SAND2015-0133R

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Historical Survey of Hydrogen Peroxide/Fuel Explosives

Origins and the German World War II Era Research Program

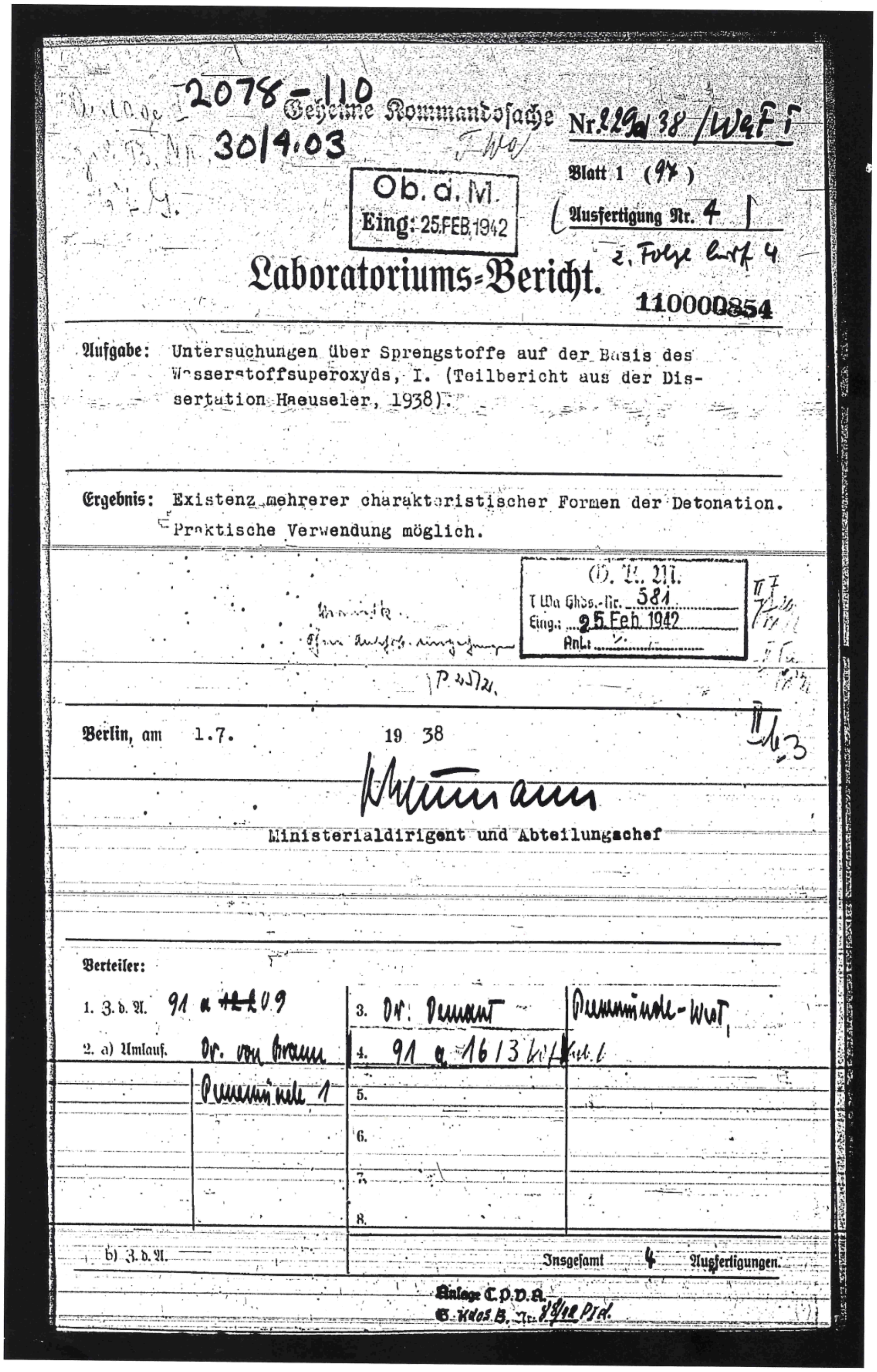
Discussion of HP/fuel explosives in the scientific literature dates back to at least 1927. A paper was published that year in a German journal entitled *On Hydrogen Peroxide Explosives* [Bamberger and Nussbaum 1927]. The paper dealt with HP/cotton/Vaseline formulations, specifically HP89/cotton/Vaseline (76/15/9) and (70/8.5/12.5). The authors performed experiments with charge masses of 250-750 g and charge diameters of 35-45 mm. This short paper provides brief discussion on the observed qualitative effects of detonations but does not report detonation velocities.

The first detailed studies of these explosives were carried out in a classified military research program on the detonation performance of HP/fuel explosives in Germany during the World War II era. Research was performed from at least 1938 to 1944 [Technischer Prüfstand Oppau 1938; 1939; 1944], though most of the work on detonation velocities that is of greatest relevance to this report appears to have been completed by 1940. Figure 1 shows the title page of a key summary report dated July 1, 1938 [Technischer Prüfstand Oppau 1938]. This document is identified as a laboratory report *(Laboratoriums Bericht*) from a secret military department (*Geheime Kommandofache*). The title (*Aufgabe*) is "Investigations of Explosives based on Hydrogen Peroxide", and it is noted that the report is derived from the Ph.D. dissertation of a student named Haeuseler. The results (*Ergebnis*) summary reads "Existence of multiple characteristic forms of detonation. Practical applications possible." However, there is no evidence that such practical applications were ever pursued. Of historical interest is the fact that one of the signatures on the cover sheet is that of "Dr. von Braun", presumably Dr. Werner von Braun whose name is synonymous with early research on rocket propulsion, including hydrogen peroxide-based rocket fuels.

The German research program investigated formulations of HP mixed with miscible liquid fuels, primarily alcohols but with limited later work on carboxylic acids [Technischer Prüfstand Oppau 1939]. The principal alcohols investigated were ethanol, methanol, and glycerol. Physical characterization of the formulations included detailed density measurements at 20 °C. Systematic variation of parameters related to detonation included the following:

- Initiation method included both blasting caps without a booster and boosting with pentaerythritol tetranitrate (PETN), the latter usually in a quantity of 10 g.
- Confinement materials included aluminum and glass.
- The charge diameter was varied from 7 to 40 mm.
- The HP concentration was varied from as low as HP61 to pure HP (HP100).
- There was a heavy emphasis on stoichiometric formulations, but limited experiments were performed in which the fuel content was varied, primarily for HP/ethanol.

The results of this research were compiled in large and meticulous tables, and the data in these tables have been used to construct the figures in this section.



2078-110 Geheime Kommandosache Nr. 229/38 /WaF I
30/4.03

Ob. d. M.
Eing.: 25.FEB.1942

Blatt 1 (97)

Ausfertigung Nr. 4

z. Folge Lief 4

Laboratoriums-Bericht.

110000854

Aufgabe: Untersuchungen über Sprengstoffe auf der Basis des Wasserstoffsuperoxyds, I. (Teilbericht aus der Dissertation Haeuseler, 1938).

Ergebnis: Existenz mehrerer charakteristischer Formen der Detonation. Praktische Verwendung möglich.

O. K. M.
I Wa Ghds.-Nr. 581
Eing.: 25.Feb.1942
Anl.: ./.

Berlin, am 1.7. 1938

[signature]

Ministerialdirigent und Abteilungschef

Verteiler:

1. Z. d. A. 91 a 209	3. Dr. Dennant	Peenemünde-West,
2. a) Umlauf. Dr. von Braun	4. 91 a 1613	
Peenemünde, 1	5.	
	6.	
	7.	
	8.	

b) Z. d. A. Insgesamt 4 Ausfertigungen.

Anlage C.P.D.A.
G. Kdos. B. Nr. 88/42

Figure 1. Title page of a report from the German research program dated July 1, 1938. The title (*Aufgabe*) is *Investigations of Explosives based on Hydrogen Peroxide, I*.

Figure 2 shows data from the German research program on the detonation velocity of HP85.5/ethanol formulations as a function of weight percent ethanol. Initiation was attempted in aluminum tubes with an inner diameter of 21 mm, and a 10 g PETN booster was used. The stoichiometric formulation, containing 16.1% ethanol, was tested three times, with an average detonation velocity of 6646±106 m/s. This corresponds to a relative standard deviation of only 1.6%, indicating how reproducible many of the results of this study were despite the use of methods and equipment that by modern standards were somewhat primitive. For alcohol contents from 6.1 to 23.7%, the detonation velocities were similar and were always above 6300 m/s, with a peak at the stoichiometric mix ratio. A formulation containing 2.95% ethanol did not detonate, while a formulation containing 36.5% ethanol was tested five times and produced much lower propagation velocities ranging from 860 to 1200 m/s.

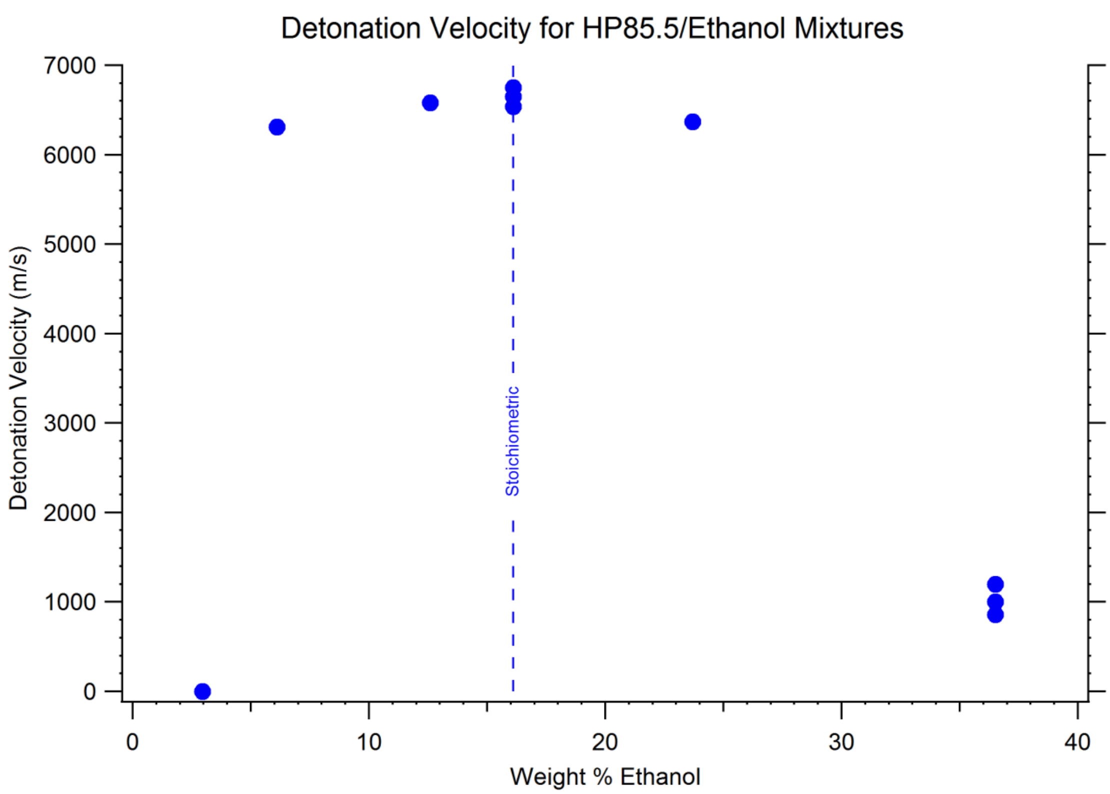


Figure 2. Dependence of detonation velocity on fuel content for HP85.5/ethanol formulations, from the German research program. Formulations were initiated with 10 g PETN in 21 mm ID/25 mm OD aluminum tubes.

Figure 3 presents German data on the dependence of detonation velocity on HP concentration for stoichiometric HP/ethanol formulations. Experiments were carried out in aluminum tubes with 21 mm ID and 25 mm OD, using a 10 g PETN booster. The detonation velocity decreased gradually and approximately linearly from > 6800 m/s for HP100 to approximately 6000 m/s for HP72.3. Further decrease to HP67 produced propagation velocities in the range of 2.3-2.6 km/s, and at HP61 the formulation failed to detonate in the test setup employed.

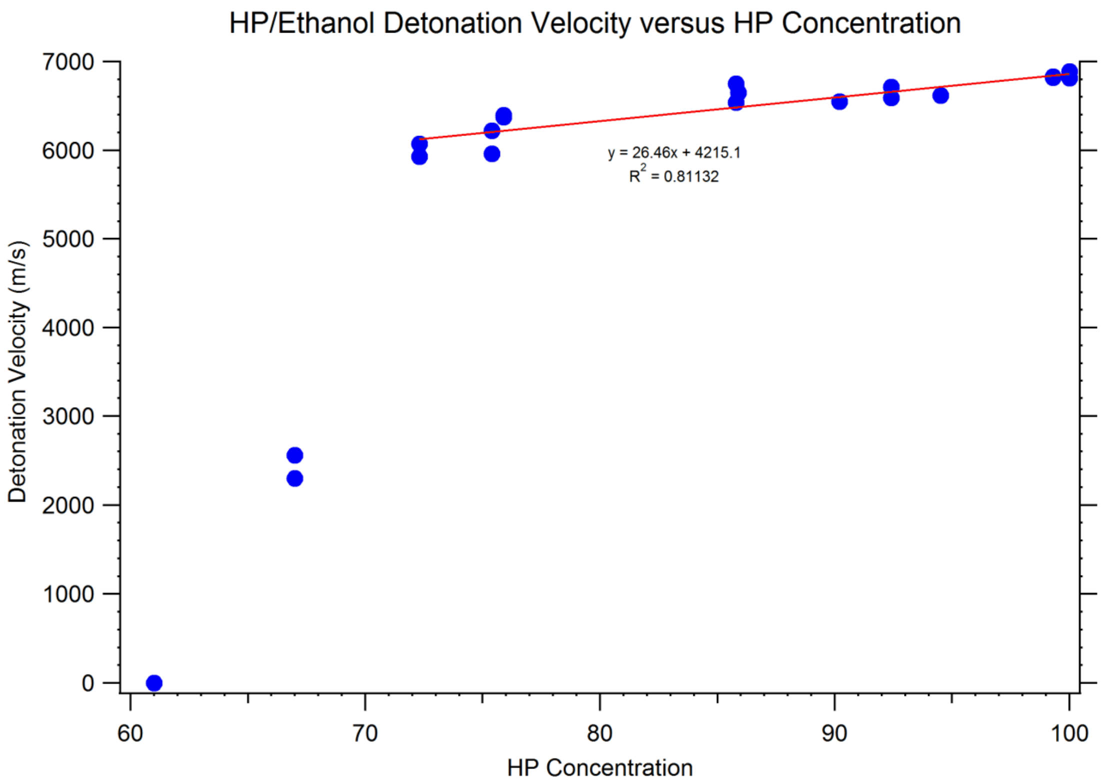


Figure 3. Data from the German research program on the detonation velocities of stoichiometric HP/ethanol formulations as a function of HP concentration. Initiation was attempted in 21 mm ID/25 mm OD aluminum tubes using a 10 g PETN booster.

Charge diameter was found to have a minor impact on detonation performance. For example, in experiments with stoichiometric HP85.7/methanol using aluminum tubes and a 10 g PETN booster, the detonation velocity increased slightly and gradually from 6130 m/s for a tube ID of 7 mm to 6430 m/s for a tube diameter of 35 mm. The effects of confinement material do not appear to have been investigated systematically enough to draw firm conclusions. However, for a tube ID of 15 mm and initiation with 10 g PETN, stoichiometric HP/ethanol formulations with HP concentrations near HP85.5 produced detonation velocities near 6250 m/s in aluminum and 6750 m/s in glass.

One of the key conclusions of the German research program was that two distinct propagation velocity regimes exist for HP/alcohol formulations. One is a high velocity regime with detonation velocities typically in the range of 6-7 km/s, and the other is a low velocity regime with propagation velocities usually in the range of 0.9-2.6 km/s. This low velocity regime may involve detonations and/or deflagrations, though the German authors referred to it as “the second detonation velocity”. Intermediate propagation velocities of 2.6-5.6 km/s were never observed despite numerous experiments varying HP concentration, HP/fuel mix ratio, charge diameter, confinement material, and means of initiation. The authors interpreted this as being due to two fundamentally different modes of propagation, and although they provided no theoretical explanation this conclusion is supported by all subsequent research on HP/fuel explosives made with miscible liquid fuels.

The German researchers also noted that the means of initiation has a considerable impact on whether high velocity or low velocity propagation occurs. While both high and low velocity propagations could be produced with either a blasting cap alone or with the addition of a PETN booster under some circumstances, high velocity detonations were favored by the more violent initiation employing the booster. For example, in one test series involving stoichiometric HP85.7/alcohol formulations made with ethanol, methanol, and glycerol in 21 mm ID aluminum tubes, use of a blasting cap alone consistently produced low velocity propagations, while use of a 10 g or 60 g PETN booster always produced high velocity detonations.