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FINAL REPORT

PROPERTIES AND REACTIONS
OF HYDROGEN PEROXIDE

Prepared for the
Office of Naval Research
Contract Nonr 1841 (11)
NR-092-008

BY
Charles N. Satterfield

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Chemical Engineering Cambridge, Mass.

Division of Sponsored Research, Project 7476
May 15, 1962

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This final report summarizes research studies on the properties and reactions of hydrogen peroxide carried out at the Massachusetts Institute of Technology during the period 1945 - 1962. The program was initiated in July, 1945 under sponsorship of the Navy Bureau of Ordnance under Contract No. 9107, Task C. In July, 1947 sponsorship of the program was assumed by the Office of Naval Research under Contract No. N50RI-78, Task Order XIX. Work continued under O.N.R. sponsorship until 1962 under contracts N5ori-07819 and Nonr-1841(11) (NR-092-008).

Below is given a complete list of all topical reports issued during the duration of the research program. In many cases, particularly during more recent years, the substance of the report was published in one of the usual technical journals. In that event a reference to the technical literature follows the listing of the report. In 1955 the book "Hydrogen Peroxide" by W. C. Schumb, C. N. Satterfield, and R. L. Wentworth was published by Reinhold as American Chemical Society Monograph No. 128. This contains summaries of and references to various other studies on hydrogen peroxide carried out at M.I.T. before 1954 that were too fragmentary to publish separately. Reports 5, 8, 13, 21, 22, 23, 25, and 26 were originally classified as "Confidential". All the reports issued by M.I.T. under O.N.R. Contracts N5ori07819 and Nonr-1841(11) are now unclassified, as authorized by letter of Dr. R. Roberts, Power Branch, O.N.R., (ONR:429:RLH:paw NR093-008 23Mar.1962).

REPORTS ON HYDROGEN PEROXIDE

ISSUED BY M.I.T., 1945-1962

<u>No.</u>	<u>Author</u>	<u>Title</u>	<u>Date</u>
1	D. B. Broughton R. L. Wentworth M. E. Laing D. M. Mauke	Mechanism of Catalytic Decomposition of H_2O_2 Solutions with Manganese Dioxide J. Am. Chem. Soc. <u>69</u> , 741 (1947)	Nov. 1, 1945
2	T. K. Sherwood C. N. Satterfield	On the Evaporation of Hydrogen Peroxide on Storage and in Stability Tests	Dec. 20, 1945
3	W. C. Schumb R. C. Young N. A. Taves R. Knodel P. L. Hancock	Stability of Aqueous Hydrogen Peroxide Solutions	Feb. 28, 1946
4	R. C. Young	Specific Conductivity of Hydrogen Peroxide Solutions	Feb. 28, 1946
5	H. Isbin J. Farrell D. Thompson A. Meadows	Flow Studies of the Cata- lytic Decomposition of H_2O_2 Solutions	Mar. 1, 1946
6	D. B. Broughton R. L. Wentworth M. E. Laing D. M. Mauke	Mechanism of Catalytic Decomposition of H_2O_2 Solutions by Manganese Dioxide J. Am. Chem. Soc. <u>69</u> , 744 (1947)	Feb. 28, 1946
7	D. B. Broughton D. M. Mauke M. E. Laing R. L. Wentworth	Activity of Metal Hydroxides as Catalysts for the Decomposition of H_2O_2	Feb. 28, 1946

<u>No.</u>	<u>Author</u>	<u>Title</u>	<u>Date</u>
8	G. M. Kavanagh J. E. Leffler R. C. St. John	Self-Igniting Fuels for Use with Hydrogen Peroxide	July 1, 1946
9	D. B. Broughton D. M. Mauke R. L. Wentworth M. E. Laing	Activity of Coprecipitated Metal Hydroxides as Catalysts for the Decompo- sition of H_2O_2	Aug. 1, 1946
10	H. S. Mickley	Note on Recommended Values for Some Thermo- dynamic Properties of Hydrogen Peroxide	Sept., 1946
11	C. C. Neas M. W. Raymond C. O. Ewing	The Catalytic Decompo- sition of Hydrogen Pero- xide in a Constant Volume Reactor	Nov. 1, 1946
12	D. B. Broughton R. L. Wentworth M. E. Laing D. M. Mauke	Mechanism of Catalytic Decomposition of Hydrogen Peroxide by Oxides of Lead	Dec. 1, 1946
13	H. S. Isbin D. B. Thompson	Preparation and Evaluation of Impregnated-Type Cata- lysts for Hydrogen Peroxide Decomposition	Jan. 27, 1947
14	B. Murray	Parts I, II, III Excerpts from Hydrogen Peroxide and the Per- Compounds (W. Machu)	April 1, 1947
15	C. E. Huckaba F. G. Keyes	The Accuracy of Estimation of Hydrogen Peroxide by Potassium Permanganate Titration J. Am. Chem. Soc., <u>70</u> , 1640 (1948)	May 1, 1947
16	D. B. Broughton R. L. Wentworth M. L. Farnsworth	Mechanisms of Decompo- sition of Hydrogen Peroxide with Cobalt Compounds J. Am. Chem. Soc., <u>71</u> , 2346 (1949) and Anal. Chem., <u>19</u> , 72 (1947)	May 15, 1947

<u>No.</u>	<u>Author</u>	<u>Title</u>	<u>Date</u>
17	C. N. Satterfield H. C. Hottel G. C. Williams	Generalized Thermodynamics of High Temperature Combustion An improved version of this report is included in Hottel, Williams, and Satterfield: "Thermodynamic Charts for Combustion Processes", Wiley, New York, (1949)	May 15, 1947
18	R. L. McMurtrie F. G. Keyes	A Measurement of the Diffusion Coefficient of Peroxide Vapor into Air J. Am. Chem. Soc. <u>70</u> , 3755 (1948)	June 30, 1947
19	B. Darling G. M. Kavanagh	Hydrazine Hydrate-Its Properties and Its Uses as a Fuel with Hydrogen Peroxide in Self-Igniting Systems	July 15, 1947
20	C. E. Huckaba F. G. Keyes	The Density of Aqueous Hydrogen Peroxide Solutions J. Am. Chem. Soc. <u>70</u> , 2578 (1948) and <u>72</u> , 5324 (1950)	Sept. 30, 1947
21	H. S. Isbin C. Richey D. B. Thompson	Experimental High Pressure Flow Studies of the Catalytic Decomposition of Hydrogen Peroxide Solutions	Oct. 1, 1947
22	H. S. Isbin	Theoretical Analyses of the Decomposition of High Strength Hydrogen Peroxide Solutions Williams, Satterfield and Isbin, J. Am. Rocket Soc., March-April, 1952, p. 70	Oct. 15, 1947
23	T. F. Kelley G. M. Kavanagh	Self-Igniting Fuels -- Exploratory Work with Hydrogen Peroxide as an Oxidant	Oct. 15, 1947

<u>No.</u>	<u>Author</u>	<u>Title</u>	<u>Date</u>
24	W. C. Schumb	The Stability of Concentrated Solutions of Hydrogen Peroxide Ind. Eng. Chem., <u>41</u> , 992 (1949)	Nov. 30, 1947
25	P. H. Blackall W. C. Schumb C. N. Satterfield	Comparison of British and United States Samples of Concentrated Hydrogen Peroxide	Oct., 1948
26	R. L. Wentworth C. F. Richey E. A. Ploen	The Role of Diffusion in the High Temperature Decomposition of Hydrogen Peroxide	March, 1949
27	J. W. Rizika B. Darling	An Investigation of Ignition Catalysts for Use at Low Temperatures with the Propellant System 76% Hydrazine-90% Hydrogen Peroxide Containing 40% Ammonium Nitrate	April, 1949
28	G. M. Kavanagh	The Vapor-Liquid Equilibrium and Related Properties of H_2O_2 -Water Solutions Scatchard, Kavanagh and Ticknor, J. Am. Chem. Soc. <u>74</u> , 3715 (1952)	Nov. 1, 1949
29	B. Darling S. Wolf	Microrocket Studies. Application to Low-Temperature Rocket Performance	Dec., 1949
30	B. Darling	Ignition Delay in H_2O_2 -Hydrazine Systems	Dec., 1949
31	C. N. Satterfield G. M. Kavanagh H. Resnick	Explosive Characteristics of Hydrogen Peroxide Vapor Ind. Eng. Chem., <u>43</u> , 2507 (1951)	July, 1950

<u>No.</u>	<u>Author</u>	<u>Title</u>	<u>Date</u>
32	R. L. Wentworth	The Mechanism of the Catalytic Decomposition of Hydrogen Peroxide by Silver	May, 1951
33	C. N. Satterfield H. Resnick R. L. Wentworth	Simultaneous Heat and Mass Transfer in the Heterogeneous Decomposition of H_2O_2 Vapor I. Mathematical Analysis in a Tubular Reactor	June 2, 1952
34	C. N. Satterfield H. Resnick R. L. Wentworth	II. Reaction in a Tubular Reactor	June 2, 1952
35	C. N. Satterfield H. Resnick	III. Reaction in a Packed Bed Reports 33, 34 and 35 are summarized in Chem. Eng. Progress, <u>50</u> , 460, 504 (1954)	June 2, 1952
36	C. N. Satterfield R. E. Wilson R. M. LeClair	Quantitative Analysis of Aqueous Mixtures of Hydrogen Peroxide, Aldehydes, and Methanol Anal. Chem., <u>26</u> , 1792 (1954)	April 10, 1953
37	C. N. Satterfield R. E. Wilson	Partial Oxidation of Propane Ind. Eng. Chem., <u>46</u> , 1001 (1954)	April 10, 1953
38	C. N. Satterfield R. E. Wilson D. O. Cooper T. W. Stein	Separation of Hydrogen Peroxide from the Products of the Partial Oxidation of Propane Ind. Eng. Chem., <u>46</u> , 1007 (1954)	April 10, 1953

<u>No.</u>	<u>Author</u>	<u>Title</u>	<u>Date</u>
39	C. N. Satterfield R. L. Wentworth S. T. Demetriades	The Viscosity of Vapor Mixtures of Hydrogen Peroxide and Water J. Am. Chem. Soc., <u>76</u> , 2633 (1954)	Aug. 1, 1953
40	C. N. Satterfield L. C. Case	Kinetics of the Initial Reaction Between Alde- hyde and Hydrogen Peroxide in Aqueous Solution Ind. Eng. Chem., <u>46</u> , 998 (1954)	Aug. 15, 1953
41	C. N. Satterfield T. W. Stein	The System Calcium Peroxide-Calcium Oxide-Oxygen Ind. Eng. Chem., <u>46</u> , 1734 (1954)	Sept. 1, 1953
42	W. C. Schumb C. N. Satterfield R. L. Wentworth	Hydrogen Peroxide Part I	Sept. 15, 1953
43	W. C. Schumb C. N. Satterfield R. L. Wentworth	Hydrogen Peroxide Part II	Dec. 1, 1953
44	W. C. Schumb C. N. Satterfield R. L. Wentworth	Hydrogen Peroxide Part III	Dec. 31, 1954
45	W. C. Schumb C. N. Satterfield R. L. Wentworth	Hydrogen Peroxide Part IV Reports 42, 43, 44 and 45 were revised and published as a book "Hydrogen Peroxide" American Chemical Society Monograph No. 128, Reinhold, New York, 1955. The book also contains summaries of and references to various other studies on hydrogen peroxide carried out at M.I.T. before 1954 that were too fragmentary to publish separately.	Nov. 1, 1953

<u>No.</u>	<u>Author</u>	<u>Title</u>	<u>Date</u>
46	C. N. Satterfield R. C. Reid	The Role of Propylene in the Partial Oxidation of Propane "Fifth Symposium on Combustion", pp511-520, Reinhold, 1955	May 1, 1954
47	C. N. Satterfield P. J. Ceccotti A. H. R. Feldbrugge	Ignition Limits of Peroxide Vapor Ind. Eng. Chem., <u>47</u> , 1040 (1955)	Nov. 1, 1954
48	C. N. Satterfield A. H. Bonnell	Interferences in the Titanium Sulfate Method for Hydrogen Peroxide Anal. Chem., <u>27</u> , 1174 (1955)	Dec. 1, 1954
49	C. N. Satterfield T. W. Stein	Decomposition of Hydrogen Peroxide Vapor Ind. Eng. Chem., <u>49</u> , 1173 (1957) and J. Phys. Chem., <u>61</u> , 537 (1957)	Feb. 1, 1956
50	W. C. Schumb	Some Aspects of the Stabilization of Concentrated Hydrogen Peroxide	Feb. 15, 1957
51	C. N. Satterfield F. Feakes	Kinetics of Decomposition of Calcium Carbonate and Barium Carbonate A.I.Ch.E. Journal, <u>5</u> , 115, 122 (1959)	March 15, 1957
52	G. E. Halpern	Perekis Vodoroda I Pere- kisnie Soedineniya (Hydrogen Peroxide and the Peroxide Compounds) - a translation from Russian into English of portions of a book which in turn consisted of a translation from German into Russian of Machu's book on hydrogen peroxide, plus added comments by the Russian editors.	April 1, 1957

<u>No.</u>	<u>Author</u>	<u>Title</u>	<u>Date</u>
53	C. N. Satterfield F. Feakes N. Sekler	Ignition Limits of Hydrogen Peroxide Vapor at Pressures Above Atmospheric J. Chem. Engr. Data, <u>4</u> , 131 (1959)	June 1, 1958
54	C. N. Satterfield E. Kehat M.A.T. Mendes	Ignition of and Flames Above Hydrogen Peroxide Solutions Combustion and Flame, <u>4</u> , 99 (1960)	Oct. 15, 1958
55	W. C. Schumb	Further Aspects of the Stability Relationships of Concentrated Solutions of Hydrogen Peroxide	July 15, 1960
56	C. N. Satterfield Ephraim Kehat	Burning Velocities of the Hydrogen Peroxide Decomposition Flame Combustion and Flame, <u>5</u> , 273 (1961)	Sept. 15, 1960
57	C. N. Satterfield	Supersaturation of Oxygen in Aqueous Hydrogen Pero- xide Solutions J. Chem. Engr. Data, <u>6</u> , 504 (1961)	Oct. 15, 1960
58	C. N. Satterfield Puran K. Sarda	Rates of Catalytic Decompo- sition of Liquid Hydrogen Peroxide on Metal Surfaces	Nov. 15, 1960

In addition to the above, the following technical articles relating to hydrogen peroxide were also published:

C. N. Satterfield, R. C. Reid and D. R. Briggs, J. Am. Chem. Soc. 76, 3922 (1954); "Rate of Oxidation of Hydrogen Sulfide by Hydrogen Peroxide."

C. N. Satterfield, Chem. & Eng. News, 32, 2726 (July 1954); "Hydrogen Peroxide"

C. N. Satterfield, R. C. Reid, J. Phys. Chem., 59, 283 (1955) "Note on the Reactions of the Propyl Radical with Oxygen".

C. N. Satterfield and R. C. Reid, J. Chem. Engr. Data, 6, 302 (1961) "Effects of Surfaces on Products Formed in the Oxidation of Propane"

Two other papers are in process of preparation and publication. Titles are tentative.

C. N. Satterfield and F. Audibert "Vapor Binding in the Decomposition of Hydrogen Peroxide on an Active Catalyst"

C. N. Satterfield and R. S. C. Yeung "Rate of Decomposition of Hydrogen Peroxide Vapor on Metal Surfaces"

Distribution

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