels are apparently higher, most probably due to higher combustion efficiencies in the present unit. For example, in the test on December 19, 1996, under slightly fuel lean conditions, the stack NOx was in the range of 1 lb/MMBtu versus about 0.7 lb/MMBtu in the prior unit. Even under slightly fuel rich conditions, NOx ranged from 0.7 to 1.1 lb/MM versus 0.55 to 0.7 lb/MMBtu previously.

In the test of the 19th, sorbent injection was used for the first time in this project to reduce the NOx levels beyond the values attainable with fuel rich–fuel lean combustion. In this test, the NOx level was reduced by 50% or greater, to as low as 0.32 lb/MMBtu. This is within striking distance of the level of 0.2 lb/MMBtu that is one of the goals of this project. (Note: In tests in early January, 1997, NOx emission levels as low as 0.07 lb/MMBtu were measured. This will be reported in the next quarterly report.) In our opinion this results is a major advance for this combustor technology because NOx reduction has been one of the difficult goals to achieve in all the tests to date. This result was achieved three times during the test in that the NOx level decreased sharply each time with sorbent injection and returned to its original level when it was turned off.

The test effort will continue in the next quarterly reporting period with the focus on further reductions in NOx and SO2 emissions, and on combustor operation in very high ash (namely up to 40%) coals. The purpose of the latter tests is to evaluate the combustor's potential for overseas markets in areas having substantial deposits of very high ash coals.

2. RESULTS AND DISCUSSION

2.1. PROJECT DESCRIPTION

2.1.1. Objectives

The primary objective of the present Phase 3 effort is to perform the final testing, at a 20 MMBtu/hr commercial scale, of an air cooled, slagging coal combustor for application to industrial steam boilers and power plants. The focus of the test effort is on combustor durability, automatic control of the combustor's operation, and optimum environmental control of emissions inside the combustor. In connection with the latter, the goal is to achieve 0.4 lb/ MMBtu of SO_2 emissions, 0.2 lb./MMBtu of NO_x emissions, and 0.02 lb. particulates/MMBtu. To meet the particulate goal a baghouse will be used to augment the slag retention in the combustor. The NO_x emission goal will require a modest improvement over maximum reduction achieved to date in the first generation combustor to a level of 0.26 lb./MMBtu. In the present second generation combustor, the best NO_x levels with fuel rich conditions in the combustor was in the range of 0.3 to 0.4 lb/MMBtu. To reach the SO_2 emissions goal may require a combination of sorbent injection inside the combustor and sorbent injection inside the boiler, or stack.

The original plan was to meet the project objectives by a series of increasingly longer duration tests totaling up to 800 hours, with over 500 hours in the task 5 "Site Demonstration" effort. In the implementation of the first three project tasks, it was determined that this objective could met by daily cycling of the combustor in these three tasks, and by focusing the test effort on fuel flexibility and optimized combustion and environmental performance. Cycling without combustor refurbishment between cycles provides a more stringent test of combustor durability. In task 5, the steam output will be blown off. However, the option has been added to use the steam for process heat or steam turbine power generation if a means for generating revenue from this energy is developed during task 5. This last option will only be implemented after the completion of the required testing under the present project.

The final objective is to define suitable commercial power or steam generating systems to which the use of the air cooled combustor offers significant technical and economic benefits. In implementing this objective both simple steam generation and combined gas turbine–steam generation systems will be considered.

2.1.2. Technical Approach

2.1.2.1. Overview

The work of this Phase 3 project is being implemented on Coal Tech's patented, 20 MMBtu/hr, air cooled cyclone coal combustor that is installed on an oil designed, package boiler. The task 2 and task 3 testing were performed at a manufacturing plant in Williamsport, PA, where this combustor was installed in 1987. The task 5 tests are being implemented at a new site in Philadelphia, PA which was selected after the completion of the task 3 tests. The combustor has undergone development and demonstration testing since 1987. The primary fuel has been coal.

Other tests, including combustion of refuse derived fuels and vitrification of fly ash, have been successfully performed.

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 spent sorbent 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. Neither of the latter two procedures has been attempted in this project to date, but they may be required to meet the task 5 operating conditions at the site selected for this effort. Final combustion takes place in the boiler.

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 Phase 3 project, the peak SO_2 reduction achieved with sorbent injection in the combustor had been 56%, (+/–) 5%. Of this amount a maximum of 11% of the total coal sulfur was trapped in the slag. On the other hand, up to 81% SO_2 reduction has been measured with sorbent injection in the boiler immediately downstream of the combustor. Tests in the past several years have revealed the critical role played by optimum operating conditions in the SO_2 reduction process. Specifically, combustor operation must be automatically controlled, and solids feed and air–solids mixing in the combustor must be optimized. Progress in both areas has been accomplished in the past 5 years by using a microcomputer to control the combustion process and by testing various methods of feeding and mixing the coal and sorbents. In the summer of 1992, tests performed in a prior project indicated that in excess of 90% SO_2 reduction could be achieved by sorbent injection in the combustor. Recently this result has been duplicated in gas samples taken in the boiler furnace. However, the SO2 reduction in the stack for the same conditions were less, and no conclusive explanation for this has been as yet been found.

Combustor durability is an essential requirement for commercial utility of the combustor. Due to the aggressive nature of the combustion process and the need to utilize refractory materials inside the combustor to withstand the 3000F gas temperatures, durability has been one of the key challenges in the development process. Here also the use of computer control has been the means whereby this problem is being solved. Since introduction of computer control four years ago, the need for frequent refractory liner patching inside the combustor has been sharply reduced. The durability issue can be addressed by accumulating running time in daily cyclic operation without combustor refurbishment between runs. This approach has been used in the latter task 2 and task 3 effort. All tests between May 1 and December 2, 1993, consisting of 26 hours of operation in task

2 and 185 hours in task 3, have been performed without significant internal combustor refurbish–ment.

The final project objective of placing the combustor in a viable industrial steam or power generating system was accomplished by detailed engineering analysis on the use of the combustor in one or more steam generating cycles. This effort included an assessment of the requirements for commercializing the combustor for several industrial application. To assure commercialization of this technology, the final project task is being implemented in a system that duplicates a commercial prototype power plant utilizing the air cooled coal combustor technology.

2.1.2.2. Task Description

Task 1: Design, Fabricate, and Integrate Components

This task consists of components design, component fabrications, and components integration, and shakedown tests. The 20 MMBtu/hr combustor will be modified to allow safe and environmentally compliant operation for periods of up to 100 hours. This task is complete.

Task 2: Preliminary Systems Tests

The modified combustor system will undergo a series of one day parametric tests of total duration of up to 100 hours to validate the design changes introduced in task 1, and to accomplish the project objectives and goals. This task is complete.

Task 3. Proof of Concept Tests

The durability of the combustor will be determined in a series of tests of between 50 and 100 hours of accumulated operation with no combustor refurbishment between tests. The total test period will be up to 200 hours. This task is complete.

Task 4. Economic Evaluation & Commercialization Plan

The economics of one or at most two different industrial scale steam based cycles using the combustor will be evaluated. A commercialization plan will be developed for marketing the combustor in an industrial environment both in the US and overseas. This task is complete.

Task 5. Conduct Site Demonstration

This task will be the final test activity in the project. Its objective will be to demonstrate the durability and hence the commercial readiness of the combustor for its intended industrial application(s). The effort will consist of two sub–tasks. In the first one any changes required as a result of prior tests will be made to the combustor. In the second one, a series of tests, each of up to 100 hours of continuous coal fired operation will be performed, with a total test time of 500 hours. For a number of reasons, this effort is being implemented in single daily shift operation with minimal combustor refurbishment between tests. The 500 hours are thus equal to 63 days of single shift operation. As of the end of the present reporting period, 57 test days have been completed.

Task 6. Decommissioning Test Facility

The test facility will be removed from the boiler installation and disposed in accordance with required regulations.

2.3. PROJECT STATUS.

2.3.1. Task 5. Site Demonstration

The installation of the combustor–boiler facility at the Philadelphia site was completed at the end of 1995 and initial shakedown tests began in December 1995. In the first phase, it was planned to operate the first 16 days (nominally 100 hours) of the 63 days (nominally 500 hours) of the task 5 combustor tests with off–site pulverized coal. The final 400 hours were to be performed using the on site raw coal storage and pulverization system. However, an economic tradeoff analysis performed late in 1995 showed that using off site pulverized coal for the bulk of the task 5 tests was more cost effective if_a simple method of loading the off site pulverized coal into the existing 4 ton bin could be developed. An effective means for accomplishing this was tested in mid–1996. Coal is delivered in ten 1 ton supersacks from a processing plant in Western Pennsylvania. It is loaded into the 4 ton pulverized coal bin pneumatically from the supersacks using a procedure perfected during this quarter. As a result of this simple and low cost procedure, all the tests in task 5 were implemented with this method. Also, with the resources available to this project, it was not possible to perform round the clock combustor operation. Therefore, all the tests were performed in single day shifts. Thus the 500 hours are equal to 63 days of single shift operation. This procedure provides a more rigorous test of the combustor durability because the many start up and shutdowns place a greater stress on the combustor internals.

The bulk of the effort in the present quarter has been on focused on a parallel DOE project on sulfur capture and retention in the slag of the combustor. A total of 15 days of combustor operation were performed in this quarter, of which 10 test days were under a parallel project on sulfur control during combustion. The latter results are reported in that project's progress report. This brings the total number of test days to 57, increased to 65 as of the date of this Report, 1/27/97.

The 10 tests on the other project focused on high slag flow conditions which are necessary for substantial sulfur retention in slag. The results contributed to the present project because high slag flow occurs in high ash coals of which extensive domestic supplies are available in a number of other countries, such as India. The five tests conducted in the present reporting period focused on several areas. One was to further improve the reliability of the slag tap. The other was to determine the processes by which slag blocking deposits in the exit nozzle of the combustor could be removed. Another was to operate the combustor under identical conditions in consecutive tests in order the evaluate the durability of the combustor internals. Finally, attention was directed toward further reducing the SO2 and NOx emissions in the combustor.

<u>2.3.1.1. Combustor–Boiler Tests</u>:

<u>*Slag Tap and Combustor Exit Nozzle Performance:*</u> Maintaining an open slag tap inside the combustor is critical to its operation, and this has been one of the development items in this project. In the present reporting period, the tests on the parallel project involved injection of calcium hydrate, limestone, and an "artificial" ash consisting of a mixture of alumina and silica powder mixed with either calcium sulfate or calcium hydrate powder. Considerably difficulties

were experienced during the injection of these minerals in satisfying the conflicting requirements of high slag temperatures for draining the slag from the combustor and preventing frozen slag from blocking the exit nozzle versus the need to keep the combustor's refractory liner cool enough to prevent significant refractory loss.

To improve the slag tap operation, the thermal heat input to the slag tap was increased and this greatly improved the reliability of the slag tap operation in all the tests in this quarter.

To address the exit nozzle blockage, one test was performed on this project on November 15th in which metal oxide powder was injected into the combustor to simulate high slag flow rates. The injection of this material exacerbated the problem of exit nozzle blockage with frozen slag deposits. The latter blocked most of the nozzle to the point that combustion gases escaped from the combustor into the slag tank. A mechanical breaker, developed in the Williamsport combustor, was used to clear the exit nozzle during combustor operation during this test. It was assumed that the coal used had a high ash melting point. However, subsequent analysis of the ash revealed that the ash composition did not differ substantially from the other coals used in the test effort.

To further explore the exit nozzle blockage three tests were performed on December 10, 12, and 17. The results indicated that the exit nozzle blockage was partly a function of the thermal input to the combustor, and by increasing the thermal input it was possible to remelt frozen slag in the exit nozzle.

Another objective of these tests was to operate the combustor regularly at one set of conditions. This would provide a data base on repeatability of the combustor's performance characteristics. Accordingly, the tests were performed with only coal injection and limestone injection into the combustor. Calcium hydrate was injected only for brief periods. The combustor's performance was excellent in all three tests, and no emergency shutdowns were required.

NO_x Emission Control: The objective of the fourth December test on the 19th was additional NOx emission control beyond that obtainable with fuel rich combustion in the combustor. Figure 1 shows the average NO_x levels measured at the stack in the prior 20 MMBtu/hr combustor in Williamsport. Note that to achieve 0.45 required a combustor stoichiometric ratio{SR1) of 0.65. At this conditions carbon conversion was very poor, being in the range of 80%. In the present combustor, the comparable NO_x emissions levels are apparently higher, most probably due to higher combustion efficiencies in the present unit. For example, in the test on the 19th, under slightly fuel lean conditions, the stack NO_x was in the range of 1 lb/MMBtu versus about 0.7 lb/MMBtu in the prior unit. Even under slightly fuel rich conditions, NOx ranged from 0.7 to 1.1 lb/MM versus 0.55 to 0.7 lb/MMBtu previously.

In the test of the 19th, sorbent injection was used to reduce the NO_x levels beyond the values attainable with fuel rich–fuel lean combustion. In the test the NO_x level was reduced by 50% or greater, to as low as 0.32 lb/MMBtu. This is within striking distance of the level of 0.2 lb/MMBtu that is one of the goals of this project. (Note: In tests in early January 1997, further reductions in the NO_x level to as low as 0.07 lb/MMBtu were measured. Details will be reported in the next quarterly report.) This result is a major advance in this project because NO_x reduction has been one of the difficult goals to achieve in all the tests to date. This result was achieved three times during the test of the 19th in that the NO_x level decreased sharply each time with sorbent injection and returned to its original level when it was turned off.

Based on the SO_2 measurements in the boiler, the SO_2 emission levels were as low as 0.2 lb/MMBtu in several test conditions. This result was achieved in coal having sulfur content between 1.3% and 2%.

2.3. Effort of the Next Quarter

The task 5 demonstration test effort will continue in the next quarter. The focus of the tests will continue to be on optimizing the combustor's combustion efficiency and environmental performance, with emphasis of further NO_x and SO_2 reduction.

In addition, testing on very high (40%) ash Indian coals will be implemented.

Efforts will be continue on finding joint venture partners, and/or licensees to market this coal fired combustion–steam generation technology worldwide in the 1 to 20 MWe output range. The results confirm that this technology is most probably the lowest cost coal fired system on the market.

3. CONCLUSIONS

The total of 57 test days completed in task 5 by the end of this quarter without any significant refurbishment of the combustor indicates that the combustor is nearing commercial readiness. The modifications and maintenance performed are relatively minor in nature. An indication of the excellent performance of this combustor is that in a three week period in January 1997 a total of 8 days of combustor operation were implemented. Furthermore, the bulk of the tests in the past several months have been implemented with only two operators. This compares with an average of 5 operators used in the earlier tasks in the project in the first generation combustor tests in Williamsport, PA.

A most significant new result in this quarter has been the observation for the first time of major NO_x reduction with sorbent injection in the combustion gas flow train to levels that meet the emission goals of this project. These results have been confirmed in a series of tests and they represent a major advance in the operation of the slagging combustor under stringent environmental control conditions.

Figure 1: Stack NOx vs Combustor Stoichiometry–
20 MMBtu/hr Williamsport Air Cooled Slagging Combustor