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SUBJECT: Helium Leak Test on HRT Heat Exchanger No. 8532
At Y-12

TO: S. E. Beall

FROM: S. I. Kaplan

1. S. E. Beall
2. E. G. Bohmann
3. J. I. C. Iv
4. W. J. C. Iv
5. L. J. C. Iv
6. C. J. C. Iv
7. J. J. C. Iv
8. J. J. C. Iv
9. J. J. C. Iv
10. P. J. C. Iv
11. S. J. C. Iv
12. H. J. C. Iv
13. W. J. C. Iv
14. R. J. C. Iv
15. J. J. C. Iv

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SUMMARY

HRT Heat Exchanger No. 8532 was Helium leak-tested at Building 9204-1, Y-12 Plant, on February 14-16, 1956. A leak rate of about 0.006 cc. per day was found between the tube and shell sides when the tubes were pressurized to 1235 psia with Helium and the shell evacuated to 7 μ . Sample calculations are presented for gas flows through capillary leaks.

EQUIPMENT AND METHODS

The shell was evacuated with a two-stage pumping system incorporating an oil diffusion pump and mechanical forepump (see Fig. 1). Leak testing was performed with a Consolidated Model 24-101A Leak Detector and a standard leak rate was established with a K-25 calibrated capillary leak rated at 2.39 micron-ft³ per hour.

The unit was prepared for testing by pumping down the shell with a Kinney DVD 8810 mechanical vacuum pump until no more water was collected in the pump oil. Projecting dead-ended nipples were heated with a gas torch during pumping to prevent ice pockets from forming. The shell was then piped to the two-stage vacuum system mentioned above, and the mechanical pump was connected to the tube side. Pumping and external leak-hunting was continued until the shell pressure levelled off at 7 μ absolute. At this point all external joints were helium-tight except the flanged connection from the shell to the vacuum line, and the leakage at this joint was barely detectable with the leak detector (i.e., insufficient to affect the shell pressure). It is felt that the residual pressure was due to outgassing by traces of organic material inside the shell. All tests were run at a shell pressure of 7 μ . To insure that no water was trapped in the annuli between the tubes and the tube socket holes in the sheet, a preliminary check was made with 1000 psig. of Nitrogen on the tube side, with the idea that warpage of the tubesheet under pressure might expand the annuli and allow water to escape.¹ No pressure rise was noted.

The actual test was performed in two stages: First, Helium was admitted to the previously evacuated tube bundle, and leak detector readings were made with tube pressures of 15 psi absolute, 400 psig., 800 psig., 1000 psig., and 1240 psig. of Helium. The main pumping system was valved off, and the vacuum maintained on the vessel by the leak detector alone. A slight rise in Helium pickup was noted on the leak detector, of insufficient magnitude to permit leak rate determination (see Appendix I). Next, the 1240 psig. of Helium pressure was allowed to remain in the tubes overnight, with the vacuum pumps valved off from the shell to isolate it. The shell pressure was 7 μ when the shell was isolated at 10:15 p.m. on 2/15/56, and had risen to 11 μ by 9:05 a.m. the following morning. The Helium leak rate indication of 0.7 μ , at 10:15 p.m., jumped to 1.8 when the leak detector was put on the line again in the morning. Both of these readings were on "Sensitivity = 1" scale.

¹Memo, S. I. Kaplan to S. E. Beall, "Interpretation of Leak Test on Heat Exchanger 8532," dated January 25, 1956.

The leak detector was calibrated, following the operations described above. The shell was again pumped down until the internal pressure was 7μ and the leak-detector background reading was 0.7, and Helium was bled in for 30 seconds through the $2.39 \text{ micron-ft}^3/\text{hr.}$ standard leak. The leak indication continued to increase for several minutes, and it was surmised that a pocket of Helium, trapped inside the leak casing, was slowly bleeding into the system through the calibrated capillary. Consequently, at 12 minutes after the initial gas introduction the leak was uncapped again, the end pocket quickly blown out with air, and the entire leak assembly blanketed with Nitrogen, to purge it. The leak was then recapped. Within 30 seconds the Helium indication levelled off, and after 7 minutes it began to subside. The total Helium introduction time was therefore entered as 12 minutes. The total rise was 7.0 leak rate units.

RESULTS

Leak indicator change, 10.8 hr. at 1230 psig. average tube pressure: 1.1 units
 Leak indicator change, 0.2 hr. He admission, $2.39 \text{ micron-ft}^3/\text{hr.}$: 7.0 units

$$\text{Total Helium admitted} = 0.2 \times 2.39 = 0.48 \mu\text{-ft}^3$$

$$\frac{0.48 \mu\text{-ft}^3 \times (28.3 \times 10^3) \text{ cc/ft}^3}{7.6 \times 10^5 \mu/\text{atm}} = .0167 \text{ cc. at S.T.P.}$$

$$\text{Leakage from tube to shell} = \frac{1.1}{7.0} \times (.0167) = .0026 \text{ cc. at S.T.P.}$$

$$\text{Leak Rate} = \frac{24}{10.8} (\text{hr.}) \times .0026 = .0058 \text{ cc./day at S.T.P.}$$

CONCLUSIONS

A small leak exists between the tube and shell sides of the heat exchanger, amounting under the test conditions to about 0.006 cc. (S.T.P.) Helium per 24-hour day. Due to the geometry of the leak (or leaks) involved, the difference in leak rate incurred by maintaining the shell pressure at 7μ , instead of the 1μ specified for HRT testing, is nil (see Appendix II).

S. I. Kaplan
 S. I. Kaplan

SIK:be

Schematic Diagram of Equipment Used for Helium Leak Test of
Heat Exchanger 8531

APPENDIX

I. LOG EXTRACTS

Date	Time	Tube Helium Pressure	Shell Pressure	Leak Detector Reading	Sensitivity Scale	Remarks
2/15	9:15P	15 psia	7 μ	0.3 - 0.45	1	
	9:35P	15 psia	7 μ	0.3 - 0.45	1	
	9:37P	400 psig	7 μ	0.3 - 0.55	1	
	9:44P	800 psig	7 μ	0.5 - 0.65	1	
	9:52P	1000 psig	7 μ	0.55- 0.7	1	
	10:06P	1000 psig	7 μ	0.55- 0.7	1	
	10:18P	1240 psig	7 μ	0.6 - 0.8	1	
2/16	9:05A	1220 psig	11 μ	1.8	1	Vessel isolated overnight
	2:46:45P	15 psia	7 μ	0.5 - 0.7	1	Admitting He to std. leak
	2:47:15P	15 psia	7 μ	0.65 av.	1	Capped leak
	2:49:00P	15 psia	7 μ	2.8	1	
	2:58:45P	15 psia	7 μ	2.50	3	Purged leak with N_2
	2:59:45P	15 psia	7 μ	2.55	3	
	3:05:45P	15 psia	7 μ	2.45	3	

II.

NATURE OF GAS FLOW THROUGH CAPILLARY LEAKS

The extreme cases which might represent the leak occurring in Heat Exchanger 8531 are: (1) a path through a tube-to-sheet weld which extends along a tube for the full thickness of the sheet; and (2) a pinhole in a tube, with a length equal to the thickness of the tube wall. Depending upon the dimensions of the leakage path and the pressure differential across it, the flow characteristics may be turbulent, laminar, transitional, or molecular, or may vary in succession along the path.

In Case (1) below, the flow pattern has been synthesized for a leak approximating the length of the tubesheet thickness. For simplicity, this model assumes a circular, uniform cross-section throughout.

$$\text{Assume leak dia.} = .019 \text{ mils} = 4.83 \times 10^{-5} \text{ cm} = 1.58 \times 10^{-6} \text{ ft.}$$

$$A = \text{Cross-section} = .785 (4.83)^2 \times 10^{-10} = 1.84 \times 10^{-9} \text{ cm}^2$$

$$C = \text{Flow} = 2.5 \times 10^{-4} \text{ cc/hr (atm.)}$$

$$V = c/A = \frac{2.5 \times 10^{-4}}{1.84 \times 10^{-9}} = 1.36 \times 10^5 \text{ cm/hr} = 4460 \text{ ft/hr.}$$

$$\mu = 0.02 \text{ cp. (at atm. and at 1235 psia), } \rho = 1.114 \times 10^{-2} \text{ lb./ft}^3$$

Since ρ and V vary inversely from each other with pressure,

$$\begin{aligned} N_{\text{Re}} (\text{atm.}) &= N_{\text{Re}} (1235 \text{ psia}) \\ &= \frac{DVP}{\mu} = \frac{1.58 \times 10^{-6} (4.46 \times 10^3) (1.114 \times 10^{-2})}{.02 (2.42)} = 1.62 \times 10^{-3} \end{aligned}$$

Therefore the flow at the leak entrance is non-turbulent.

Knudsen's expression² for gases in transitional flow may be written as follows, for Helium:

$$C = 0.182 \frac{D^4}{N} \bar{P} + (32.7 \frac{D^3}{N}) \left(\frac{1 + .095 \bar{DP}}{1 + .117 \bar{DP}} \right) \quad (1)$$

where C = flow in liters/sec.

N = path length, cm.

D = diameter, cm.

$\bar{P}$ = average pressure along path, microns.

²A. Guthrie and R. K. Wakerling, "Vacuum Equipment and Techniques," McGraw-Hill 1949, pp. 27-28.

Equation (1) may be rearranged as follows:

$$C = \frac{32.7D^3}{N} (J), \quad \text{where } J = \frac{1 + .1006 \bar{D}\bar{P} + .000652 (\bar{D}\bar{P})^2}{1 + .117 \bar{D}\bar{P}} \quad (2)$$

As $\bar{D}\bar{P}$ becomes small, $J \rightarrow 1$, and $C = \frac{32.7D^3}{N}$, which is the expression for pure molecular flow.

As $\bar{D}\bar{P}$ becomes large, $J \rightarrow \frac{.000652 (\bar{D}\bar{P})^2}{.117 \bar{D}\bar{P}} = .00557 \bar{D}\bar{P}$

and $C = 0.182 \frac{D^4}{N} \bar{P}$, the expression for viscous flow.

Values of J vs. $\bar{D}\bar{P}$ are tabulated below:

$\bar{D}\bar{P}, \mu\text{-cm}$	J	$.00557 \bar{D}\bar{P}$
10	.96	
20	.98	
40	1.06	.223
50	1.12	
1000	6.38	5.57
2000	11.9	11.1
3000	17.5	16.7

As the above table indicates,

$J = 1 (\pm 10\%)$ when $\bar{D}\bar{P} \leq 40$

$J = .00557 \bar{D}\bar{P} (\pm 10\%)$ when $\bar{D}\bar{P} \geq 2000$.

The above diagram breaks the leak path into regions within which the flows are viscous, transitional, and molecular, respectively.

For $D = 4.83 \times 10^{-5}$ cm,

$$P_2 = \frac{2000}{D} \frac{2000}{4.83} \times 10^5 = 4.15 \times 10^7 \mu = \underline{801 \text{ psia}}$$

$$P_3 = \frac{40}{D} \frac{40}{4.83} \times 10^5 = 8.30 \times 10^5 \mu = \underline{16.0 \text{ psia}}$$

$$\bar{P}_{12} = 801 + \frac{1235-801}{2} = 1018 \text{ psia} = 69.2 \text{ atm.}$$

$$V \text{ at } \bar{P}_{12} = \frac{4460}{69.2} = 64.5 \text{ ft/hr.}$$

Since the flow is viscous along N_{12} ,

$$N_{12} = \frac{(\Delta P)gD^2}{32\mu V} = \frac{4.34 (32.2) (1.58)^2 \times 10^{-12}}{32 (.0484) 69.2} \times 3600^2 \times 144 = .608 \text{ ft.} = \underline{7.3''}$$

$$\bar{P}_{23} = \frac{801-16}{2} + 16 = 408 \text{ psi} = 27.8 \text{ atm.} = 2.11 \times 10^7 \mu$$

$$\bar{P}D = 2.11 \times 10^7 \times 4.83 \times 10^{-5} = 10.2 \times 10^2; \quad J = 6.38 \text{ from table.}$$

$$N_{23} = \frac{32.7 D^3}{\bar{C}_{23}} J, \text{ where } \bar{C}_{23} = \frac{2.5 \times 10^{-7}}{27.8} = 9.0 \times 10^{-9} \text{ 1/hr.}$$

$$N_{23} = \frac{32.7 \times (4.83)^3 \times 10^{-15}}{9 \times 10^{-9}} \times 6.38 \times 3600 = 9.45 \text{ cm.} = \underline{3.72 \text{ inches.}}$$

$$\bar{P}_{34} = 8 \text{ psia} = .545 \text{ atm.} = 4.14 \times 10^5 \mu;$$

$$\bar{P}D = 4.14 \times 10^5 \times 4.83 \times 10^{-5} = 20; \quad J = 1$$

$$\bar{C}_{34} = \frac{2.5}{.545} \times 10^{-7} = 4.59 \times 10^{-7} \text{ 1/hr.,}$$

$$N_{34} = \frac{32.7 (4.83)^3 \times 10^{-15}}{4.59 \times 10^{-7}} \times 3600 = 2.9 \times 10^{-2} \text{ cm.} = \underline{.01 \text{ inch.}}$$

This gives a total length for the leak model of $N_{12} + N_{23} + N_{34} = \underline{11 \text{ inches}}$, which approximates roughly the tubesheet thickness.

In Case (2), representing a pinhole leak through a tube wall, the leak diameter can first be roughly approximated by setting $P_1 D = 2000$, where $P_1 = 1235$ psia:

$$D = \frac{2000}{6.38 \times 10^7} = 3.14 \times 10^{-5} \text{ cm. Tube wall} = 0.125 \text{ cm. thick.}$$

$$A = .785 (3.14)^2 \times 10^{-10} = 7.75 \times 10^{-10} \text{ cm}^2$$

$$\bar{P}_{12} = 3.19 \times 10^7 \mu = 42 \text{ atm.; } \bar{C} = \frac{2.5 \times 10^{-7}}{42} = 5.95 \times 10^{-9} \text{ liters/hr.}$$

$$\bar{P}D = 1000, J = 6.38$$

$$N = \frac{32.7 (3.14)^3 \times 10^{-15}}{5.95 \times 10^{-9}} \times 6.38 \times 3600 = 3.91 \text{ cm.}$$

$$\text{Try } \bar{P}D = 400, J = 3.02:$$

$$D = \frac{400}{3.19 \times 10^7} = 1.25 \times 10^{-5} \text{ cm}$$

$$A = .785 (1.25)^2 \times 10^{-10} = 1.23 \times 10^{-10}$$

$$N = \frac{32.7 (1.25)^3 \times 10^{-15}}{5.95 \times 10^{-9}} \times 3.02 \times 3600 = .117 \text{ cm., a good approximation of the actual tube-wall thickness.}$$

In both of the above cases, it can be observed that a change in exit pressure from 1μ to 7μ will make no perceptible difference in the leak rate, since the average pressure would be affected by only a few parts per million.