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PRD-66 Hot Gas Filter Development

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PRD-66 Hot Gas Filter Development

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Introduction

The PRD-66 manufacturing process offers a unique approach to the production of hot gas candle filters for application in Pressurized Fluidized Bed Combustors (PFBC) and Integrated Gas Combined Cycle (IGCC) power generation systems. Fabricated from readily available and inexpensive raw materials, the PRD-66 process uses an admixture of textile and ceramic concepts to produce an all-oxide filter element containing no refractor ceramic fiber (RCF) residues in the finished products. The use of textile grade glass yarn as a consumable reactant gives the advantages of fabrication versatility and shape control and a unique micro-layered phase structure in the fired product, resulting in unsurpassed thermal shock resistance and operating temperature capability of greater than 1200°C in a low-cost package. This high throughput, adaptable process allows tailoring of filter element dimensions and operating properties to specific system needs with short lead times and low cost penalties.

Despite early successes, the PRD-66 elements experienced significant damage during the final phase of testing at AEP's TIDD PFBC facility. Filters produced by this process appeared to lack absolute filter membrane integrity and showed indications of a failure mode believed to result from infiltration of ash particles into the filter body. A research program was undertaken aimed at understanding this leakage phenomena and developing a more reliable membrane. Additional testing of the improved element would then be conducted in both laboratory and pilot-scale facilities. Concurrently, the reproducibility and scaleability of modifications would be demonstrated.

Objectives

1. Develop testing equipment and methodology for assessment of membrane integrity and filtration efficiency of PRD-66 candle filters.

2. Develop new membrane application technology to supplement or replace the 'wound-on' membrane of the original demonstration filters.

3. Conduct an extended process capability demonstration to assess controllability and product uniformity.

Approach

Equipment and techniques were developed to simulate in-use exposure to coal ash residue dust using short filter segments to determine the leakage mode leading to the previously observed infiltration failures. Based upon the results of this evaluation, an enhanced performance membrane and application process were developed. Research focused on modifications to methods and materials which were either consistent with the basic PRD-66 technology or reasonable extensions of it. Testing of filter segments made using modified membrane applications led to the selection of two 'preferred' candidates differing slightly in flow resistance and filtration characteristics. Elements of each type were subjected to high temperature, high pressure (HTHP), simulated PFBC testing in Westinghouse's facility in Pittsburgh, PA.

Results

In order to rapidly evaluate the filtration efficiency of the PRD-66 filter membrane, a particle infiltration tester (PIT) was designed and fabricated (Figure 1). Short segments (5-8 cm long) were cut from complete filters and mounted in this apparatus. A small amount of representative coal ash, from the TIDD reactor test, was placed in the chamber and deposited onto the exterior surface of the specimen by applying a brief vacuum induced air flow while agitating the dust. The ash layer was then removed by brushing; the process was repeated as many cycles as desired. A typical test included exposure to 25 cycles of ash impingement. Samples were then removed for evaluation.

As an indirect effect of its low density highly crystalline nature, and its total oxide composition containing no transition elements, PRD-66 is highly transparent/translucent in nature. The TIDD ash, containing significant concentrations of iron, has high opacity and excellent hiding power. These two factors, when taken together, suggested an evaluation of PIT-exposed specimens based on the use of transmitted light to determine the extent and location of ash infiltration through the membrane. Figure 2 shows an example of a PIT-exposed segment made with the 'wound-on' membrane of the initial demonstration filters viewed with transmitted light. When compared to an untested filter segment (Figure 3), areas of ash infiltration appear as dark streaks and spots; in the case of the original membrane, these areas are many and widespread. Samples of PRD-66 filters having a wide range of membrane structures were evaluated by this method and a subjective scale of appearance ranking from 1 (many large wide-spread infiltration areas) to 10 (no detectable areas of ash infiltration) was established.

Figure 1: Particle Infiltration Tester (PIT)

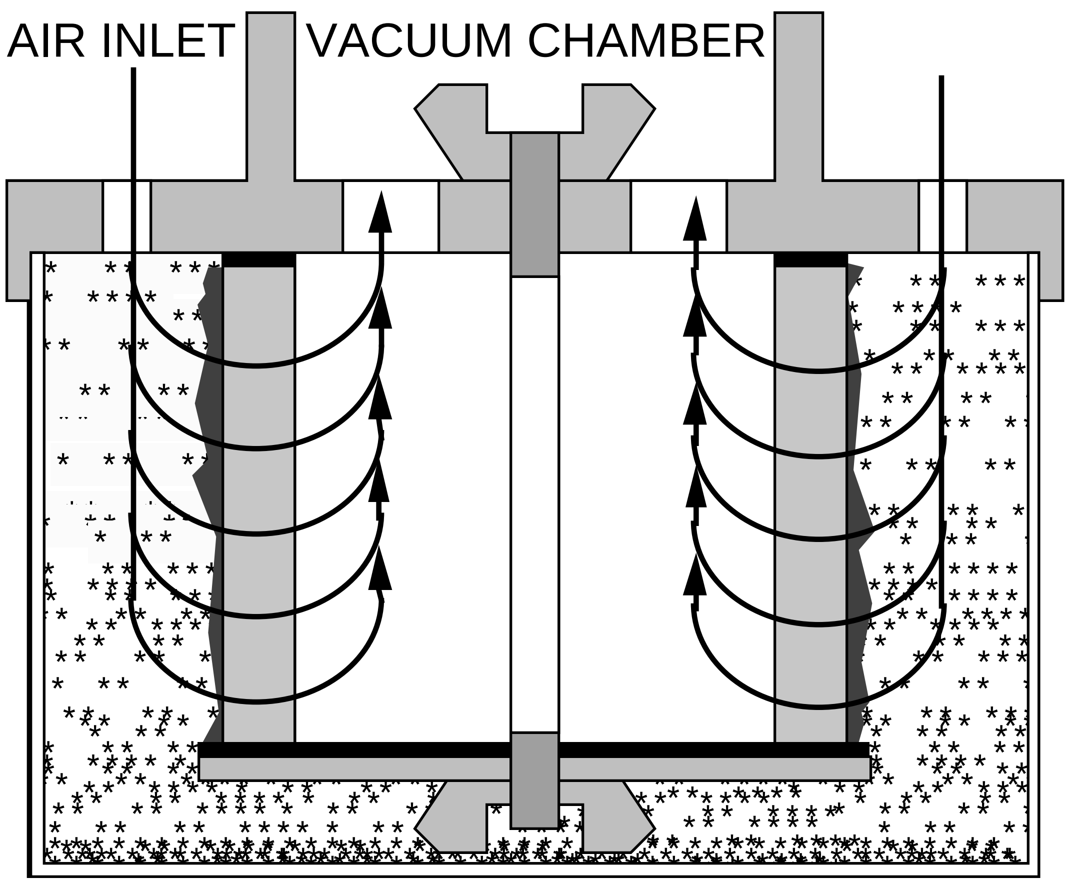


Figure 2: Original PRD-66 membrane after 25 PIT cycles

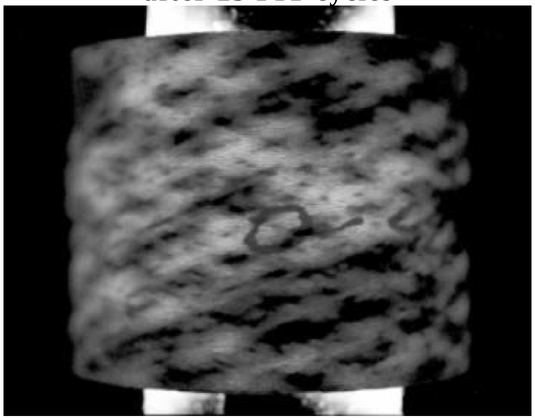
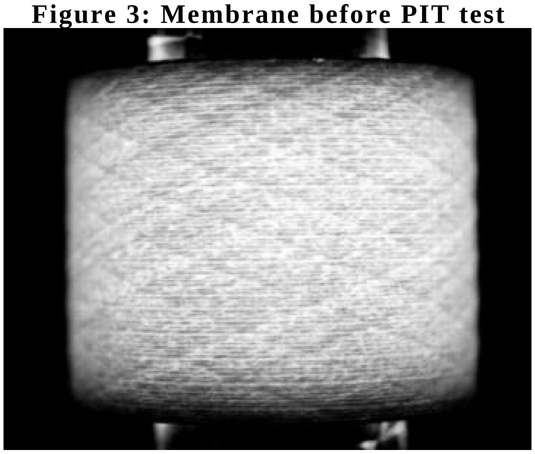


Figure 3: Membrane before PIT test



Closer examination of the filter segment shown in Figure 2 and similar samples indicated that the infiltration had occurred in areas between the adjacent yarns of the 'wound-on' membrane. Apparently, the alumina slurry coating on the fiberglass yarns did not consistently bridge the gaps between the yarns and an incomplete membrane had formed. These observations gave primary direction to the membrane improvement effort, suggesting the addition of membrane material between the as-wound yarns to enhance the membrane coverage.

To facilitate this addition, a new pattern was chosen for the 'hoop-wound' yarns allowing broader spacing between adjacent yarns. Instead of relying on the microcracks in the alumina slurry to provide adequate filtration, a more controlled material would be used to fill in the gaps and provide a more uniform porosity. The approximate relationship of this new spacing to the original membrane spacing is depicted in Figures 4 and 5, showing the additional filler material between the 'wound-on' yarns, and the additional membrane area created in this process.

Figure 4: Original wound membrane (wall cross-section)

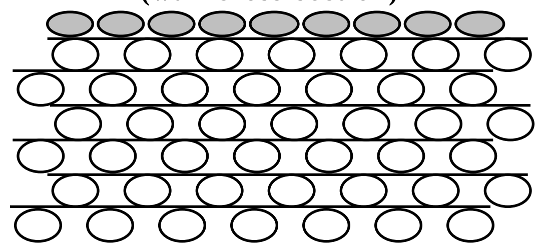
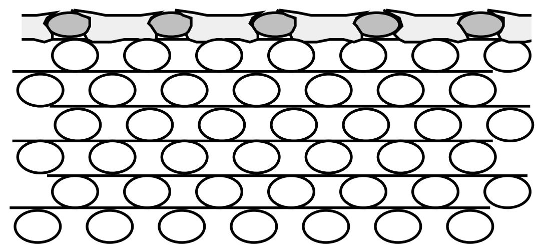
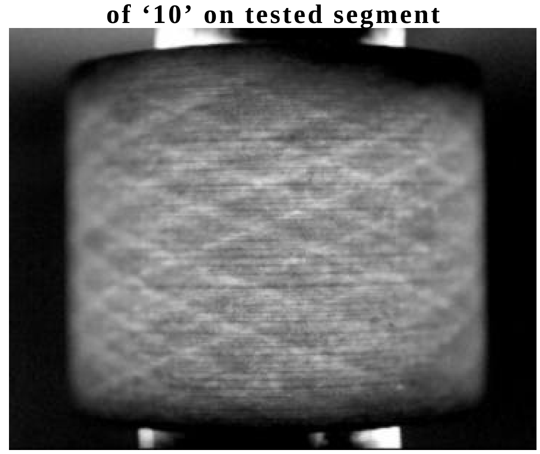


Figure 5: Membrane with added filler (wall cross-section)



The compositions of the slurry coating of the membrane yarn and the filler materials were varied over as wide a range of options, and representative samples were subjected to 25 PIT-exposure cycles. Candidate membranes were selected for further evaluation only if they scored a PIT rating >'9'. Figure 6 illustrates a unit with a rating of '10'.

Figure 6: Modified membrane with PIT rating of '10' on tested segment



After assessment of a large number of filter segments, another advantage of transmitted light inspection became readily apparent. Any defects which appeared as ash infiltrated darkened areas in the PIT tested samples were also apparent in the untested samples when examined by transmitted light. Although small membrane defects on the order of 100-200 μ diameter were not readily apparent on routine visual inspection (Figure 7), they became visible as intensely bright points of light in transmitted light inspection (Figure 8). Further, these defects were detectable in the filters prior to firing, allowing for the application of addition membrane filler before the final ceramic conversion firing.

Figure 7: Hole in membrane undetectable under direct light

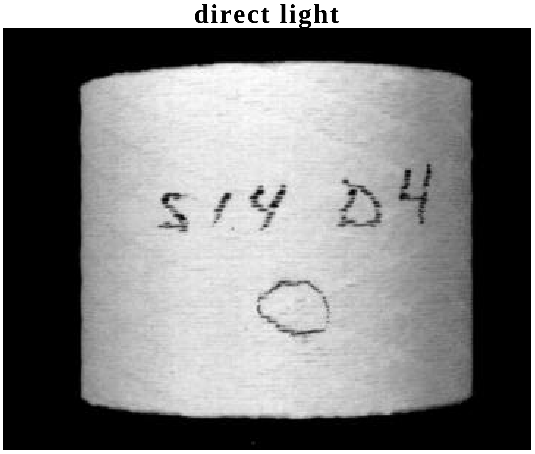
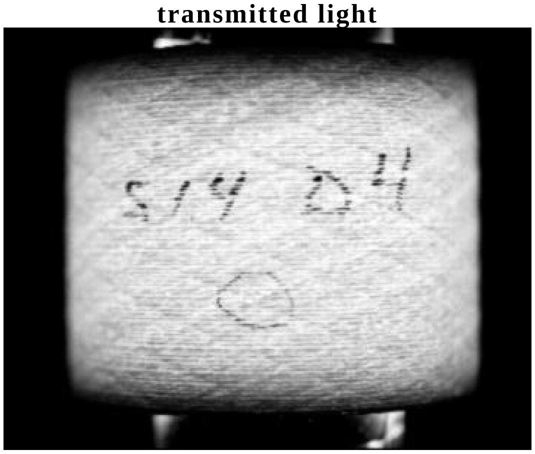


Figure 8: Hole in membrane visible in transmitted light



Controlled testing of specimens with membrane defects was conducted. Each sample was examined in transmitted light prior to firing, some pinholes were filled with additional material, some were left open. Specimens were subjected to 25 PIT cycles. All sites where ash penetration occurred during PIT exposure had been easily located prior to firing. None of the filled pinholes showed signs of leakage. No additional defects developed during the final ceramic conversion firing. Figures 9 and 10 show the result of testing a defective segment where a pinhole, detected prior to firing, was allowed to remain.

Figure 9: Hole in membrane after 25 PIT cycles viewed in transmitted light

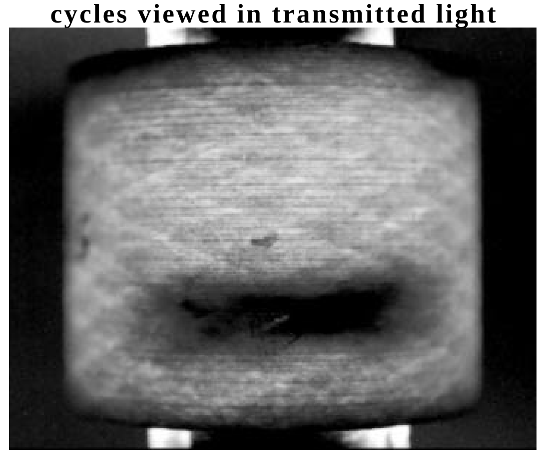
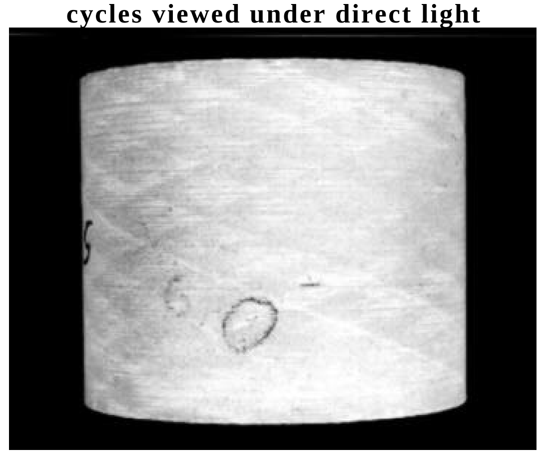


Figure 10: Hole in membrane after 25 PIT cycles viewed under direct light



This defect was virtually undetectable when examined in direct light, but immediately obvious in transmitted light. This test and defect elimination procedure has now been added to our standard manufacturing protocol for 100% of PRD-66 production filters.

From the many candidate processes, two variants were selected for further evaluation. These membrane versions, PRD-66M and PRD-66C, were selected for their excellent but different combinations of filtration performance and flow resistance characteristics. Both of these membrane candidates were processed into full size filter elements for testing at the Westinghouse HTHP facility. The first of these, membrane candidates PRD-66M, has a mean pore size for filtration of about 10.5µ (Figure 11) with flow resistance comparable to the close wound membrane filters. Flow resistance curves of full filters from this membrane both before and after HTHP testing are shown in Figure 12.

Figure 11: Pore Distribution of PRD-66M

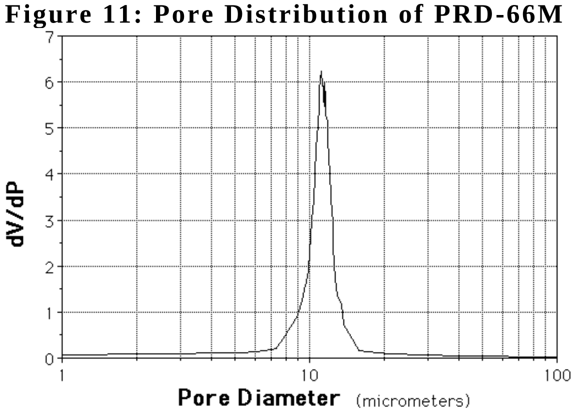
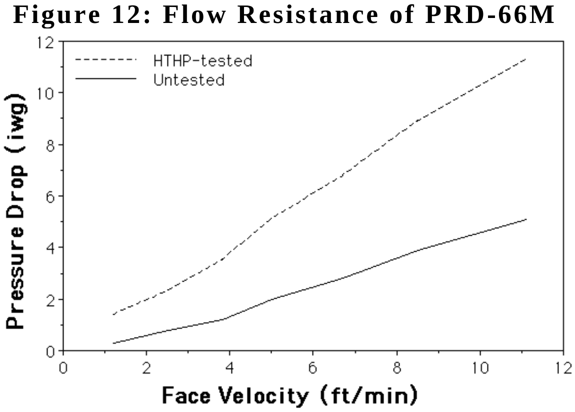


Figure 12: Flow Resistance of PRD-66M



The second membrane candidate, PRD-66C, was chosen because of its unusually low flow resistance in combination with excellent filtration performance. With a mean pore size of about 25µ (Figure 13) its flow resistance is less than half that of filters with PRD-66M membranes (Figure 14).

Figure 13: Pore Distribution of PRD-66C

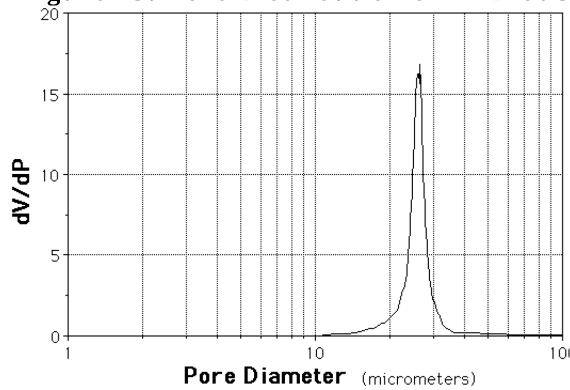
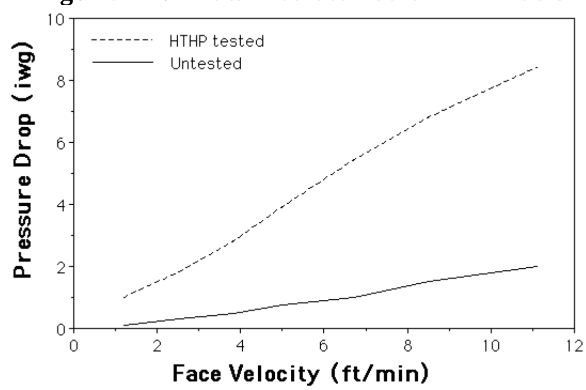


Figure 14: Flow Resistance of PRD-66C



Based on the HTHP results, both membrane types are considered viable candidates for future commercialization. The choice will depend on system requirements.

Future Activities

Both candidates were found by Westinghouse to be suitable for further testing to be conducted at the Foster Wheeler 10 MWt PFBC facility in Karhula, Finland. Room for only one filter candidate, however, could be allowed; PRD-66C was chosen for this evaluation.

DLC is currently engaged in an ongoing extended process capability demonstration to assess controllability and product uniformity. Data from this study will allow statistical determination of product variability and process economics for product commercialization. Candles produced during this evaluation will be submitted to Westinghouse for the PFBC test initiatives in Karhula.

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Contract Information

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