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HRP BLANKET PROCESSING STUDIES OF O_2-H_2 HAZARDS IN A LOOP PRESSURIZER

P. A. Haas

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CHEMICAL TECHNOLOGY DIVISION

Unit Operations Section

HRP BLANKET PROCESSING
STUDIES OF O_2-H_2 HAZARDS IN A LOOP PRESSURIZER

P. A. Haas

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ABSTRACT

Results of experiments made under conditions proposed for homogeneous reactor blanket-processing loop studies indicated that spontaneous $H_2 + O_2$ reactions will not occur frequently to seriously hamper operation for reasonable steady state periods and will not result in hazardous equipment failures. Calculated ($2\ H_2$-O_2) concentrations below literature values for explosive concentration limits were detonated with an ignition coil. This result was probably due to segregation of gases, which would be expected from the test system geometry. The pressurizer was not damaged in more than 25 detonation reactions, some of which were for 200 psi H_2 + 100 psi O_2 with no diluent at room temperature. Recorded pressure peaks indicated that pressure rises would be less than 1600 psi in other loop components. The peak pressures would be within the test limit of the pump rotor can (4000 psi) and of all other loop components.

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1.0 INTRODUCTION

The hazards due to the proposed use of O_2-H_2 gas pressurization were investigated for the procedures and equipment planned for an aqueous homogeneous reactor blanket processing loop program. The behavior of plutonium in 1.4 m uranyl sulfate was to be studied at 250°C and the valence of the plutonium was to be controlled by O_2 and H_2 concentrations in solution. Any release of plutonium, such as might be caused by an O_2-H_2 explosion, would be a costly and hazardous failure. The experimental studies were designed to determine whether the proposed P-1 loop procedures and conditions would; (a) result in spontaneous explosive reactions, (b) permit rapid reactions or detonations started by an ignition coil or spark, and (c) avoid release of loop contents due to component failure from detonation effects.

The use of both O_2 and H_2 gas overpressure appeared necessary from the results of the initial uranyl sulfate blanket chemistry studies.[1] The oxygen is required to minimize corrosion and to stabilize the uranyl sulfate solution and has been used in core processing development loops. In quartz tubes, in the absence of hydrogen, the solubility of plutonium was more than 30 times that predicted for a reactor blanket system. Hydrogen, which would be produced by the radiolytic decomposition of water in an in-pile system, can reduce relatively soluble Pu(VI) to insoluble Pu(IV). Based on these results, loop P-1 was designed for the safe addition and containment of oxygen and hydrogen together. Partial pressures of 100 psi of each gas would maintain the required concentrations of dissolved gases in the loop solution. Subsequent laboratory results in stainless steel systems indicated that the presence of stainless steel corrosion products controlled the behavior of plutonium and the addition of hydrogen to stainless steel development loops was not effective for reducing Pu(VI) to Pu(IV).

One method of avoiding gas phase explosions would be to have a loop completely filled with liquid with some mechanism for permitting expansion and contraction of the liquid phase. About half the dissolved H_2 would be recombined each hour. Unless O_2 and H_2 additions were very frequent or continuous, a gas reservoir would be needed. The use of an inert diluent gas such as N_2 was rejected since it would make determination of the composition of the gas in the loop much more difficult.

2.0 SELECTION OF TEST CONDITIONS

Studies of recombination reactions in O_2-H_2-steam systems by other investigators have shown three regions of reaction.[2,4] Spark ignition of $O_2 + 2\ H_2$ mixtures saturated with water vapor[2] (Fig. 1) under controlled conditions gave a basis for selecting theoretically safe operating conditions. However, they did not permit estimation of the effects of concentration gradients due to condensation of steam, the conditions which would give spontaneous reactions, or of the effects of a detonation on the loop components.

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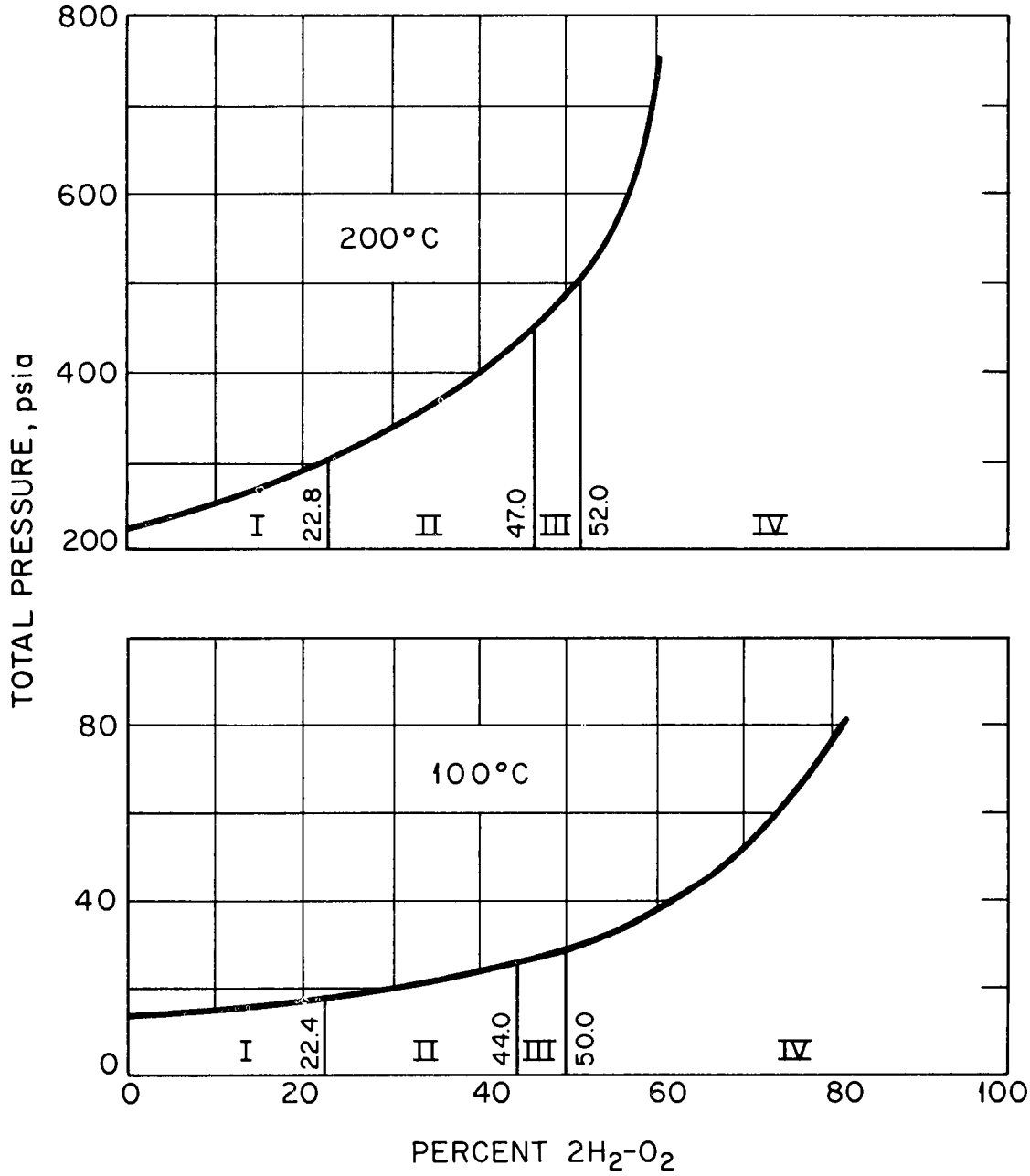

Fig. 1. Composition $2H_2$-O_2 versus total pressure $2H_2$-O_2-H_2O showing limits for reaction type. (I) No reaction; (II) partial reaction; (III) explosion; (IV) detonation.

A special pressurizer was designed with two basic safety features to minimize the dangers of $O_2 + H_2$ reactions causing the release of plutonium into the operating area. First, there were no unmixed volumes in the pressurizer vapor space in which hydrogen and oxygen from water vapor could segregate. Solution passing through the pressurizer to be saturated with hydrogen and oxygen entered through a spray nozzle placed to thoroughly swirl and stir material in the vapor space (Fig. 2). The space below the normal liquid level (at 250°C) was packed with 1.4-in.-dia 3/8-in.-long rings to reduce the detonation concentration and break up detonation waves. These features, plus control of H_2 and O_2 concentrations, were intended to prevent concentrations above detonation limits.

The pressurizer and loop designs provided two containments for severe overpressures such as would occur from a O_2-H_2 detonation. The 6-in. IPS schedule 160 pipe and caps used for the pressurizer body would be a safe working design for 4,000 psi and would probably contain 20,000 psi. The entire loop, including the pump and hydroclone, was canned in a pressure vessel designed to contain the entire loop contents discharged at 250°C. A blast shield was installed around the pressurizer to contain shrapnel that might be produced by a pressurizer rupture and to thus prevent puncturing of the container can. This blast shield was prestressed for resistance to shock and was vented through numerous holes to release the vapor into the loop can (Fig. 3).

The uranyl sulfate solution acts as a catalyst to recombine H_2 and O_2; therefore continuous or intermittent addition of H_2 and O_2 would be required to avoid depletion of one or both gases. Combinations of operating conditions and procedures to meet specified concentration limits were calculated.[5,6] These calculations and reasonable operating schedule considerations indicated that the addition of O_2 and H_2 once each 8 hours would be satisfactory. An excess of O_2 would be maintained at all times. The gas composition would be checked by not adding H_2 for several H_2 "half-lives" until the residual gas was essentially all O_2 and steam.

A test pressurizer fabricated with a spark plug tap for ignition coil leads was installed and tested in Bank A, Cell A, Bldg. 3503. Circulation was by natural convection, heating being by four 1000-watt calrod heaters cast in aluminum around a 1/2-in.-dia schedule 80 pipe. Instrumentation included a 12-point Brown Multipoint temperature recorder, a Baldwin-Lima strain-gage pressure element with a conventional and a special fast recorder, and a 0-3000 psi pressure gage. The apparatus (Fig. 4) and procedures are described in more detail in the appendix (Sec. 5.1).

3.0 RESULTS AND CONCLUSIONS

The experimental studies demonstrated that the proposed procedures and equipment design adequately minimized the hazards of adding both hydrogen gas and oxygen gas to a loop for studying the behavior of plutonium. The

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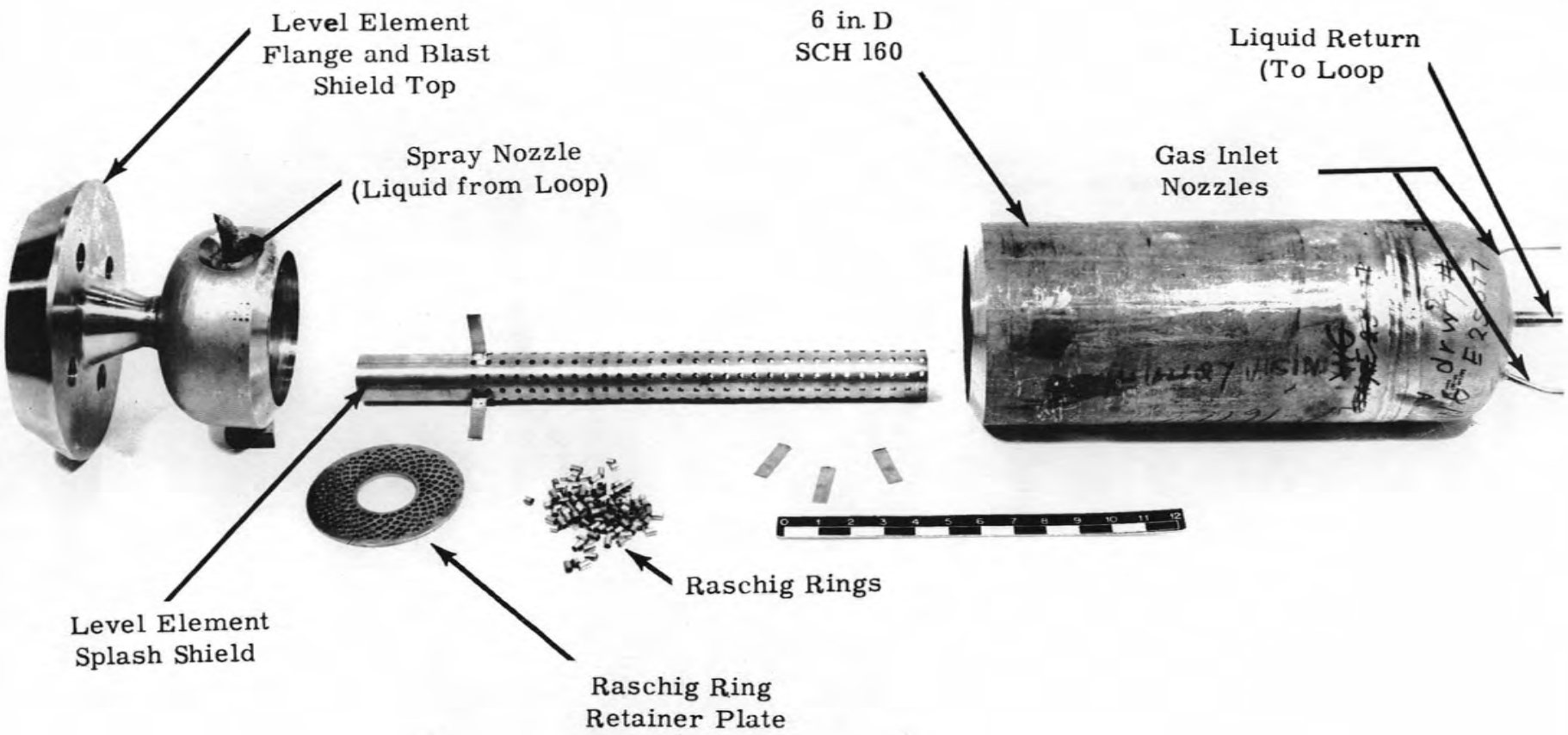

Fig. 2. Loop P-I Pressurizer Components Before Assembly.

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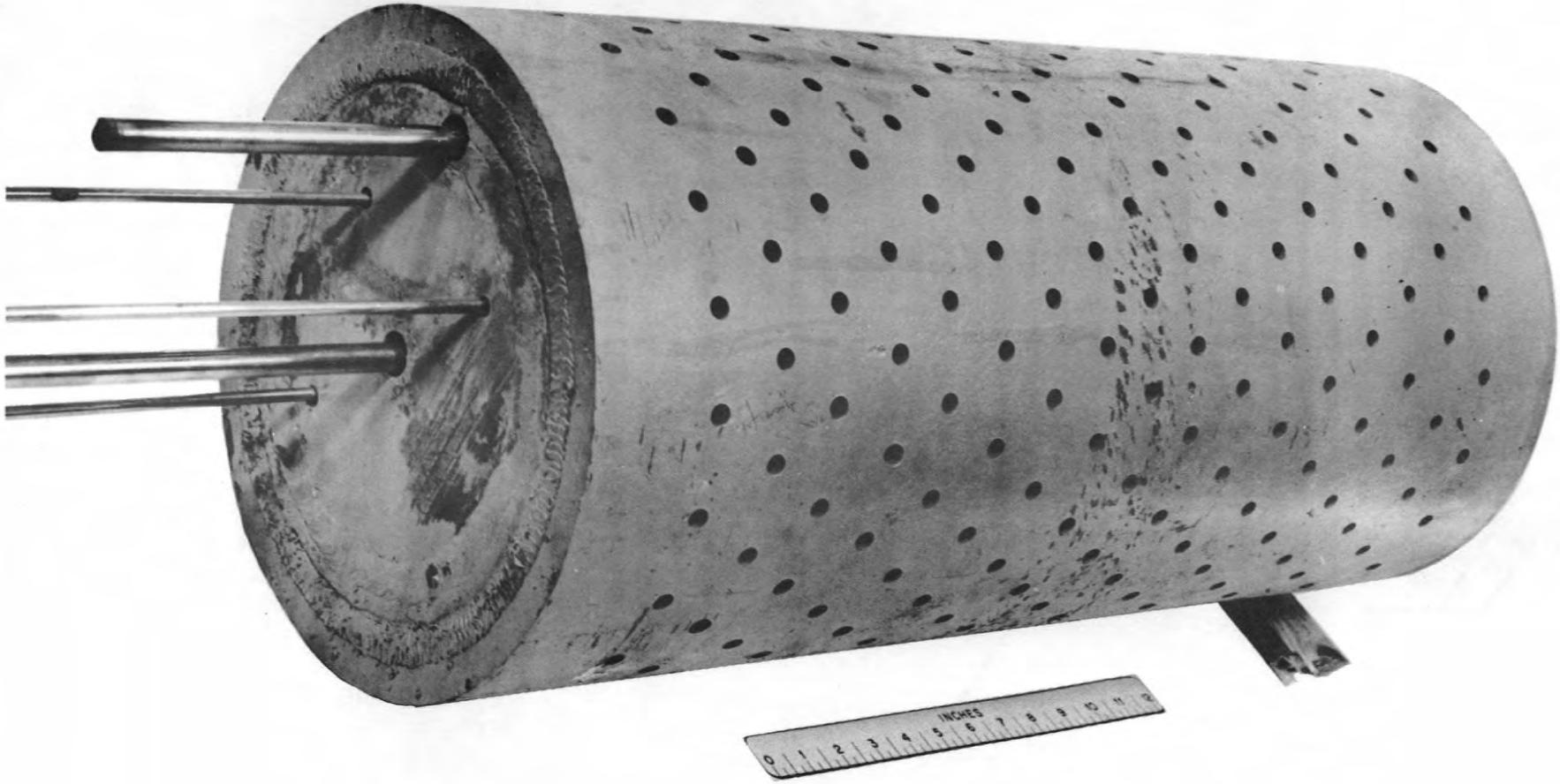

Fig. 3. Assembled Pressurizer-Blast Shield Unit.

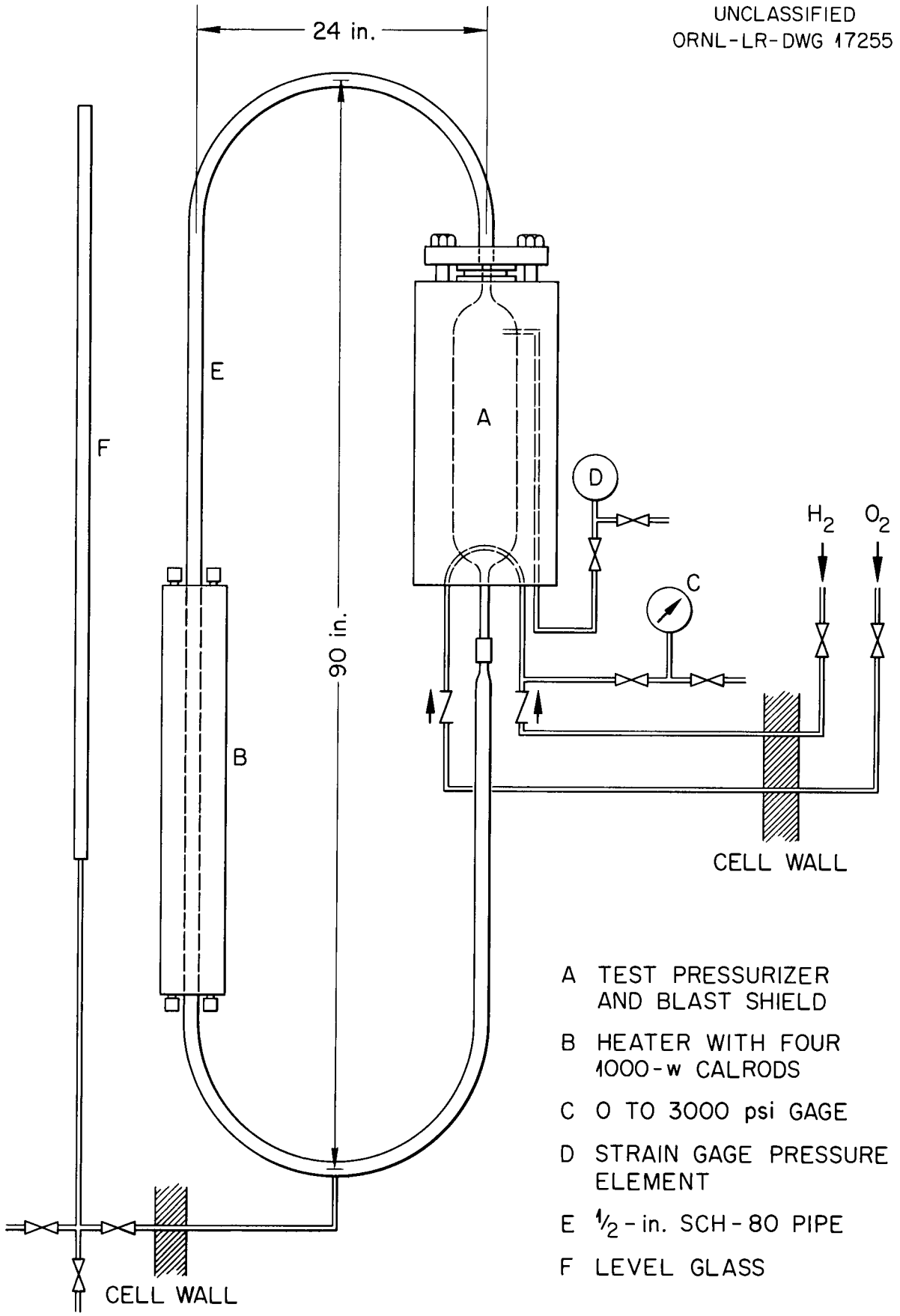

Fig. 4. Pressurizer Test Loop.

results and conclusions are based on experimental data as presented or referred to in the appendix (Sec. 5.4).

3.1 Spontaneous Reactions

No spontaneous $O_2 + H_2$ reactions were observed during operation for 153 hr with concentrations* up to 90% (2 H_2-O_2). This time was accumulated during four runs (TP-5, 6, 7, and 8) with numerous gas additions and temperatures of 50-310°C. At the proposed loop operating temperature of 260°C, the maximum (2 H_2-O_2) concentration tested for spontaneous reactions was 57%. These results indicate that experimental studies can be made without frequent upsets due to fast or explosive hydrogen + oxygen reactions. It was not practical to operate for enough time to prove that detonations would never occur. Therefore the experimental program was limited to demonstrations that spontaneous fast reactions were not frequent and that detonations could be safely contained.

Reactions occurred during two runs made with a platinum ignition coil in the pressurizer. The first such reaction (run TP-3) was an almost instantaneous pressure decrease of about 100 psi starting at 27% (2 H_2-O_2) without any noticeable sound or pressure peak. Four other detonation reactions with audible sound and recorded pressure peaks up to 800 psi increase were observed (run TP-14) for calculated (2 H_2-O_2) concentrations of 23 to 45%. Platinum is a highly active $O_2 + H_2$ recombination catalyst. The frequency and rapidity with which platinum-initiated explosive reactions occur probably means that complete avoidance of spontaneous reactions would be difficult. New metal surface due to mechanical damage or dried metal oxides would be expected to have catalytical activity.

3.2 Ignited Reactions

With a heated nickel ignition coil in the pressurizer, more than 25 reactions resulting in a pressure peak on the recorder and rumbles or bangs audible outside the cell were obtained. The calculated gas concentrations were 18-100% (2 H_2-O_2). Heating the ignition coil resulted in no noticeable effect in more than 50 tests with concentrations of 0-50% (2 H_2-O_2). This indicates that mixing was an important variable. The tests were made without use of the spray nozzle that was expected to prevent gas segregation in loop P-1.

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* The concentrations are expressed as volume percent or mole percent stoichiometric mixture, i.e., 2 parts H_2 to 1 part O_2. Any excess of either gas is considered a diluent along with the steam. Actually, an excess of one gas tends to lower the concentration of the other gas required for a reaction to occur.

3.3 Detonation Effects on Loop Components

The results showed that detonations would not cause serious damage either to the pressurizer components or to loop components connected to the pressurizer by 3/16-in.-i.d. tubing. The pressurizer, including the thermoprobe flange, was directly exposed to the shock waves from any explosive reactions in the vapor space. The loop components would be subjected only to damped shock waves through more than 3 ft of 3/16-in.i.d. tubing. The effects of the detonations on the pressurizer were tested directly while the effects on loop components were inferred from the pressures indicated by the strain gage pressure elements. The connection between the elements and the test pressurizer was equivalent to that between the P-1 loop and its pressurizer.

The thermoprobe flange would be expected to be a vulnerable point, but it showed no leakage after the loop had cooled down following any of the tests. The conditions immediately after a detonation were not steady state owing to temperature and gas solubility changes. No abnormal pressure decreases (indicating leakage) were apparent after 30 minutes following detonations occurring with nickel coils.

The test pressurizer was cut open after the experimental program was completed. No physical damage to the pressurizer or its contents was observed. Fatigue failure might have to be considered for containing repeated detonations.

Tests indicated that the pressure peaks transmitted to the loop would be less than 1600 psi higher than the predetonation pressures; these peaks would not exceed the 4000 psi test pressure of the pump can, which was probably the weakest loop component as far as pressure was concerned.

The Foxboro Dynalog Recorder was not fast enough to accurately follow the strain gage pressure element signal, but detonations were clearly shown and relative magnitudes were indicated (Fig. 5). The recorder tracings shown are typical of those obtained in operations above 200°C. For room temperature tests with 100% (2 H_2-O_2), the sound of the detonations was much sharper and louder, but the recorded pressure peaks were less than 200 psi above the preignition pressures. The small peaks are believed to be due to slow recorder response.

More accurate measurement of the pressure peaks at the pressure element were obtained with a Sanborn heated-wire oscillograph as the pressure recorder for TP-11, TP-12, and TP-13. The largest single peak observed (at 1050 on 11-2-56) was 1550 psi above the base pressure of about 1400 psi (Fig. 6).

There was only one high-pressure fitting or valve failure during operation. The use of threads and a sealing face machined into the stainless steel vessel wall for the spark plug ignition coil leads was not satisfactory. A brass adapter with standard pipe threads tapped into the pressurizer was required to permit resealing after ignition coil charges.

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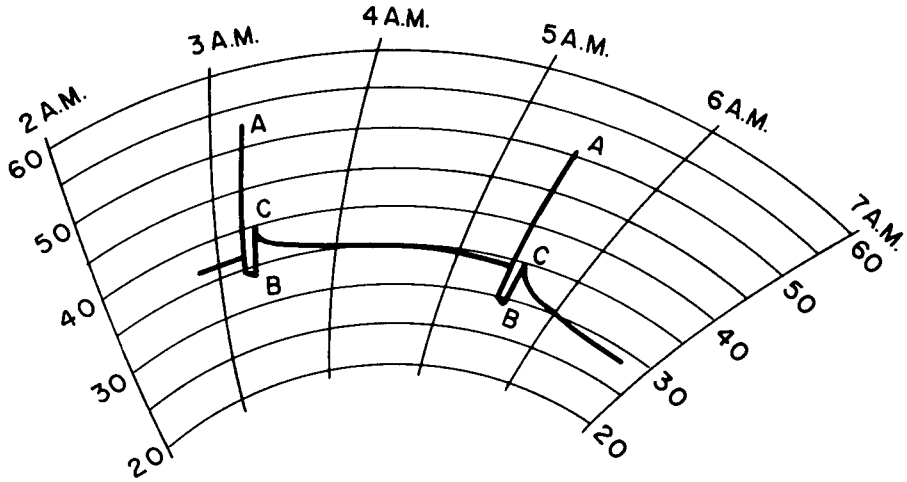

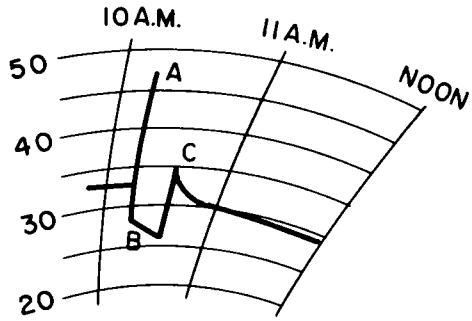

A Pressure Peaks
B Pressure Minimums After Condensation of Steam
C Additional H_2 or O_2 Added at This Time

RUN NO: TP-9
DATE: 10-10-56
CONDITIONS: Detonations Initiated By 4 Amps Through 0.010 in D. Nickel Wire
INSTRUMENT: Baldwin-Lima Pressure Element To Foxboro Dynalog Recorder, 100% = 5000 psi.

Fig. 5. Tracings of PR Chart During H_2+O_2 Reaction

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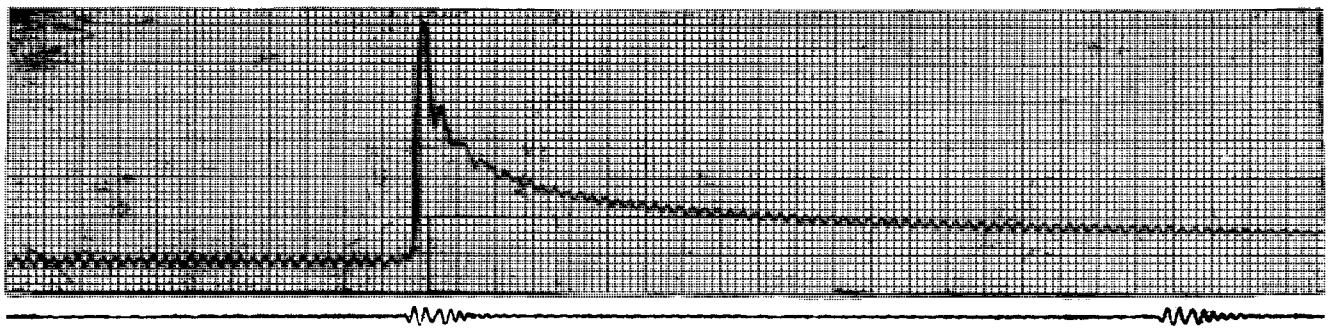
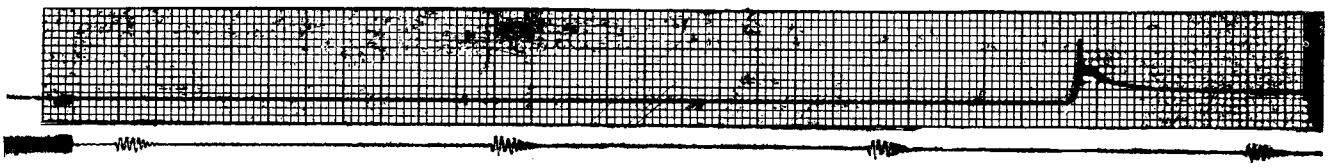


RUN: TP-13
TIME: 1050, 11-2-56
SCALE: 1 DIVISION (mm) =50 psi
10 cm = 1 sec
TEMPERATURE: 255°C



RUN: TP-13
TIME: 0005, 11-2-56
SCALE: 1 DIVISION (mm)=100psi
5 cm = 1 sec
TEMPERATURE: 240°C

Fig. 6. Typical pressure peaks recorded by a Sanborn heated-wire oscillograph.

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5.0 APPENDIX

5.1 Apparatus

Installation of the test pressurizer as part of a convection loop was selected as an adequate and simple method of making the required tests. This arrangement (Fig. 4) did not permit use of the mixing spray nozzle which was designed for a flow of about 0.5 gpm at 100 ft head pressure drop. The use of a canned-rotor circulating pump was rejected on the basis that it would be the weakest part of the test system, it would probably be severely damaged during the test program, and the objectives of the test did not require duplication of the mixing expected in the loop pressurizer.

The test pressurizer and shield assembly (Drawing E-26376) duplicated that constructed for loop P-1 except for a hole into the vapor space tapped for 14-mm spark plug threads. The hydrogen and oxygen were supplied through 1/4-in.-o.d. 1/12-in.-i.d. tubing through 30,000 psi check valves from 0 to 4000 psi pressure regulators. The 0 to 3000 psi Bourdon tube pressure gage and 0 to 5000 psi Baldwin-Lima strain gage pressure elements were installed with shutoff and vent valves equipped with extension handles through the cell wall. A liquid-level sight glass and drain-fill correction were connected to a 9/16-in.-o.d. 3/16-in.-i.d. tubing line with a 30,000 psi valve outside the cell wall. Four 1000 watt calrod heaters were cast in aluminum around a 1.2-in.-dia sch. 80 pipe with two of the heaters on a variac. The blast shield was lagged with about 500 watts of tape heaters, and the whole loop was covered with magnesia insulation. Temperatures were recorded by a Brown Multipoint Recorder. The pressure element readings were usually recorded by a Foxboro Dynalog; a Sanborn two-channel heated-wire oscillograph with variable chart speeds was used for a short period since the Foxboro was not fast enough to accurately follow the stain gage pressure signal.

5.2 Procedures

The procedures used for operation of the test pressurizer convection loop were evolved from variations tested during the initial periods of operation. Before startup, the loop was leak checked for its ability to hold about 1000 psi of O_2 pressure for several hours. The H_2O volume was adjusted by using the gage glass level for the vented loop at room temperature. The closed loop was heated to 100°C and steam was vented to purge out N_2 and O_2. The loop was then heated to the desired steady-state temperatures. The desired amount of H_2 or O_2 was added; at least 0.5 hr was required to saturate the liquid with gas. When new equilibrium conditions were reached the other gas was added. Constant variac settings were maintained throughout these operations. When the resistance coil was to be heated the power supply variac was adjusted to give the voltage which gave a bright red coil in air. Gas phase concentrations were varied by adding H_2 or O_2, or by changing temperatures to change the amount of diluent steam.

5.3 Calculations

The pressure-volume-temperature relations in the convection loop calculated from material balances agreed with observed values. These calculations assumed no leakage and no losses of noncondensable gases due to recombination or corrosion. Water and steam densities were taken from steam tables while H_2 and O_2 densities were calculated from the ideal gas law. The H_2 and O_2 solubilities are from a BMI report.[7] The room temperature (70°F or 21°C) volumes and pressures were used as the base point.

From the assumptions and by inspection, the convection loop can be characterized by the following equations:

$$V_t = V_L + V_g = V_L^\circ + V_g^\circ \tag{1}$$

$$P_t = P_g + P_s \tag{2}$$

$$V_L = f(T_L, V_L^\circ\ V_g^\circ) \tag{3}$$

$$P_g = f(T_L, V_L, V_g^\circ, P_g^\circ, T_g, S) \tag{4}$$

where V_t is the total volume and is 330 in.^{3} for the convection loop

V_L is the volume of the liquid phase

V_g is the volume of the gas phase

V_L° and V_g° are these volumes at 70°F

P_t is the total pressure

P_g is the partial pressure of noncondensable gases

P_s is the steam pressure obtained from steam tables and the temperature, T

$T_L = T = T_g$ are the temperatures of the material in the test pressurizer

S is the solubility of the gas in liquid

ρ_L, ρ_s, and ρ_g are densities of liquid, steam, and gas, respectively.

The solubilities of H_2 and O_2 in terms of the amount of gas per unit mass or unit volume of liquid is given by $P_g S(T)$ where $S(T)$ is a function of temperature only for a given gas composition. The terms V_g, $V_g°$, P_t, and P_s are eliminated as variables by $V_t = 330$ in.^{3}, eqs. 1 and 2 and $P_s = f(T)$ obtained from steam tables. Equations 3 and 4 are thus simplified:

$$V_L = f(T, V_L°) \tag{5}$$

$$P_g = f(T, V_L V_L°, P_g°) \tag{6}$$

Equation 5 can be written in the following forms since $\rho_s°$ is essentially zero:

$$\rho_L° V_L° + \rho_s° V_g° = [\rho_L(T)][V_L(T)] + [\rho_s(T)][V_g(T)] \tag{7}$$

$$\frac{V_L}{V_L°} = \frac{\rho_L°}{\rho_L(T)} - \left[\frac{V_g(T)}{V_L°}\right]\left[\frac{\rho_s(T)}{\rho_L(T)}\right] \tag{8}$$

The second term on the right-hand side of eq. 8 represents the water vaporized and is less than 1% of the water for all proposed convection loop conditions. Values calculated from this equation are plotted as $V_L°/V_L(T)$ (Fig. 7), which is almost identical to the liquid-density curve.

Equation 6 can be most easily written on a basis of cc of gas under standard conditions with $S_g(T)$ in terms of standard cc per cc per psi of gas overpressure to give eq. 9:

$$V_g° \frac{P_g°}{14.7} \frac{273}{273 + 21} + V_L° P_g° [S(T)] = V_g \frac{P_g}{14.7} \frac{273}{273 + T} + V_L P_g S(T) \tag{9}$$

$$\frac{P_g}{P_g°} = \frac{V_g° \dfrac{273}{(14.7)(294)} + V_L° S(21°C)}{V_g \dfrac{273}{(14.7)(273 + T)} + V_L[S(T)]} \tag{10}$$

For a stoichiometric 2 H_2-O_2 mixture at 21°C, $S(21°C) = 0.00095$ standard ml/ml psi. Substituting this value and $V_g° = 330 - V_L°$, $V_g = 330 - V_L$ gives $P_g/P_g° = f(T, V_L°)$ since $V_L = f(T, V_L°)$ as shown by eq. 8. Then

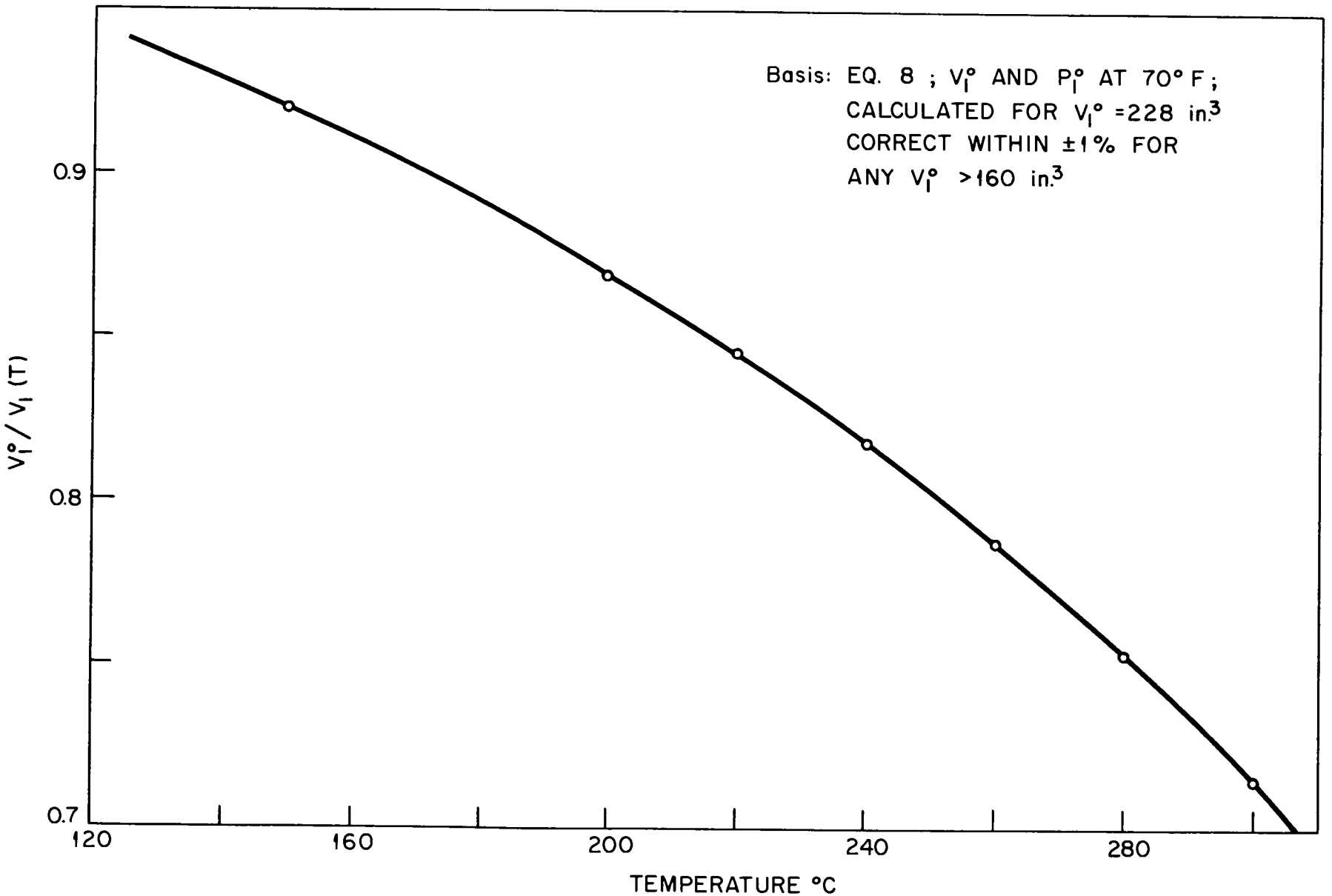

Fig. 7. Effect of temperature on convection loop liquid volume.

$$\frac{P_g}{P_g^\circ} = \frac{20.85 - 0.0621\ V_L^\circ}{\frac{6130}{273 + T} - \left[\frac{18.58}{273 + T} - S(T)\right] V_L} \tag{11}$$

Values calculated from this equation are plotted in Fig. 8 with V_L° as a parameter.

The peak in the gas overpressure which occurs between 260 and 300°C is the most important effect shown by these calculations. The physical meaning of this peak is that the increase in gas solubility as the temperature increases causes a larger decrease in gas overpressure than the increase due to compression caused by liquid expansion. The area right of $V_L = 330$ in.^{3} (Fig. 8) is imaginary in that 330 in.^{3} is the total loop volume. If the pressure and the percent stoichiometric 2 H_2-O_2 are calculated from eqs. 9 and 2, they are functions of three independent variables (T, V_L°, and P_g°), and cannot be simply represented by a graph.

On each side of eq. 9, one term represents the amount of gas in the vapor phase and the other the amount of gas in the liquid phase. The amount in the liquid phase over the total amount, as in eq. 12, gives the fraction of gas dissolved in the liquid (Fig. 9):

$$G_L = \frac{P_g V_L [S(T)](100)}{V_g P_g \frac{273}{273 + T} + P_g V_L [S(T)]} = \frac{100\ V_L S}{V_g \frac{273}{273 + T} + V_L S} \tag{12}$$

G_L is the percentage of the gas in the loop which is dissolved in the liquid phase.

Similar calculations later made for O_2 and 1.4 m UO_2SO_4 in Loop P-1 gave similar curves without the pronounced maximum in the P_G/P_G° versus temperature curves at 260-280°C. In loop P-1, the gas/liquid volume ratio is smaller and the gas solubility is smaller in uranyl sulfate than in H_2O; therefore the increasing gas solubility with temperature does not overcome the effects of the expanding liquid volume until temperatures above 300°C are reached.

5.4 Tabulated Data

The conditions and results of the 15 periods of test pressurizer experimental operations are summarized in Tables 1 and 2. Data typical of those for all runs and data for room temperature tests with 100% (2 H_2-O_2) are presented in Tables 3 and 4.

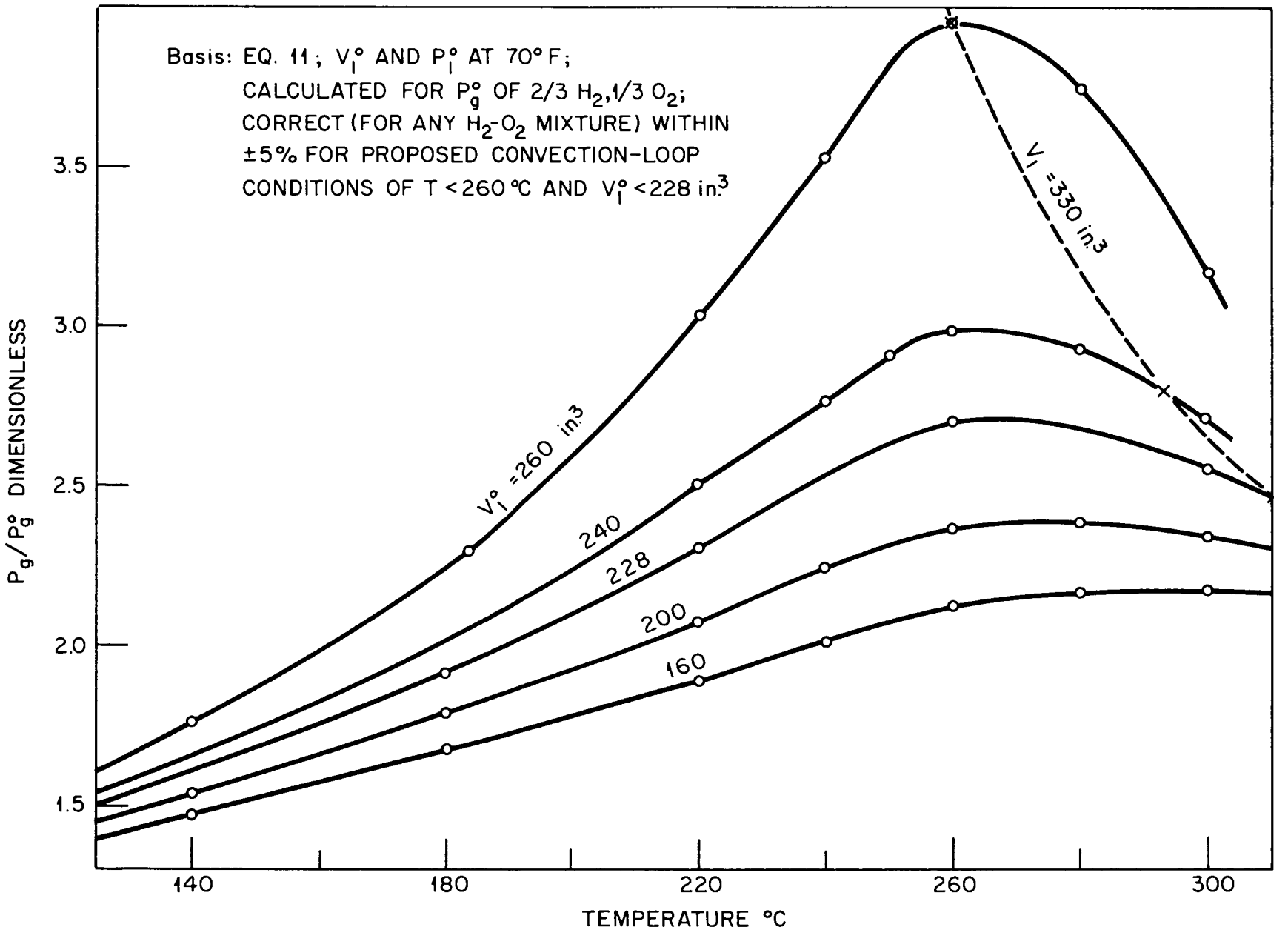

Fig. 8. Effect of temperature on convection loop gas pressure.

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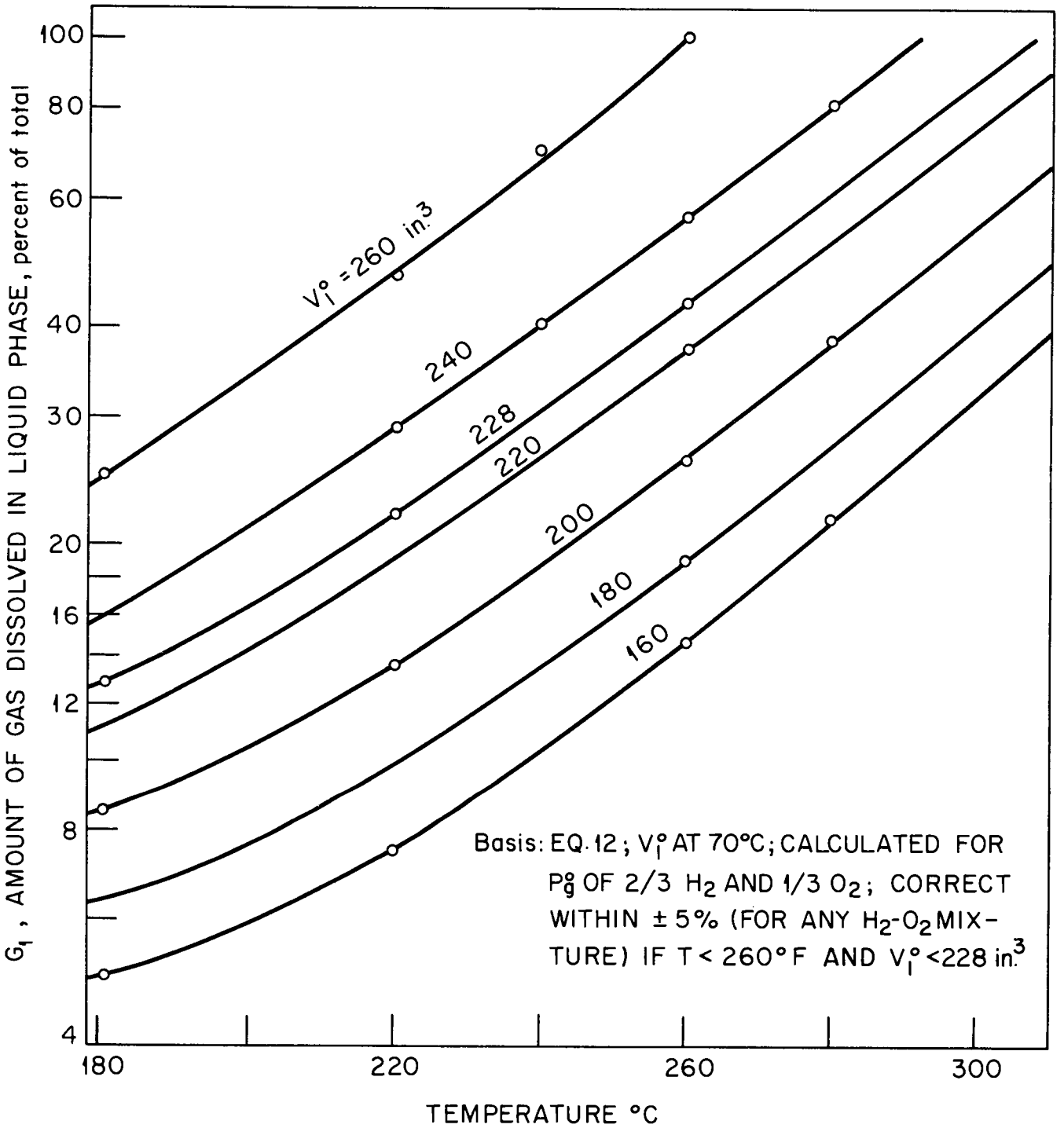

Fig. 9. Fraction of convection loop gas dissolved in liquid phase.

Table 1. Summary of Test Pressurizer Convection Loop Operation

TP Run No.	Run Length, hr	Initial Amounts of Liquid		Initial Gas Pressures, psia		Total Gas Added, psia			Final Gas Overpressure, psia
		Level, cm	Vol, in.^{3}	O_2	N_2	O_2	H_2	N_2	
1	25	184	220	250	12	250	0	12	100
2	26	175	155	140	12	140	0	12	110
3	26	171	125	90	12	90	180	12	90
4	25	167	100	40	12	40	0	12	0
5	46	176	160	0	0	160	130	--	90
6	61	169	110	0	0	200	130	--	125
7	37	180	195	0	0	120	400	--	260
8	108	184.5	225	0	0	230	330	--	480
9	69	184.5	225	0	0	570	300	--	200
10	54	186	235	0	0	330	580	--	200
11	70	184	220	0	0	250	570	--	400
12	20	181	200	0	0	200	350	--	0[a]
13	48	182	210	0	0	275	720	--	290
14	60	184	220	0	0	430	1100	--	250
15	--	181-192	200-275	0	0	---	---	--	---

[a]Run ended by leak at tubing fitting.

TP Run No.	Purpose	Coil Used	Fast Reactions Observed	Comments
1	Conditioning, operability check	None	0	
2	Leak and pressure element check	None	0	
3	Leak check, H_2 addition	Pt	1	Pt recombined H_2 and O_2
4	Behavior of $H_2 + O_2$ without ignition coil	None	0	Run ended because of low H_2O level
5	Same	None	0	20 hr of operation after 23% (2 H_2-O_2) conc.
6	Same	None	0	28 hr of operation after 23% (2 H_2-O_2) conc.
7	Same	None	0	Up to 45% (2 H_2-O_2) conc.
8	Same	None	0	Up to 57% (2 H_2-O_2) conc.
9	Test with ignition coil	Ni	3	Three explosive reactions at 29, 46, 45% calculated (2 H_2-O_2) conc.
10	Same	Ni	10	Five reactions at 21, 24, 18, 33, and 49% calculated (2 H_2-O_2) conc.
11	Same	Ni	2	Fast recorder used, run ended by broken ignition plug connection
12	Same	Ni	1	Run ended by leak; fast recorder used
13	Same	Ni	3	Fast recorder used
14	Same	Pt	3	Spontaneous reactions
15	Room temperature tests with ignition coil	Ni	3	Reactions for 100% (2 H_2-O_2) concentrations, no steam diluent

Table 3. Summary of H_2 and O_2 Behavior in Test Pressurizer, Run TP-10

Dates: 10-17-56 through 10-21-56
Coil: 0.010 in. dia nickel wire; heated with 4.5 amp in initiate reactions
Gas overpressure basis: calculated at loop pressures, temperatures, volumes

Time	Pressures, psia		Gas Overpressures			$2\ H_2 + O_2$, %	Result of Heating Nickel Coil	Remarks
	Total Pi or Pr	Steam	Total psi	H_2 psia	O_2 psia			
1100	460	480	---	---	---	--	----------	Added ~600 psi O_2 at 0010
0200	950	460	490	---	490	--	----------	
0700	1070	560	510	---	510	--	----------	
1200	1290	710	580	---	580	--	----------	Added ~150 psi H_2 at 1230
1445	1390	730	660	100	560	11	No Reaction	Added ~150 psi H_2 at 1455
1708	1490	740	750	210	540	21	Explosion	Added ~200 psi H_2 at 1720
1900	1490	800	690	240	450	24	Explosion	Added ~200 psi H_2 at 1910
2105	2830	2400	430	140	290	7	No Reaction	
2310	1550	1200	480	180	300	18	Explosion	Added ~400 psi H_2 at 2320
0100	1500	1000	500	330	170	33	Explosion	Added ~100 psi H_2 at 0115
0310	1200	930	270	210	60	15	No Reaction	Added ~100 psi H_2 at 0315
0520	1100	810	390	330	60	16	No Reaction	Added ~150 psi H_2 at 0525
0705	1160	700	460	420	40	10	No Reaction	Added ~100 psi H_2 at 0710
0905	1130	600	530	500	30	8	No Reaction	Added ~300 psi H_2 at 0908
0920	1450	640	810	790	20	4	No Reaction	Added ~390 psi O_2 at 0920
0945	1860	680	1180	790	390	63	----------	Spontaneous reactions 0950 to 1010
1100	1400	830	570	380	190	41	----------	
1240	1360	830	530	350	180	39	----------	Added ~150 psi H_2 and 100 psi O_2
1241	1600	830	770	500	270	47	----------	Spontaneous reaction
1246	1540	830	710	460	250	45	----------	Added ~100 psi H_2 and observed another spontaneous reaction-added more O_2
1455	1440	780	660	380	280	39	No Reaction	
1730	1160	480	680	380	300	49	Explosion	
1920	780	300	480	250	230	48	No Reaction	
2115	700	250	450	230	220	49	No Reaction	Heat turned off
2000	240	---	240	120	120	75	----------	

Table 4. Summary of Room Temperature Detonation Tests, Run TP-15[a]

Test No.	Gas Phase Vol in.^{3}	Gas Pressures, psia		Stoichiometric $2\ H_2$-O_2		Coil Used	Remarks
		H_2	O_2	Pressure, psi	% of total		
1	55	100	200	150	50	Ni[b]	No observed reaction
3	55	200	100	300	100	Ni[b]	No observed reaction
7	55	300	150	450	100	Ni[b]	No observed reaction
8	130	300	150	450	100	Pt	Fast reaction with over 80% of the gas recombined[c]
9	130	300	150	450	100	Pt	Same
10	130	300	150	450	100	Ni	Same

[a] Tests were intermittent studies grouped as TP-15 for identification purposes only.

[b] At the end of test 7, the spark plug lead was removed and the nickel coil was found to be blown back into the space between the insulation and the outer shell. This location was probably the result of previous detonation reactions and probably prevented heating up of the coil.

[c] Pressure peaks recorded were only ~150 psi above the initial pressures even though the audible reports were sharper and louder than those at 260°C.

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