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COAL FIRED COMBUSTION SYSTEM,PHASE 3"

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## 1. SUMMARY

The effort of the first quarter of calendar year 1995 focused on task 5, "Site Demonstration". The task 5 effort involves testing the combustor over extended periods under conditions that fully simulate commercial operation and that meet the combustion and environmental specifications for this project. To meet this project objective within the current work scope requires 500 hours of testing. Operation beyond this period is dependent on recovering the added costs by placing the steam production from the boiler to beneficial use. During the present quarterly reporting period, all the major components needed to implement the initial 100 hours of testing under task 5 were delivered to the test site, the necessary modifications to the test site were completed, and installation of several of the major components was initiated.

The previous quarterly report for the period ending December 31, 1994, was submitted in mid-February 1995. It contains the progress made to the end of January 1995. The present report is a summary of the activities in February and March 1995. Details are given in Section 3.

The primary activities during these two months was to monitor the fabricator of the combustor extension in order to assure completion of the work according to the design, to procure the additional components needed to install the combustor-boiler system at the Arsenal test site, and on initial installation of auxiliary components at the site.

Welding of the combustor extension major sections began in mid-January. However, the quality of the welds was poor and a number of non-critical flanges were warped during welding. As a result the fabricator replaced the welders and the quality assurance personnel in early February. To assure that the welded sections would properly mate with the existing combustor, Coal Tech personnel regularly visited the fabricator until the end of March. The combustor extension section was completed and delivered to the Arsenal at the end of March, three months behind the promised delivery date. A number of discrepancies between the drawing and fabricated parts were noted. Almost all of them were the result of inadequate quality control or poor welding. However, the critical mating flanges between the original and extension sections of the combustor were found to fit properly during check assembly at the Arsenal test site in late March..

The only significant deviation from design in the fabricated extension section was a slightly enlarged exit nozzle diameter. This was due to a discrepancy between the cooling section detail drawing and the assembly section draing which was not noticed until the pipe sections had already been cut. Based on a fluid mechanical analysis, this change in the exit nozzle dimensions should not result in a significant change in combustor performance.

To meet the Philadelphia particulate emission standard of 0.06 lb/MMBtu a baghouse was procured in February. It was delivered and placed in the newly paved allay adjacent to the building at the end of March. Competitive procurement of the stack ducting from the boiler to the baghouse and to the atmosphere was initiated. Pneumatically controlled valves for the combustor extension section's air cooling sub-system were ordered and delivered.

Work on other parts of the installation was implemented in parallel with the above effort. A new approach, which will be used in future commercial installations, namely, modular assembly of each sub-system is being used for the present installation. This will greatly reduce the installation time and cost. For example, the propane pilot gas assembly which preheats the combustor was reinstalled in a much simplified configuration compared to the one used in Williamsport. The oil burner sub-system was reassembled as before. The various air flows from the combustion air fans, blower air flows, and compressor air flows, were redesigned in order to simplify the installation. The cooling water piping was also redesigned, as was the electric power sub-system to these components. As a result the power consumption was lowered by 33% from over 180 kW to a little over 130 kW. The local utility's power rates under the planned operating conditions can reach 23 cents/kW-hr. Therefore, this will result in a major saving in power costs.

The design of the coal and sorbent feed systems was simplified in a manner that reduced the power consumption and the pneumatic ducting. Also, work began on a simplified raw coal delivery, storage and pulverization system with the aim of reducing the cost of this sub-system by at least 50% from the cost of the original system designed in mid-1994. The latter had twice the storage capacity of the newly proposed system, and it was capable of operation under all weather conditions. The new, simplified system will be loaded only in dry weather conditions.

As reported in the 12th Quarterly Report, the installation and operating plan has been revised at the beginning of this year in a manner that will optimize project objectives with available resources. In the new plan the combustor, boiler and the auxiliary components will be installed and operated for the first 100 hours of task 5 as in Williamsport with off site pulverization of the coal. The pulverized coal tanker will be leased for the one week periods of each group of tests in the first 100 hours of operation. Also, instead of condensing the steam, it will be blown off, as before. In this initial phase all the key items related to the modified combustor and boiler operation, including combustion and environmental performance, will be resolved. Following successful conclusion of this effort, the raw coal handling system will be installed and used for the remaining 400 hours of the required task 5 test period. Depending on the nature of the revenues attainable with operation of the power system, a steam turbine, steam condenser, and cooling tower will be acquired and installed for subsequent testing.

Due to the delay in delivery of the combustor extension, the installation period for the equipment needed to implement the initial task 5 test phase extend through the second quarter of 1995. However, the benefit of this effort is that the new installation is substantially simpler, less costly, and suitable as a prototype for commercial modular power systems based on the air cooled slagging combustor. In the original project plan, the task 5 testing was to be implemented in Williamsport with only modest modifications to the combustor.

## **2. PROJECT DESCRIPTION**

### **2.1. 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<sub>2</sub> emissions, 0.2 lb./MMBtu of NO<sub>x</sub> emissions, and 0.02 lb. particulates/MMBtu. Meeting the particulate goal will require the use of a baghouse to augment the nominal slag retention in the combustor. The NO<sub>x</sub> emission goal will require a modest improvement over maximum reduction achieved to date in the combustor to a level of 0.26 lb./MMBtu. To reach the SO<sub>2</sub> emissions goal may require a combination of sorbent injection inside the combustor and sorbent injection inside the boiler, especially in high (>3.5%) sulfur coals. Prior to the initiation of this project in 1992, SO<sub>2</sub> levels as low as 0.6 lb./MMBtu, equal to 81% reduction in 2% sulfur coals, were measured with boiler injection of calcium hydrate.

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.

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.

### **2.2. Technical Approach**

#### **2.2.1. Overview**

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 installed on an oil designed, package boiler. The task 2 and task 3 testing will be performed at a manufacturing plant in Williamsport, PA, where this combustor was installed in 1987. The task 5 tests will be 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<sub>2</sub>, NO<sub>x</sub>, 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<sub>2</sub> 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<sub>x</sub> 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.

As described in Section 2.1. 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<sub>2</sub> reduction in the combustor. Prior to the start of the present Phase 3 project, the peak SO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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 4 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<sub>2</sub> reduction could be achieved by sorbent injection in the combustor. However, to date this result has not been duplicated, in part due to focus on other areas of combustor testing. In general, 70% SO<sub>2</sub> reduction has consistently obtained in tasks 2 and 3 at Ca/S ratios between 3 and 4.

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 refurbishment.

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

### 2.2.2. Task Description

#### Task 1: Design, Fabricate, and Integrate Components

This task consists of three sub-tasks: 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.

#### 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.

#### 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.

#### 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.

#### 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.

#### Task 6. Decommissioning Test Facility

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

### 3. PROJECT STATUS.

#### 3.1. Task 5. Site Demonstration

##### 3.1.1. Task 5 Test Site Modifications

As reported previously, the task 5 test site is a 3000 square foot building (No. 238) in the Arsenal Business Center, 2275 Bridge Street, Philadelphia, PA 19137. As reported in the 12th Quarterly Report, on January 18 and 19, 1995, the 17,500 lb/hr boiler and all the combustor and auxiliary equipment were moved from Williamsport, PA to the Arsenal. and installed on a specially designed support structure. At the same time, the 4 ton coal bin was reinstalled in the newly paved alley.

##### 3.1.4. Installation of Auxiliary Equipment

Propane Pilot Burner: The pilot gas burner and slag tap auxiliary burner were fired with natural gas in Williamsport. As reported previously, in the present site the fuel will be propane drawn from the 2000 gallon propane tank located next to the building. The piping, valves, controls, and diagnostics for the new installation were simplified and installed on a support structure that allows its removal for maintenance work on the combustor. The piping from the propane tank to this structure was installed. The only remaining work is to connect the assembly to the burners. This will be done after the combustor is installed on the combustor support structure.

Oil Burner: The oil burner assembly was installed on a separate support structure. The remaining work is to procure a 500 gallon tank, an oil pump, and to connect the assembly to the oil burner after the combustor is installed.

Electric Power & Diesel Generator: In the previous quarter it was reported that a used 200 kW diesel generator would be procured to operate the combustor's auxiliary sub-systems. In the present quarter a detailed review of all the power requirements was made. This included evaluating the power needs of the fans, blowers, compressors, solids feeders, etc. It was determined that much of the air supply could be rearranged in a manner that would reduce the power requirements, especially the compressed air and blower requirements. In Williamsport access to a large compressed air source used by the factory resulted in operating all air sources other than the fans from the compressed air lines. For example, one air cooling line which requires only 2 psi was operated from the compressed air line in Williamsport. In the current design, the 2 psig air will be supplied by one of the fans.

Another improvement was to integrate all the coal and sorbent pneumatic feed lines. This also reduces the compressed air requirements. Finally, the sequencing of the various operational events such as heatup and steady state coal firing was modified to minimize power needs. The shift from a wet stack particle scrubber to a baghouse reduces the stack fan power. The rearrangement of the combustion air and combustor air cooling also reduced the power. However,

the addition of the combustor extension section increased the power requirements as an additional fan is required to drive this section.

The net result of this effort was that the total power needed was reduced from over 180 kW to 137 kW. The building is presently supplied with a 480 Volts, 200 Amp., 3 phase safety power source. This yields 141 kW with a 85% power factor. Normally a margin of 20% is desired from a power source, which would indicate a reduction to 112 kW. While as much as 1000 kW of power is available from a sub-station across the street for the test building, running an underground power line is not cost effective. To provide this margin it is planned to lease a 25 hp oil fired compressor which will reduce the power needs to 118 kW which should be adequate for the existing power source.

As part of the simplified installation a central safety switch and motor control center was assembled. The additional switches and controllers needed for the modified installation were procured and installed.

The above discussion excludes the raw coal delivery, storage, and pulverization system. As stated above, this system will be installed for the remaining 400 hours of the task 5 tests. By that time, the current air cooling system will have been tested in the first 100 hours. Using this data it is planned to modify the high pressure air cooling fan to reduce its power use. On the other hand, the coal mill and the fan to operate mill will increase the power needs. It is estimated that this will increase the power needs from 137 kW to 154 kW. This will clearly exceed the 141 kW available from the existing power center in the building. The most probable solution will be to lease or purchase a small diesel electric generator to provide the added power. Alternatively, if the revenue generation effort is successful, then a used diesel generator rated at 175 to 200 kW will be procured. An air quality permit for its operation in the City of Philadelphia has already been obtained.

Boiler Installation: The two 6 inch steam outlet valves and the two 2 inch boiler blowdown valves were completely refurbished. One of the 6 inch valves was replaced with a rebuilt valves as the original valve was damaged beyond repair. Also, the two 2 inch steam safety valves are damaged beyond repair and will be replaced with new valves. Arrangements have been made to connect the water and steam blowoff lines for the boiler in May. As reported previously, the boiler will operate at 15 psi to eliminate the need for a boiler operator. If future operation with a steam turbine is implemented, one of the technicians or engineers will be licensed as an operator.

Appearance: Since this will be a prototype commercial plant, considerable attention is being paid to appearance. All metal parts of the boiler, combustor, combustor supports, ducting, piping, fans, bins are being painted with rust resistance paint.

Water System: Heat exchangers have been procured for the water cooled sections of the combustor and for the slag cooling water tank. This will allow isolating the slag cooling water and combustor cooling circuit from the cooling water discharge to the sanitary system. This has the advantage that additives can be introduced into the cooling circuits without continuous monitoring of the discharge. The cooling water will be integrated with the boiler feedwater which will be

operated initially in a once through mode with steam blowoff. It is planned to use the municipal water supply or an underground water source to this purpose. The piping for both sources has been connected to the inside of the building.

*Combustor Extension and Exit Nozzle:* The fabrication of the extension to the combustor and a new exit nozzle was finally completed in this quarter. The promised completion date was originally December 31, 1994. By the end of January, it became very clear that a major problem existed with the welding and with the quality control. Several of the small flanges on the combustor were warped, and we were concerned that the main flanges which connect to the other combustor components would be warped and not fit to the existing sections. Accordingly, we made provisions to remove the entire work and to hire another firm to weld these sections in February. However, in February, the fabricator's management replaced the welders, quality assurance, and foreman personnel. This substantially improved progress. Nevertheless, we increased our monitoring of the work with an average of twice weekly visits to the shop. The extension section was finally completed and delivered at the end of March.

A fork lift and operator were hired to check the fit between the extension section and the original combustor section. This was accomplished by lifting the extension section axis in a vertical and placing it on the original section. The circumferential and axial alignment were verified to be correct. This was a critical step because any misalignment would have required refabrication of the extension section.

A quality check of the work against the design drawings showed several deviations. As noted several of the access flanges were warped in welding by the original welders. However, all these flanges are sealed with gaskets and the warpage does not appear to be sufficient to prevent their use. For example, the flange that connects the combustor to the front wall of the boiler is warped. However, use of a thicker flat gasket combined with the very low differential gas pressure across this flange should yield a satisfactory seal. Similarly, the air outlet plenum chamber, the air outlet flange, the slag tap outlet flange, and a probe access flange were warped to various degrees. These deviations it should not affect gas tight sealing in suitable gaskets are used.

During preparation for installing the refractory liner in the combustor, the extension section was turned upside down, and it was discovered that the inner weld ring to the air inlet plenum chamber was not welded. This was not noted during the check assemble several weeks earlier because the missing weld was located at the inside bottom of the section. A welder has been retained to complete this weld at the Arsenal site. In addition, two dozen half couplings for probe insertion in the combustor shell were missing. These will also be welded at the Arsenal. In addition, several small deviations which are attributable to carelessness were found. These can also be corrected without rebuilding the extension section.

There was one deviation that was the result of the failure of the checker of the design drawings to note a discrepancy between the detail and assembly drawings of the exit nozzle assembly. As a result, the exist nozzle inner diameter is larger than the value used in the Williams-port installation. Examination of the literature on cyclonic flows indicates that this should not change the combustor's particle retention significantly. Also, the wall heat transfer analysis of this

section indicates that this deviation will not significantly affect the wall cooling. The larger inner diameter simplifies personnel access for maintenance of the inner refractory wall of the combustor.

It is to be noted that in the past two decades there has been a major decrease in qualified fabrication and machine shops in this region. Coal Tech solicited 9 bids within a 200 miles radius of Philadelphia and only three bids were received. The fabricator that was selected was one of the two low bidders. The third bidder's price was two-thirds higher. Both low bidders appeared to have the same qualifications. The selected fabricator was located within 20 miles of Coal Tech's offices, while the other low bidder was 80 miles, or a two hour drive, away. The fabricator of the previous section of the combustor, was also a two-hour-drive-away. In that case we only had to visit his site less than one-half dozen times during the entire fabrication process, and only one minor discrepancy was noted in the final product. That Company, which is no longer in that business, had a substantial in house technical staff to support the fabrication effort. In the future, Coal Tech will exercise more care in selecting fabricators and greater control of all steps of the fabrication process.

Coal Storage, Pulverization, and Fuel Feed: All quotations for a 25 tons raw coal storage, raw coal delivery, and refurbishment of the used loaned coal mill were obtained. However, the total cost is excessive for the resources remaining in the project. Also, this was not a planned element of the original task 5 effort in Williamsport. Accordingly, it was decided to revise the raw coal system to reduce the storage capacity to 12 tons. In addition, the original plan to allow all weather operation which requires enclosing the coal storage bin will be eliminated. These changes should reduce the cost of the coal system by at least 50%, and possibly much more if used components can be located. The decision on this system will be made in the next quarter.

Refractory Installation. A key issue in the reinstallation of the combustor is the selection of the refractory for the combustor's air cooled liner and its method of installation. A considerable effort was devoted to this matter which included analysis of the combustor's wall heat transfer based on the previous operational data in Williamsport. The analysis indicated that a mixture of metal oxides having a thermal conductivity that matched the anticipated wall heat transfer would be preferred. Accordingly a brief set of thermal conductivity tests of several mixtures of metal oxides were performed in a laboratory furnace. The results showed that qualitatively the effective conductivity was proportional to the relative concentration of each component in the mixture. It was subsequently determined that the desired mixture could be purchased commercially. However, the thermal conductivity of this mixture was a function of the method of preparing and installing the refractory in the combustor. In addition, no information could be obtained on the slag resistance of the mixture. Coupons of the refractory were prepared for exposure to coal ash. However, the abovenoted test furnace could not reach a high enough temperature to melt the ash, and this test has not been implemented.

In view of the uncertain effect of refractory installation on the properties of a ceramic mixture and in view of the lack of data on slag resistance, it was decided to use a single oxide refractory. Also, while chrome oxide mixed in the refractory provided good slag resistance, it was decided not to use this material due to potential disposal difficulties.

Two bidders were invited to quote on the installation of the refractory liner at the Arsenal tests site. The difference between the two bids was so great that it was decided to use the low bidder for installation and to have this bidder work with the on site Coal Tech personnel during the installation process. Coal Tech personnel will be responsible for preparing the combustor sections for the refractory installation and for high temperature curing of the refractory liner. It is anticipated that this work will be complete by early May. This will be followed by installation of the combustor on its support stand and boiler at the Arsenal.

### 3.2. Internal Use of Energy Generated by the 20 MMBtu/hr Combustor

As noted previously, it is planned to use the combustor's energy to generate electricity for melting metal scrap. To this end a pilot scale metal melting system of proprietary design was fabricated with Coal Tech resources and it is now in the initial assembly stage. If successful, a melter capable of using about one half of the power output of the boiler will be fabricated and placed in operation.

### **4. Effort of the Next Quarter**

The focus of the next quarter will be install the combustor and its auxiliary components in order to implement a 100 hour shakedown test by mid-year. The primary focus will be on installing the combustor on the boiler, connecting the combustor to its air, fuel, and slag rejection components, and installing the power and control elements. As part of the latter the combustor controls that were operated with relays in the past will now be operated with programmable control logic circuits