Metal Filter Materials in Combustion Environments*

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Introduction

Hot gas filtration in pressurized fluidized bed combustion (PFBC) systems is an essentially proven technology at temperatures less than about 750°C (1400°F). Advanced PFBC designs are focused on operational and efficiency improvements and will require filtration at substantially higher temperatures. For example, in first-generation advanced PFBCs, the filters will have to perform at 870°C (1600°F), while second-generation units, which include both carbonizers for fuel-gas production and fluidized-bed combustors, will eventually require filters to operate at temperatures as high as 930 and 870°C (1700 and 1600°F), respectively. Results from the final test campaign at the Tidd PFBC Demonstration Project showed that, at these higher temperatures, ceramic filter technology reliability may be problematical. It is, therefore, of interest to re-examine the possibility of using advanced metal hot-gas filters for these advanced PFBC applications in view of the exceptional corrosion resistance of iron aluminides in high-temperature sulfur-bearing atmospheres.

For the second-generation PFBCs, performance criteria for the carbonizer filters are essentially the same as those for integrated gasification combined cycle (IGCC) systems (reducing environments). For the combustor, the issues are similar to those of advanced first-generation units (oxidizing) except that the fuel (byproduct char from the carbonizer) should be somewhat cleaner and the filter performance requirements less demanding than for PFBC systems such as the Tidd plant. For the carbonizer system, the nearer term (market entry) goals are to develop filter materials that will perform at temperatures of 650-760°C (1200-1400°F), with an increase to 800-930°C (1500-1700°F) for improved cycle efficiency.

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Background

Materials used in hot gas filters are required to withstand prolonged exposure to potentially corrosive, high-temperature gaseous environments as well as to condensable vapors and solid species, some of which may have the potential for localized interaction with the filter material after extended times. The gas streams may be oxidizing (in the case of flue gases from PFBCs) or reducing, in which the sulfur species are largely in the form of H_2S (in the case of the product gas from IGCC processes or from carbonizers). The growth of any significant thickness of corrosion product on the filter material cannot be tolerated, since this will lead to rapid pore blockage and failure of the filter. Further, any interaction of the filter material with the deposit or filter cake to form a dense layer, either by sintering or by the formation of low-melting products, also would degrade the functioning of the filter. It is, therefore, necessary to carefully evaluate the environmental compatibility of candidate filter materials with the combination of environmental factors that could potentially cause corrosion to determine the type of corrosion products expected and their rate of formation.

Degradation of metallic filter elements has been observed as an environmental effect under oxidation, sulfidation, and / or carburization conditions and acts as a driving force for the development of ceramic hot-gas filters, particularly for the higher temperatures associated with advanced gasification and combustion designs. However, iron aluminides can also be considered for such applications because of their good to exceptional high-temperature corrosion resistance in a variety of sulfur-bearing environments relevant to coal-derived energy production systems.[1-11] In most cases, the results from these laboratory studies have been directly compared to austenitic stainless steels (particularly type 310). With respect to such alloys, iron aluminides with greater than about 20 at. % Al show exceptional corrosion resistance in coal-gasification environments (high p_{S_2}, low p_{O_2}, and sulfur present as H_2S).[1,4-6,8] While the relative differences in corrosion resistance between these iron aluminides and stainless steels are not as pronounced as in the gasification environment, Fe_3Al and its alloy modifications also show better corrosion behavior under many coal-combustion-gas conditions (high p_{O_2}, low p_{S_2}, and sulfur as SO_2)[2,4,5,8] and in the presence of $CaSO_4$ and circulating-PFBC-type ash deposits[4] up to at least 900°C. Such results, therefore, serve as a basis on which to examine the specific use of selected iron aluminides as materials of construction for hot-gas filters in PFBC systems.

The Oak Ridge National Laboratory (ORNL) is presently working on a project in support of Pall Corporations's development of iron-aluminide filters for coal gasification that can serve as an evaluation of these components for the carbonizer filtration system in second generation PFBCs. Pall Corporation's development of processing techniques for manufacture of the filters is applicable to this project as well. However, some issues associated with the use of iron-aluminide filters for the combustors in the advanced PFBC designs are not being addressed presently. For these environments, iron-aluminide alloys also have potential at both the market entry (650-760°C) and improved cycle efficiency (870°C) temperatures. However, the efficacy of this material has not been specifically demonstrated in the actual environments that obtain in PFBCs. A need, therefore, exists to examine the corrosion behavior and associated environmental effects on properties relevant to the use of porous iron aluminides as hot-gas filters for the combustion gas stream of advanced PFBC systems.

Approach

This work is structured to examine the corrosion behavior and associated environmental effects on properties relevant to the use of iron-aluminide hot-gas filters for advanced PFBC systems. The project will focus on exposure of porous iron aluminides in mixed gases containing N_2, O_2, H_2O, and CO_2, both with and without the presence of ash. Issues associated with corrosion in gases containing N_2, O_2, H_2O, CO, CO_2, and CH_4 typical of the carbonizer gas stream in second-generation PFBCs will not be addressed, as similar work is being conducted in a project on iron-aluminide filters for coal gasification environments. In this and other ways, the present effort will only focus on the aspects of corrosion that are unique to PFBC applications or are not being examined elsewhere. In so doing, this work complements previous or ongoing research and development associated with the corrosion of iron aluminides in oxidizing/sulfidizing environments related to coal-based energy production. It takes advantage of experience in iron-aluminide alloy development, materials processing, and corrosion testing in appropriate fossil environments at the Argonne and Oak Ridge National Laboratories and will involve the expertise of Pall Corporation in producing porous iron aluminides and evaluation of filter performance.

This project will examine the corrosion behavior of Fe_3Al-type iron aluminides, vis-à-vis other alloys such as stainless steels, that can be used for filter applications. Iron aluminide compositions based on Fe-28Al-2Cr and Fe-28Al-5Cr (at. %) will be used. Although higher chromium levels may be considered for added resistance to corrosion by the alkali metal salts present in the ash, recent results by Foster Wheeler Development Corporation suggest the iron aluminides may possess the necessary resistance to this type corrosion.[11] Both porous and dense iron-aluminide alloys of the compositions cited will be evaluated. Comparison of results for the respective materials will allow evaluation of any effects on corrosion behavior associated with differences in processing and the determination of whether previously generated data for cast iron aluminides can be used to guide material selection for the present hot-gas filter applications.

Bare coupons and ash-coated specimens will be isothermally and cyclically exposed in a simulated combustion gas environment. The ash to be used is that obtained by the University of North Dakota Energy and Environmental Research Center from the Westinghouse Advanced Particle Filter installed at the American Electric Power Company's Tidd PFBC Demonstration Project. Corrosion performance will be evaluated using gravimetric data, optical metallography, X-ray diffraction, and scanning electron microscopy with associated energy dispersive X-ray analysis. Corrosion exposures will be conducted at 650°C (1200°F), 750°C (1380°F), and 900°C (1650°F) so that the temperature range encompasses both first- and second-generation PFBC hot-gas filtration conditions.

Project Description

This project will begin in the last quarter (July-September) of Fiscal Year (FY) 1996. Specific test environments will be defined on the basis of appropriate thermochemical calculations and in consultation with the University of North Dakota Energy and Environmental Research Center. Procurement of specific iron aluminide compositions (Fe-28Al-2Cr-0.1Zr and Fe-28Al-5Cr-0.1Zr) in porous form will be initiated. While these are being obtained, experimental exposures will be conducted with cast iron aluminides of the same compositions. The first set of experiments will be with uncoated specimens in the simulated combustion gas at 650, 750, and 900°C. Similar exposures of like specimens coated with ash will be initiated.

In FY 1997, the experiments aimed at comparing the corrosion behavior of the two cast iron aluminide compositions in the presence and absence of ash will be completed. Based on those results, a second set of experiments with the porous materials will also be conducted at the specified temperatures. Possible effects of the process used to make the porous iron-aluminide alloys (such as surface conditioning or impurities) on corrosion behavior can then be evaluated. For selected cases, the effects of such exposures on the mechanical behavior can be examined. An assessment of the ability of iron-aluminide alloys to function as the material of construction for the combustion gas stream of PFBCs will be made. If the results for iron-aluminide alloys are promising, testing of actual filter components made from such alloys (in collaboration with Pall Corporation) will be pursued.

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