Hot-Gas Filter Testing with a Transport Reactor Development Unit

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Introduction

The U.S. Department of Energy's Morgantown Energy Technology Center (DOE METC) has a hot-gas cleanup (HGC) program intended to develop and demonstrate gas stream cleanup options for use in combustion- or gasification-based advanced power systems. One objective of the METC HGC program is to support the development and demonstration of barrier filters to control particulate matter. The goal is not simply to meet current New Source Performance Standards (NSPS) with respect to particulate emissions, but also to protect high-efficiency gas turbines and control particulate emissions to levels low enough to meet the more stringent regulatory requirements anticipated in the future. DOE METC is investing significant resources in the Power Systems Development Facility (PSDF) under a cooperative agreement with Southern Company Services, Inc. (SCS). The PSDF will comprise five modules, including an advanced gasifier module and a HGC module. The gasifier module involves the M.W. Kellogg transport reactor technology for both gasification and combustion (1, 2). Several other demonstration-scale advanced power systems that will also utilize hot-gas particulate cleanup technology will benefit indirectly from this research. These systems include the Clean Coal IV Piñon Pine IGCC Power Project located at the Sierra Pacific Power Company's Tracy Station near Reno, Nevada.

The transport reactor demonstration unit (TRDU) was built and operated at the Energy & Environmental Research Center (EERC) under Contract No. C-92-000276 with Southern Company Services, Inc. The M.W. Kellogg Company designed and procured the reactor and provided valuable on-site personnel for start-up and operation. The Electric Power Research Institute (EPRI) was involved in establishing the program and operating objectives with the EERC project team.

The purpose of the previous program was to build a reactor system larger than the Transport Reactor Test Unit (TRTU) located in Houston, Texas, in support of the Wilsonville PSDF transport reactor train. The program was to address design and operation issues for the Wilsonville unit and also help develop information on the operation of the unit to decrease start-up costs.

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The TRDU (91–136-kg/hr coal–limestone feed rate) now provides an intermediate scale to the TRTU (4.5 kg/hr coal–limestone feed rate) and the Wilsonville transport reactor (1540 kg/hr feed rate). Some of the design, construction, start-up, and operational issues for the Wilsonville transport train were addressed during this project (3, 4).

Objectives

The objective of the HGC work on the TRDU located at the EERC is to demonstrate acceptable performance of hot-gas filter elements in a pilot-scale system prior to long-term demonstration tests. The primary focus of the experimental effort in the 2-year project will be the testing of hot-gas filter elements as a function of particulate collection efficiency, filter pressure differential, filter cleanability, and durability during relatively short-term operation (100–200 hours). A filter vessel will be used in combination with the TRDU to evaluate the performance of selected hot-gas filter elements under gasification operating conditions. This work will directly support the PSDF utilizing the M.W. Kellogg transport reactor located at Wilsonville, Alabama (5) and indirectly the Foster Wheeler advanced pressurized fluid-bed combustor, also located at Wilsonville (6, 7) and the Clean Coal IV Piñon Pine IGCC Power Project.

Approach

This program has a phased approach involving modification and upgrades to the TRDU and the fabrication, assembly, and operation of a hot-gas filter vessel (HGFV) capable of operating at the outlet design conditions of the TRDU. Phase I upgraded the TRDU based upon past operating experiences. Additions included a nitrogen supply system upgrade, upgraded LASH auger and coal feed lines, the addition of a second pressurized coal feed hopper and a dipleg ash hopper, and modifications to spoil the performance of the primary cyclone. Phase II included the HGFV design, procurement, and installation. Phases III through V consist of 200-hour hot-gas filter tests under gasification conditions using the TRDU at temperatures of 540°–650°C (1000–1200°F), 9.3 bar, and face velocities of 1.4, 2.3, and 3.8 cm/s, respectively. The increased face velocities are achieved by removing candles between each test.

Project Description

The TRDU is a 91–136-kg/hr (200–300-lb/hr) pressurized circulating fluid-bed gasifier similar to the gasifier being tested at the Wilsonville facility. The TRDU has an exit gas temperature of up to 980°C (1800°F), a gas flow rate of 590 m^3/hr (340 scfm), and an operating pressure of 9.3 bar (120 psig). The TRDU system can be divided into three sections: the coal feed section, the TRDU, and the product recovery section. The TRDU proper, as shown in Figure 1, consists of a riser reactor with an expanded mixing zone at the bottom, a disengager, and a primary cyclone and standpipe. The standpipe is connected to the mixing section of the riser by a J-leg transfer line. All of the components in the system are refractory-lined and designed mechanically for 11.4 bar (150 psig) and an internal temperature of 1090°C (2000°F). A detailed description of the TRDU and HGFV design has been given in other reports (4, 8).

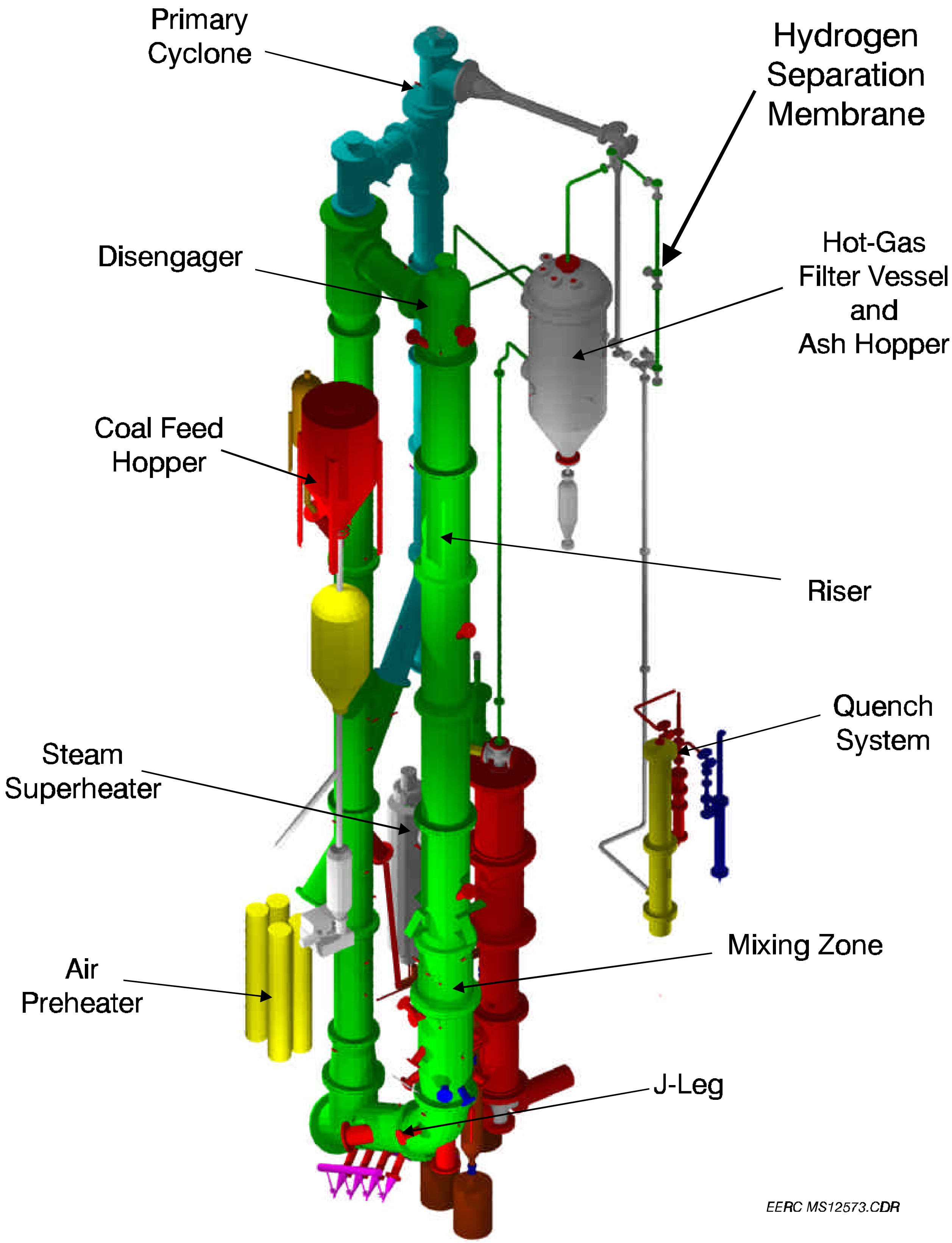

Figure 1. TRDU with HGFV in EERC gasification tower.

The HGFV is designed to handle all of the gas flow from the TRDU at its nominal operating conditions. This vessel has a 1.22-m inner diameter and is 4.7 m long with a refractory inside diameter of 71 cm (28 in.) and a shroud diameter of 61 cm (24 in.). The filter design criteria are summarized in Table 1. Filter vessel design capabilities include operation at elevated temperatures (to 950°C) and pressures (up to 11.4 bar), with the initial test program operating in the 540°–650°C range. The HGFV can operate with filter face velocities in the range of 1.25 to 5.1 cm/s. Nineteen 1-meter candles were used in the initial tests, but 1.5-meter candles can be installed in the filter vessel. An existing heat exchanger has been modified to allow for the reduction of the gas stream temperature at the inlet to the filter vessel. An unheated nitrogen backpulse system was constructed to test the effects of backpulsing parameters on candle performance and cleanability. The nitrogen back-pulse system was constructed to backpulse up to four sets of four- or five-candle filters in a time-controlled or differential pressure-controlled sequence. During this test, the candles were typically pulsed at 87 mbar (35 in. H_2O) pressure drop across the candles. Sample ports for obtaining particulate and hazardous air pollutant samples were added to the piping system. A high-pressure and high-temperature sampling system (HPHTSS) was used to extract dust-laden flue gas isokinetically from the TRDU's reducing environment. Details of the HPHTSS are given elsewhere (8). A Fibroplate™ ceramic tube sheet and seven Fibrosic™ candle filters from Industrial Filter & Pump Mfg. Co., six silicon carbide fiber ceramic candle filters from the 3M Corporation, and six (one iron aluminide and five Vitropore™ silicon carbide) candle filters from Pall Advanced Separations Systems were tested in the filter vessel. A schematic of the internal design of the filter vessel is presented in Figure 2.

TABLE 1

Design Criteria and Operating Conditions for the Pilot-Scale Hot-Gas Filter Vessel

Operating Conditions	Design	Actual
Inlet Gas Temperature	540°–980°C	460°–475°C
Operating Pressure	8.6–11.4 bar	8.3 bar
Volumetric Gas Flow	550 m^3/hr	590 m^3/hr
Number of Candles	19 (1- or 1.5-meter)	19 (1-meter)
Candle Spacing	10.2 cm ℄ to ℄	10.2 cm ℄ to ℄
Filter Face Velocity	1.25–5.1 cm/s	1.4 cm/s
Particulate Loading	<10,000 ppm	6700 ppm
Temperature Drop Across HGFV	< 30°C	25°–30°C
Nitrogen Backpulse System Pressure	up to 56 bar	11.4 bar
Backpulse Valve Open Duration	up to 1-s duration	¼-s duration

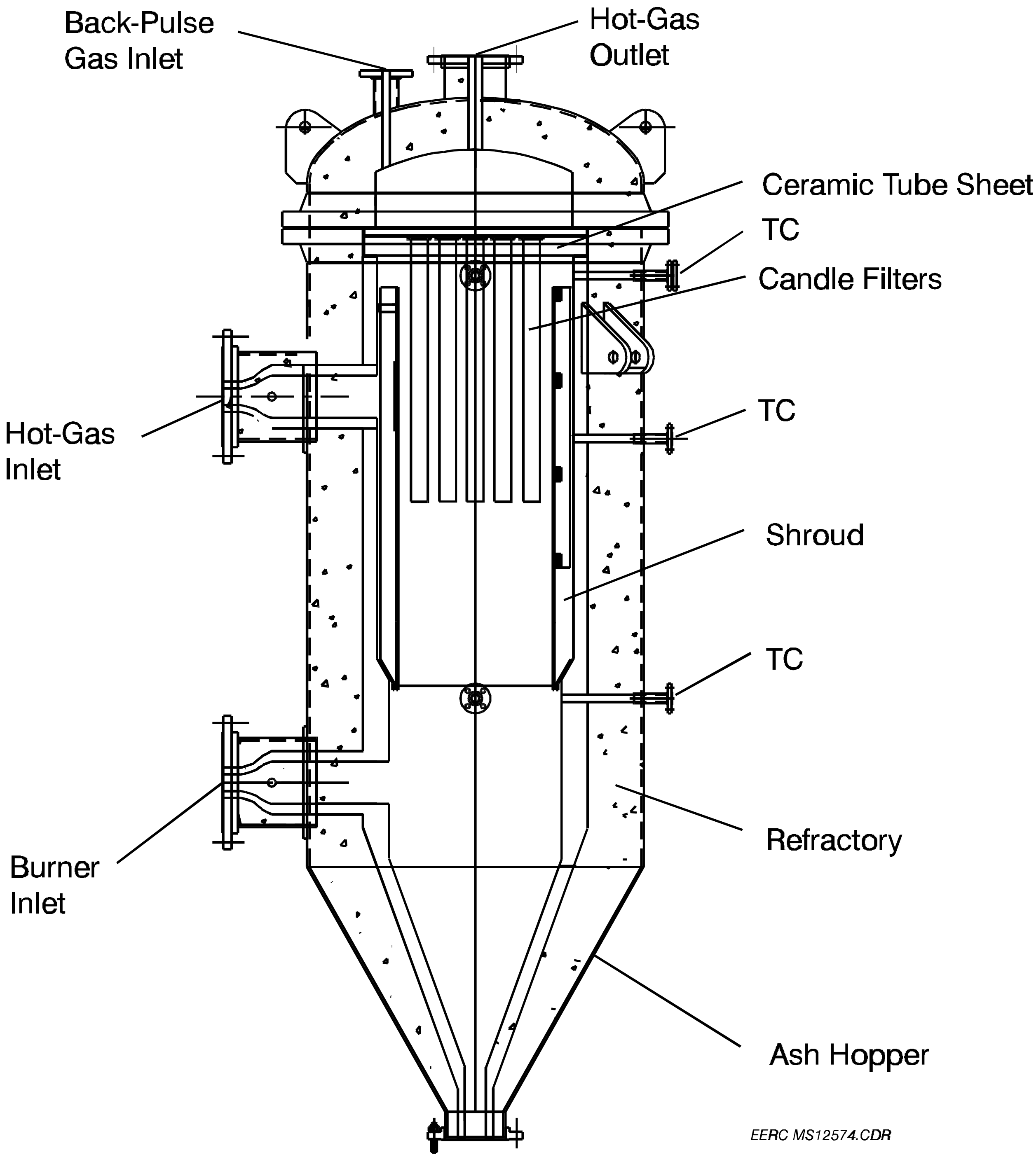

Figure 2. Schematic of the internal design of the HGFV.

Results

Two test campaigns were conducted during the weeks of March 25–31, 1996, and April 15–21, 1996. During these weeks, 138.5 hours of coal feed and 107 hours of gasification were achieved, with the system gases and fly ash passing through the filter vessel during the whole test campaign.

The TRDU was operated at three different average temperatures of 925°, 900°, and 860°C to alleviate some deposition problems seen in the disengager. Analysis of the deposits indicated that a low melting eutectic between the calcium in the coal ash and the aluminosilicate in the fluid catalytic cracking (FCC) starting bed material resulted in the disengager deposits. Table 2 summarizes the operational performance for the TRDU during these test periods. Coal feed rates ranged from 100 to 109 kg/hr, and the gasifier pressure ranged from 8.3 to 8.6 bar. The dry product gas produced was 4%–6% CO and H_2, 10%–12% CO_2, 0.1%–1% CH_4, with the balance being N_2 and other trace constituents. The moisture in the fuel gas averaged 14%. The H_2S concentration averaged 400 to 600 ppm. Calculated recirculation rates ranged from 3630 to 8200 kg/hr.

TABLE 2

TRDU Actual Operating Conditions

Parameter	P046B	P047A	P047B
Conditions	Gasification	Gasification	Gasification
Coal	Wyodak	Wyodak	Wyodak
Moisture Content, %	23.3	23.3	23.3
Pressure, bar	8.3	8.3	8.3
Steam:Coal Ratio	0.28	0.28	0.30
Air:Coal Ratio	3.49	3.33	3.25
Ca:S Ratio, mole	4.7	4.7	4.7
Coal Feed Rate, kg/hr	100	100	100
TC411, °C , average (min.) (max.)	816 (733) (872)	857 (690) (902)	800 (606) (838)
Conversion, %	98	93	89
Carbon in Bed, %, Standpipe (dipleg)	ND[1]	0.5 (1.0)	1.0 (3.0)
Riser Velocity, m/s	8.5 (12.8)	9.8 (12.2)	9.1 (12.2)
Standpipe Velocity, m/s	0.061	0.12	0.12
Circulation Rate, kg/hr	ND	4000	6804
Duration, hr	28.5	41.5	56
Time	12:00–14:00	22:00–13:00	21:00–10:00
Date	3-29 to 3-30	4-15 to 4-17	4-18 to 4-21

[1] Not determined.

The HGFV was operated at ~460° to 475°C, with an average temperature drop across the filter vessel of 25° to 30°C. The candles were backpulsed 70 times, with no major candle failures. Backpulse operating parameters were an 11.4-bar reservoir pressure with a ¼-second full open time. The N_2 backpulse system and the filter vessel ash letdown system presented no operational problems. The only observed problems were a leak around the ceramic tube sheet and three of the candles that did not seal in the tube sheet correctly. In addition, the gas inlet temperature was approximately 80°C lower than the desired inlet temperature of 540°C. The average particulate loading going into the HGFV was 6700 ppm, with a d_{50} of 11.3 μm, while the outlet loading was 300 ppm with a d_{50} of 2.3 μm. A small increase in the "cleaned" filter baseline (from ~12.5 to 35.0 mbar) was observed over the course of the testing.

The leakage around the candles is the result of mixing four different candle types in a tube sheet with a common holddown plate. The tube sheet and holddown plate were specifically designed for the square-flanged IF&P Fibrosic™ candles. Pall's metal iron aluminide candle had its flange machined to match that of the IF&P candles; however, the Pall Vitopore and the 3M candles were installed using specially machined stainless steel adaptors to convert their hemispherical flange design to match that of the square-flanged tube sheet, resulting in slightly uneven candle flange heights. The tube sheet seal leak was probably due to the lower-than-expected temperature of the HGFV not expanding the intumescent sealing gaskets properly.

One bridge was observed between two adjacent candles. The bridge was very soft and fell off during removal of the tube sheet from the filter vessel; however, samples from the bridge were obtained before the bridge fell. It appeared that the bridge was the result of a slightly bowed candle coming close enough to the adjacent candle that a bridge was able to be formed and sustained during operation of the TRDU HGFV. Chemical analysis of the bridge material indicates that the bridge formed at the bottom (smallest distance between the candles) and built upward. Chemical analysis of the particulate samples indicates that mostly the finest size fraction was comprised by the coal ash and very little of the aluminosilicate FCC start-up material. Chemical analysis of the TRDU standpipe, dipleg, and filter vessel samples indicates that the standpipe material was approximately 50% coal ash, while the dipleg and filter vessel samples were approximately 75% coal ash. Sodium also seemed to be preferentially remaining in the larger particle sizes, indicating a possible interaction with the standpipe material.

Applications

In addition to direct support for the PSDF at Wilsonville, TRDU operation and filter element testing will benefit other ongoing projects at the EERC. The first sampling and analysis activities were conducted to generate HAPs data concerning trace metal transformations, speciation of mercury, and metal concentrations at selected points within the TRDU and HGC in support of a project entitled "Trace Element Emissions" funded by METC. In addition, materials and ash data concerning the high-temperature filter media and ash interactions were collected and analyzed in support of a project entitled "Hot-Gas Filter Ash Characterization" jointly funded by METC and EPRI. Testing of a hydrogen separation membrane by Bend Research, Inc., was also conducted on a slipstream of product gas from the TRDU. While the cost of this specific data collection was covered by the individual projects, the synergy that results from the integration of these projects minimizes the cost for collecting this information for all projects involved.

Future Activities

Future plans are to perform two HGFV tests at slightly higher temperatures and much higher filter face velocities to evaluate filter operation at these conditions and to ensure the ceramic tube sheet seal integrity and durability. Other future plans could include piping modifications to allow higher- temperature filter tests (at temperatures up to 900°C).

Acknowledgements

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