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IGNITION REACTIONS IN THE
HYDROGEN-OXYGEN-WATER SYSTEM
AT ELEVATED TEMPERATURES

by

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	1
INTRODUCTION	1
THEORY OF THE HYDROGEN-OXYGEN REACTION	2
EXPERIMENTAL PROCEDURE	3
EXPERIMENTAL RESULTS	3
REFERENCES	7

APPENDIX

IGNITION-REACTION DATA AND CURVES	A-1

LIST OF TABLES

IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A 1.5-IN. -DIAMETER
AUTOCLAVE WITH SPARK IGNITION

Table A-1. 1 Part Hydrogen to 1 Part Oxygen	A-1
Table A-2. 2 Parts Hydrogen to 1 Part Oxygen	A-2
Table A-3. 3 Parts Hydrogen to 1 Part Oxygen	A-4
Table A-4. 4 Parts Hydrogen to 1 Part Oxygen	A-5
Table A-5. 5 Parts Hydrogen to 1 Part Oxygen	A-6
Table A-6. 12 Parts Hydrogen to 1 Part Oxygen	A-7
Table A-7. 1 Part Hydrogen to 2 Parts Oxygen	A-8
Table A-8. 1 Part Hydrogen to 3 Parts Oxygen	A-9
Table A-9. 1 Part Hydrogen to 4 Parts Oxygen	A-10
Table A-10. 1 Part Hydrogen to 12 Parts Oxygen	A-11

IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A 2.5-IN. -DIAMETER
AUTOCLAVE WITH SPARK IGNITION

Table A-11. 2 Parts Hydrogen to 1 Part Oxygen	A-12

IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A
3-IN. -DIAMETER AUTOCLAVE WITH SPARK IGNITION

Table A-12. 2 Parts Hydrogen to 1 Part Oxygen	A-13
Table A-13. 1 Part Hydrogen to 1 Part Oxygen	A-14
Table A-14. 1 Part Hydrogen to 12 Parts Oxygen	A-15

IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A 1.5-IN. -DIAMETER
AUTOCLAVE WITH HOT-WIRE IGNITION

Table A-15. 2 Parts Hydrogen to 1 Part Oxygen	A-16

IGNITION REACTIONS IN THE NITROGEN-HYDROGEN-OXYGEN-WATER SYSTEM IN A
1.5-IN. -DIAMETER AUTOCLAVE WITH SPARK IGNITION

Table A-16. 1 Part Hydrogen to 1 Part Oxygen	A-17

IGNITION REACTIONS IN THE ARGON-HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN. -DIAMETER AUTOCLAVE WITH SPARK IGNITION

Table A-17. 1 Part Hydrogen to 1 Part Oxygen	A-18

LIST OF TABLES
(Continued)

	<u>Page</u>
IGNITION REACTIONS IN THE HELIUM-HYDROGEN-OXYGEN-WATER SYSTEM IN A 1.5-IN. -DIAMETER AUTOCLAVE WITH SPARK IGNITION	
Table A-18. 1 Part Hydrogen to 1 Part Oxygen	A-19
Table A-19. 1 Part Hydrogen to 2 Parts Oxygen	A-20
Table A-20. 1 Part Hydrogen to 3 Parts Oxygen	A-21

PEAK-REACTION PRESSURES SHOWING THE EFFECT OF DILUTING A
STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN

Table A-21. 100 PSIA of the Stoichiometric Mixture, 300 F	A-22

PEAK-REACTION PRESSURES IN THE HYDROGEN-OXYGEN-WATER SYSTEM

Table A-22.	A-23

LIST OF FIGURES

IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A
1.5-IN. -DIAMETER AUTOCLAVE WITH SPARK IGNITION

Figure A-1. One Part Hydrogen to 1 Part Oxygen	A-24
Figure A-2. Two Parts Hydrogen to 1 Part Oxygen	A-25
Figure A-3. Three Parts Hydrogen to 1 Part Oxygen	A-26
Figure A-4. Four Parts Hydrogen to 1 Part Oxygen	A-27
Figure A-5. Five Parts Hydrogen to 1 Part Oxygen	A-28
Figure A-6. Twelve Parts Hydrogen to 1 Part Oxygen	A-29
Figure A-7. One Part Hydrogen to 2 Parts Oxygen	A-30
Figure A-8. One Part Hydrogen to 3 Parts Oxygen	A-31
Figure A-9. One Part Hydrogen to 4 Parts Oxygen	A-32
Figure A-10. Composite of Various Hydrogen and Oxygen Mixtures	A-33

IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A
2.5-IN. -DIAMETER AUTOCLAVE WITH SPARK IGNITION

Figure A-11. Two Parts Hydrogen to 1 Part Oxygen	A-34

IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A
3.0-IN. -DIAMETER AUTOCLAVE WITH SPARK IGNITION

Figure A-12. Two Parts Hydrogen to 1 Part Oxygen	A-35
Figure A-13. One Part Hydrogen to 1 Part Oxygen	A-36
Figure A-14. One Part Hydrogen to 12 Parts Oxygen	A-37

IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A 1.5-IN. -DIAMETER
AUTOCLAVE WITH HOT WIRE IGNITION

Figure A-15. Two Parts Hydrogen to 1 Part Oxygen	A-38

IGNITION REACTIONS IN THE NITROGEN-HYDROGEN-OXYGEN-WATER SYSTEM IN A
1.5-IN. -DIAMETER AUTOCLAVE WITH SPARK IGNITION

Figure A-16. 200 PSIA Nitrogen, 1 Part Hydrogen to 1 Part Oxygen	A-39

IGNITION REACTIONS IN THE ARGON-HYDROGEN-OXYGEN-WATER SYSTEM IN A
1.5-IN. -DIAMETER AUTOCLAVE WITH SPARK IGNITION

Figure A-17. 200 PSIA Argon, 1 Part Hydrogen to 1 Part Oxygen	A-40

LIST OF FIGURES
(Continued)

	<u>Page</u>
IGNITION REACTIONS IN THE HELIUM-HYDROGEN-OXYGEN-WATER SYSTEM IN A 1.5-IN.-DIAMETER AUTOCLAVE WITH SPARK IGNITION	
Figure A-18. 200 PSIA Helium, 1 Part Hydrogen to 1 Part Oxygen	A-41
Figure A-19. 200 PSIA Helium, 1 Part Hydrogen to 2 Parts Oxygen	A-42
Figure A-20. 200 PSIA Helium, 1 Part Hydrogen to 3 Parts Oxygen	A-43
PEAK-REACTION PRESSURES OF A STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN WITH NO DILUENT AT 300 F	
Figure A-21.	A-44
EFFECT ON PEAK-REACTION PRESSURES BY DILUTION WITH HELIUM OF A STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN AT 300 F	
Figure A-22.	A-45
EFFECT ON THE PEAK REACTION PRESSURES BY DILUTION WITH ARGON OF A STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN AT 300 F	
Figure A-23.	A-46
EFFECT ON PEAK-REACTION PRESSURES BY DILUTION WITH NITROGEN OF A STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN AT 300 F	
Figure A-24.	A-47
EFFECT ON PEAK-REACTION PRESSURES BY DILUTION WITH OXYGEN OF A STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN AT 300 F	
Figure A-25.	A-48
EFFECT OF WATER VAPOR ON THE PEAK REACTION PRESSURES	
Figure A-26.	A-49

1 F. 1135

IGNITION REACTIONS IN THE HYDROGEN-OXYGEN- WATER SYSTEM AT ELEVATED TEMPERATURES

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Ignition-reaction limits, defined here as the lowest partial pressure of the reactive gases, hydrogen and oxygen, in saturated water vapor which will produce a reaction upon ignition at a particular temperature, were established in a 1.5-in.-diameter autoclave at temperatures up to 550 F and gas partial pressures up to 200 psia. An induced spark was used for ignition. Tests in a 3.0-in.-diameter autoclave with the same limiting conditions of temperature and pressure showed no definite reaction limits. The data indicate that the larger vessels produce lower limits. Hot-wire ignition instead of spark ignition also lowers the reaction limit. Dilution of the mixture with argon or nitrogen raises the limit, but helium lowers the limit through part of the temperature range. Peak reaction pressures were measured under a variety of conditions.

The experimental data are presented in tabular and graphic form.

INTRODUCTION

Processes in which mixtures of hydrogen and oxygen can accumulate are potential hazards to equipment and personnel. While the reaction between hydrogen and oxygen under a variety of conditions has been studied in great detail by numerous investigators, a literature search prior to this investigation revealed no published data for ignition reactions of hydrogen-oxygen mixtures in saturated water vapor at elevated temperatures.

As part of the reactor program, a considerable amount of data has been obtained on the ignition reactions of hydrogen-oxygen mixtures in saturated water vapor at elevated temperatures and pressures. The primary purpose of the study was to obtain data of an engineering character for the design of nuclear-reactor equipment and to determine the safety factors in handling such mixtures.

The initial phase of this ignition-reaction study was reported in BMI-705, November 1, 1951, in which the apparatus and experimental techniques were described and some experimental data and theoretical considerations were presented. That work was continued and included studies on the effects of varying the hydrogen-to-oxygen ratio; diluting the hydrogen-oxygen mixtures with argon, nitrogen or helium; reaction-vessel diameter on the reactions, as well as measurements of some peak reaction pressures; and hot-wire ignitions instead of spark ignition.

This report is a final report on the entire study and summarizes all the data obtained during the entire investigation, including those presented in BMI-705.

THEORY OF THE HYDROGEN-OXYGEN REACTION

A chain theory for the mechanism of the reaction between hydrogen and oxygen has been proposed by several investigators. The development and experimental evidence to support the chain theory will not be discussed here in detail but reference is made to Lewis and Von Elbe⁽¹⁾ and Jost and Croft⁽²⁾ for a detailed discussion.

The theory proposes that the rate of chain branching is equal to the rate of chain breaking at the reaction limit. When the rate of chain branching exceeds that of chain breaking, propagation of the reaction from the ignition source is possible. A chain-propagating reaction and two chain-branching reactions are illustrated below:

In Reaction (1), the chain-propagation reaction, an active particle and a nonactive particle react to produce another active and a nonactive particle. In Reactions (2) and (3), the chain-branching reaction, an active particle and a nonactive particle produce two active particles.

The chain-breaking reactions, by which the radicals and atoms produced in Reactions (1), (2), and (3) are removed, occur both in the gas phase and at the wall or at any other surface in the reaction chamber. Some of these reactions are given below:

Under this theory, the propagation of the reaction from the point of ignition will be influenced by (1) source, type, and intensity of the ignition

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(1) References at end of text.

for producing the initial active particles; (2) the type and concentration of nonactive constituents in the gas phase; and (3) the nature and proximity of the walls or other surfaces in the reaction chamber.

EXPERIMENTAL PROCEDURE

The experimental procedure is, in general, the same as described in BMI-705⁽³⁾. The essential changes made in the procedure are listed below:

- (1) The sparking mechanism was altered so that the spark gap could be adjusted at temperature and pressure from outside the autoclave. This was necessary because the sparking becomes more difficult at increased pressures and must be adjusted.
- (2) The gases were premixed instead of adding each individually to the autoclave. This procedure saved considerable time in obtaining equilibrium conditions.
- (3) Tests were made in reaction vessels of larger diameter in order to study the effect on the reaction limits.

The peak reaction-pressure measurements were made with a Hydrauliscope. * The pressure-sensitive pickup was attached near the autoclave head in the gas-inlet line.

EXPERIMENTAL RESULTS

The experimental results are presented in both tabular and graphic form. This report summarizes all the data including that previously reported in BMI-705.⁽³⁾

In this investigation, a reaction is considered to have taken place when there is a measurable change in temperature and pressure upon ignition. In general, the reactions are rapid and explosive in character, but, sometimes under certain conditions, they are of the slow-burning type and produce little if any increase in temperature and pressure. Reactions of this type are indicated by a gradual loss in pressure.

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* Aeroquip Corporation, Jackson, Michigan.

The reaction limit is defined as the lowest partial pressure of the reactive gas mixture, hydrogen and oxygen, in saturated water vapor which will react at a particular temperature. This partial pressure was not determined directly but was obtained by subtracting the vapor pressure of the saturated water vapor, as reported in the steam tables for the temperature indicated by the thermocouple in the vapor phase, from the total pressure of the system.

Tables A-1 through A-10 in the Appendix present the data from induced-spark ignition tests in a 1.5-in.-diameter autoclave with various hydrogen-oxygen mixtures in saturated water vapor. Within the conditions of testing, 200 psia partial pressure of the hydrogen-oxygen mixture and 600 F maximum, reaction limits were established for all the mixtures except the 1 part hydrogen-12 parts oxygen mixture, which was nonreactive at all of the temperatures and pressures tested. These data, showing the reaction limits as a function of temperature and the partial pressure of the hydrogen-oxygen mixture, are plotted in Figures A-1 through A-9. The limit line on the figures represents the lowest partial pressure of the hydrogen-oxygen mixture at which a reaction could be made to occur. There appears to be no sharp dividing line between reactive and nonreactive pressures of the mixtures, but a region exists above the line where reaction can be expected, though it may not always occur. The data show clearly the influence of the amount of water vapor on the reaction limit. As the temperature of the system is increased, the amount of water vapor increases and a higher partial pressure of the hydrogen-oxygen mixture is necessary before a reaction can propagate.

Figure A-10 compares the limits for the various mixtures. Of the mixtures, the stoichiometric 2 parts hydrogen-1 part oxygen mixture has the highest limit. As the hydrogen-to-oxygen ratio is increased beyond the stoichiometric, the reaction limit becomes lower and even a 12 parts hydrogen-1 part oxygen mixture is reactive. As this hydrogen-to-oxygen ratio is decreased from the stoichiometric, the limit decreases until the ratio is 1:2 then appears to increase again. A 1 part hydrogen-12 parts oxygen mixture is nonreactive under any of the conditions tested.

A number of tests were made in larger diameter autoclaves to study the effect of reaction-vessel size on the limits. In these tests the distance from the head of the autoclave to the surface of the water was constant for all sizes of autoclaves so that only the diameter of the autoclave was a variable. The data for a stoichiometric hydrogen-oxygen mixture in saturated water vapor in a 2.5-in.-diameter autoclave are presented in Table A-11 and graphically shown in Figure A-11. The results of tests with various mixtures in a 3.0-in.-diameter autoclave are shown in Tables A-12, A-13, and A-14, and Figures A-12, A-13, and A-14.

The reduction of the reaction limit due to increasing the diameter of the reaction chamber from 1.5 in. to 2.5 in. can be seen by comparing

Figure A-11 with Figure A-2. For example, at 400 F the limit is reduced from 80 psia to 45 psia, and at 475 F the reduction is from 200 psia to 85 psia.

The data for the tests in the 3-in.-diameter autoclave do not establish a definite reaction limit. The reactive and nonreactive regions are not so clearly defined as in the smaller diameter autoclaves, but reactions at much lower partial pressures than those obtained in the 2.5-in.-autoclave did occur, and again illustrated that the reaction limit is lowered by increasing the distance from the ignition source to the walls of the reaction chamber. The random scattering of the data for reaction and nonreaction tests lends some doubt as to the validity of the results. Several reasons for this scattering can be offered. These tests were made under conditions near the extreme maximum in temperatures and pressures for the available equipment. In the larger equipment at the test temperatures, isothermal conditions in the reaction chamber are more difficult to attain and to maintain during the time necessary to carry out a test. Nonisothermal conditions could lead to an error in determining the partial pressure of the mixture. Also, the difficulty in sparking the mixture increases as the temperature and pressure increases. There is no assurance that sparking did occur in all the tests where reaction did not occur.

Several tests were made in the 1.5-in.-diameter autoclaves using a hot wire instead of the induced spark for the ignition. The wire was 3 in. of No. 17 Chromel A coiled in a spiral. The current was controlled by a Variac. The data are presented in Table A-15 and graphically shown in Figure A-15. Within the range of temperatures and pressures investigated, no definite limits were established because reactions occurred through the entire range. The larger ignition surface of the wire produced reactions at much lower partial pressures than were obtained by spark ignition.

From the chain theory of the mechanism of the hydrogen-oxygen reaction, the addition of a nonreactive gas should raise the limit because it would tend to promote chain-breaking reactions in the gas phase. A limited number of tests were made in the 1.5-in.-diameter autoclave to determine the effect of argon, nitrogen, and helium, in addition to the water vapor, on the reaction limits. The tests with 200 psia of nitrogen at 400, 425, and 450 F are shown in Table A-16 and compared graphically in Figure A-16 with the results of tests without nitrogen. The nitrogen addition increased the limit from 70 psia of the hydrogen-oxygen partial pressure to about 125 psia at 400 F, from 95 psia to 160 psia at 425 F, and from 130 psia to 210 psia at 450 F.

The results of tests with argon instead of nitrogen as the diluent are shown in Table A-17 and Figure A-17. At 400 F, 200 psia of argon increased the limit from 70 psia of the hydrogen-oxygen mixture to 95 psia, and at 450 F it increased it from 130 to 190 psia.

Dilution with helium produced some unexpected results. The tests made in three different hydrogen-to-oxygen ratios, 1:1, 1:2, and 1:3, are presented in Tables A-18, A-19, and A-20, and graphically shown in Figures A-18, A-19, and A-20. The pattern of the effect of helium dilution is similar in all three mixtures. At 400 F the limit is raised about 10 psia by the helium addition, at 450 F the limit is lowered from 10 to 20 psia, and at 480 F the limit is about the same as without the helium. Of the three diluents tested, nitrogen appears to be more effective in raising the limit.

Some peak-reaction-pressure measurements were made during the investigation. These measurements were made on a Hydrauliscope.* Unfortunately the pressure-sensitive pickups operate at a maximum of 200 F; therefore, they could not be mounted directly at the reaction chamber but were attached to the gas-inlet line with 0.25-in.-diameter high-pressure tubing about 3 in. from the head of the autoclave where the temperature was below 200 F when the autoclave is below 400 F.

The conditions and results of the peak-pressure-measurement tests at 300 F in a 1.5-in.-diameter autoclave are presented in Table A-21. In all the tests, the stoichiometric hydrogen-oxygen mixture was maintained at 100 psia. These tests were made with no water vapor present. Peak pressures 50 times that of the static pressure were measured. The tests with nitrogen and oxygen show the reduction in peak pressures by increasing the amount of diluent. The spread of peak-pressure values depends upon the degree of completeness of the hydrogen-oxygen reaction. Figures A-21 to A-25 are photographs of the oscilloscope during some of the reactions. The pressure contours show the brief induction period, usually less than 0.05 sec, before the pressure begins to increase to the peak. After the peak is reached, the pressure is maintained or very slowly decreases for several tenths of a second. The induction time is lengthened by nitrogen or excess oxygen.

Table A-22 shows the results of peak-pressure measurements of various hydrogen-oxygen mixtures in saturated water vapor at temperatures between 300 and 400 F. The peak pressures are greatly reduced by the water vapor and are only two or three times that of the pressure before ignition. The oscilloscope photos in Figure A-26 illustrate the variation in pressure contour for tests under the same conditions. The pressures are more oscillating than those obtained with dry mixtures.

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* Aeroquip Corporation, Jackson, Michigan.

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- (1) Lewis, B., and Von Elbe, G., Combustion, Flames, and Explosions of Gases, University Press, Cambridge, England (1938).
- (2) Jost, Wilhelm, and Croft, Hubert O., Explosion and Combustion Processes in Gases, McGraw-Hill Book Company, Inc., New York (1946).
- (3) Pray, H. A., Schweickert, C. E., and Stephan, E. F., "Explosion Limits of the Hydrogen-Oxygen-Water System at Elevated Temperatures", BMI-705 (November 1, 1951).

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APPENDIX

IGNITION-REACTION DATA AND CURVES

**TABLE A-1. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**1 Part Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressures Before Reaction, psia					Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
308	96	75	10	11	21	Yes	83	13
310	94	77	8	9	17	No		
320	107	89	9	9	18	No		
324	117	95	11	11	22	Yes	113	4
387	276	213	30	31	63	Yes	244	32
402	313	251	31	31	62	No		
410	328	268	30	30	60	No		
418	395	302	43	50	93	Yes	315	80
425	429	324	49	56	105	Yes	Total loss, rupture	
431	471	337	58	66	124	Yes	412	59
437	467	369	47	51	98	No		
450	602	422	92	88	180	Yes	462	140
447	542	410	64	68	132	Yes	Total loss, rupture	
462	596	476	59	61	120	No		
475	690	540	76	74	150	No		

**TABLE A-2. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**2 Parts Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressures Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss of Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ +O ₂			
60	66.2	0.2	44	22	66	Yes		
64	66.3	0.3	44	22	66	Yes		
64	30.3	0.3	20	10	30	Yes		
66	30.3	0.3	20	10	30	Yes		
68	30.3	0.3	20	10	30	Yes		
68	66.3	0.3	44	22	66	Yes		
70	66.4	0.4	44	22	66	Yes		
72	104.4	0.4	70	34	104	Yes		
76	66.4	0.4	44	22	66	Yes		
79	66.5	0.5	44	22	66	Yes		
80	66.5	0.5	44	22	66	Yes		
81	66.5	0.5	44	22	66	Yes		
126	69	2.0	45	22	67	Yes		
187	52	8.5	27	14.5	41.5	Yes		
214	32	16	10.5	5.5	16	Yes	16	16
235.5	35	22	8.5	4.5	13	Yes	25	10
240	39	25	9.5	4.5	14	Yes	27	12
246	39	28	7	4	11	No		
258	55.5	34	14.5	7.0	21.5	Yes	43.5	12
265	52	38.5	9	4.5	13.5	Yes	42	10
269	63	41	15	7	22	Yes		
275	97	45	34	18	52	Yes		
284	72.5	52	13.5	7.0	20.5	Yes	67	5.5
287	70	55	10	5	15	Yes	63	7
297	78	64	9	5	14	No		
299	113	66	32	15	47	Yes		
301.5	93	69	16	8	24	Yes	71	22
304	254	71	122	61	183	Yes		
305	103	72	21	10	31	Yes		
313	112	82	20	10	30	Yes	103	9
326	140	97	29	14	43	Yes	106	34
329	129	99	20	10	30	No		
338	161	115	31	15	46	Yes	138	23
339	146	115	21	10	31	No		
343	168	123	30	15	45	Yes	155	13
345.5	204	127	51	26	77	Yes	140	64
346	236	128	69	35	104	Yes		
348	179	131	32	16	48	Yes		
350	320	134	124	62	186	Yes	170	150
352	294	138	104	52	156	Yes	146	148
353	350	140	140	70	210	Yes		
354.5	189	142	32	15	47	No		
360.5	209	154	37	18	55	Yes		
362.5	203	158	30	15	45	No		
364	285	161	83	41	124	Yes		
366	264	165	66	33	99	Yes	221	43
366	355	165	60	30	90	Yes	219	36
373	270	193	51	26	77	Yes		
380	340	196	96	48	144	Yes		
380	256	196	40	20	60	Yes	246	10

TABLE A-2. (Continued)

Temperature, F	Pressures Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss of Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ +O ₂			
381	259	198	41	20	61	Yes	231	28
383	484	208	117	59	176	Yes		
388	309	215	63	31	94	Yes	285	24
389.5	279	219	40	20	60	No		
390	340	220	80	40	120	Yes	239	101
390	403	220	122	61	183	Yes		
395	383	233	100	50	150	Yes		
396	416	236	120	60	180	Yes	250	156
396	340	236	70	34	104	Yes	292	48
397	302	239	42	21	63	No		
399	400	244	104	52	156	Yes		
400	329	247	55	27	82	Yes	304	25
400	307	247	40	20	60	No		
402	343	253	60	30	90	Yes	330	13
404	382	258	83	41	124	Yes		
404	372	258	76	38	114	Yes		
405	389	262	85	42	127	Yes		
405.5	408	263	97	48	145	Yes	292	116
408	351	271	54	26	80	No		
411	482	282	134	66	200	Yes	357	125
413	425	286	93	46	139	Yes		
414	439	289	100	50	150	Yes	344	95
414.5	369	290	53	26	79	No		
418	410	302	72	36	108	Yes	386	24
418.5	477	304	116	57	173	Yes	366	111
419	395	305	60	30	90	No		
421	480	312	94	46	140	Yes	358	122
421	452	312	112	56	168	Yes	368	84
422	436	316	80	40	120	Yes	424	12
422.5	500	315	123	62	185	Yes		
425	405	326	53	26	79	No		
427	424	333	61	30	91	No		
430	464	344	80	40	120	No		
440	500	382	78	40	118	No		
441	528	386	95	47	142	Yes	415	113
442	563	390	115	58	173	Yes	447	116
443	532	394	93	45	138	No		
446	575	408	111	56	167	Yes	485	90
447	597	410	123	64	187	Yes	482	115
448.5	619	416	136	67	203	Yes	514	105
448.5	534	416	78	40	118	No		
450	565	423	95	47	142	No		
451.5	627	429	131	67	198	Yes	500	127
451.5	610	429	121	60	181	Yes		
452	605	431	116	58	174	Yes		
454	608	440	112	56	168	No		
454	575	440	90	45	135	No		
460.5	666	469	131	66	197	Yes		
463	657	481	117	59	176	No		
474.5	742	537	137	68	205	Yes		
476	733	545	126	62	188	No		
481	756	571	123	62	185	No		
48.6	799	599	134	66	200	No		

TABLE A-3. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER
SYSTEM IN A 1.5-IN.-DIAMETER AUTOCLAVE

3 Parts Hydrogen to 1 Part Oxygen
Spark Ignition

Temperature, F	Pressures Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss of Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
70	40		30	10	40	Yes		
212	36.6	14.6	16.5	5.5	22	Yes	25.6	11
229	34	20.4	10.8	3.2	14	Yes	22.0	12
242	58.6	26.0	24.6	8	32.6	Yes	42.6	16
242	42.6	26.0	12.6	4	16.6	No		
244	41	27	10	4	14	Yes	28	13
288	73	56	13	4	17	No		
289.5	78	57	16	5	21	No		
290	88	57	23	8	31	Yes	68	20
291	94	58	27	9	36	Yes	71	23
293	102.6	60	32.6	10	42.6	Yes	72.6	30
293	83.6	60	17.6	6	23.6	No		
299	82	66	12	4	16	No		
301.5	88	68.5	14.5	5	19.5	Yes		
320.5	110	90	15	5	20	No		
322	123	92	23	8	31	Yes		
323	154	94	45	15	60	Yes	124	30
324	134	95	29	10	39	No		
324	151	95	42	14	56	Yes	113	38
324	119	95	18	6	24	Yes	110	9
325	145	96	37	12	49	No		
326.5	130	98	24	8	32	No		
340	178	118	45	15	60	Yes	139	39
342	199	121	59	19	78	Yes	144	55
349	166	133	25	8	33	No		
351	176	136	30	10	40	Yes	155	21
351	182	136	34	12	46	Yes	143	39
352	190	138	39	13	52	Yes	149	41
355	227	144	62	21	83	Yes		
372.5	232	178	41	13	54	Yes	204	28
373	271	180	68	23	91	Yes	198	73
377	229	189	30	10	40	No		
377.5	242	190	39	13	52	Yes	218	24
391.5	304	224	60	20	80	Yes	286	18
392	300	226	56	18	74	Yes		
394	294	230	48	16	64	No		
395	300	233	50	17	67	Yes	251	49
396	306	236	52	18	70	Yes	267	39
409	408	273	101	34	135	Yes	334	74
412.5	393	284	82	27	109	Yes		
420	437	308	97	32	129	Yes	351	86
422	450	315	101	34	135	Yes	370	80
422	406	316	68	22	90	No		
423	429	319	83	27	110	Yes	353	76
424.5	427	323	78	26	104	Yes	394	33
425	505	326	134	45	179	Yes		
426.5	478	331	110	37	147	Yes	360	118
427	491	333	119	39	158	Yes	363	128
443	515	394	91	30	121	No		
445.5	539	403	102	34	136	Yes	454	85
449	540	418	92	30	122	No		
474.5	701	539	121	41	162	No		
475.5	731	547	138	46	184	Yes	612	119
477	722	550	129	43	172	No		

**TABLE A-4. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A
1.5-IN.-DIAMETER AUTOCLAVE**

**4 Parts Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressures Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss of Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
277	62	47	12	3	15	Yes	59	3
298	80	65	12	3	15	No		
300	89	67	18	4	22	Yes	75	14
326.5	118	98	16	4	20	No		
329.5	130	102	22.5	5.5	28	No		
329.5	139	102	30	7	37	Yes	109	30
331	141	104	30	7	37	Yes	119	22
355.5	178	144	27	7	34	No		
357	189	147	34	8	42	Yes	160	29
358	189	149	32	8	40	Yes	173	16
358	194	149	36	9	45	Yes	173	21
359	205	150	44	11	55	Yes	167	38
364.5	205	162	35	8	43	No		
377.5	232	189	35	8	43	No		
388	258	215	35	8	43	No		
388	276	215	49	12	61	Yes	266	10
395.5	296	235	49	12	61	No		
398.5	285	243	34	8	42	No		
402	330	253	62	15	77	Yes	300	30
403.5	297	256	33	8	41	No		
406.5	326	266	48	12	60	No		
410.5	354	278	61	15	76	No		
414.5	350	290	48	12	60	No		
416	439	296	115	28	143	Yes		
417	411	299	90	22	112	Yes	311	100
418	378	302	61	15	76	No		
423	515	319	157	39	196	Yes		
425.5	386	327	47	12	59	No		
428.5	414	339	60	15	75	No		
433	458	355	82	21	103	Yes	445	13
434.5	491	360	105	26	131	Yes		
435.5	467	364	82	21	103	No		
443	569	393	141	35	176	Yes	403	166
446.5	551	407	115	29	144	Yes	415	136
446.5	579	408	137	34	171	Yes	442	137
452.5	618	434	147	37	184	Yes		
454	621	440	145	36	181	Yes	471	150
458	601	458	114	29	143	No		
465	663	490	138	35	173	Yes	511	152
472	700	525	140	35	175	Yes	564	137
477	734	550	147	37	184	No		
478.5	748	558	152	38	190	Yes	575	173
485	793	593	160	40	200	No		
490	822	622	160	40	200	No		

**TABLE A-5. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**5 Parts Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressure Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss of Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
295.5	80	63	14	3	17	Yes	73	7
304.5	89	72	14	3	17	No		
317	110	86	20	4	24	Yes	102	8
319	106	88	15	3	18	No		
333	131	107	20	4	24	No		
338.5	143	114	24	5	29	Yes	139	4
354.5	172	142	25	5	30	No		
356.5	186	146	33	7	40	Yes	174	12
364	207	161	38	8	46	Yes	198	9
379	236	193	36	7	43	No		
392.5	269	226	36	7	43	No		
409.5	350	275	63	12	75	Yes	310	40
412.5	393	285	90	18	108	Yes		
417	372	299	61	12	73	No		
427.5	437	335	85	17	102	Yes	359	78
431	478	347	109	22	131	Yes		
437	468	370	82	16	98	No		
439	511	378	115	23	138	Yes		
446	502	406	80	16	96	No		
464	606	486	100	20	120	Yes		
465	597	490	89	18	107	No		
467	625	500	104	21	125	Yes		
469	679	509	142	28	170	Yes		
487	759	604	129	26	155	Yes		
495	805	650	129	26	155	No		
496	853	657	164	33	197	Yes		
496	835	657	148	30	178	No		
502	895	693	168	34	202	Yes		
506.5	927	723	170	30	204	No		

**TABLE A-6. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER
SYSTEM IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**12 Parts Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressure Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss of Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ +O ₂			
304	149	71	72	6	78	Yes	135	14
305	126	72	50	4	54	Yes	116	10
297	103	64	36	3	39	Yes	94	9
309	113	76	34	3	37	Yes	97	16
355	171	143	26	2	28	Yes		
396.5	408	237	159	12	171	Yes		
396.5	374	237	126	11	137	Yes	328	46
394.5	308	232	70	6	76	Yes		
394.5	245	232	12	1	13	Yes		
434.5	378	360	16.5	1.5	18	Yes		
429.5	415	342	66	7	73	Yes		
463	504	481	21	2	23	Yes		
463	504	481	21	2	23	Yes		
468	528	505	21	2	23	Yes		
483	598	585	12	1	13	No		
486	625	599	24	2	26	Yes	617	8
501.5	770	690	74	6	80	Yes		
539	975	955	18.5	1.5	20	No		
540	1035	966	64	5	69	No		
541.5	1071	974	90	7	97	Yes		
557.5	1283	1110	168	14	182	No		
565.5	1311	1184	117	10	127	No		
565.5	1240	1184	70	6	76	No		
569	1290	1221	64	5	69	No		
569	1274	1216	53	5	58	No		
571	1358	1237	111	10	121	No		
571.5	1327	1242	81	7	88	No		
578	1376	1307	64	5	69	No		
581	1424	1348	70	6	76	No		

**TABLE A-7. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**1 Part Hydrogen to 2 Parts Oxygen
Spark Ignition**

Temperature, F	Pressures Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss of Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
288	70	55	5	10	15	Yes	67	3
309	90	76	4.5	9.5	14	No		
313	110	81	9	20	29	Yes	104	6
316	106	85	7	14	21	Yes	93	13
318	97	88	3	6	9	No		
324	141	93	16	32	48	Yes	111	30
325	112	96	5.5	10.5	16	No		
329	139	101	13	25	38	Yes	126	13
330	147	103	15	30	45	Yes		
333	133	106	9	18	27	No		
333	142	106	12	24	36	Yes		
345	165	125	14	26	40	Yes	140	25
353	149	140	3	6	9	No		
353	168.5	140	10	18.5	28.5	No		
359	186	152	11	23	34	Yes	166	20
369	219	172	17	30	47	Yes	203	16
379	223	194	9	20	29	No		
394	275	230	15	30	45	Yes	234	41
397	347	239	36	72	108	Yes	275	72
402	325	251	28	46	74	Yes	Leak	
409	328	270	21	37	58	Yes	281	47
417	364	300	19	45	64	Yes	324	40
425	375	325	16	24	50	No		
424	454	322	41	91	132	Yes	Rupture	
438	467	374	30	63	93	Yes	437	30
443	559	302	53	101	157	Yes	522	37
487	814	605	71	138	209	Yes	801	113
491	763	627	42	94	136	Yes	669	94
500	790	681	36	73	109	No		
500	801	681	40	80	120	No		
500	823	681	47	95	142	Yes	736	87

**TABLE A-8. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER
SYSTEM IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**1 Part Hydrogen to 3 Parts Oxygen
Spark Ignition**

Temperature, F	Pressures Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
292	117	59	15	43	58	Yes	81	36
293	84	60	6	18	24	Yes	67	17
300	112	68	11	36	47	Yes	91	21
308	88	72	3.5	12.5	16	Yes	81	7
322	109	92	6	11	17	Yes	100	9
323	108	93	4	11	15	Yes	99	9
323	118	93	6	19	25	Yes	102	16
326	114	97	4	13	17	Yes	106	8
330	123	104	4	15	19	No		
330	143	103	10	30	40	Yes	128	15
336	152	111	11	30	41	Yes	134	18
340	176	119	14	43	57	Yes	157	19
340	161	119	10	32	42	No		
343	154	122	7	25	32	Yes	141	13
346	205	126	20	59	79	Yes	149	56
353	203	139	16	48	64	Yes	186	17
361	198	154	11	33	44	Yes	167	31
367	215	165	12	35	47	Yes	178	37
369	210	171	10	29	39	No		
370	347	173	43	131	174	Yes	257	90
379	276	194	20	62	82	Yes	234	42
379	265	195	18	52	70	Yes	234	31
386	384	211	42	131	173	Yes	Rupture	
393	292	229	16	49	63	Yes	252	40
393	359	228	32	99	131	Yes	289	70
401	312	250	15	47	62	No		
406	322	265	14	43	57	No		
409	328	273	13	42	55	No		
419	384	306	18	60	78	Yes	335	49
435	434	362	17	55	72	No		
435	452	362	23	67	90	Yes	Leak	
459	593	463	33	97	130	Yes	Leak	
468	628	504	32	92	124	No		
471	659	519	35	105	140	Yes	590	69
484	722	588	33	99	132	No		

TABLE A-9. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A 1.5-IN.-DIAMETER AUTOCLAVE

**1 Part Hydrogen to 4 Parts Oxygen
Spark Ignition**

Temperature, F	Pressures Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
303	87.5	70	3.5	14	17.5	Yes	74.0	13.5
312	96.5	80	3.5	13	16.5	No		
321	106.5	91	3.0	12.5	15.5	No		
330	116.5	103	2.5	11.0	13.5	No		
348	235	131	21	83	104	Yes	191	44
351	190	136	11	43	54	Yes		
351	264	136	25	103	128	Yes		
364.5	202	162	8	32	40	Yes	194	8
370.5	212	174	7.5	30.5	38	Yes		
373	217	180	7.5	29.5	37	No		
380	228	196	6.5	25.5	32	No		
383.5	270	204	13	53	66	Yes	228	42
400.5	351	249	20	82	102	Yes	304	47
401	393	250	28	115	143	Yes	325	68
404	323	258	13	52	65	Yes	298	25
404.5	340	260	16	64	80	Yes	295	45
413	367	286	16	65	81	Yes	301	66
415.5	332	293	8	31	39	No		
422	365	315	10	40	50	No		
425	395	326	14	55	69	Yes	360	35
434.5	469	360	22	87	109	Yes	385	84
446.5	523	406	23	94	117	Yes	471	52
449	536	418	23	95	118	Yes		
449	514	418	19	77	96	No		
452	551	431	24	96	120	No		
453	562	435	25	102	127	Yes		
454	530	440	18	72	90	No		
457	554	453	20	81	101	Yes	513	41
461.5	585	473	22	90	112	Yes	533	52
465	585	490	19	76	95	No		
468	613	505	21	87	108	No		
478	679	556	25	98	123	Yes	Slow burning Slow burning Slow burning Slow burning	
486	741	599	28	114	142	Yes		
488	782	610	34	138	172	Yes		
494.5	798	649	30	119	149	Yes		
498	831	669	32	130	162	No		
497.5	832	666	53	113	166	Yes	756	76
506	870	718	30	122	152	No		
507	885	725	32	128	160	Yes		
507	899	725	35	139	174	Yes		
507.5	908	728	36	144	180	Yes		
513	963	765	40	158	198	Yes		
515.5	956	781	35	140	175	Yes	869	87
527	1060	863	40	157	197	No		
531.5	1087	895	39	153	192	No		
534	1115	917	40	158	198	No		

**TABLE A-10. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**1 Part Hydrogen to 12 Parts Oxygen
Spark Ignition**

Note: No reactions occurred in any of the tests

Temperature, F	Pressures Before Ignition, psia				
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂
150	122	4	8	110	118
203	137	12	9	116	125
215	145	15	10	120	130
248	167	28	10	129	139
300 ^(a)	182	67	9	106	115
303	218	70	11	137	148
349 ^(b)	240	133	8	99	107
349	260	133	10	117	127
350	213	135	6	72	78
351	341	137	15	189	204
353	292	140	12	140	152
354	272	142	10	120	130
358	255	149	8	98	106
402	405	253	11	131	142
405	379	262	9	108	117
414	377	288	6	83	89
448	478	414	5	59	64
449	575	419	12	144	156
458	554	457	7	90	97
459	534	463	5	66	71
480	661	566	7	88	95
506	775	718	4	53	57
508	790	730	4	55	59
532	945	900	3	42	45
553	1111	1071	3	37	40
253 ^(c)	143	31	10	102	112

(a) 7 psia more hydrogen added; a slight reaction occurred with 2-psia loss. 10 psia more hydrogen added, a crisp explosion occurred.

(b) 10 psia more hydrogen added, reacted on ignition.

(c) This is a 1 part hydrogen-10 parts oxygen mixture, no reaction on ignition. 6 psia more hydrogen added, reacted on ignition.

**TABLE A-11. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER
SYSTEM IN A 2.5-IN.-DIAMETER AUTOCLAVE**

**2 Parts Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressures Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
286	74	54	14	6	20	Yes	61	13
361	195	155	26	14	40	Yes	169	26
417.5	375	301	49	25	74	Yes	325	50
418.5	393	304	59	30	89	Yes	334	59
419	363	305	38	20	58	Yes	340	23
420.5	376	310	44	22	66	Yes	322	54
421	392	312	53	27	80	Yes	340	52
424	384	322	41	21	62	No		
444	594	397	131	66	197	Yes	465	129
448.5	517	416	67	34	101	Yes		
460.5	660	469	131	66	197	Yes	520	140
474.5	742	537	137	68	205	Yes	605	137
476	644	545	66	33	99	Yes	584	60
477	668	550	78	40	118	Yes		
477	628	550	52	26	78	No		
477	642	550	61	31	92	Yes	560	82
478.5	647	558	59	30	89	Yes	586	61
499.5	752	678	50	24	74	No		
504.5	813	708	70	35	105	No		
505.5	854	765	93	46	139	Yes	715	98
506	809	719	60	30	90	No		

**TABLE A-13. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER
SYSTEM IN A 3-IN.-DIAMETER AUTOCLAVE**

**1 Part Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressure Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
458	475	457	9	9	18	No		
466	516	495	10.5	10.5	21	No		
468	543	504	19.5	19.5	39	No		
477.5	590	533	28.5	28.5	57	Weak reaction		Leak
479	586	561	12.5	12.5	25	No		
489	644	619	12.5	12.5	25	No		
545	1016	1003	6.5	6.5	13	Yes		10
545	1020	1003	8.5	8.5	17	Yes	1009	11
555	1104	1088	8	8	16	Yes	1100	4
563	1181	1161	10	10	20	Yes		Blew 3900-lb rupture disc
566	1196	1190	3	3	6	Yes		
570	1240	1228	6.5	6.5	13	Yes		Blew 3900-lb rupture disc
573	1273	1257	8	8	16	Yes		Blew 6000-lb rupture disc
587	1420	1400	10	10	20	Yes	1405	15

**TABLE A-12. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER
SYSTEM IN A 3-IN.-DIAMETER AUTOCLAVE**

**2 Parts Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressures Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
357	192	147	30	15	45	Yes		
387	225	212	9	4	13	Yes		
391	243	222	14	7	21	Yes		
395	285	233	25	17	52	Yes		
404	277	258	13	6	19	Yes		
427	353	333	13.5	6.5	20	Yes		
435	382	362	13.5	6.5	20	No		
435	384	362	15	7	22	No		
441	444	385	39	20	59	Yes	(a)	
441	410	385	17	8	25	Yes		
443	413	393	13.5	6.5	20	No		
447	425	410	10	5	15	Yes		
450	433	422	7	4	11	Yes	425	8
450	460	422	25	13	38	No		
459	472	466	8	4	12	Yes		
462	495	476	13	6	19	Yes	480	15
462	496	476	13.5	6.5	20	Yes	478	18
479	617	561	37	19	56	Yes	567	50
481	625	571	36	18	54	No		
482	590	580	7	3	10	Yes		
487	645	604	27	14	41	No		
487	630	604	17	9	26	Yes	614	16
492	687	633	36	18	54	No		
500	720	681	26	13	39	Yes	690	30
505	720	712	5	3	8	Yes		
506	768	718	33	17	50	No		
520	835	812	15	8	23	No		
522	858	827	21	10	31	No		
524	866	841	17	8	25	Yes	(a)	
547	1030	1020	7	3	10	No		
550	1085	1045	27	13	40	No		
550	1075	1045	20	10	30	Yes	1050	25
570	1250	1227	15	8	23	Yes	1229	21
578	1337	1307	20	10	30	Yes	1309	28
600	1582	1544	25	13	38	Yes	1552	30

**TABLE A-14. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER
SYSTEM IN A 3-IN.-DIAMETER AUTOCLAVE**

**1 Part Hydrogen to 12 Parts Oxygen
Spark Ignition**

Temperature, F	Pressure Before Ignition, psia					Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂			
Room temperature	54				54	Yes	44	10
212	54	14	3	3.7	40	Yes		
292	120	59	4.5	56.5	61	Yes	51	10
300	98	67	2.5	28.5	31	No		
300	87	67	2	18	20	No		
363	192	158	2.5	28.5	34	No		
364	200	160	3	37	40	No		
374	251	182	5	64	69	No		
375	284	184	7	93	100	No		
440	454	381	6	67	73	No		

**TABLE A-15. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER
SYSTEM IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**2 Parts Hydrogen to 1 Part Oxygen
Hot-Wire Ignition**

Temperature, F	Pressures Before Ignition, psia					Reaction	Wire Temperature at Reaction, F	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	H ₂	O ₂	H ₂ + O ₂				
302	140	69	57	24	71	Yes		90	50
352	208	138	57	23	70	Yes	1800	143	65
358	216	149	45	22	67	Slow burning	1800	171	45
400	358	247	74	37	111	Yes	1800	308	50
425	345	325	13	7	20	Yes	1600	330	15
430	452	343	73	36	109	Yes	900	393	59
472	620	524	64	32	96	Yes	1400	536	84
480	650	566	56	28	84	Yes	1600	566	84
480	641	566	50	25	75	Yes	1900	596	45
490	667	621	31	15	46	Yes	1800	627	40
492	718	633	57	28	85	Yes	1600	698	20
500	701	681	13	7	20	No	(a)		
505	760	706	36	18	54	No	(a)		
508	761	731	20	10	30	Yes	1800		
510	860	744	77	39	116	Yes	1800	790	70
513	855	765	60	30	90	Yes	1600	815	40
518	821	798	15	8	23	No	(a)		
525	935	848	58	29	87	Yes		870	65
525	886	848	25	13	38	Yes	1600	(b)	
526	895	855	27	13	40	Yes	1800	875	20
535	942	923	13	6	19	Yes	1800	927	15
541	1050	970	53	27	80	No	(a)		
544	1018	995	15	8	23	Yes	1800	1003	15
545	1078	1003	50	25	75	Slow burning	2000		
545	1091	1003	59	29	88	Slow burning	2000		
550	1075	1045	20	10	30	Yes	1800	1060	15
550	1066	1045	14	7	21	Yes	1800	1051	15
551	1083	1054	19	10	29	Yes	1800	1068	15
566	1240	1189	34	17	51	No	(a)		
566	1269	1189	53	27	80	No	(a)		
570	1308	1228	53	27	80	No	(a)		
571	1295	1237	39	19	58	No	(a)		

(a) Heated until wire burned off >2000 F.

(b) 3900-psi rupture disk blown.

**TABLE A-16. IGNITION REACTIONS IN THE NITROGEN-HYDROGEN-OXYGEN-WATER
SYSTEM IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**200 PSIA Nitrogen
1 Part Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressures Before Ignition, psia						Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	N ₂	H ₂	O ₂	H ₂ + O ₂			
400	547	247	200	50	50	100	No		
	567	247	200	60	60	120	No		
	567	247	200	60	60	120	No		
	577	247	200	65	65	130	Yes	547	30
	577	247	200	65	65	130	Yes	550	27
	597	247	200	75	75	150	Yes	547	52
	627	247	200	90	90	180	Yes	532	95
	647	247	200	100	100	200	Yes	527	120
425	675	325	200	75	75	150	No		
	675	325	200	75	75	150	No		
	680	325	200	78	77	155	No		
	685	325	200	80	80	160	Yes	665	20
	705	325	200	90	90	180	No		
	710	325	200	93	92	185	Yes	615	95
	725	325	200	100	100	200	Yes	635	90
438	773	373	200	100	100	200	Yes	763	10
450	802	422	200	90	90	180	No		
	822	422	200	100	100	200	No		
	822	422	200	100	100	200	No		
	822	422	200	100	100	200	No		
	832	422	200	105	105	210	No		

**TABLE A-17. IGNITION REACTIONS IN THE ARGON-HYDROGEN-OXYGEN-WATER
SYSTEM IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**200 PSIA Argon
1 Part Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressures Before Ignition, psia						Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	A	H ₂	O ₂	H ₂ + O ₂			
400	317	247	0	35	35	70	Yes		
	537	247	200	45	45	90	No		
	542	247	200	47	48	95	No		
	547	247	200	50	50	100	No		
	547	247	200	50	50	100	Yes	532	15
	576	247	200	64	65	129	Yes	482	94
	587	247	200	70	70	140	Yes	495	92
	607	247	200	80	80	160	Yes	517	90
	627	247	200	90	90	180	Yes	537	90
450	547	422	0	63	62	125	Yes		
	782	422	200	80	80	160	No		
	802	422	200	90	90	180	No		
	822	422	200	100	100	200	No		
	822	422	200	100	100	200	Yes	762	60

**TABLE A-18. IGNITION REACTIONS IN THE HELIUM-HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**200 PSIA Helium
1 Part Hydrogen to 1 Part Oxygen
Spark Ignition**

Temperature, F	Pressures Before Ignition, psia						Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	He	H ₂	O ₂	H ₂ + O ₂			
392	520	225	200	48	47	95	Yes	495	25
395	527	233	210	41	41	82	Yes	507	20
398	541	241	200	43	57	100	No		
400	522	247	200	37	38	75	No		
400	526	247	200	39	40	79	No		
400	527	247	200	42	38	80	No		
400	547	247	200	51	49	100	No		
400	562	247	200	55	60	115	No		
400	593	247	200	70	76	146	Yes		
404	560	260	200	50	50	100	No		
404	577	260	200	58	59	117	No		
404	589	260	200	64	65	129	Yes	522	67
405	542	262	200	43	37	80	No		
406	580	264	200	60	56	116	Yes	509	71
408	616	270	197	75	74	149	Yes	585	39
409	589	275	200	57	57	114	Yes	562	27
409	641	273	204	78	76	154	Yes	581	60
409	668	273	200	97	98	195	Yes		
440	672	381	200	43	48	91	No		
450	726	423	200	53	50	103	Yes	676	50
450	742	422	200	60	60	120	Yes	710	32
450	838	422	200	105	111	216	Yes	775	63
450.5	740	425	200	56	59	115	Yes	711	29
453	795	436	197	74	88	162	Yes	680	115
454	832	440	202	95	95	190	Yes	723	109
454	729	441	200	43	45	88	No		
455	800	444	200	78	78	156	Yes	710	90
480	906	566	200	70	70	140	No		
480	914	566	200	74	74	148	No		
480	952	566	200	93	93	186	Yes	892	60
480	966	566	200	100	100	200	Yes	886	80
480	968	566	200	100	102	202	Yes		
480	1001	566	205	110	120	230	Yes	902	99
481	922	570	200	75	77	152	Yes	850	72
481	930	570	200	80	80	160	Yes	880	50
481	950	570	200	90	90	180	Yes	830	120

**TABLE A-19. IGNITION REACTIONS IN THE HELIUM-HYDROGEN-OXYGEN-WATER
SYSTEM IN A 1.5-IN.-DIAMETER AUTOGRAVE**

**200 PSIA Helium
1 Part Hydrogen to 2 Parts Oxygen
Spark Ignition**

Temperature, F	Pressure Before Ignition, psia						Reaction	Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	He	H ₂	O ₂	H ₂ + O ₂			
398	585	241	200	43	101	144	Yes	470	115
400	593	247	200	49	97	146	Yes		
402	611	253	217	53	88	141	Yes	542	69
402	585	253	200	43	89	132	Yes	542	43
403	548	255	200	31	62	93	Yes	467	81
404	532	258	200	21	53	74	Yes	475	57
405	572	262	200			110	No		
409	547	275	200	24	48	72	Yes	495	52
410	633	276	200	55	102	157	Yes		
410	598	276	200	40	82	122	No		
410	588	276	200	37	75	112	No		
411	592	279	200	36	77	113	Yes	575	17
411	593	279	200	39	75	114	No		
411	554	281	204	21	48	69	No		
413	552	286	202	20	44	64	No		
418	583	302	200	27	54	81	Yes	557	26
448	734	414	212	36	72	108	Yes	702	34
449	677	420	200	18	39	57	Yes	646	31
449	699	420	200	26	53	79	Yes	665	34
450	740	422	200	37	81	118	Yes	690	50
450	812	422	198	60	132	192	Yes	682	134
451	676	426	200	17	33	50	No		
452	690	432	210	16	32	48	No		
453	752	435	200	39	78	117	No		
453	767	435	200	42	90	132	Yes	700	62
453	712	437	204	23	48	71	Yes	701	11
454	815	440	190	61	124	185	Yes		
455	782	444	198	46	94	140	Yes	670	112
455	772	444	200	40	88	128	Yes	710	62
455	818	444	200	56	118	174	Yes	730	88
457	815	454	200	51	110	161	Yes	735	80
459	752	463	193	33	63	96	Yes	707	45
480	866	566	200	35	65	100	No		
481	881	571	200	39	71	110	No		
482	891	577	200	41	73	114	Yes	831	60
483	911	582	200	43	86	129	Yes	852	59

**TABLE A-20. IGNITION REACTIONS IN THE HELIUM-HYDROGEN-OXYGEN-WATER
SYSTEM IN A 1.5-IN.-DIAMETER AUTOCLAVE**

**200 PSIA Helium
1 Part Hydrogen to 3 Parts Oxygen
Spark Ignition**

Tempera- ture, F	Pressures Before Ignition, psia						Reaction	Total Pressure After Reaction, psia	Loss in Pressure by Reaction, psia
	Total	H ₂ O	He	H ₂	O ₂	H ₂ + O ₂			
392	497	227	200	18	52	70	No		
398	515	241	200	17	57	74	No		
400	497	247	200	18	52	70	No		
400	522	247	200	18	57	75	Yes	452	70
400	658	248	205	50	155	205	Yes	578	80
402	593	254	200	34	105	139	Yes	585	8
402	598	254	200	36	108	144	Yes	530	68
404	570	260	192	28	90	118	Yes	552	18
404	621	259	200	40	122	162	Yes	535	86
406	591	264	200	31	93	124	Yes		
407	567	268	200	22	77	99	Yes	563	4
407	601	268	201	32	100	132	Yes	551	50
408	538	272	200	16	50	66	No		
409	580	273	200	26	81	107	Yes	570	10
409	585	273	199	28	85	113	Yes	553	32
411	567	279	201	20	67	87	Yes	532	35
411	635	279	200	39	117	156	Yes	605	30
411	711	279	202	55	175	230	Yes	638	73
425	731	329	200	49	153	202	Yes	691	40
442	667	389	200	19	59	78	Yes	680	7
448	746	414	200	32	100	132	Yes	660	86
448	667	415	200	13	39	52	No		
449	742	418	204	30	90	120	Yes	700	42
450	747	422	200	31	94	125	Yes	690	57
450	768	420	200	38	110	148	No		
450	689	423	200	17	49	66	Yes	620	68
451	693	428	202	15	44	59	No		
452	693	431	200	16	46	62	Yes	626	67
452	759	433	212	29	85	114	Yes	724	35
453	737	435	200	26	71	102	Yes	728	9
453	808	435	200	44	129	173	Yes	670	138
453	817	435	192	46	144	190	Yes	731	86
454	778	442	200	32	100	132	Yes	660	86
455	716	444	200	18	54	72	Yes	672	44
457	716	455	200	15	46	61	No		
458	819	458	202	36	123	159	Yes	738	81
460	802	467	198	33	104	137	Yes	710	92
480	891	566	200	31	94	125	No		
480	939	566	200	37	133	170	Yes	903	36
482	937	577	200	40	120	160	Yes		

TABLE A-21. PEAK-REACTION PRESSURES SHOWING THE EFFECT OF DILUTING A STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN

100 PSIA of the Stoichiometric Mixture, 300 F

Diluent	Gas Composition at Ignition						Peak Pressure, X ± 100 psi	Time From Ignition to Peak Pressure, sec
	Partial Pressure, psia			Per Cent				
	H ₂	O ₂	Diluent	H ₂	O ₂	Diluent		
None	66.7	33.0	0	66.7	33.3	0	3600	0.1
							>5000	0.1
							>5000	0.2
							5000	0.1
							3000	0.1
							3250	0.1
Helium	66.7	33.0	200	22.2	11.1	66.7	4800	0.1
							4800	0.1
							5000	0.1
							4800	0.1
Argon	66.7	33.0	200	22.2	11.1	66.7	4300	0.1
							4200	0.1
							>4000	0.1
							4000	0.1
							3500	0.125
							4000	0.1
Nitrogen	66.7	33.3	100	33.35	16.65	50.0	4000	0.1
	66.7	33.3	100	33.35	16.65	50.0	3900	0.125
	66.7	33.3	200	22.2	11.1	66.7	3200	0.2
	66.7	33.3	200	22.2	11.1	66.7	No reaction	
	66.7	33.3	200	22.2	11.1	66.7	2000	0.15
	66.7	33.3	200	22.2	11.1	66.7	900	Sustained over 0.3 sec, no peak
Oxygen	66.7	33.3	66	40	60		4000	0.1
	66.7	33.3	165	25	75		3500	0.125
	66.7	33.3	200	21	89		3100	0.125
	66.7	33.3	264	18.5	81.5		2100	0.3
	66.7	33.3	264	18.5	81.5		1500 at end of 0.3-sec sweep, still slowly increasing	
	66.7	33.3	330	15.5	84.5		Slow-burning reaction, no peak	

TABLE A-22. PEAK-REACTION PRESSURES IN THE HYDROGEN-OXYGEN-WATER SYSTEM

Temperature, F	Total Pressure, psia	Partial Pressure of Mixture, psia	Hydrogen-to-Oxygen Ratio	Pressure Above Total Pressure, psia	Loss of Pressure on Ignition, psia
305	190	118	1:2	250	30
360	250	103	1:2	100	50
408	380	110	1:2	110	30
353	242	103	1:2	175	55
351	239	102	1:2	80	17
404	360	101	1:1	150	80
403	360	105	1:1	Rupture	Disc blown
400	347	100	1:1	200	4
354	243	102	1:1	105	27
354	240	99	1:1	190	55
354	241	100	1:1	100	30
353	240	100	1:1	182	65
300	167	100	1:1	180	82
300	167	100	1:1	180	75
403	362	107	2:1	200	90
403	361	105	2:1	Above 250	Rupture
401	393	103	2:1	100	10
351	242	105	2:1	300+	60
354	241	100	2:1	325	75
352	243	105	2:1	310	90
300	168	101	2:1	300+	65
300	167	100	2:1	310	Leak after reaction
300	167	100	2:1	175+	90
303	170	100	2:1	250+	80
300	167	100	2:1	350+	89
300(a)	167	100	2:1	190	
303	172	103	2:1	250+	
300(b)	167	100	2:1	290	
303(c)	170	100	2:1	190	
300	167	100	2:1	230	

(a), (b), and (c) are oscilloscope photos in Figure A-26.

FIGURE A-1. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN. -DIAMETER AUTOCLAVE

One part hydrogen to 1 part oxygen with spark ignition.

FIGURE A-2. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN. -DIAMETER AUTOCLAVE

Two parts hydrogen to 1 part oxygen with spark ignition.

FIGURE A-4. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN. -DIAMETER AUTOCLAVE

Four parts hydrogen to 1 part oxygen with spark ignition.

FIGURE A-5. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN.-DIAMETER AUTOCLAVE

Five parts hydrogen to 1 part oxygen with spark ignition.

FIGURE A-6. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN. - DIAMETER AUTOCLAVE

Twelve parts hydrogen to 1 part oxygen with spark ignition.

FIGURE A-7. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN. -DIAMETER AUTOCLAVE

One part hydrogen to 2 parts oxygen with spark ignition.

FIGURE A-8. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN. -DIAMETER AUTOCLAVE

One part hydrogen to 3 parts oxygen with spark ignition.

FIGURE A-9. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN. -DIAMETER AUTOCLAVE

One part hydrogen to 4 parts oxygen with spark ignition.

FIGURE A-10. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN. -DIAMETER AUTOCLAVE

Composite of various hydrogen and oxygen mixtures with spark ignition.

FIGURE A-11. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 2.5-IN.-DIAMETER AUTOCLAVE

Two parts hydrogen to 1 part oxygen with spark ignition.

FIGURE A-12. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 3.0-IN. -DIAMETER AUTOCLAVE

Two parts hydrogen to 1 part oxygen with spark ignition.

FIGURE A-13. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM IN A 3.0-IN. -DIAMETER AUTOCLAVE

One part hydrogen to 1 part oxygen with spark ignition.

FIGURE A-14. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 3.0-IN. -DIAMETER AUTOCLAVE

One part hydrogen to 12 parts oxygen with spark ignition.

A-38

FIGURE A-15. IGNITION REACTIONS IN THE HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN. -DIAMETER AUTOCLAVE

Two parts hydrogen to 1 part oxygen with hot-wire ignition.

FIGURE A-16. IGNITION REACTIONS IN THE NITROGEN-HYDROGEN-OXYGEN-WATER SYSTEM IN A 1.5-IN. -DIAMETER AUTOCLAVE

200 psia nitrogen, 1 part hydrogen to 1 part oxygen with spark ignition.

FIGURE A-17. IGNITION REACTIONS IN THE ARGON-HYDROGEN-OXYGEN-WATER SYSTEM IN A 1.5-IN. -DIAMETER AUTOCLAVE

200 psia argon, 1 part hydrogen to 1 part oxygen with spark ignition.

FIGURE A-18. IGNITION REACTIONS IN THE HELIUM-HYDROGEN-OXYGEN-WATER SYSTEM IN A 1.5-IN. -DIAMETER AUTOCLAVE

200 psia helium, 1 part hydrogen to 1 part oxygen with spark ignition.

FIGURE A-19. IGNITION REACTIONS IN THE HELIUM-HYDROGEN-OXYGEN-WATER SYSTEM
IN A 1.5-IN.-DIAMETER AUTOCLAVE

200 psia helium, 1 part hydrogen to 2 parts oxygen with spark ignition.

FIGURE A-20. IGNITION REACTIONS IN THE HELIUM-HYDROGEN-OXYGEN-WATER SYSTEM IN A 1.5-IN. - DIAMETER AUTOCLAVE

200 psia helium, 1 part hydrogen to 3 parts oxygen with spark ignition.

3600-PSIA Peak Pressure in 0.1 Sec,
Sensitivity 8, No Diluent, Time
Setting, 0.1 Sec

Greater Than 5000-PSIA Peak
Pressure in 0.1 Sec,
Sensitivity 7, No Diluent

Greater Than 5000-PSIA Peak
Pressure in 0.2 Sec,
Sensitivity 5, No Diluent

5000-PSIA Peak Pressure in 0.1
Sec, Sensitivity 5, No Diluent

3000-PSIA Peak Pressure in 0.1
Sec, Sensitivity 5, No Diluent

3250-PSIA Peak Pressure in 0.1 Sec,
Sensitivity 5, No Diluent

FIGURE A-21. PEAK-REACTION PRESSURES OF A STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN WITH NO DILUENT AT 300 F
100-psia stoichiometric mixture.

4800-PSIA Peak Pressure in 0.1 Sec,
Sensitivity 5, 200 PSIA Helium

4800-PSIA Peak Pressure in 0.1 Sec,
Sensitivity 5, 200 PSIA Helium

5000-PSIA Peak Pressure in 0.1 Sec,
Sensitivity 5, 200 PSIA Helium

4800-PSIA Peak Pressure in 0.1 Sec,
Sensitivity 5, 200 PSIA Helium

FIGURE A-22. EFFECT ON PEAK-REACTION PRESSURES BY DILUTION WITH HELIUM OF A STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN AT 300 F

100-psia stoichiometric mixture.

4200-PSIA Peak Pressure in 0.1 Sec,
Sensitivity 6, 200 PSIA Argon

Greater Than 4000-PSIA Peak Pressure
in 0.1 Sec, Sensitivity 8, 200
PSIA Argon

4000-PSIA Peak Pressure in 0.1 Sec,
Sensitivity 5, 200 PSIA Argon

3500-PSIA Peak Pressure in 0.125 Sec,
Sensitivity 5, 200 PSIA Argon

Greater Than 4000-PSIA Peak Pressure
in 0.1 Sec, Sensitivity 8, 200
PSIA Argon

FIGURE A-23. EFFECT ON THE PEAK REACTION PRESSURES BY DILUTION WITH ARGON OF A
STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN AT 300 F

100-psia stoichiometric mixture.

4000-PSIA Peak Pressure in 0.1 Sec,
Sensitivity 7, 100 PSIA Nitrogen
Diluent

3900-PSIA Peak Pressure in 0.125 Sec,
Sensitivity 5, 100 PSIA Nitrogen
Diluent

3200-PSIA Peak Pressure in 0.2 Sec,
Sensitivity 5, 200 PSIA Nitrogen
Diluent

900-PSIA Pressure, Sustained Over 0.3
Sec, Sensitivity 7, 200 PSIA Diluent

FIGURE A-24. EFFECT ON PEAK-REACTION PRESSURES BY DILUTION WITH NITROGEN OF A
STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN AT 300 F

100-psia stoichiometric mixture.

4000-PSIA Peak Pressure in 0.1 Sec,
Sensitivity 5, 66 PSIA Oxygen Diluent

3500-PSIA Peak Pressure in 0.125 Sec,
Sensitivity 5, 165 PSIA Oxygen Diluent

3100-PSIA Peak Pressure in 0.125 Sec,
Sensitivity 5, 200 PSIA Oxygen Diluent

2100-PSIA Peak Pressure in 0.3 Sec,
Sensitivity 5, 264 PSIA Oxygen Diluent

Greater Than 1500-PSIA Peak Pressure
in 0.3 Sec, Sensitivity 5, 264 PSIA
Oxygen Diluent

Slow-Burning Reaction, No Peak Recorded,
Sensitivity 5, 320 PSIA Oxygen Diluent

FIGURE A-25. EFFECT ON PEAK-REACTION PRESSURES BY DILUTION WITH OXYGEN OF A
STOICHIOMETRIC MIXTURE OF HYDROGEN AND OXYGEN AT 300 F

100-psia stoichiometric mixture.

(a)

(b)

(c)

FIGURE A-26. EFFECT OF WATER VAPOR ON THE PEAK REACTION PRESSURES

Reactions are described in Table A-22.