2011 Engineering Materials Achievement Award

Porous Iron Aluminide: Innovative Filtration Technology for Refineries and Clean Coal Applications

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The environmental contribution of porous iron aluminide filters is enormous, considering that the two largest niche markets are power generation and oil refining.

After several years of cooperative development between industry and government, porous iron aluminide (Fe_3Al) gained a reputation as one of the most innovative materials in the history of filtration technology. Fe_3Al processed into sintered metal powder, weldable, seamless tubes (Fig. 1) provides both an environmental benefit to society and a critically needed economic contribution to the power-generation and oil-refining communities. Used in both power-generation plants and catalytic refineries, it represents the first commercial use of an intermetallic compound in an industrial filtration system.

Robust filter material needed in fossil-fuel processing

For decades, the lack of a robust porous material restricted progress in advanced hot gas filtration. It was a significant discovery that relatively low-cost porous Fe_3Al could provide years of service under the corrosive, high-temperature conditions of advanced coal gasification. Fe_3Al is considered to be one of the most robust materials for long-term reliability in high-temperature treatment of sulfur-containing fossil fuels, providing a combination of sulfidation resistance, strength, ductility, and reasonable cost.

Fig. 1 — *Iron-aluminide single element filter (2 in. diameter by 20 in. long) and an internal fuse.*

The application of greatest interest for sour crude oil is the fluidized catalytic cracking (FCC) system that breaks down long hydrocarbon chains into useable fuel sources such as diesel and gasoline. In clean coal applications, filters in the integrated gasification combined cycle (IGCC) coal gasifier is of great interest. The U.S. Department of Energy cited the IGCC as a national core technology. Iron aluminide is the only sintered metal powder filter media that has been successfully used in both commercial FCC and IGCC facilities.

In addition to the sulfidation resistance, Fe_3Al provides a 400% increase in ductility, a critical feature because filter tubes are back-pressurized from the inside out with a short blast of cold gas at frequent intervals to remove ash build-up. The resulting thermal shocks were devastating to ceramics, significantly reducing their service life. As a result, they never provided the fail-safe confidence the industry required.

Dealing with severe conditions

Operating conditions in fossil fuel applications include temperature from 370 to 700°C, a design pressure of around 20 atmospheres, and abrasive ash particle loading in the gas stream that can reach 10,000 ppm and contain volatile chlorides, sulfides, and alkali compounds. Filter material must tolerate thermal stresses and shock caused by pulsed cleaning, severe vibrations, mechanical resonance, and process transients. Thermal gradients of 60°C/min or greater are possible and stresses high enough to bend steel and crack ceramics can be generated by the bridging and expansion of ashcake between adjacent filter elements.

The development of advanced, coal-fired power-generation systems such as pressurized fluid-bed combustion (PFBC) and IGCC is an important part of the future energy strategy of the U.S. and Japan to economically supply high-efficiency fossil fuel power while maintaining low environmental emissions.

Materials scientists and engineers have been searching to find the missing piece of this power-generation puzzle; i.e., a durable, high-temperature filtration system that can remove high-volume ash particles left by the coal gasification process and feed a clean, nonabrasive gas stream to the power generating turbines. The filter system, comprising hundreds of individual porous tubes, must be fail-safe because even a single cracked element can provide a direct path for the abrasive ash to enter the turbine inlet. Therefore, the porous media must perform flawlessly for years under very harsh industrial conditions.

Societal benefits of porous iron aluminide

The environmental contributions of porous Fe_3Al are enormous considering that the two largest niche markets for Fe_3Al filter products are power generation and oil refining. In power generation, filter systems enable fossil-fuel combustion to be a competitive technology

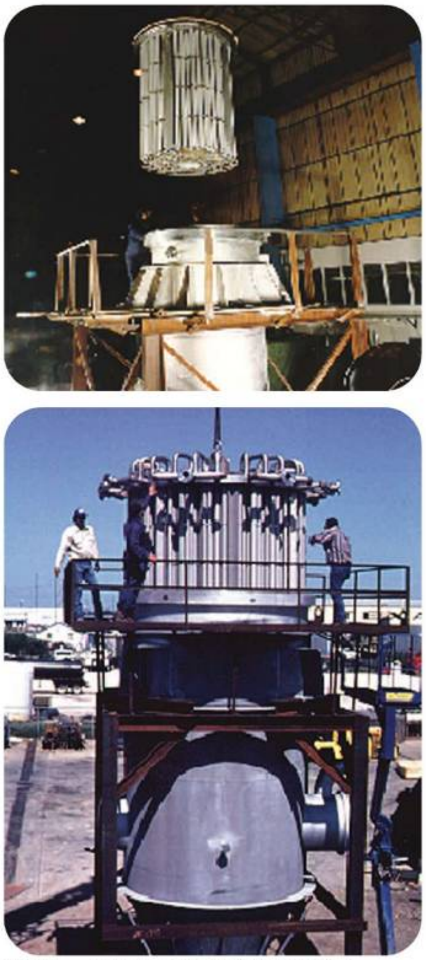


Fig. 2 — *Typical coal-gasification filter system illustrating tube sheet bundles consisting of hundreds of iron-aluminide porous tubes being lowered into their housings (top). A high-temperature gas feed stream laden with ash initially enters the housing and contacts the outside surfaces of the filter tubes. Filtered ash falls to the bottom of the vessel (bottom) where it is transported out of the system. Clean, hot gas that is filtered through the system is directed to a common outlet pipe and sent to the turbine inlet for power generation.*

with oil-burning and natural-gas systems, thereby reducing the dependence of the U.S. and Japan on foreign oil, with a secondary effect being lower cost energy through energy source competition.

Refiners face the challenge of converting heavier, increasingly sour feeds at a time when emission limits are becoming

The History of Porous Iron-Aluminide Development

After many years of cooperative materials development, scientists at Oak Ridge National Laboratory (ORNL), Tenn., and Pall Corp. succeeded in creating a commercial grade, sintered metal powder, porous iron-aluminide (Fe_3Al) filter, which solved the ceramic-replacement dilemma for integrated gasification combined cycle (IGCC) systems. It not only provided superior corrosion resistance, but also provided the improvement in ductility required by the industry. However, the development was not without obstacles.

Several formulations and microstructures of Fe_3Al powder metal were tried in the initial stages of the project. The sinterability of these formulations was not acceptable because they resulted in low strength and ductility in the media. Another major obstacle was poor weldability, caused ironically by the same intrinsic alumina coating that provided high corrosion resistance. Although the alloy was nearly 70 wt% Fe, the thin ceramic coating made the material useless in terms of assembling filter tubes. The project was put on hold, and the industry was left with ceramic filter elements. Pall reinitiated a project to develop porous, seamless Fe_3Al filter tubes for hot gas processes in May 1995 after signing a Partnership Research and Development Agreement (PRDA) with the U.S. Department of Energy, Office of Fossil Energy, Morgantown Energy Technology Center, W. Va.

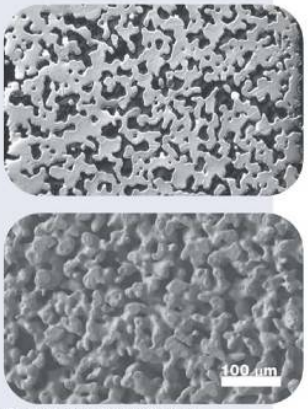
PRDA program objectives were to develop, qualify, and test porous Fe_3Al filter elements for corrosion in a high-temperature, reducing, sulfur-bearing atmosphere; to develop manufacturing processes; and to make a batch of 50 commercial grade filters. The four-year program was successful with Pall researchers overcoming the sintering and welding obstacles, releasing a full topical report in April 1999. The solution involved a series of innovative manufacturing processes, some of which were later patented (U.S. 6,436,163, August 20, 2002), and some of which remain trade secrets.

Specific technical achievements of the manufacturing process include:

- Uniform through-thickness pore size distribution
- Dimensional control of the alumina-coated intermetallic tubes on a production basis
- A coupler design to join porous Fe_3Al to solid stainless steel
- Development of a new weld filler alloy
- Balancing opposing properties; i.e., high void volume and high sinter bond strength
- Creating a stable, non-spalling alumina passive layer by adjusting the composition of the intermetallic compound

This represented a pioneering achievement in sintering science because it was the first commercially available intermetallic compound to be fabricated into a micron-level porous filter media through a patented compaction and vacuum sintering process (see figure).

The commercial goals of the project were achieved; specifically, to offer weldable, crack-resistant, sintered metal powder porous Fe_3Al filter elements, which would provide years of service in fossil-fuel power-generation systems and crude-oil refineries. Pall has provided Fe_3Al as a filter media throughout the world since 2005. To date, around ten full-scale filter systems have been made. The plants rely on porous Fe_3Al to separate abrasive submicron catalyst fines so the syngas and regenerated catalyst can be recirculated. Reliability is the key, because a plant shutdown could cost over $1 million per day. Because there are more than 400 existing fluidized catalytic cracking units in the world today and many more planned, the significance of reliable filtration is apparent.



Cross-section of iron aluminide illustrating uniform pore size distribution and high void volume with a tortuous filter path (top) and microscopic image of the outside surface of sintered iron aluminide (bottom).

Fig. 3 — *Mitsubishi Heavy Industries' 250-MW integrated gasification combined cycle (IGCC) coal-gasification pilot plant for a Clean Coal Power R&D Co. Ltd. initiative containing a porous iron-aluminide ash-filtration system (not visible) from Pall Corp.*

tighter. Therefore, the high-temperature corrosion resistance of Fe_3Al is critical in systems that must reduce sulfur emissions, recirculate high-volume catalysts, and provide lower cost energy.

The impact of Fe_3Al on reducing air pollution is not limited to the U.S. Efficient, multisource energy production is also a national initiative in Japan because of its high-density population, restrictive real estate, and limited natural resources. The primary sources for power generation in Japan are hydroelectric (20%), thermal (natural-gas fired - 27%, oil fired - 22%, and coal fired -11%), and nuclear power (20%). Because coal is an abundant, economical fuel, Japan is committed to developing coal-fired power. However, coal has a natural disadvantage of carbon-dioxide emission, and therefore, must be processed to be both highly efficient and environmentally friendly.

Seeking the new potential of coal, IGCC is an innovative, environmentally friendly, coal-to-power technology. Japan considers it to play the most important role as the future of coal-based power generation. The Japanese Ministry of Economy, Trade and Industry and 11 corporations agreed on the necessity of coal-fueled IGCC, and jointly launched a 250-MW IGCC demonstration plant. Details on the environmental and economic advantages of IGCC can be found at the Clean Coal Power R&D Co. Ltd. website: www.ccpower.co.jp/english/index.html.

Five key points about the IGCC project are:

- IGCC provides a high net efficiency of 48-50% compared to 42% for traditional coal-fired plants.
- Along with the improvement in efficiency, IGCC provides coal-fired power generation at about the same carbon-dioxide emission rate as oil-fired power generation.
- It enables a wide choice of raw coal because IGCC can use low ash fusion temperature coal, which is difficult to use in pulverized-coal thermal energy systems. This type of coal is abundant in North America, China, and India.
- Its high efficiency reduces the emissions of SOx, NOx, and dust per kilowatt-hour.
- IGCC glassy slag is half the volume of fly ash from a conventional coal-fired plant. It has no emission of trace constituents and can be used for fine concrete aggregate or asphalt paving.
- After heat exchange, an IGCC system reduces warm seawater return by 30% compared to traditional coal-fired energy, and also reduces water use for flue gas desulfurization.

Until the arrival of porous Fe_3Al, IGCC technology was being developed using porous ceramic filter tubes. However, because of the potential risk of catastrophic thermal fatigue failure, which could cause full plant shutdown, the use of ceramic filters for IGCC was limited from relatively low to moderate operating temperatures. Therefore, for IGCC owners who aimed for the high-efficiency, high-temperature system, the technology was at a standstill, preventing construction of large commercial IGCCs.

The improved ductility of porous Fe_3Al as a filter media encouraged utility companies and the Japanese government to step forward for a larger IGCC system. The intermetallic material is well-suited for the corrosive, high sulfur-bearing, reducing gas atmosphere operating in heat cycles at more than 400°C and up to 650°C (or >700°C). The filter system forms a critical in-line component where unburned char from the coal gasifier must be separated before going to the gas-turbine combustor (Fig. 2). The filtered char is recycled to the gasifier to realize the high-efficiency of the coal fuel conversion to synthetic gas. To date, Pall produced more than 6000 porous Fe_3Al cylinders for the 250-MW IGCC demonstration plant in Japan (Fig.3). The next phase is at least one full-scale 500 or 600 MW commercial unit. ❍

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