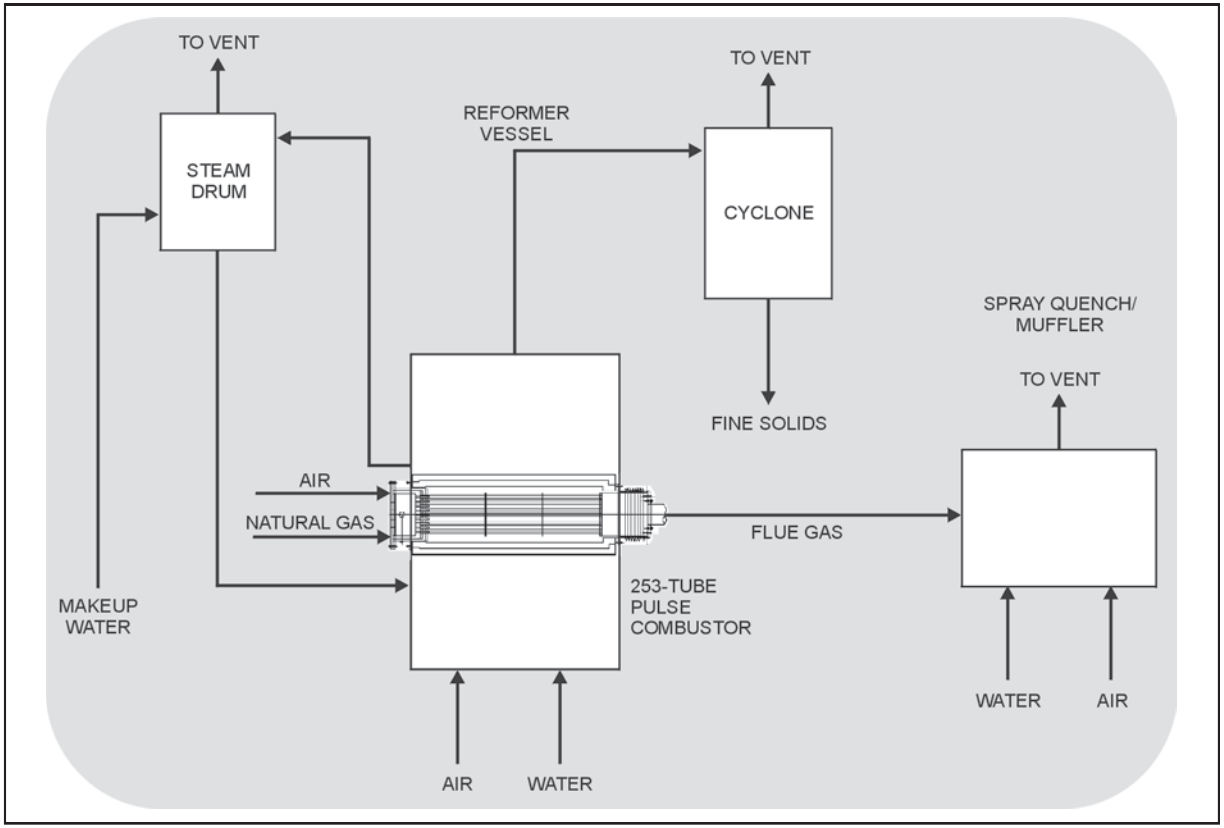


Pulse Combustor Design Qualification Test

Project completed

Participant

ThermoChem, Inc.

Additional Team Member

Manufacturing and Technology Conversion International, Inc. (MTCI)—technology supplier

Location

Baltimore, MD (MTCI Test Facility)

Technology

MTCI's Pulsed Enhanced™ Steam Reforming process using a multiple resonance-tube pulse combustor.

Plant Capacity/Production

30 million Btu/hr (steam reformer)

Coal

Black Thunder (Powder River Basin) subbituminous

Project Funding

Total	$8,612,054	100%
DOE	4,306,027	50
Participants	4,306,027	50

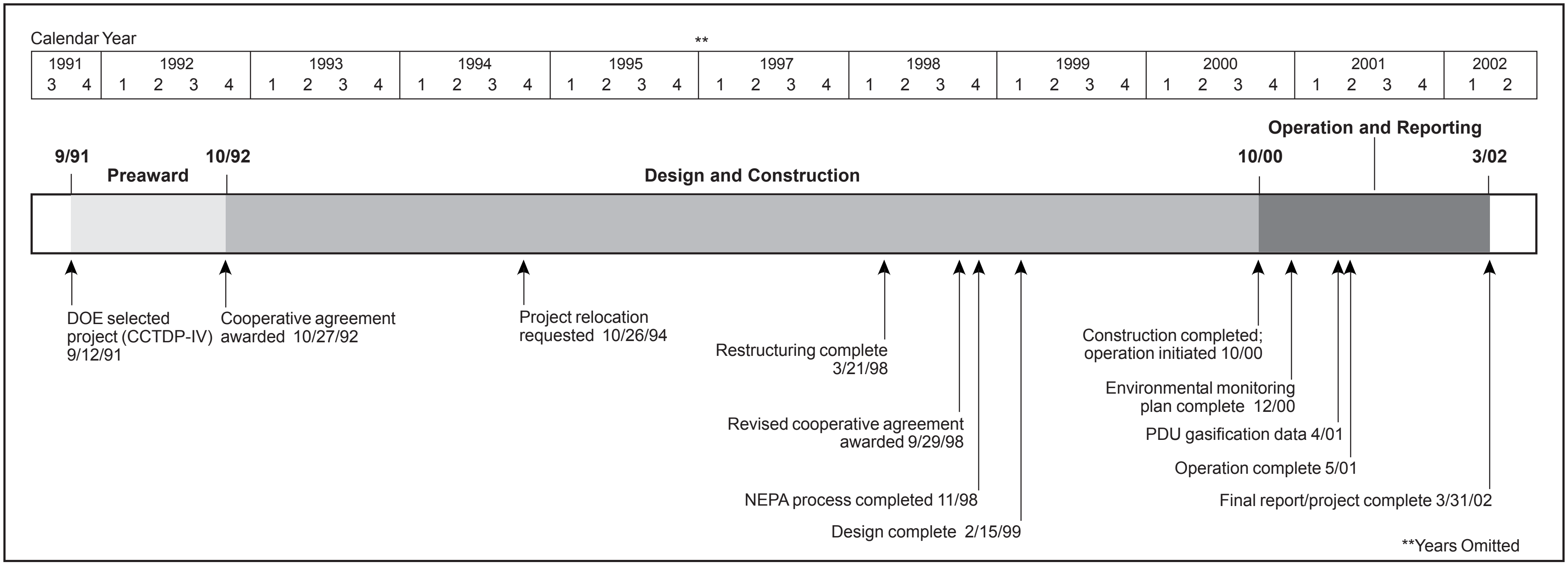
Project Objective

To demonstrate the operational/commercial viability of a single 253-resonance-tube pulse combustor unit and evaluate characteristics of coal-derived fuel gas generated by an existing Process Development Unit (PDU).

Technology/Project Description

MTCI's Pulsed Enhanced™ Steam Reforming process incorporates an indirect heating process for thermochemical steam gasification of coal to produce hydrogen-rich, clean, medium-Btu-content fuel gas without the need for an oxygen plant. Indirect heat transfer is provided by immersing a multiple resonance-tube pulse combustor in a fluidized-bed steam gasification reactor.

The combustor design qualification test facility consisted of a reformer vessel, pulse combustor, fuel train and burner management system, combustion air system, pulse combustor cooling water circuit, cyclone, and water injection system. The reformer was a one-inch thick carbon steel rectangular vessel. The pulse combustor consisted of a 253-tube bundle complete with refractory-lined combustion chamber, aerovalve plate assembly, inlet air plenum, and exhaust expansion bellows. The fuel train and burner management system consisted of a natural gas pressure reducing station, double block and bleed, modulating control valve, and orifice metering station. The combustion air system included forced draft fans, damper control, and flow measurement instrumentation. The pulse combustor cooling water circuit consisted of a steam drum, recirculation pump, balancing valves, and feedwater makeup. The cyclone was a single-stage unit with drip leg isolation valve and catch drum. The water injection system consisted of eight injection nozzles, modulating control valve, and purge air system.



Results Summary

Environmental

- For the condensate from the coal characterization tests, the biological oxygen demand (BOD) was 13.98, 15.27, and 3.04 pounds per ton of dry coal for the 1,000 °F; 1,100 °F; and 1,200 °F tests, respectively.
- For the condensate from the coal characterization tests, volatile organic compounds (VOCs) were 593.7, 183.2, and 52.2 milligrams/kilogram (mg/kg) of dry feed for the 1,000 °F; 1,100 °F; and 1,200 °F tests, respectively.
- For the condensate from the coal characterization tests, semi-volatile organic compounds (SVOCs) were 1,868.3; 1,117.5; and 278.3 mg/kg of dry feed for the 1,000 °F; 1,100 °F; and 1,200 °F tests, respectively.

Operational

- The char product from the coal characterization tests was deemed acceptable for use in direct reduction of iron (DRI).
- The heat transfer rate for the pulse combustor tubes was 2.5 times higher than for conventional fire tubes.
- The sound pressure level varied from 165 dB (approximately 1.5 psi peak-to-peak pressure fluctuation) at about a 6 x 10^6 Btu/hr firing rate to about 173 dB (approximately 4 psi peak-to-peak pressure fluctuation) at about a 21 x 10^6 Btu/hr firing rate, although it may be possible to reduce these levels in a full-scale project.

Economic

- The total project installed cost for five 253-tube pulse combustors rated at 40 tons/hr to be used for char production is estimated at $28,184,000, which includes $8,095,170 for direct equipment and material costs, $3,438,830 for direct installation and subcontract costs, $6,100,000 for indirect costs, and $10,500,000 for start-up, escalation, land, preliminary expenses, insurance, permits, warranties, licenses, and contingency.
- Fixed operating costs for char production were estimated at $4,508,200 per year, and variable operating costs were estimated at $8,696,600 per year, which includes a $25/ton coal feedstock price. A by-product credit for the syngas was estimated at $9,968,900 per year.

Project Summary

On September 10, 1998, DOE approved revision of ThermoChem, Inc.'s Cooperative Agreement for a scaled-down project. The original project, awarded in October 1992, was a commercial demonstration facility that would employ 10 identical 253-resonance-tube pulse combustor units. After fabrication of the first combustor unit, the project went through restructuring. The revised project demonstrated coal characterization tests on a single 2-tube pulse combustor operating on coal and combustor qualification tests on a single 253-tube pulse combustor operating on natural gas as a proxy for coal-derived synthesis gas (syngas). NEPA requirements were satisfied on November 30, 1998, with a Categorical Exclusion. ThermoChem initiated shakedown and commissioning tests in October 2000 and carried out emissions testing from December 2000 through May 2001.

Operational Performance

Pulse combustion involves the combustion-induced flow oscillations produced intentionally by the design of the equipment. The ThermoChem pulse combustor consists of an aerodynamic air inlet valve, a combustion chamber, and a resonance tube (tailpipe) as shown in Exhibit 3-51. The combustor configuration has no moving parts and is inherently reliable.

Operating as a fire tube boiler, ThermoChem claims that its pulse combustor increases heat transfer rates 3–5 times higher than conventional fire tubes used to heat fluidized-bed reactors. The increased heat transfer is probably due to flue gas oscillations resulting in a reduction in the boundary layer inside the tube. The data indicate that the heat transfer rate was 2.5 times higher than that in conventional fire tubes.

Coal Characterization Tests. For the 2-tube pulse combustor, tests were conducted on Black Thunder Powder River Basin coal supplied by Northside Mining. The choice of coal was based on the specific application of producing char for DRI.

The primary variable is an operating temperature that is the lowest possible temperature where satisfactory volatile matter and sulfur content in the char is achieved. The lowest possible operating temperature will result in the lowest amount of fixed carbon converted to gas and the highest char yield.

The coal characterization tests were conducted in a PDU consisting of a steam reformer reactor and two-stage cyclone, coal metering and injection equipment, steam boiler and reverse osmosis unit, two stages of steam superheat, gas chromatography dry gas sampling and measurement, and instrumentation and controls. A schematic of the PDU is shown in Exhibit 3-52.

Three operating temperatures were evaluated for the coal characterization test—1,000 °F;1,100 °F; and 1,200 °F. Despite some questions regarding the operating data collected, the resultant char was deemed suitable for DRI.

Pulse Combustor Qualification Test. Six series of tests were completed while firing the 253-tube pulse combustor. Data were obtained for both the up and down ramp of the pulse-combustor firing rate. Based on available data, the heat transfer coefficient inside the pulsed tube was about 2.5 times higher than for a non-pulsed tube.

The natural gas firing rate was ramped up to about 21 x 10^6 Btu/hr and held steady for about 10 hours. The pulse combustor operated well with strong pulsations and air suction with self-aspiration increasing significantly with firing rate. The dynamic pressure in the combustion chamber was monitored during the test through a Hewlett-Packard spectrum analyzer. The pulsation frequency was generally on the order of 58 Hz. The sound pressure level varied from 165 dB (approximately 1.5 psi peak-to-peak pressure fluctuation) at about a 6 x 10^6 Btu/hr firing rate to about 173 dB (approximately 4 psi peak-to-peak pressure fluctuation) at about a 21 x 10^6 Btu/hr firing rate. Due to self-aspiration, the demand on static pressure in the air plenum of the pulse combustor was rather low, less than 12 inches of water at a 21 x 10^6 Btu/hr firing rate. ThermoChem states that sound levels can be reduced to 85 dB at 3 feet by operating the combustors in a tandem arrangement at 180 degrees out of phase to cancel out noise emissions.

Environmental Performance

Coal Characterization Tests. For the 2-tube pulse combustor coal characterization tests, VOCs and SVOCs were collected and measured in the condensate. The total VOCs were 593.7, 183.2, and 52.2 mg/kg of dry feed for the 1,000 °F; 1,100 °F; and 1,200 °F tests, respectively. The total SVOCs were 1,868.3; 1,117.5; and 278.3 mg/kg of dry feed for the 1,000 °F; 1,100 °F; and 1,200 °F tests, respectively.

A process condensate is the only waste stream generated in this process because the gas would be used as a fuel and the char is the primary product. Biological oxygen demand is the primary concern with the process condensate effluent. For the 1,000 °F; 1,100 °F; and 1,200 °F tests, the BOD was 13.98, 15.27, and 3.04 pounds per ton of dry coal, respectively. There is very little difference between the two lower operating temperatures as would be expected because there was little difference in char and gas yields for those two temperatures. However, at higher temperatures, gasification appears to begin and the organics that contribute to BOD are being somewhat destroyed.

Pulse Combustor Qualification Test. The composition of the flue gas from the combustor was monitored by a continuous emissions monitoring system. The oxygen (O_2) concentration was in the 4-10% range during stable firing of the combustor, corresponding to between 20% and 80% excess air. When there was no flue gas recycle, the O_2 concentration was relatively high. The high excess air operation was necessary to modulate combustion

Exhibit 3-51
Schematic of Pulse Combustor Operation

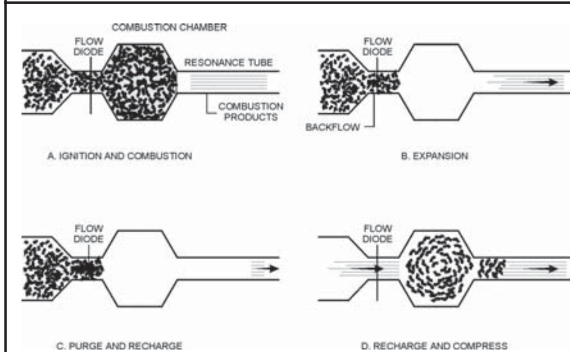
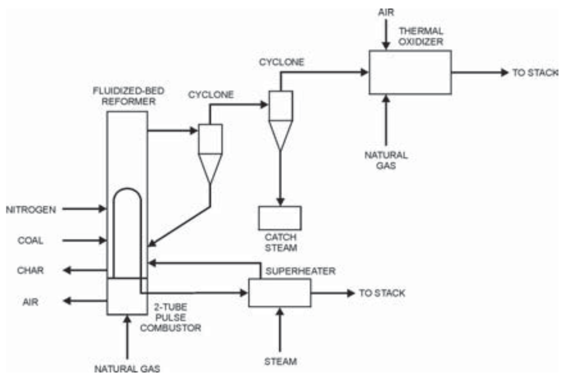


Exhibit 3-52
Schematic of ThermoChem's Process Development Unit



chamber temperature, and NO_x emissions were relatively high due to the high O_2 concentration. With flue gas recycle, the O_2 and NO_x levels were reduced significantly. NO_x concentrations were in the 10–30 parts per million by volume (ppmv) range.

Carbon monoxide (CO) concentration ranged from 100–400 ppmv during stable firing. Flow and temperature profiles had to be established and stabilized to achieve complete combustion. Total hydrocarbons (THC) emissions were generally low (<20 ppmv) except during transients, indicating high combustion efficiency. Carbon dioxide concentration ranged 7–10% during stable firing. With only two exceptions, combustion efficiency was in the range of 99.6–100%, independent of firing rate, excess air, or fluidized-bed temperature. The percent of the heat released that is transferred to the fluidized-bed and the water jacket as a function of firing rate. This percent remains relatively constant at a little over 50%, except at low firing rates (less than about 7×10^6 Btu/hr).

Economic Performance

A capital cost estimate was prepared based on a reactor with five 253-tube pulse combustors having a nominal coal processing (mild gasification) capacity of 40 tons/hr. The plant was assumed to be operating at 36 tons/hr (90% onstream factor). The total project installed cost is estimated at $28,184,000, which includes $8,095,170 for direct equipment and material costs, $3,438,830 for direct installation and subcontract costs, $6,100,000 for indirect costs, and $10,500,000 for start-up, escalation, land, preliminary expenses, insurance, permits, warranties, licenses, and contingency.

Fixed operating costs for char production were estimated at $4,508,200 per year and variable operating costs were estimated at $8,696,600 per year, which includes a $25/ton coal feedstock price. A by-product credit for the syngas was estimated at $9,968,900 per year. The resulting levelized cost of char would be $88.67/ton (current 2002 dollars) and $63.19/ton (constant 2002 dollars).

Commercial Applications

Pulsed Enhanced™ Steam Reforming has application in many different processes. Coal, with world production on the order of four billion tons per year, constitutes the largest potential feedstock for steam reforming. Other potential feedstocks include spent liquor from pulp and paper mills, refuse-derived fuel, municipal solid waste, sewage sludge, biomass, and other wastes.

Although the project demonstrated mild gasification of coal only, the technology has application to (1) black liquor processing and chemical recovery; (2) hazardous, low-level mixed waste volume reduction and destruction; (3) coal processing for production of hydrogen for fuel cell power generation and other uses, production of gas and char for the steel industry, and production of solid Clean Air Act compliance fuels, production of syngas for use as a fuel or as a feedstock for chemicals or high-quality liquid fuels production; (4) coal-pond waste and coal rejects processing for overfiring/reburning for utility NO_x control; and (5) utilization of a range of other fuels and wastes to produce a variety of value-added products. Application of the technology to the production of char for use in DRI has the potential for accomplishing significant reductions in pollutant emissions by reducing production of conventional metallurgical coke and facilitating the use of a new efficient iron-making process.

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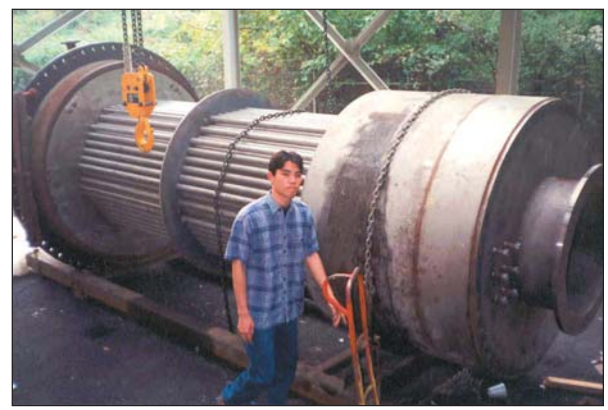

ThermoChem's 253-tube pulse combustor.