Catalytic Combustor for Fuel-Flexible Turbine

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ABSTRACT

Under the sponsorship of the U. S. Department of Energy's National Energy Technology Laboratory, Siemens Westinghouse is conducting a three-year program to develop an ultra low NOx, fuel flexible catalytic combustor for gas turbine application in IGCC. The program is defined in three phases: Phase 1- Implementation Plan, Phase 2- Validation Testing and Phase 3 – Field Testing. The Phase 1 program has been completed. Phase II is scheduled to start in October 2004.

In IGCC power plants, the gas turbine must be capable of operating on syngas as a primary fuel and an available back-up fuel such as natural gas. In this program the Rich Catalytic Lean (RCL™) technology is being developed as an ultra low NOx combustor. In this concept, ultra low NOx is achieved by stabilizing a lean premix combustion process by using a catalytic reactor to react part of the fuel, increasing the fuel/air mixture temperature.

In Phase 1, the feasibility of the catalytic concept for syngas application has been evaluated and the key technology issues identified. In Phase II the catalytic concept will be demonstrated through subscale testing.

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EXECUTIVE SUMMARY

The Rich Catalytic Lean (RCL ^{TM}) technology, Figure 1, is being developed as an ultra low NOx gas turbine combustor for Integrated Gasification Combined Cycle (IGCC). In this concept, ultra low NOx is achieved by stabilizing a lean premix combustion process by using a catalytic reactor that produces a nominal gas temperature increase in the fuel/air mixture (by converting part of the fuel).

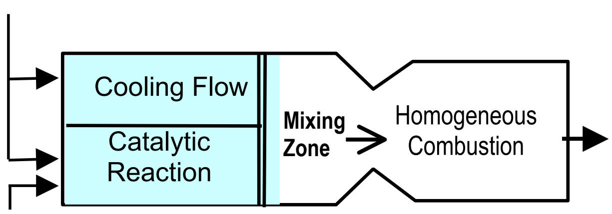

Figure 1 – SWPC Catalytic Stabilized Combustor

A key challenge in developing a fuel flexible catalytic combustor is the ability to provide one base design that will accommodate the different process flow conditions that are indicative of different IGCC plant designs. Cold Vs hot gas cleaning, degree that the gas turbine is integrated with the IGCC plant and how the plant might be optimized for efficiency Vs power output all impact the process flows that must be managed within the combustor. In Phase 1, the feasibility of the concept for syngas applications was evaluated, benchmarked and a validation test program (Phase 2) is defined. Specifically,

Catalytic module and combustor design concepts are defined for fuel flexible operation that minimize changes to the current catalytic reactor design, thus retaining the product of prior engineering and development. The proposed module design options are summarized in Table 1. In Phase 2 these design options will be developed, tested and evaluated,

Table 1 – Summary of Catalytic Combustor Design Options for IGCC

Concept Approach	Syngas Operation	Natural Gas Operation
No change to the current catalytic module design.	Options include staging or bypassing syngas and nitrogen to increase fuel conversion on the reactant side.	No impact
No change to the current catalytic	Syngas air split can be optimized but will require	No impact

module design. Utilize an eductor to control air split.	higher syngas pressure to drive the eductor.	
Modify current catalytic module for syngas.	Can be optimized for syngas conversion.	Requires device to control air split during natural gas operation.

During Phase II these concepts will be developed and tested. The catalytic combustor and module product definition will be further developed for the IGCC W501FD engine application. The focus will be on improvements required for syngas and the higher firing temperature of the W501FD engine. This phase of the project was a transitional period toward the Phase II. The primary focus during this period was the development of the test facilities required to validate the design. The program relies on subscale testing to validate the technology before moving to full scale tests in a combustor basket. The facilities used in this program are the single tube rig for coatings development and durability studies, sixty tube rig for flashback studies and module design validation, full scale module test facility for development of catalytic modules and the full scale basket facility.

EXPERIMENTAL

The validation plan for the catalytic combustor on syngas and natural gas uses a combination of subscale and full scale laboratory facilities. To reduce cost and risks when developing a catalytic design capable of syngas operation, this program uses a stepped approach to evaluate new technologies. New reactor design concepts are evaluated at the subscale module level then full scale module and finally at the full basket level. New coatings are evaluated on a single tube before they are applied to the full scale module or basket. Four testing facilities are used in this program. These facilities and their purposes are described below.

Single Tube Facility

The single tube facility enables testing of catalytic coatings under various fuels and fuel air splits. Figure 2 shows a picture of the single tube facility. In this facility a single coated tube is tested at full 501FD engine conditions. The rig is designed to simulate the pressure, temperature and velocity of the flow streams at the inner and outer tube surface. The cooling air inside the tubes and the air to the rich reaction section outside the tube is independently controlled so variations in air split can be investigated. This facility will be used to screen catalytic coatings for lightoff and fuel conversion for syngas and natural gas. It will also be used for coating durability testing. During this contract period the single tube test facility was relocated from STC Pittsburgh to the Casselberry Laboratory in Florida.

Figure 2 Single Tube Test Facility

Sixty tube facility

The sixty tube facility enables testing a small scale catalytic modules. This facility will be used for flashback testing, reactor design studies and coating durability. The sixty tube rig is roughly a 1/6 scale model of the catalytic module. This facility is capable of producing flow rate temperature and pressure required to simulate full W501FD conditions. Figures 3 and 4 show the basic layout of the sixty tube rig. This facility consists of a backside cooled reaction zone, a 60 tube catalytic reactor module (roughly 1/6 full scale) and a manifolding system to distribute the fuel in the rich region and control the spilt between the reaction air and the cooling air. During this project period the reactor section of the sixty tube rig was redesigned to make it more representative of a full scale module. The old reactor design was a circular tube bundle, the new design will have the same trapaziodal shape as the full scale module. Three reactor designs have been developed for this rig. They include the standard flared tube design, the tube with capture plate design and an alternative to the tube design. During this period the single tube facility was relocated from STC Pittsburgh to Casselberry Laboratory in Florida.

The sixty tube facility is a cost effective way of evaluating new reactor design concepts for syngas. Because of the high flame speed of hydrogen, it is expected that syngas will be more prone to flashback than natural gas. With the 60 tube rig the flashback potential of the catalytic reactor and the down stream mixing section can be evaluated. Design changes to eliminate flashback can be tested. New staging option for syngas can be evaluated first in this facility. New and novel reactor designs will be evaluated first in this subscale rig before full scale testing is performed.

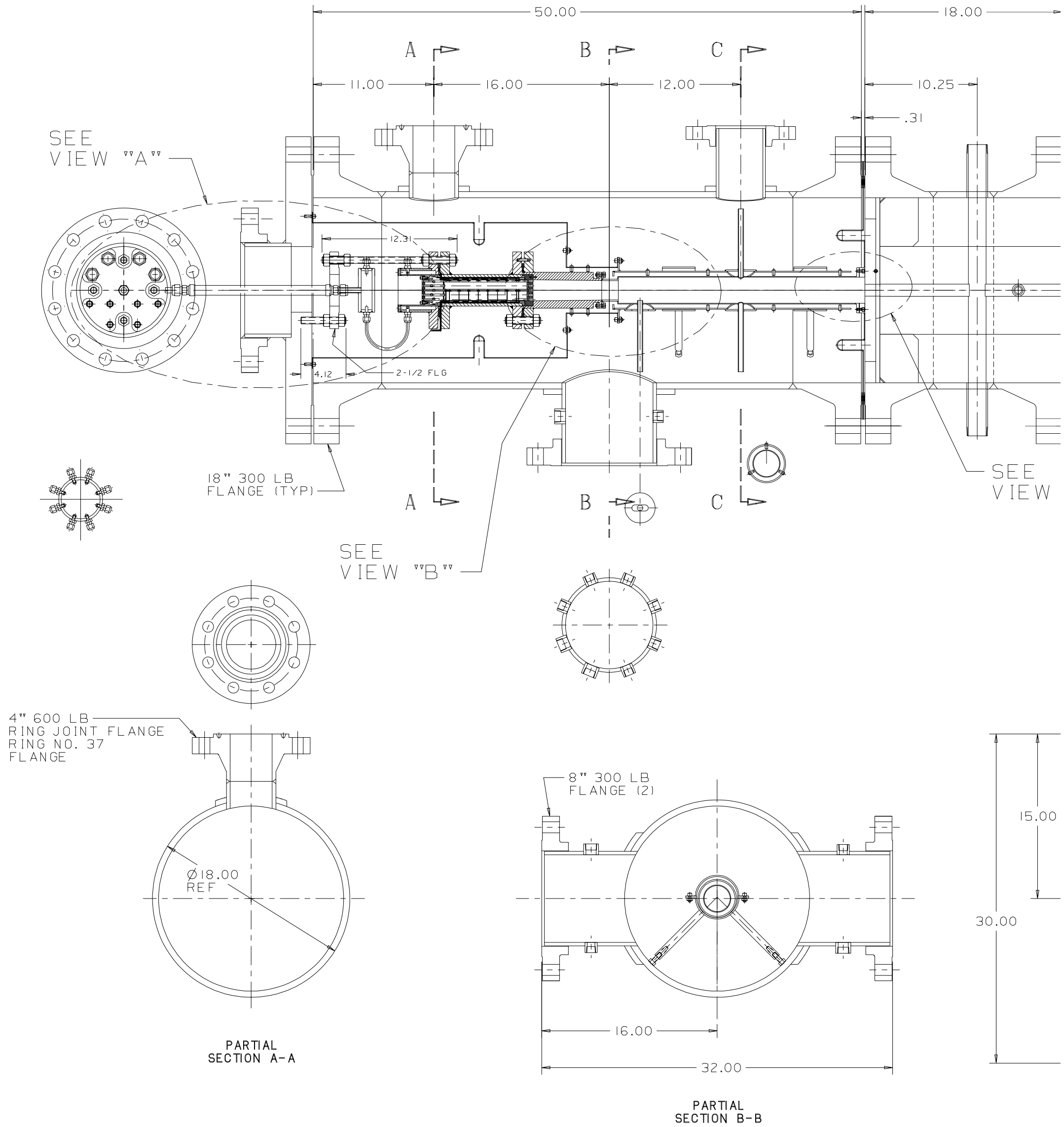

Figure 3 Sixty Tube Subscale Rig

Figure 4 Sixty Tube Test Facility

Full Scale Module Test Facility

The Siemens design for the catalytic basket consists of 6 catalytic modules grouped around a central pilot (US Patent # 6,415,608). After the design has been verified for syngas in the sixty tube rig, full scale modules will be tested at 501FD temperature pressure and flow conditions using both natural gas and syngas fuels. The module test facility is shown in Figure 5. This modules are attached to a backside cooled test section. The module test facility requires a compressor capable of producing 7 lb/sec air flow at 240 psia pressure. In order to meet the flow requirements of this rig, Siemens relies on an outside contractor for test support. The test section shown in Figure 5 is owned by Siemens and is installed in the test facility. Figure 6 shows the module test setup as installed at the Solar Turbine Laboratory in San Diego, California. Currently Siemens is evaluating options for location of future module tests. The requirements are the ability to provide full 501FD air flow conditions and provide the required fuel flows for natural gas and syngas.

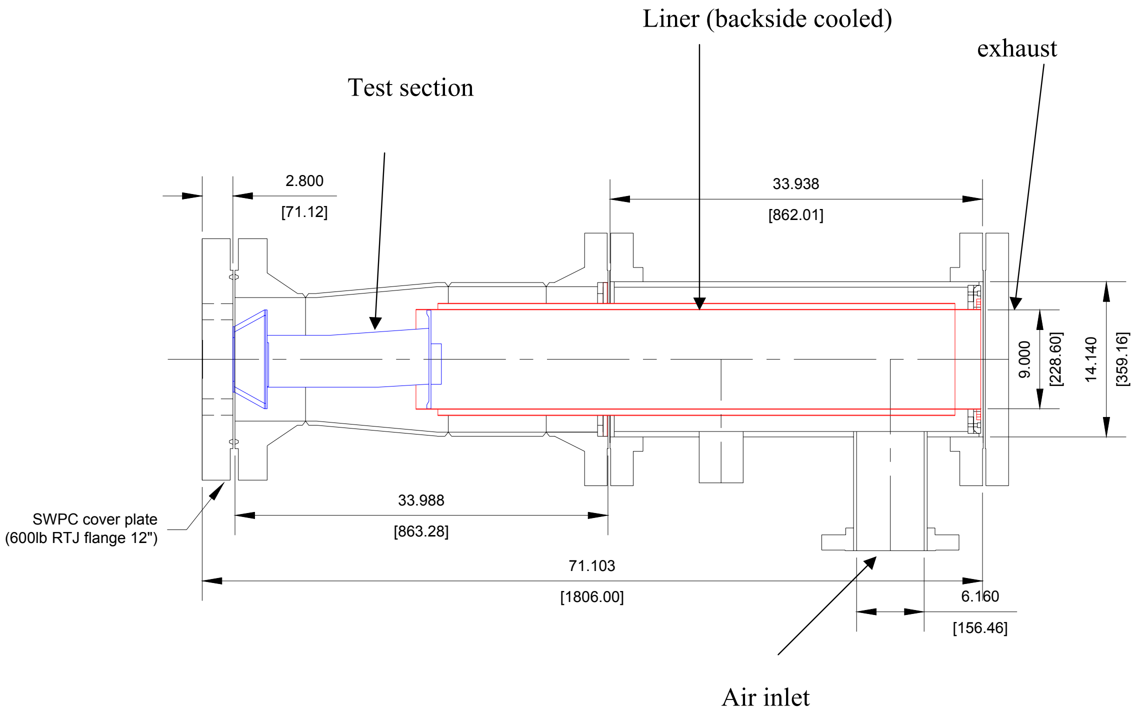

Figure 5 Module Test Rig

Figure 6 Module Test Rig as Installed at Solar Turbines Test Facility

ENEL Basket Facility

Siemens uses the ENEL test facility in Italy for full scale combustor basket testing. This facility can produce the required pressure, temperature and flows to simulate 501FD conditions in a single basket. This facility has the capabilities to provide both natural gas and syngas fuel at base load 501FD conditions. Siemens has a rig which simulates the geometry of the engine casing for a single basket in the 501F frame. Figure 7 shows the 501FD test rig.

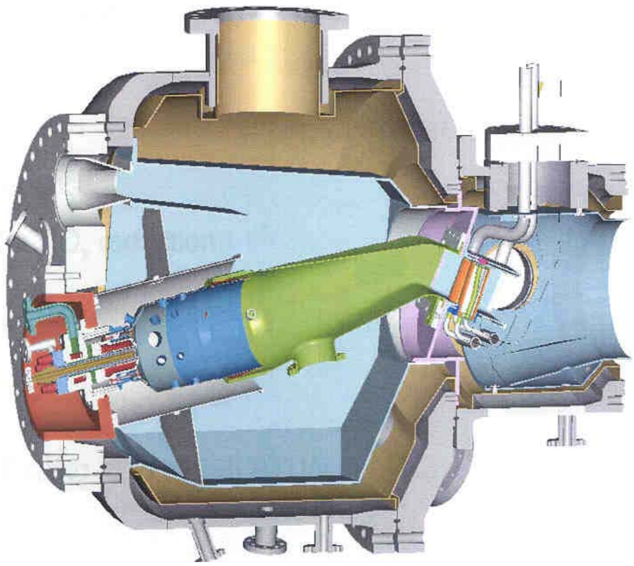

Figure 7 – Combustor basket test facility

Siemens has performed full basket testing on a catalytic basket designed for the 501D5 engine. This design produced NOx emissions in the range of 2 – 3 ppm NOx at 501D5 conditions. The main limitations of the design were CO burnout due to the short length of the basket and relatively low firing temperature of the 501D5 engine. The 501D5 basket used for this testing is shown in Figure 8. The next planed test at ENEL will be in spring 2005. For this test the basket designed and built for the 501D5 program will be modified to the 501FD design and tested with natural gas to verify the basket capability and that emission targets are reasonable. Modifications to the 501FD design include lengthening the burnout region, relocation of the module fuel supply tubes, redesign of the basket head end. A new cover plate has been designed for the rig to enable testing of the catalytic basket. The completed design of the 501FD version of the catalytic basket is shown in Figure 9. The 501FD engine runs at a firing temperature of roughly 300 F higher than the 501D5. Basket testing will verify the emission capabilities of the design at the higher firing temperatures. Testing during the 501D5 program indicated that increasing in firing temperature did not produce a significant adverse effect on NOx emissions. The higher firing temperature improved the CO burnout and flame stability. Syngas testing on the basket will proceed after the design has been verified through subscale testing.

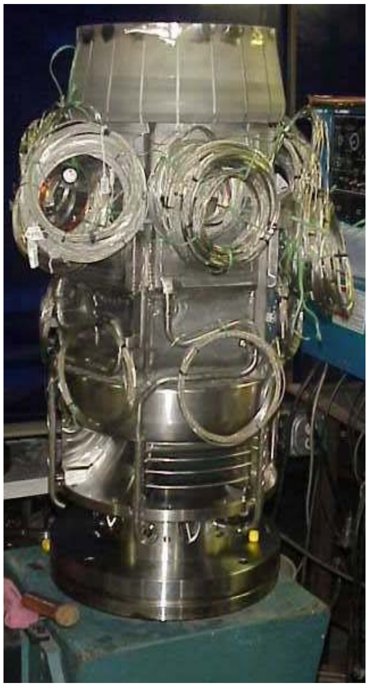

Figure 8 Catalytic Combustor Basket for the 501D5 Engine

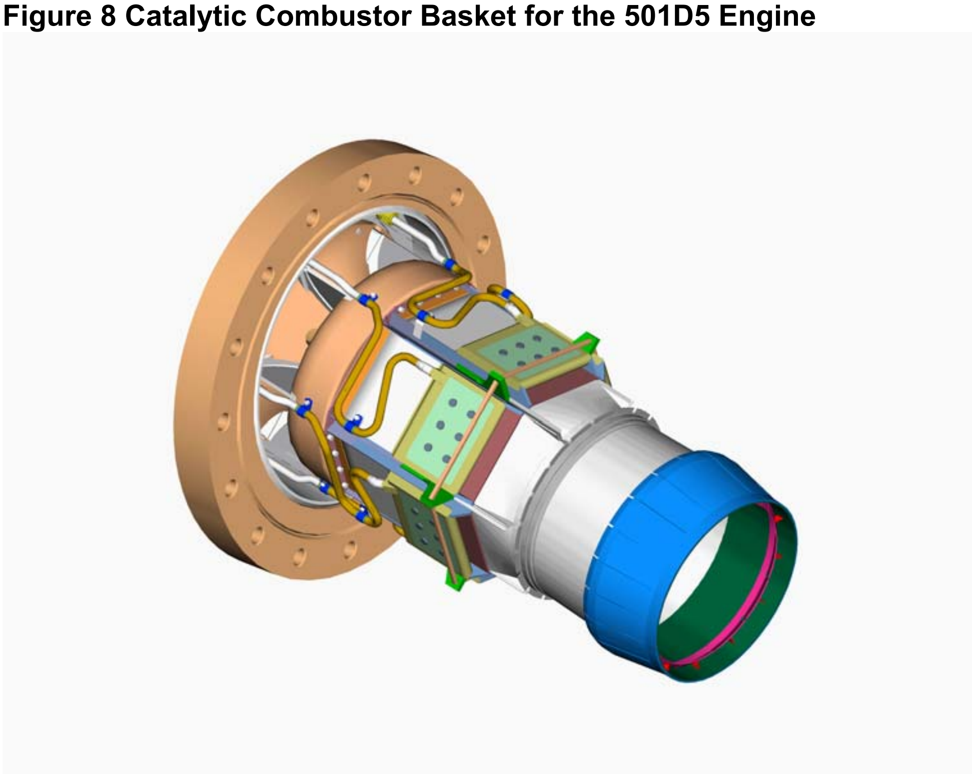

Figure 9 Catalytic Combustor Basket Design for the 501FD Engine

CONCLUSIONS

Siemens has several unique facilities for validation testing of catalytic combustion system for natural gas and syngas. Using an approach of component and subscale testing, the cost and risk of development of a new combustion system for syngas can be reduced significantly. Siemens testing strategy requires new concepts be validated at the first at the single tube level followed by subscale module testing, full scale module testing and full scale basket testing.