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SHELL TEMPERATURES FOR A SINGLE-HEATER DIFFUSER

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A new diffuser/permeator design has been proposed for a new Savannah River Site tritium project. The use of a single heaterwell in the center of the shell had raised concerns that the Pd/Ag coils may be shielding radiative heat transfer to the walls thus reducing Pd/Ag tube temperatures near the shell below the recommended minimum operating temperature.

The diffuser was fitted with thermocouples to measure shell temperatures during testing. Tests were run with the shell evacuated, helium Feed flows of 0, 1000, and 2000 sccm; Bleed pressures ranging from 0 to 203 kPa, and heater temperatures of 650, 675, and 700°C. Hydrogen permeation tests were run with two hydrogen/helium mixtures and Feed rates to simulate 1st and 2nd stage diffuser operations.

Approximately 20 hours were required to bring the diffuser from ambient temperature to steady-state conditions. For tests with a heater temperature of 675°C and no hydrogen flow, helium flow rate and pressure had little impact on the measured shell temperatures, the thermowell temperature, roughly 415°C, and altered heater output by only 11 watts. Conversely, controlling the thermowell temperature to 415°C during hydrogen permeation tests increased heater power output, lowered heater temperature, and increased shell temperatures. The tests showed the diffuser can perform its intended function with reasonable assurance that the Pd/Ag tubes were within the recommended temperature range.

I. INTRODUCTION

The Savannah River Site (SRS) Tritium Facilities is in the design and construction phase of the Tritium Extraction Facility (TEF). The TEF is to extract tritium from tritium producing burnable absorber rods (TPBARs) irradiated in light-water reactors. The extraction gas obtained from the TPBARs is expected to contain tritium, protium, He-3 and He-4, and low levels of impurities such as methane and carbon oxides.

The system for processing the extraction gas stream will utilize diffusers/permeators. Diffusers constructed of palladium-silver (Pd/Ag) alloy tubing wound into coils have been used for many years at SRS to separate hydrogen isotopes from other gases.[1] A new diffuser design will be used in the TEF.

The new diffuser design uses a single heater in the center of the vessel's shell. Concerns were expressed about uneven heating of the Pd/Ag tubing by the single heater: tubing closest to heater being above the vendor's recommended maximum temperature of 454°C and tubing closest to the shell below the vendor's recommended minimum temperature of 316°C. This paper describes the results of shell temperature measurements made during diffuser tests without and with hydrogen permeation and the conditions to be used to keep the Pd/Ag tubes within the vendor's recommended temperature range.

II. BACKGROUND

The TEF extraction gas clean-up system is similar to fusion reactor plasma exhaust clean-up systems[2] where a diffuser is first used to remove hydrogen isotopes (Q_2). Next, cracker/purifier/reformer bed(s) are used to process impurities which are followed by another diffuser for further Q_2 removal. The hydrogen isotopes are sent for isotopic separation while the 2nd diffuser Bleed stream is sent to an effluent clean-up system.

The design basis for the TEF tritium clean-up system, treating all carbon impurities as methane, was 87.5 percent Q_2, 0.34 percent CQ_4, with a balance of helium isotopes. The Q_2 composition leaving the 1st stage diffuser will be controlled to 20 percent by throttling the Q_2 permeate ("Pure") flow from the 1st stage diffuser shell. This process reduces the amount of gas fed to the purifier bed by a factor of six and concentrates the methane to 2.2 percent. SAES® St909 will be used to crack methane followed by a 2nd stage diffuser for additional hydrogen isotopes removal.

The current SRS diffuser had been described in a previous paper.[1] Both the current and new diffusers have five Pd/Ag coils and a thermowell contained within a shell. The coils are distributed radially about the center at a 72° spacing. The previous design had one heater located in the center of each diffuser coil and the thermowell located in the center of the shell. The new design had a single heaterwell located in the center of the shell and the thermowell located inside one of the diffuser coils.

Both diffuser designs utilize "In-Out" Q_2 flow: Feed introduced into the inside of the coils and hydrogen isotopes diffuse out into the diffuser shell evacuated to a lower hydrogen isotope partial pressure. The retentate exits the coils through the Bleed outlet line. Both diffusers have the Feed and Bleed lines on one end of the vessel while the "Pure" process line and access for inserting heaters and thermocouples is at the other end of the diffusers.

Insulation covers the shell and end caps in both diffuser designs. Figure 1 shows an internal picture of the new style diffuser using a video scope inserted into the Pure process line.

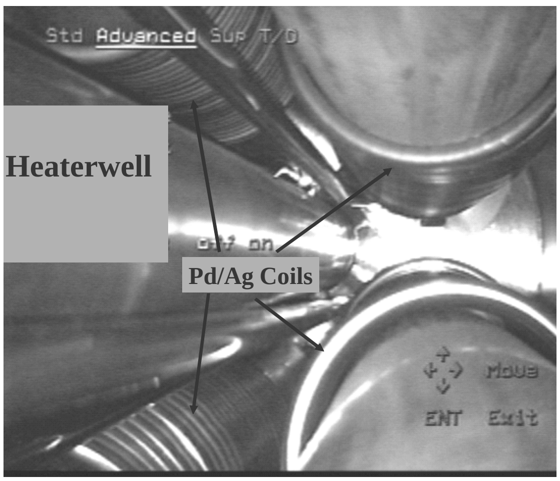

Fig. 1. Internal Diffuser Videoscope Picture

III. EXPERIMENTAL

The tests used a TEF diffuser manufactured by RSI.[3] Diffuser coil temperatures were to be estimated by measuring heater temperature, thermowell temperature, and diffuser shell temperatures without breaching the integrity of the welded vessel.

Twelve, 1.59 mm (1/16 inch) holes were drilled perpendicular to the circumference of the process shell, through the aluminum skin which held the insulation in place, for insertion of type K thermocouples (TCs). Figure 2 shows the TC placement schematic and Figure 3 shows the TCs after installation into the vessel. The Figure 3 inset shows the TC bends used to help hold the TC tip in mechanical contact with the shell. Electrical resistance measurements were made between the TCs and the diffuser to verify mechanical contact between the TC's tip and the diffuser shell.

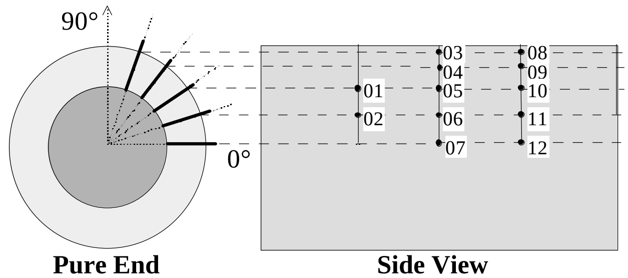

Fig. 2. Diffuser TC Placement Schematic

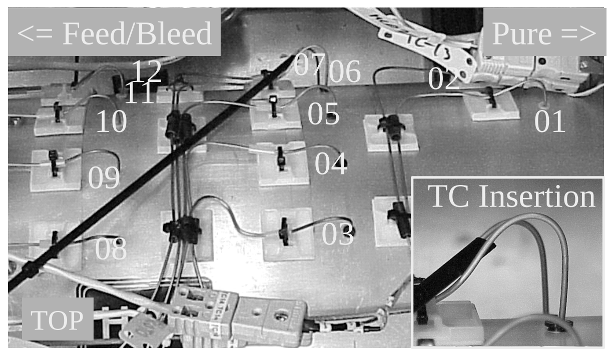

Fig. 3. Diffuser Top View with Installed Thermocouples

The three rows of TCs were positioned to measure shell temperatures at the ends and the middle of the diffuser coils. TCs at the Feed/Bleed end were anticipated to produce lower temperatures than those at the Pure end due to greater conductive heat losses from the Feed/Bleed end diffuser coil manifolds. Radial spacing of 18°C between the TC was to measure temperature gradient along the wall due to shielding of radiant heat transfer by the diffuser coil.

A 1200 watt Watlow cartridge heater was used which had two, type K TCs in the "A" position: in the heater core to indicate internal heater temperature. A SCR controller was used for temperature control. Gas flows were supplied by mass flow controllers and test pressures controlled at the outlet of the Bleed line using a pressure control valve. The Pure line was evacuated using a molecular drag pump back by a scroll pump to less than 67 Pa (0.5 torr) during the helium test.

The first test had helium flow through the coils, the shell evacuated, a 400°C thermowell temperature set point, and a 650°C heater interlock temperature. As anticipated, diffuser heat-up was not obtained due to the thermal lag between the heater and the thermowell. Manually resetting the heater interlock controller 7 times over a 45 minute time period yielded only a 140°C thermowell temperature.

Different control methods were used for the other tests. Automatic temperature control with heater temperature set points were used for tests without hydrogen and manually set power output control using the thermowell temperature was used for tests with hydrogen. Table I summaries conditions for the diffuser tests.

TABLE I. Diffuser Test Conditions

Test #	Control Temp.[a], °C	Feed Flow, sccm		Pressure, kPa	
		He	H_2	Bleed	Pure
2	650	2000	0	101	0
3	675	2000	0	101	0
4	675	1000	0	101	0
5	675	1000	0	203	0
6	675	2000	0	203	0
7	700	1000	0	101	0
8	675	0	0	0	0
9	415	252	64	203	"best"
10	415	252	1760	203	40.5

[a]Test #2-#8: heater. Test #9-#10: thermowell

Test #9 started at the conclusion of Test #8 by swapping the SCR controller input signal from the heater TC to the thermowell TC. During this transfer, TC02 and its anchor were knocked loose and could not be reliably reinserted into its previous configuration. Thus, direct comparison of TC02 data for Test #9 and #10 to previous data can not be made. Test #10 started at the conclusion of Test #9 by increasing the feed hydrogen flow rate and routing the Pure flow through a pressure control valve set at 40.5 kPa.

IV. RESULTS

Using heater temperature control took about 20 hours for the diffuser to reach steady-state operating temperatures. Starting at ambient, the heater initially goes to full power for several minutes and then decrease to less than one-third to one-fourth of full power for the remainder of the test.

Figure 4 shows steady-state shell temperatures and Table II summarizes steady-state results for the tests. The shell pressure was less than 20 Pa (0.15 torr) for Tests #2 through #8, 307 Pa (2.3 torr) for Test #9 and 40.7 kPa (305 torr) for Test #10. Figure 5 is a plot of some Table II data versus heater temperature. The symbols connected by solid lines in Figure 5 indicate tests with helium while symbols connected with dashed lines indicate test with helium and hydrogen.

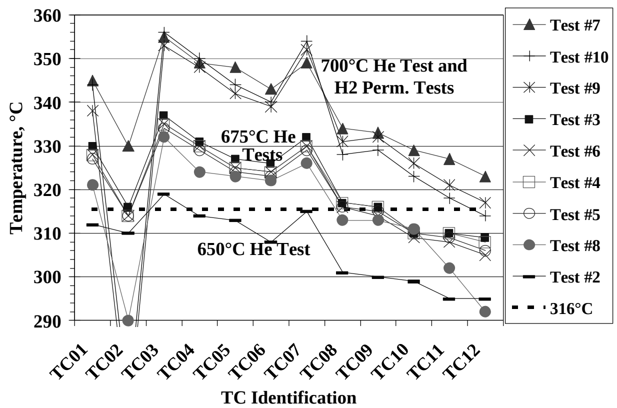

Fig. 4. Steady-State Shell Temperatures

TABLE II. Steady-State Results

Test #	Heater Power, Watts	Temperature, °C			
		Heater	T.well	Max.[a]	Min.[b]
2	226	649	393	319	295
3	247	674	416	337	309
4	241	674	416	335	307
5	239	674	416	334	306
6	245	674	415	335	306
7	262	699	438	355	323
8	236	674	416	332	292
9	256	624	413	353	317
10	263	617	415	356	314

[a]TC03 for all tests.
[b]TC12 for all tests.

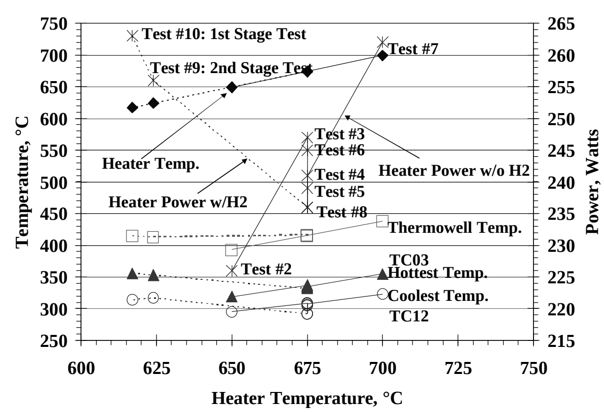

Fig. 5. Steady-State Results versus Heater Temperature

V. DISCUSSIONS

Table II and Figures 4 and 5 shows that for tests with 675°C heater control and no hydrogen feed, helium flow rate and pressure had little impact on measured shell temperature and altered heater power output by 11 watts between Test #3 (fastest gas velocity) and Test #8 (full vacuum). These helium-only tests showed doubling the mass flow rate at constant pressure increased power consumption by 6 watts and that doubling the pressure at constant mass flow rate increased power consumption by 2 watts.

For tests with a thermowell temperature of approximately 415°C, Tests #3-6 and Tests #8-10, Figure 4 shows an approximately 20°C increase in shell temperatures when hydrogen permeates into the shell. Figure 5 also shows heater power output increased and heater temperature decrease when hydrogen was permeating.

Figure 4 shows that for Test #8, TC08 through TC12 were below the vendor's recommended minimum temperature of 316°C, but when hydrogen was permeating the tubes, only TC12, at 314°C, was below 316°C. It is reasonable to infer that the Pd/Ag tubes are at temperatures higher than the shell temperatures and thus operating the diffuser with a thermowell temperature near 415°C does not expose the Pd/Ag tubes to temperatures below 316°C.

For Test #8, with a thermowell temperature near 415°C, the maximum heaterwell O.D. temperature was estimated to be 464°C: 10°C above the vendor's recommended maximum Pd/Ag operating temperature. Assumptions for this calculation were a 75°C temperature drop between the heater type A TC measurement and the heater sheath (based on conversations with a Watlow technical representative), 236 watts of radiant heat transfer from the heater cartridge to the heaterwell with emissivities of 1.0, and conductive heat transfer through the heaterwell. Again, it is reasonable to infer that the Pd/Ag tubes are at temperatures lower than the heaterwell temperature and thus operating the diffuser with a thermowell temperature near 415°C does not expose the Pd/Ag tubes to temperatures above 454°C.

If the Test #10 Pure pressure is equal to the partial pressure of hydrogen in the Bleed stream, the Bleed stream hydrogen composition was 0.15 percent.

VI. CONCLUSIONS

Diffuser temperature control, especially during heating from ambient temperature, using only the thermowell temperature is not a viable control scheme due to the thermal lag time between heater temperature and thermowell temperature. Temperature control is better performed using heater temperature for the controller set point until a thermowell temperature near 415°C is obtained. Once the thermowell is heated to this temperature, control can be switched to using thermowell temperature.

Tests without hydrogen permeation showed steady-state shell and thermowell temperature increased with increased heater temperature. Changes in Feed helium flow rate or pressure produced only small changes in heaterwell or shell temperatures. Compared to test without hydrogen, tests with hydrogen permeating the Pd/Ag tubes increased heater power consumption, increased shell temperatures, and lowered heater temperature: even with larger power outputs.

Operating the diffuser with a thermowell temperature near 415°C gives reasonable assurance that the Pd/Ag coils are within the vendor's recommended operating temperature range of 316°C to 454°C. A test simulating 1st stage diffuser operation showed that temperature control of the diffuser can be maintained while controlling the pressure of the Pure stream to produce a 20 percent Q_2 Bleed stream. A test simulating 2nd stage diffuser operation showed a Bleed stream of less than 0.2 percent Q_2 can be obtained.

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