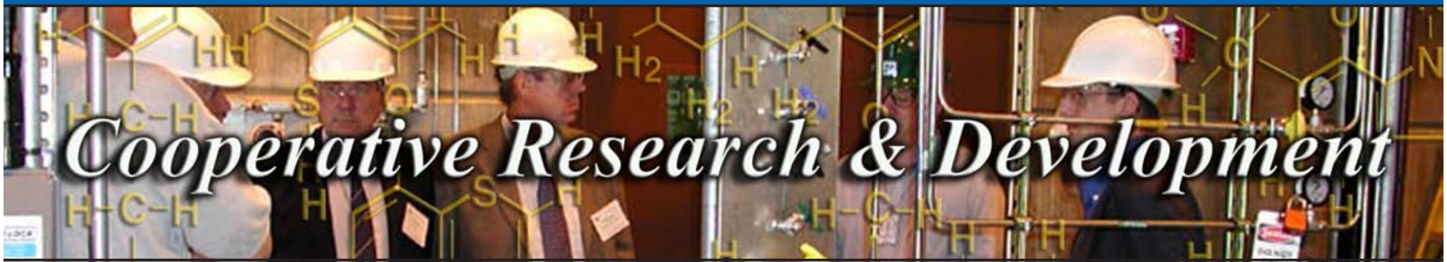


Successes

Development of Improved Metallic Hot Gas Filters for IGCC and PFBC Systems

Advanced Research

To support coal and power systems development, NETL's Advanced Research Program conducts a range of pre-competitive research focused on breakthroughs in materials and processes, coal utilization science, sensors and controls, computational energy science, and bioprocessing—opening new avenues to gains in power plant efficiency, reliability, and environmental quality. NETL also sponsors cooperative educational initiatives in University Coal Research, Historically Black Colleges and Universities, and Other Minority Institutions.

Accomplishments

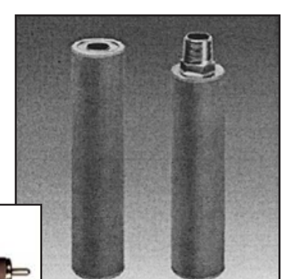
- ✓ Process innovation
- ✓ Cost reduction
- ✓ Greater efficiency
- ✓ Innovative materials

Description

A joint technology development effort between government and industry has resulted in long-lasting filters for high-efficiency power generation systems. This effort began when Inorganic Membrane Technology Laboratory (IMTL) at the Oak Ridge National Laboratory (ORNL) developed a process to manufacture low-cost, porous filter media. Under a Cooperative Research and Development Agreement (CRADA) with the National Energy Technology Laboratory's (NETL) Advanced Research Materials Program, IMTL adapted this manufacturing process to iron aluminide (Fe_3AI) materials.

Iron alurninide is a corrosion-resistant material that can serve as a long-lasting filter medium in leading edge fossil-fueled combustion processes such as integrated gasification combined-cycle (IGCC) and pressurized fluidized-bed combustion (PFBC). The filter traps particles from hot synthesis gas (syngas) or vitiated air (i.e., air with the oxygen removed) before those particles can contaminate the gas and steam turbines, reducing their efficiency and lowering their lifetimes. Filter cost can be reduced by 25 percent through optimized design of the system, filter vessel cost being about 75 percent of the total system cost. However, the same property that makes iron alurninide corrosion resistant makes bonding and fusing it to stainless steel filter tubes difficult.

To overcome this challenge, the project team investigated a variety of alloying materials to improve the iron aluminide's bonding capability. They then developed a fabrication process that incorporated high-shear, gas-atomized powder developed and fabricated at Ames Laboratory with assistance from IMTL metallurgists. The team then conducted extensive testing to verify microstructural stability, transport properties, and other characteristics. A separate CRADA with Pall Corporation, a leading manufacturer of filter elements, enabled ORNL to transfer the new technology. Pall Corporation added the resulting iron aluminide filter to its S-Series PSS® Filter Element product line, where it has become one of its best-selling filters, with over 2,000 distributed to date.



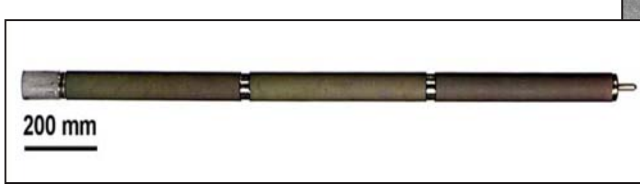


Figure 1 – Photographs of a Pall Corporation iron aluminide hot gas filter assembly and filter elements. These filters, made from an alloy developed by ORNL, give excellent performance in coal gasification plants. Over 2,000 ore now in use and some have been in use for over six years.

Project Duration

Start Date
05/01/95

End Date
12/31/04

Cost

Total Project Value
$1,141,000

DOE/Non-DOE Share
$1,141,000 / $0

Partners

Oak Ridge National Laboratory
Oak Ridge, TN

Pall Corporation
Cortland, NY
Los Altos, CA

Ames Laboratory
Ames, IA

Energy and Environmental
Research Center
Grand Forks, ND

Global Energy, Inc.
West Terre Haute, IN

Southern Company Services, Inc.
Wilsonville, AL

Technical Approach

ORNL researchers first developed modified iron aluminides having industrial value in the late 1980s. They were looking for a noncorrosive substitute for stainless steel, so they turned to intermetallic compounds including nickel-, cobalt-, and iron-based "superalloys" comparable to those developed for the aerospace industry and for high-temperature turbines. ORNL's first success was with nickel aluminides (Ni_3Al), modified by the addition of alloying elements such as boron to reduce brittleness, improve ductility at room temperature, and to enhance resistance to wear, deformation, and fatigue at high temperatures. These materials—and the industry award-winning ExoMelt™ process necessary to form them safely—have found specialized applications in industries such as automotive and heat-treatment manufacturing.

For demanding IGCC and PFBC power plant hot gas filter applications, ORNL researchers turned to iron aluminides, which, unlike conventional ceramic filters, are resistant to air oxidation and corrosion. They form an aluminum oxide ($A1_20_3$) coating that resists attack by sulfur in syngases containing hydrogen sulfide (H_2S) and sulfur dioxide (SO_2). To overcome the alloy's tendency to break easily at room temperature, researchers investigated the reasons for its brittleness and found that, when aluminum reacts with moisture in the air, hydrogen is formed and diffused into the alloy. They experimented until they found the key alloying elements—chiefly small amounts of chromium (Cr)—that, when added, improve ductility by preventing or minimizing the harmful effects of aluminum/water vapor reactions. They also found that preoxidizing the filter material by heat treatment increased its resistance to corrosion, impacts, and thermal fatigue, improving filter reliability.

Advanced PFBC systems operate in the 1,400 °F to 1,550 °F temperature range to filter both syngas and vitiated air. However, operation at higher temperatures is necessary for the IGCC carbonizer and PFBC combustor to achieve high efficiencies. Coal gasification plants produce a low-to-medium-BTU fuel gas that must pass through filters to separate the fine fly ash particles from the hot gas so that these harmful by-products are deposited on the filter tubes and do not reach the high-speed gas turbine during combustion or the atmosphere as emissions. Candle filters (see Figure 2) often are used that have parallel tubular filter banks that expose a maximum surface area to the gas. To prevent fly ash from clogging the inside of the filters to the extent that they reduce gas flow and lower filter efficiency, compressed air blasts periodically are used to "back flush" the filters to knock off the accumulated particles. This procedure can cause thermal shock and cracking of fragile ceramic materials. If even a single candle filter tube breaks, the filtering ability of the entire array is lost. Supplementary hybrid cyclone cleanup filter systems are under evaluation for use to reduce the load on the candle filter and extend filter life; however, this adds cost relative to the substitution of more durable iron aluminide filters.

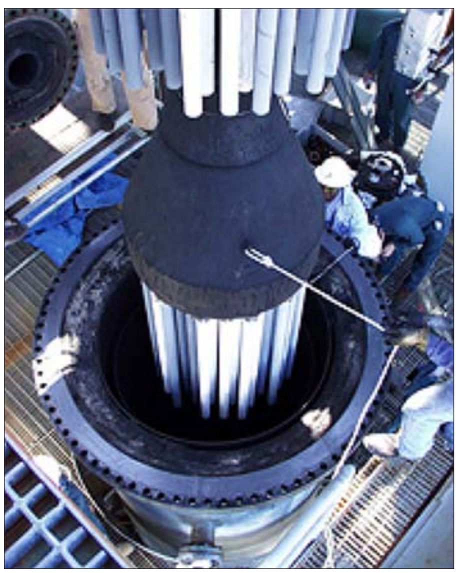


Figure 2 – Photograph of a candle filter assembly at Southern Company's Power Systems Development Facility (PSDF), Wilsonville, Alabama.

Fabrication and Testing

Following initial short-duration laboratory-scale testing of filter materials by ORNL and by Ames Laboratory under ORNL's direction, Pall Corporation successfully developed and fabricated the sintered iron aluminide filter media. This allowed ORNL researchers to focus on analyzing longer-duration field-exposed materials. Aided by ORNL's guidance as to the composition of the alloys to be tested, Pall provided iron aluminide filter elements to both NETL in Morgantown, West Virginia (then the Morgantown Energy Technology Center), and to the Energy and Environmental Research

Center (EERC) in Grand Forks, North Dakota, for exposure to representative atmospheres under both oxygen-blown and air-blown conditions in their pilot-scale gasification units.

Analysis by ORNL of the resulting samples determined that, as predicted, the corrosion was negligible under the corrosive atmospheres, high temperatures, and high pressures. However, the laboratory and pilot-scale test bed exposures were not long enough to allow for accurate corrosion analysis, given that the filters were expected to be in commercial service for two years or more. Accordingly, Pall-fabricated iron aluminide filter elements and 0-ring specimens were submitted for long-duration testing at Global Energy Inc.'s Wabash River (Indiana) gasification plant, and also at the Southern Company's Power Systems Development Facility (PSDF), an engineering-scale plant near Wilsonville, Alabama, whose operations are sponsored by the U.S. Department of Energy (DOE) and funded by industry partners.

The PSDF train features a KBR (formerly Kellogg, Brown & Root) Transport Gasifier and a Siemens Particulate Control Device (PCD), which are designed and sized to provide data for commercial scale-up. The Transport Reactor is an advanced circulating fluidized-bed reactor that can operate in either combustion or gasification mode, while the PCD in gasification mode cleans the syngas of particulate, enabling it to be utilized in a gas turbine or fuel cell. As of May 2007, the PSDF train described above had operated for more than 10,000 hours, yielding valuable data for future IGCC plants.

The Wabash River and PSDF initial testing of filter elements at IGCC temperatures of around 750 °F to 850 °F raised concerns about long-term corrosion resistance of the iron aluminide sintered metal powder filters. Examination revealed plugging in certain areas of the filter that was attributed to steam attack on the underlying iron layer and sulfidation of the resulting iron oxide (Fe203) to FeS by reaction with H2S. Analysis suggested that the sulfidation could be attributed to cracking of the protective alumina layer due to differential expansion during startup and other thermal transients. For that reason, subsequent rounds of testing at the PSDF also featured Haynes HR-160 Dynalloy sintered metal fiber elements. Both elements provided excellent particulate collection performance in terms of their ability to meet gas turbine specifications on total particle loading that are less than 0.1 ppmw. The iron aluminide elements in general offered superior particle collection efficiency, while the Dynalloy elements demonstrated greater corrosion resistance. Further monitoring of the iron aluminide filters was necessary to resolve concerns about pressure drop and tensile strength, and to determine whether a two-year service life is realistic.

"Iron aluminide is a corrosion-resistant material that holds strong potential for use as a long-lasting filter medium in integrated gasification combined-cycle (IGCC) and other advanced, fossil-fueled combustion system applications—such as advanced, pressurized, fluidized-bed combustion (PFBC)."

Accomplishments

Ceramic and metallic filter element durability, filter-ash bridging, and system costs are critical development issues for IGCC and PFBC systems that continue to be addressed by NETL's fossil energy R&D programs. The challenge of producing candle-filter elements that are able to operate for more than two years is being met by enhancing monolithic filter elements made of various materials, such as clay-bonded silicon-carbide, porous-sintered metal, and aluminamullite oxide. A number of composite-type ceramic and metallic filter elements are also continuing to undergo research, development, and demonstration. Other turbine protection methods also are being developed, such as reliable filter failsafe mechanisms to contain and forestall possible particulate leakage.

Benefits

Advanced, coal-fired, power generation systems such as IGCC and PFBC having high efficiency and low emissions will play an important role in the future for the United States and the world, as long as coal remains an abundant and economical energy source. These systems' success will depend in large part on development and commercialization of durable, economical, high-temperature, hot gas filter systems. While the principal beneficiaries of this innovative research are the utility industry and their suppliers, the effort, and the results, will ultimately benefit rate payers and end users of electricity.

States and Localities Impacted

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Ames, IA

West Terre Haute, IN

Grand Forks, ND

Oak Ridge, TN

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U.S. Department of Energy
Office of Fossil Energy

Printed in the United States on recycled paper

September 2008

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