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Task 3.13 - Hot-Gas Filter Testing

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By
Michael D. Mann

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For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

By
Energy and Environmental Research Center
University of North Dakota
P. O. Box 9018
Grand Forks, North Dakota 58202-9018

DISCLAIMER

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1.0 OBJECTIVES

The objectives of the hot-gas cleanup (HGC) work on the transport reactor demonstration unit (TRDU) located at the Energy & Environmental Research Center (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 is the testing of hot-gas filter element performance (particulate collection efficiency, filter pressure differential, filter cleanability, and durability) as a function of temperature and filter face velocity during short-term operation (100–200 hours). This filter vessel is used in combination with the TRDU to evaluate the performance of selected hot-gas filter elements under gasification operating conditions. This work directly supports the power systems development facility (PSDF) utilizing the M.W. Kellogg transport reactor located at Wilsonville, Alabama (1) and, indirectly, the Foster Wheeler advanced pressurized fluid-bed combustor, also located at Wilsonville (2, 3).

2.0 BACKGROUND INFORMATION

The U.S. Department of Energy (DOE) Morgantown Energy Technology Center (METC) has a 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 low enough levels to meet more stringent regulatory requirements anticipated in the future. DOE METC is investing significant resources in the PSDF under a Cooperative Agreement with Southern Company Services, Inc. (SCS). The Wilsonville facility will include five modules, including an advanced gasifier module and a hot-gas cleanup module. The gasifier module involves the M.W. Kellogg transport reactor technology for both gasification and combustion (4, 5). 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 TRDU was built and operated at the 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 during 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.

The TRDU (200-lb/hr coal–limestone feed rate) now provides an intermediate scale to the TRTU (up to 10-lb/hr coal–limestone feed rate) and the Wilsonville Transport Reactor (3400-lb/hr feed rate). Some of the design, construction, start-up, and operational issues for the Wilsonville transport train were addressed during this project.

Five test periods were completed in the TRDU using Wyodak subbituminous coal. These were shakedown tests, which included cold and hot solids circulation, coal combustion, and coal gasification. The TRDU operated under solids circulation for a period of 256 hr, coal combustion for 46.5 hr, and coal gasification for 34 hr. Data from four steady-state gasification periods (a total of approximately 18 hr) were analyzed (6, 7).

The four major design criteria that were established by EPRI were met. These included coal feed rate, operating pressure, carbon conversion, and high heating value of the product gas. Major accomplishments included showing that the TRDU performed well hydrodynamically, that it had the ability to switch from combustion mode to gasification mode easily and safely, that solids could be fed to and removed from the system, and the J-leg/standpipe and cyclone performed according to their design specifications. The staged char combustion mixing zone design was not verified because of the lack of nonvolatile char and a reduced operational schedule. This resulted in oxygen breakthrough from the mixing section into the riser as a result of insufficient carbon inventory in the circulating solids.

3.0 PROJECT DESCRIPTION

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 capable of operating at the outlet design conditions of the TRDU. The TRDU is a 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 300 scfm, and an operating pressure of 120–150 psig. Phase I includes upgrading the TRDU based upon past operating experiences. Additions will include a nitrogen supply system upgrade, upgraded LASH (lime ash) auger and coal feed lines, adding a second pressurized coal feed hopper and a dipleg ash hopper, and modifications to spoil the performance of the primary cyclone.

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 150 psig and an internal temperature of 1090°C (2000°F). Table 1 summarizes the operational performance for the TRDU under the previous contract (6).

The premixed coal and limestone feed to the transport reactor can be admitted through three nozzles, which are at varying elevations. Two of these nozzles are located near the top of the mixing zone (gasification), and the remaining one is near the bottom of the mixing zone (combustion). During operation of the TRDU, feed is admitted through only one nozzle at a time. The coal feed is measured by an rpm-metering auger. Oxidant is fed to the reactor through two

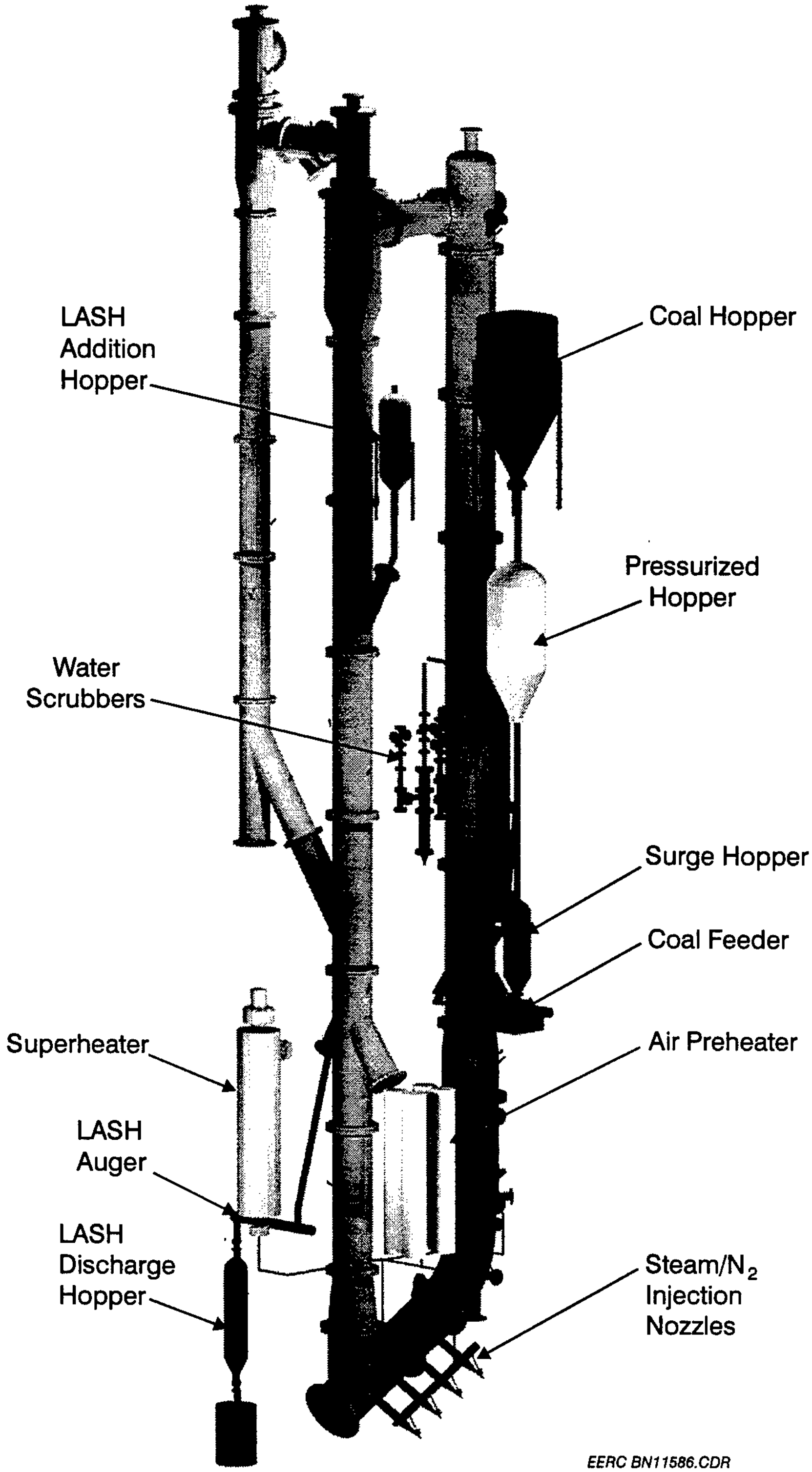

Figure 1. TRDU in EERC gasification tower.

TABLE 1

TRDU Operational Parameters

Parameter	Actual Operating Condition[1]
Coal	Wyodak
Moisture Content, %	20
Pressure, psig	117–122
Steam:Coal Ratio	0.38
Air:Coal Ratio	3.5–4.7
Ca:S Ratio, mole	1.5
Air Inlet Temperature, °C	425
Steam Preheat, °C	390
Coal Feed Rate, lb/hr	173
Gasifier Temperature, maximum °C	850
ΔT, maximum °C	121
Conversion, %	96
High Heating Value of Fuel Gas, Btu/scf	104
Heat Loss as Coal Feed, %	27
Riser Velocity, ft/sec	28–30
Heat Loss, Btu/hr	420,000[2]
Standpipe Superficial Velocity, ft/sec	0.4–0.54

[1] Steady-state conditions were not achieved.
[2] Estimated heat loss; steady-state conditions were not achieved.

pairs of nozzles at varying elevations within the mixing zone. For the combustion mode of operation, additional nozzles are provided in the riser for feeding secondary air. Hot solids from the standpipe are circulated into the mixing zone where they come into contact with the oxidant and the steam, which is injected into the J-leg. This feature enables spent char to contact oxidant and steam prior to the fresh coal feed. This staged gasification process is expected to enhance the process efficiency. Gasification or combustion and desulfurization reactions are carried out in the riser, as coal, sorbent, and oxidant (with steam for gasification) flow up the tube. The solids circulation into the mixing zone is controlled by the solids level in the standpipe.

The riser, disengager, standpipe, and cyclones are equipped with several internal and skin thermocouples. Nitrogen-purged pressure taps are also provided to record differential pressure across the riser, disengager, and the cyclones. The bulk of entrained solids leaving the riser is separated from the gas stream in the disengager and circulated back to the riser via the standpipe. A solids stream is withdrawn from the standpipe via an auger to maintain the system's solids inventory. Gas exiting the disengager enters a primary cyclone that has been modified to provide variable particulate collection performance. Solids from diplegs of the primary cyclone are collected in a lock hopper. Gas exiting this cyclone enters a jacketed pipe heat exchanger before entering the HGC filter vessel. The cleaned gases leaving the HGC filter vessel enter a quench system before being depressurized and vented to a flare.

The quench system uses a sieve tower and two direct-contact water scrubbers to act as heat sinks and to remove impurities. All water and organic vapors are condensed in the first scrubber, with the second scrubber capturing entrained material and serving as a backup. The condensed liquid is separated from the gas stream in a cyclone that also serves as a reservoir. Liquid is pumped either to the shell-and-tube heat exchanger for reinjection into the scrubber or down to the product receiver barrels.

3.1 Hot-Gas Filter Vessel (HGFV)

Subtask 3.13 – Hot-Gas Filter Testing is a new hot-gas filter program started in January 1995 as an addition to the METC Cooperative Agreement. This new subtask, which supported upgrades to the TRDU, is supporting three 200-hour filter tests. First-year funding made available in March 1995 has supported upgrades to the TRDU, installation of the new filter vessel and new inlet–outlet piping requirements and will support one 200-hour filter test if initial shakedown of the TRDU demonstrates acceptable performance after the upgrades have been completed. The preliminary filter design criteria are summarized in Table 2.

This vessel is designed to handle all of the gas flow from the TRDU at its expected operating conditions. The vessel will be approximately 48 in. ID and 185 in. long and is designed to handle gas flows of approximately 325 scfm at temperatures up to 980°C (1800°F) and 130 psig. The refractory will have a 28-in. ID with a shroud diameter of approximately 24 in. The shroud diameter might change, depending on the results from some computational fluid dynamic calculations that are currently being performed, but is not expected to change significantly. The vessel is sized such that it could handle candle filters up to 1.5 m long; however, 1-m candles are expected to be utilized in the initial 540°C (1000°F) gasification tests. Candle filters are projected to be 2.375 in. OD with a minimum 4-in. center line-to-center line spacing. It has been

TABLE 2

Design Criteria for the Pilot-Scale Hot-Gas Filter Vessel

Range of Operating Conditions	
Inlet Gas Temperature	540°–980°C (1000°–1800°F)
Operating Pressure	120–150 psig
Volumetric Gas Flow	325 scfm
Number of Candles	19 (1 or 1.5 m)
Candle Spacing	4.25 in. ℄ to ℄
Filter Face Velocity	2.5–10 ft/min
Particulate Loading	<10,000 ppm
Temperature Drop Across HGFV	< 30°C (50°F)
Nitrogen Backpulse System	Unheated

recommended to go with an even larger candle spacing. The total amount of 1-m candles that can be mounted in the current geometry of the hot-gas filter vessel (HGFV) tube sheet is 19. With this number of candles, it will be possible to go to a candle spacing as large 4.25 in. in our filter vessel.

This will enable filter face velocities as low as 2.5 ft/min to be tested. Phases III through V consist of 200-hr hot-gas filter tests under gasification conditions using the TRDU with the HGC operating at temperatures of 540°-650°C (1000°-1200°F), 120 psig, and increasing face velocities for each test. Higher face velocities would be achieved by using fewer candles. The preliminary test matrix will be to perform the first test at 540°-650°C (1000°-1200°F), 120 psig, 2.7 ft/min face velocity. The second test will remove six candles to increase the face velocity to approximately 4.0 ft/min at the same operating temperature and pressure. The openings for the six removed candles will simply be blanked off. If this test is successful, the third test will remove another six candles, seal off the candle openings, and repeat the procedure. The filter face velocity would increase up to 7.5 ft/min It has been proposed to look at seven Industrial Filter & Pump (IF&P) Fibrosic candles along with their ceramic tube sheet. Six ceramic fiber candles from the 3M company will also be tested, along with six metal candles from Pall Advanced Separation Systems Corporation.

Because an existing vessel could not meet our cost limitations or the size constraints dictated by the gasification tower space, a new filter vessel was purchased. The design specifications were for a metal temperature of 425°C (800°F) and operating pressures of up to 150 psi. A drawing of the new vessel design is presented in Figure 2. The anticipated delivery date for the new vessel is late June 1995. Installation of filter vessel and piping runs to and from the hot-gas filter vessel are expected to be completed by September 1, 1995, with leak checking and shakedown testing of components occurring in the first few weeks of September, followed by an 200-hr gasification test on Wyodak subbituminous coal with operation of the filter vessel by the end of September.

Ports have been added in the filter vessel for allowing temperature and pressure measurements to be obtained and for the insertion of a water-cooled boroscope probe for inspecting candle filters on-line. The ash letdown system consists of two sets of alternating high-temperature valves with a cylindrical pressure vessel to act as a lock hopper. Additionally, a preheat natural gas burner will be required to prevent condensation from collecting in the vessel while the gasifier is starting up. The hot gas from the burner will enter the vessel via a nozzle inlet separate from the dirty gas.

The nitrogen backpulse system will be constructed to backpulse up to four sets of four or five candle filters in a time-controlled sequence. Because of cost limitations, the backpulse nitrogen will not be capable of being heated to more than ambient temperatures. The pulse length and volume of nitrogen displaced into the filter vessel is controlled by the regulated pressure (up to 800 psig) of the nitrogen reservoir and the solenoid valves used to control the timing of the gas pulse. Figure 3 depicts the preliminary filter vessel location in the gasifier tower and piping requirements for its future use in conjunction with the TRDU. Since the first series of gasification tests are to be completed in the 540°-650°C (1000°-1200°F) range, a length of heat exchanger is

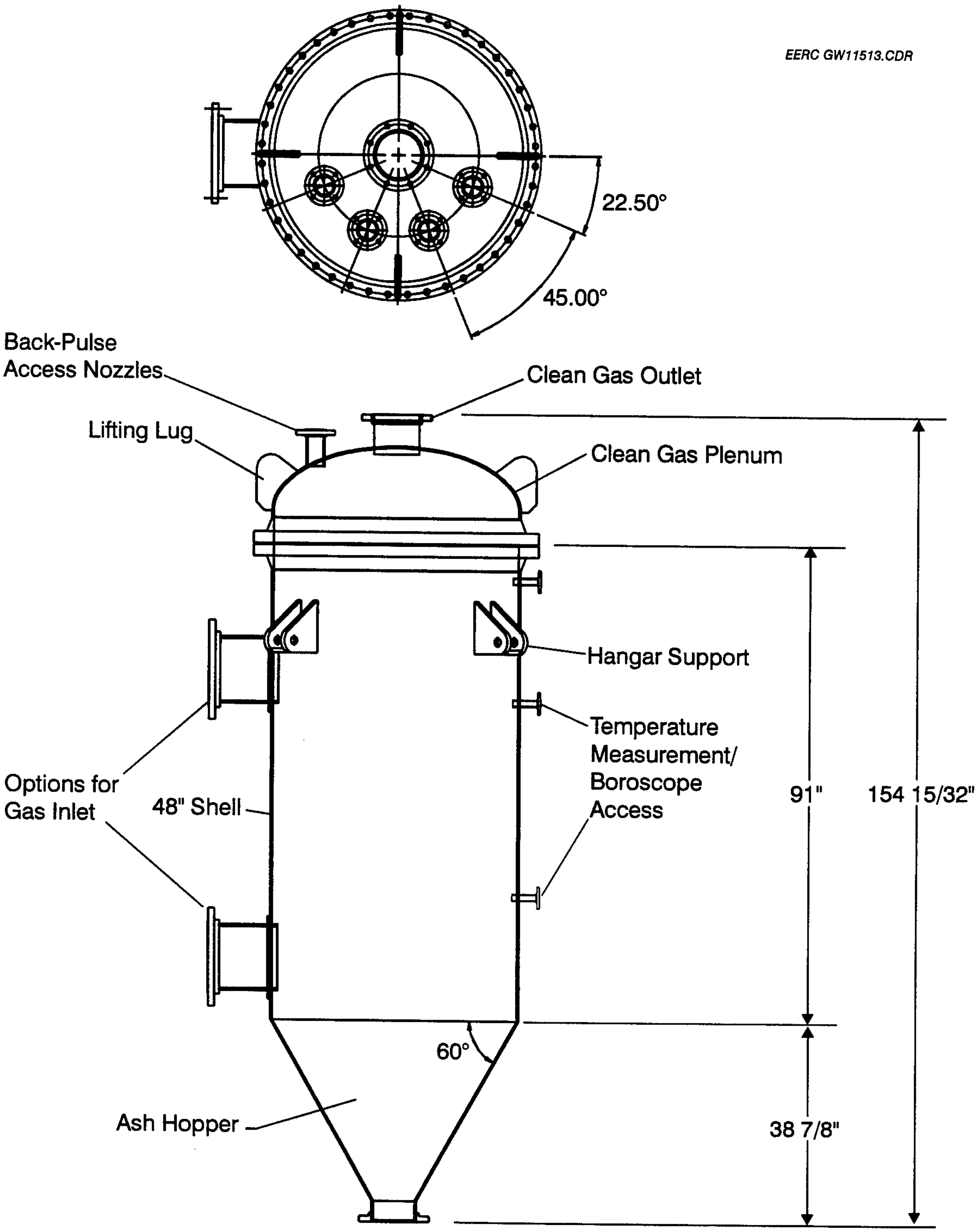

Figure 2. Schematic of the new filter vessel design.

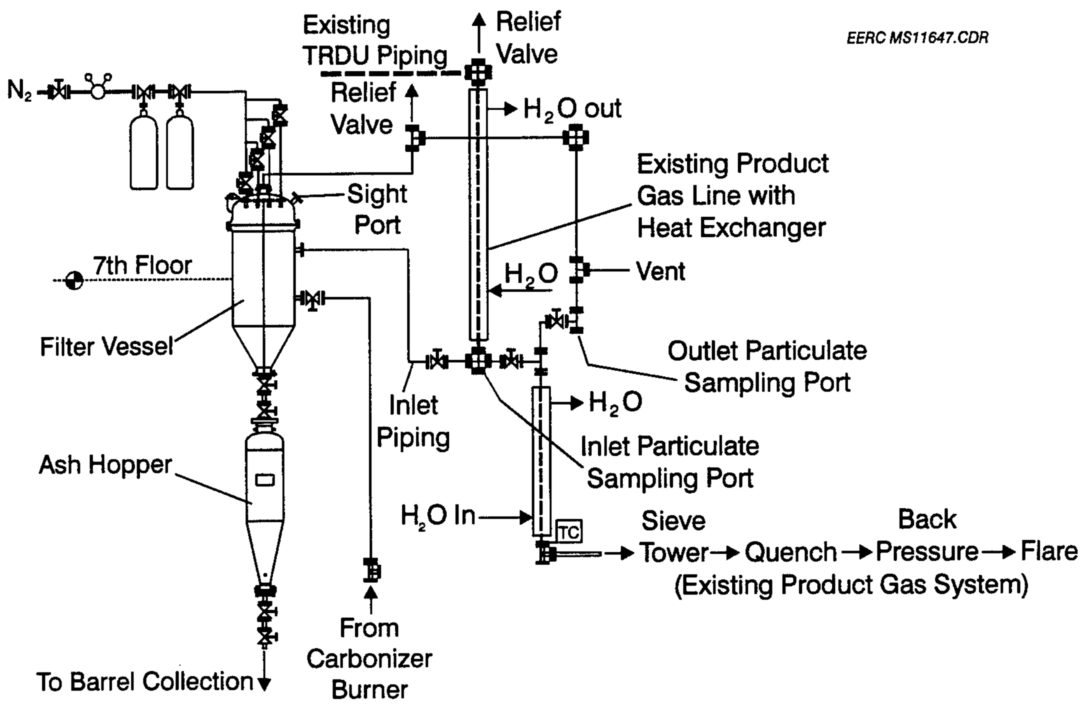

Figure 3. Schematic showing additional high-temperature, high-pressure piping needed for moderate-temperature (540°–650°C) filter testing.

utilized to drop the gas temperature to the desired range. Inserting an existing set of high-temperature valves in the fuel gas heat exchanger will allow bypassing the filter vessel during start-up and shakedown of the TRDU and enable switching to the preheated filter vessel when steady-state conditions are achieved. In addition, sample ports for obtaining particulate and hazardous air pollutant (HAP) samples have been added.

TRDU operation and filter element testing will benefit other ongoing projects at the EERC. The first sampling and analysis activities will be conducted to generate hazardous air pollutant 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 will be collected in support of a project entitled "Hot-Gas Filter Ash Characterization" jointly funded by METC and EPRI. While the cost of this specific data collection will be covered by the individual projects, the synergy that results from the integration of these projects will minimize the cost for collecting this information for all involved projects.

3.2 High-Pressure and High-Temperature Sampling System

The high-pressure and high-temperature sampling system (HPHTSS) was designed to extract dust-laden flue gas isokinetically from either an oxidizing or reducing environment. The maximum design temperature of the gas stream is specified as 980°C (1800°F) for the HPHTSS. The maximum working pressure of the gas stream for the HPHTSS is specified as 150 psig.

The probe for the HP is a 3/8-in.-OD and 1/8- in.-ID 304 stainless steel tube. The probe is used for only one sampling test and then discarded. The key to the sampling system is the use of a vessel, designed to withstand high-pressure and high-temperature conditions, to enclose the low-pressure sampling devices.

The vessel was constructed of 5-in. Schedule 80 pipe and fitted with raised face 300-lb flanges. The material used for the HPHTSS pressure vessel was 316L stainless steel. The HPHTSS was designed to house both multicyclone assemblies with backup filter and a backup filter alone.

The principle of operation is to pressurize the outside of the sampling device (i.e., multicyclone assembly or backup filter) with nitrogen at a slightly higher gas pressure then the system pressure of the flue gas. The pressure differential between the nitrogen gas within the pressure vessel and the flue gas within the sampling device will be maintained at less than 5 psig.

If the HPHTSS is operating in a reducing environment where the presence of organic vapors is a possibility, the pressure vessel is capable of operating at temperatures as high as 540°C (1000°F) and maintaining nitrogen gas pressures up to 150 psig. This will prevent the heavier organic vapors from condensing while passing through the particulate sampling assembly. Electric resistance heaters of sufficient wattage will be used to heat pressure vessel to specified temperatures.

Once the process gas exits the sampling assembly, the gas pressure is reduced through a throttling valve to approximately 50 psig. The throttling valve will also act as the flow control valve for the sampling system. A second valve was installed in series in the event that the primary throttling valve failed to close.

After the throttling valve, the process gas is cooled through a set of impingers to remove moisture and organic vapors if present. A set of up to six impingers may be used in this sampling system. These impingers are rated for 200 psig at 120°C (250°F) maximum operating conditions. The impingers are made of 304 stainless steel, with the interior surfaces coated with teflon. The teflon-coated surfaces allow the HPHTSS to be used for trace metal sampling.

The dry gas is then throttled to atmospheric pressure and metered through a rotometer and orifice in order to measure total flow. The process gas then reenters the main gas stream for cleanup and disposal.

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