January 23, 1997

MEMORANDUM TO: Richard H. Wessman, Chief
Mechanical Engineering Branch
Division of Engineering
Office of Nuclear Reactor Regulation

FROM: Michael E. Mayfield, Chief
Electrical, Materials and Mechanical
Engineering Branch
Division of Engineering Technology, RES

SUBJECT: TRANSMITTAL OF PRELIMINARY PRESSURE LOCKING DATA FROM DOUBLE DISC GATE VALVE TESTS

The subject data in the attachment is transmitted per your request. The attachment also includes information about the valve that was tested at the Idaho National Engineering Laboratory, the steps for performing the tests, and summaries of the test results. The data and the figures describing the test results are preliminary since the final report will not be completed until February 1997. However, the data can be utilized for detecting valve trends and behaviors under pressure locking conditions.

If you have any questions on the attachment, please call Gerald H. Weidenhamer (415-6015) of my staff.

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Pressure Locking Test Results, 6-inch Anchor/Darling Valve

The U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research, recently funded research at the Idaho National Engineering Laboratory (INEL) to provide technical information to support NRC's evaluations of industry responses to Generic Letter 95-07, "Pressure Locking and Thermal Binding of Safety-Related Power-Operated Gate Valves." Pressure locking and thermal binding are potential operational phenomena that can prevent a closed gate valve from opening. Pressure locking can be either hydraulically or thermally induced. Hydraulically induced pressure locking can occur when operating sequences leave fluid at high pressure trapped in the bonnet after the upstream and downstream sides have been depressurized; thermally induced pressure locking can occur when a temperature increase causes fluid trapped in the bonnet to pressurize (as a result of thermal expansion). Either way, the effect is to cause the pressure of the fluid in the bonnet (and, in most valves, between the discs) to be higher than the pressure on the upstream and downstream sides of the disc assembly. This high fluid pressure forces the discs against both seats, making the disc assembly harder to unseat than anticipated by the typical design calculations, which generally consider frictional effects at only one of the two disc/seat interfaces.

The objectives of the INEL gate valve pressure locking research include the following:

1. Study the relationship between the pressure in the bonnet and the opening thrust, both with the valve cold and with the valve hot
2. Evaluate the impact of temperature changes in the bonnet region on the rate of bonnet pressurization
3. Evaluate the effect of valve leakage for mitigating or eliminating pressure locking
4. Evaluate the effect of entrapped air for mitigating or eliminating pressure locking.

Test Setup

The test program consisted of testing two gate valves at various pressure locking conditions. The first valve tested was a 6-in., 600-lb-class Walworth flexible wedge gate valve equipped with a Limitorque SMB-0-25 motor actuator. Preliminary results from those tests were reported earlier (available in the NRC Public Document Room, Accession Number 9606270097). The second valve tested was a 6-inch. 900-lb-class Anchor/Darling double disc gate valve equipped with a Limitorque SMB-1-60 motor actuator. This paper reports the results from the tests of the Anchor/Darling valve. Important specific information about the Anchor/Darling valve is listed below:

Upstream mean seat diameter	5.594 in.
Downstream mean seat diameter	5.438 in.
Stem diameter	1.50 in.
Internal wedge angle	25°
Disc and disc guide material	A515-70 w/COCR
Disc and body seat hardfacing	Stellite 6
Internal wedge hardfacing	Stellite 6

The valve was tested in the laboratory with the upstream and downstream flanges capped. The valve was instrumented to provide measurements of stem force, upstream, bonnet, and downstream pressures and temperatures, and other parameters.

The seat leakage for this valve, as it was received from the manufacturer, was well below accepted limits. No seat reconditioning was required. Before any testing, the valve was stroked many times (preconditioning of sliding surfaces) to provide stable disc-to-seat friction factors.

The valve was subjected to two test sequences: cold pressure locking tests and hot pressure locking tests. Both the cold tests and the hot tests examined the relationship between bonnet pressure and the unwedging load. Pressure in the bonnet was limited to 1200 psig. In addition, the hot testing evaluated the relationship between bonnet temperature and bonnet pressure (an issue related to thermally induced pressure locking) and the effects of air entrapped in the bonnet. Temperature for the hot pressure locking tests was limited to 290°F.

Cold Pressure Locking Tests

The cold pressure locking tests evaluated the relationship between the fluid pressures occurring at various locations in the valve and the valve opening thrust. The test matrix consisted of various upstream, downstream, and bonnet pressures to represent the full range of possible conditions. The test matrix also included periodic valve strokes throughout the testing to provided baseline information on the seating versus unseating relationship, the upstream and downstream seat friction values, and the load due to packing friction. The baseline strokes included a static valve closing and opening cycle and two differential pressure opening stokes, one with the downstream side and the bonnet pressurized, and one with the upstream side and the bonnet pressurized.

Two different methods were used to simulate pressure locking conditions. The first method began with the valve in the open position, and the entire valve was pressurized to 1200 psig. The valve was then closed, and the pressures in the upstream leg, downstream leg, and bonnet were reduced to the desired test values. Then the valve was subjected to an opening stroke, with measurements taken of the stem force required to extract the valve disc. The second method began with the valve in the open position and depressurized. The valve was closed, and the pressures in the upstream leg, downstream leg, and bonnet were increased (using a high-pressure pump) to the desired test values. As before, the valve was then subjected to an opening stroke, with measurements taken of the stem force required to extract the valve disc. There was no distinguishable difference in the results between the two methods. The results of the tests are listed in Table 1, corresponding with test numbers 201 through 229. The table shows the maximum stem force measured during the opening stroke (F_{test}), along with the upstream, bonnet, and downstream pressures that correspond in time with the F_{test} measurement. Where the stem packing load was measured in a static test, that value is also shown.

An additional set of cold pressure locking tests was performed after the hot tests were completed, to provide information on the repeatability of the measurements. The results of those tests are included in Table 1, corresponding with test numbers 401 through 409.

Hot Pressure Locking Tests

Tests similar to those described above were performed on the valve at elevated temperatures. Like the cold tests, these hot tests examined the relationship between bonnet pressure and the thrust required to unseat the disc during opening. Also, as part of the hot test series, tests were performed to evaluate the impact of temperature changes on the rate of bonnet pressurization, and to evaluate the effects of air entrapped in the bonnet.

Testing was performed with the valve heated both internally and externally. For the tests with internal heating, the heater in the upstream leg of the valve heated the fluid at approximately 80°F per hour until the upstream fluid temperature reached 290°F or until the bonnet pressure reached 1200 psig; the upstream pressure was controlled at 50 psig. Discharge from the downstream side of the valve was measured as an indication of leakage from the bonnet to the downstream side. For external heating, heat tape wrapped around the valve body was used to heat the fluid in the valve. As before, the target heatup rate was 80°F per hour, the fluid temperature was limited to 290°F, the bonnet pressure was limited to 1200 psig, and the upstream pressure was controlled at 50 psig.

The bonnet pressure was monitored during the heatup and compared to the measured leakage to establish the relationship between leakage and thermally induced bonnet pressurization. If and when the bonnet pressure reached approximately 1200 psig, the heatup was terminated and the valve was subjected to an opening stroke, with measurements taken of the stem load required to extract the disc.

Six heatup tests were performed. Four of those tests produced bonnet pressures capable of causing pressure locking loads. For the other two tests, the bonnet pressure was increased by other means (a high-pressure pump) before the valve was stroked open; this strategy allowed measurement of the opening stem load at hot pressure locking conditions for all six tests. The results of all the tests in the hot test series are listed in Table 1, corresponding with test numbers 301 through 383. The six heatup tests were immediately followed by pressure locking tests, identified as test numbers 306, 318, 331, 344, 361, and 375. The leak rates measured during the six tests are summarized in Table 2.

The six heatup tests included efforts to evaluate the relationship between the increasing bonnet temperature and the bonnet pressure, and to determine the effect of entrapped air on the bonnet pressure during heatup. The results of those efforts are described in the following paragraphs. The bonnet temperature and pressure were monitored during heatup, and the heatup was terminated when the bonnet pressure was established at about 1200 psig, or when the upstream temperature reached about 290°F.

Temperature Versus Pressure

Figure 1 shows valve bonnet pressure versus bonnet fluid temperature for the first three heatup tests. For these tests, the valve was heated at a rate of approximately 80°F per hour, using the external heaters (heat tape). Test 1 began at 300 psig bonnet pressure; the duration of the heatup was 1.9 hours (the bonnet pressure reached the target of 1200 psig). The bonnet pressurized rapidly after reaching 100°F. Test 2 began at 0 psig and did not pressurize, because of slight seat leakage. The duration of the heatup was 2.9 hours. Test 2 was terminated when the upstream fluid temperature

reached 290°F. Test 3 began at 600 psig and pressurized rapidly, as in Test 1. The duration of the heatup was 1.6 hours.

Effects of Entrapped Air

The last three heatup tests (Tests 4, 5, and 6) were performed to determine the effects of entrapped air on the bonnet pressure with the valve exposed to thermally induced pressure locking conditions. Tests were performed with air pockets representing 0% and 2.0% of the bonnet volume. The air pockets were established by draining a known volume from the lower valve body drain line while allowing air to enter through the high bonnet vent. Once the appropriate air volume was established, the valve was heated, as before, until the upstream fluid temperature reached 290°F or until the bonnet pressure reached approximately 1200 psig.

Figure 2 shows bonnet pressure versus bonnet fluid temperature for these tests. Test 4 was conducted with no entrapped air and internal fluid heating only, with a target heatup rate of 80°F per hour. The duration of the heatup was 1.3 hours. Test 5 had 2.0% entrapped air and internal fluid heating only (with the same heatup rate). The bonnet did not pressurize. The duration of the heatup was 4.1 hours, and the heatup was terminated when the upstream fluid temperature reached 290°F. Slight valve leakage, possibly combined with the effects of the air bubble, contributed to the failure to pressurize. Test 6 had 2.0% entrapped air but used all heaters, both internal and external, so the bonnet heated more quickly than in the other two tests. The duration of the heatup was 2.3 hours. A comparison of the results from Tests 4 and 6 illustrates the effect of entrapped air. With air trapped in the valve bonnet, rapid pressurization due to heating is delayed until a higher temperature is reached.

Table 1. Summary of pressure locking test results

Test number	Test type[a]	Test temp.[b]	Test measurements				Packing load (lb)	Disc factor
			P_{up} (psig)	P_{bonnet} (psig)	P_{down} (psig)	F_{test} (lb)		
201	S	cold	5	8	4	3726	1357	
202	HD	cold	1058	1060	-5	9420		0.403
203	HU	cold	-3	1010	1003	10599		0.446
204	S	cold	0	3	-1	3807	1350	
205	PL	cold	-4	231	-5	6626		
206	PL	cold	-4	496	-4	12588		
207	PL	cold	-4	775	-5	18128		
208	PL	cold	-4	1077	-5	23165		
209	PL	cold	-4	1085	298	20490		
210	PL	cold	-4	1119	592	19952		
211	PL	cold	-3	1100	878	15429		
212	HU	cold	-3	1025	1018	11396		0.473
213	S	cold	3	5	1	2945	1318	
214	HD	cold	1114	1117	-3	11057		0.451
215	PL	cold	307	1024	-4	21276		
216	PL	cold	609	1082	-4	19437		
217	PL	cold	927	1073	-5	15891		
218	HD	cold	1108	1111	-4	12739		0.518
219	PL	cold	606	1071	288	17579		
220	PL	cold	307	1066	296	21356		
221	PL	cold	-4	208	-5	8248		
222	PL	cold	-4	488	-5	14739		
223	PL	cold	-4	774	-5	23069		
224	PL	cold	-4	1021	-5	29277		
225	S	cold	0	2	-2	4066	1402	
226	HD	cold	1063	1066	-5	13281		0.554

Table 1. (continued)

Test number	Test type[a]	Test temp.[b]	Test measurements				Packing load (lb)	Disc factor
			P_{up} (psig)	P_{bonnet} (psig)	P_{down} (psig)	F_{test} (lb)		
227	HU	cold	-2	1014	1007	12126		0.504
228	S	cold	0	2	-2	5743	1386	
229	PL	cold	0	1006	-1	28258		
301	S	cold	189	191	186	2425	1383	
302	HD	cold	1002	1004	45	8507		0.400
303	HU	cold	55	1018	1011	10099		0.447
304-305	heatup	hot						
306	PL	hot	49	1046	-6	26627		
307	S	hot	90	93	88	3077	1383	
308	HD	hot	1090	1092	52	10509		0.458
309	HU	hot	54	992	986	10854		0.489
311	S	cold	244	247	242	2723	1346	
312	HD	cold	1089	1092	49	10265		0.449
313	HU	cold	51	1047	1040	11737		0.503
314-317	heatup	hot						
318	PL	hot	48	1025	-4	28596		
319	S	hot	57	60	55	3232	1421	
320	HD	hot	1123	1126	45	12231		0.511
321	HU	hot	59	1018	1010	12518		0.551
323	S	cold	2	4	0	3330	1465	
324	HD	cold	1050	1053	0	11291		0.479
325	HU	cold						
326	S	cold	164	168	162	2287	1358	
327	HD	cold	1079	1081	54	10475		0.463
328	HU	cold	52	1095	1088	10719		0.443
329-330	heatup	hot						
331	PL	hot	52	1065	-4	26877		

Table 1. (continued)

Test number	Test type[a]	Test temp.[b]	Test measurements				Packing load (lb)	Disc factor
			P_{up} (psig)	P_{bonnet} (psig)	P_{down} (psig)	F_{test} (lb)		
332	S	hot	140	142	137	3057	1423	
333	HD	hot	1116	1118	48	10937		0.463
334	HU	hot	52	1022	1015	11224		0.490
336	S	cold	2	4	0	3213	1418	
337	HD	cold	1102	1105	0	12046		0.491
338	HU	cold	-3	1137	1130	12616		0.474
339	S	cold	347	350	344	3848	1389	
340	HD	cold	1086	1090	50	11304		0.492
341	HU	cold	53	1108	1101	11740		0.478
342-343	heatup	hot						
344	PL	hot	47	1105	-4	28301		
345	S	hot	281	284	278	4264	1351	
346	HD	hot	1098	1101	46	13020		0.557
347	HU	hot	53	1089	1082	12357		0.511
349	S	cold	0	1	-1	3555	1417	
350	HD	cold	1091	1093	0	14184		0.580
351	HU	cold	-3	1130	1122	12875		0.486
352	S	cold	287	292	284	1661	1384	
353	HD	cold	1108	1111	51	14234		0.603
354	HU	cold	51	1094	1087	12674		0.519
355-360	heatup	hot						
361	PL	hot	61	1096	-3	32540		
362	S	hot	791	793	787	1020	1168	
363	HD	hot	1124	1127	46	10765		0.463
364	HU	hot	139	1083	1075	7348		0.351
366	S	cold	4	6	2	2597	1373	
367	HD	cold	1092	1095	-4	10123		0.420

Table 1. (continued)

Test number	Test type[a]	Test temp.[b]	Test measurements				Packing load (lb)	Disc factor
			P_{up} (psig)	P_{bonnet} (psig)	P_{down} (psig)	F_{test} (lb)		
368	HU	cold	-3	963	956	7881		0.348
369	S	cold	633	636	629	1149	1274	
370	HD	cold	1127	1129	51	10511		0.449
371	HU	cold	52	997	990	7828		0.360
372-374	heatup	hot						
375	PL	hot	53	1105	2	25479		
376	S	hot						
377	S	hot	1218	1221	1214	-431	1180	
378	HD	hot	1090	1093	64	8078		0.370
379	HU	hot	66	969	962	7459		0.362
381	S	cold	11	13	9	1626	1351	
382	HD	cold	1078	1080	4	7690		0.330
383	HU	cold	-1	1006	999	6584		0.287
401	S	cold	2	5	1	1633	1328	
402	HD	cold	1036	1038	-5	6929		0.307
403	HU	cold	-3	1036	1028	5983		0.255
404	PL	cold	-4	1028	-5	15371		
405	PL	cold	-4	1094	-4	18803		
406	PL	cold	-4	1062	-5	17774		
407	S	cold	1	3	-1	1824	1273	
408	HD	cold	1092	1095	-3	9474		0.398
409	HU	cold	-3	988	981	7487		0.329

a. Test Type: S = static opening test (no internal pressure), HU = hydrostatic opening test across the upstream seat, HD = hydrostatic opening test across the downstream seat, PL = pressure lock opening test.

b. Cold (ambient) temperatures were between 70 and 80°F; hot temperatures ranged from 113 to 221°F.

Table 2. Leak rates for leakage from the valve bonnet during heatup tests

Test number	Maximum leakage[a] to upstream side (cm^3/min)	Average leakage to upstream side (cm^3/min)	Maximum leakage[a] to downstream side (cm^3/min)	Average leakage to downstream side (cm^3/min)
1	6.266	2.67	0.688	0.13
2	41.657	5.97	2.275	0.60
3	1.724	0.70	0.540	0.15
4	1.694	0.35	1.059	0.49
5	47.313	9.22	10.711	2.40
6	1.414	0.27	boiling occurred	boiling occurred

a. Leakage volume was measured at 15-minute intervals during the heatup. Values reported here represent the leak rate for the 15-minute interval from which the largest volume was collected.

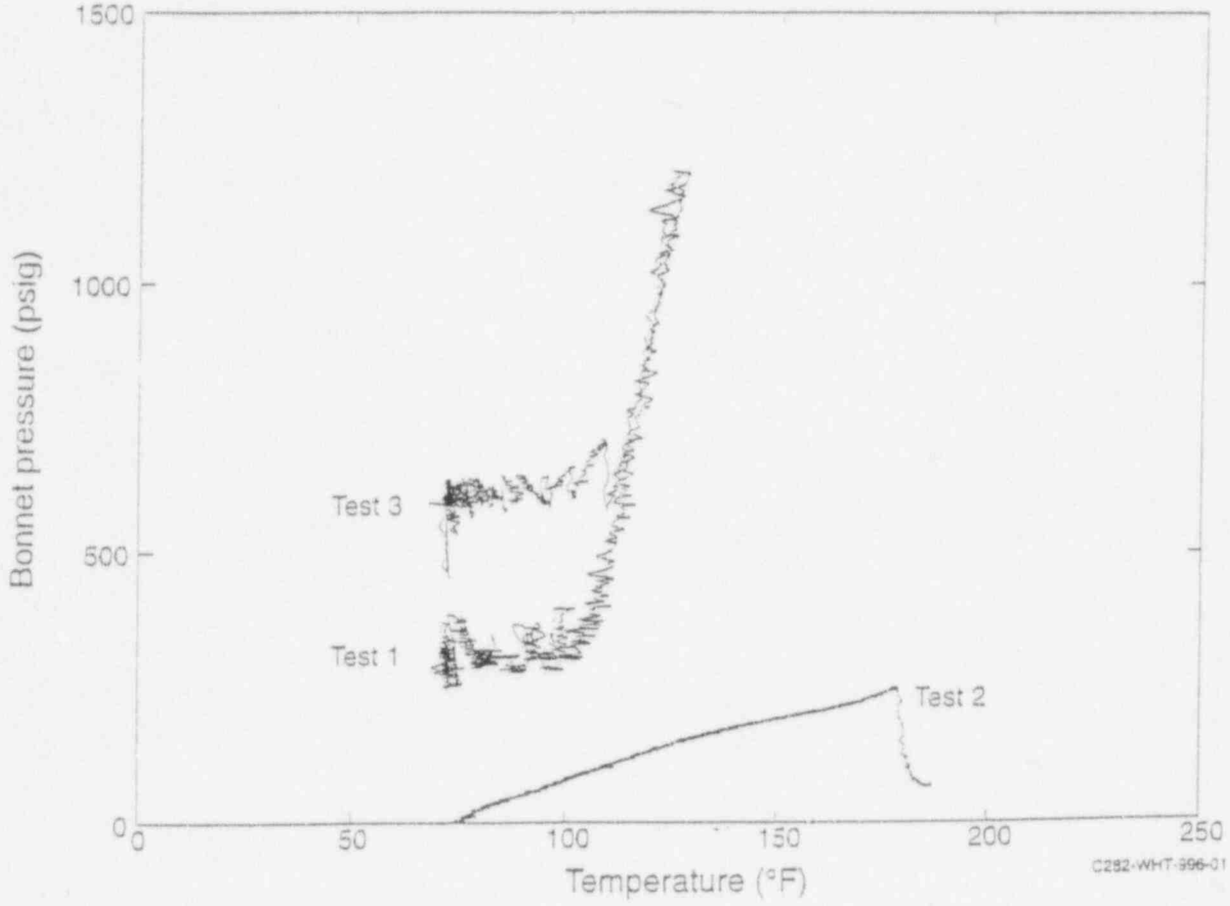

Figure 1. Results from Tests 1 through 3, showing the increase in bonnet pressure as the bonnet temperature increases.

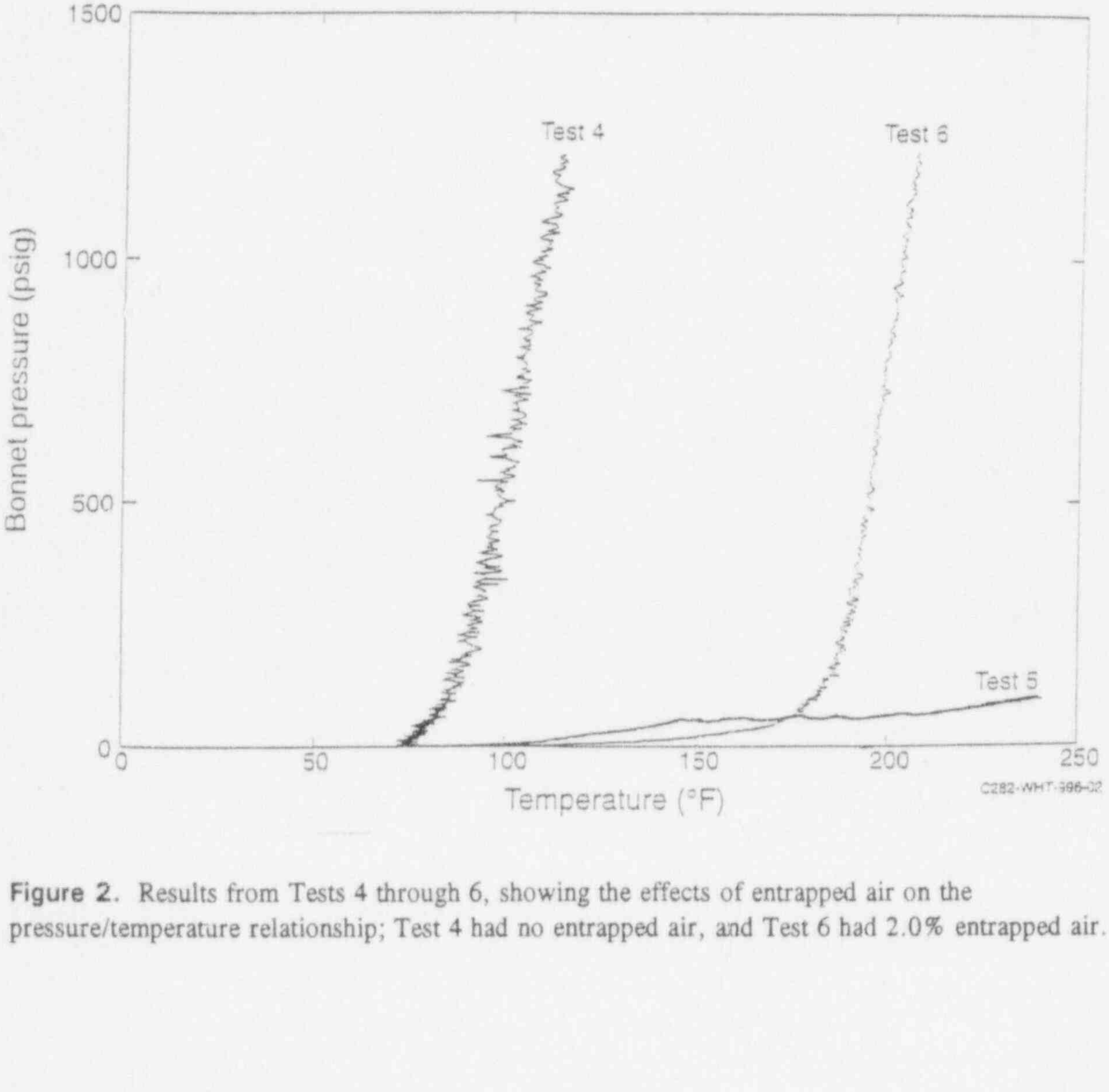

Figure 2. Results from Tests 4 through 6, showing the effects of entrapped air on the pressure/temperature relationship; Test 4 had no entrapped air, and Test 6 had 2.0% entrapped air.