

High Test Peroxide Incident at Stennis Space Center

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ABSTRACT

A renewed interest in hydrogen peroxide as a rocket engine propellant has created a void in the experience base since the last era of significant peroxide use. Advanced catalyst beds and high concentration formulations are currently being developed and tested in the propulsion community. Although peroxide has many positive attributes, there are situations where peroxide must be handled with extreme care. An incident occurred at NASA's Stennis Space Center (SSC) in December 2000 where a significant over pressurization event damaged facility and test hardware. A description of the event and findings of the investigation board are presented and discussed.

INTRODUCTION

Hydrogen peroxide is a popular choice to meet the need for a "green" storable propellant. High-test peroxide (HTP at concentrations up to 98% mass basis) has been tested in the past [1] and is currently being tested to meet the needs of the industry. Many of the lessons learned from previous work have been documented and put aside in out of the way storage locations for safekeeping. The explosive hazards of peroxide vapor are well defined and documented in numerous publications [2,3,4] to mention only a starting list. Much of the practical test experience has been lost to a previous generation. The loss of experience provides opportunities to rediscover the hazards of working with hydrogen peroxide and vapor decomposition specifically. Just such an incident is documented in this paper including lessons learned that may be beneficial to anyone working with high concentration hydrogen peroxide.

DESCRIPTION OF EVENT

An explosive event occurred at NASA's SSC in December 2000 during monopropellant testing with 98% HTP. There were no injuries to personnel and minimal damage to the test facility. The test article sustained moderate damage; some components could be reused with machine rework.

The event occurred approximately one second into the test following the completion of a successful test. Damage to the facility included rupturing a one inch diameter stainless steel supply line rated for 29 MPa (4200 PSI) and the destruction of a pre-valve rated for 20.7 MPa (3000 PSI) service. For the test article, fourteen 1.27 CM (0.5 inch) diameter stainless steel bolts failed in tension and a portion of the test article (~ 7.3 Kg or 16 Lbm) was ejected thirty meters from the test stand. Figures 1-4 show post test photographs of selected hardware.

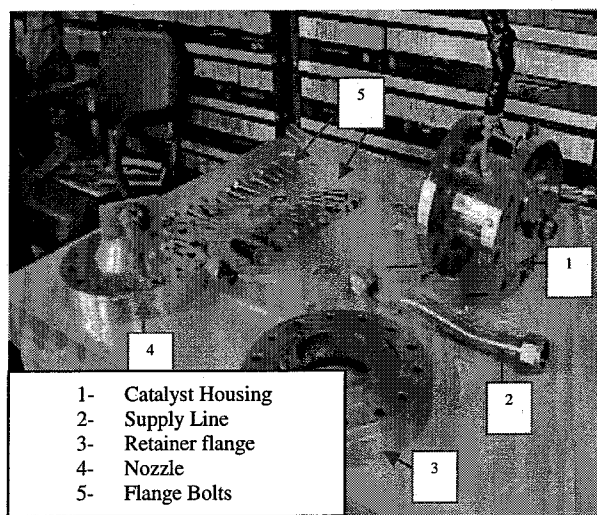


Figure 1: Test Hardware Overview

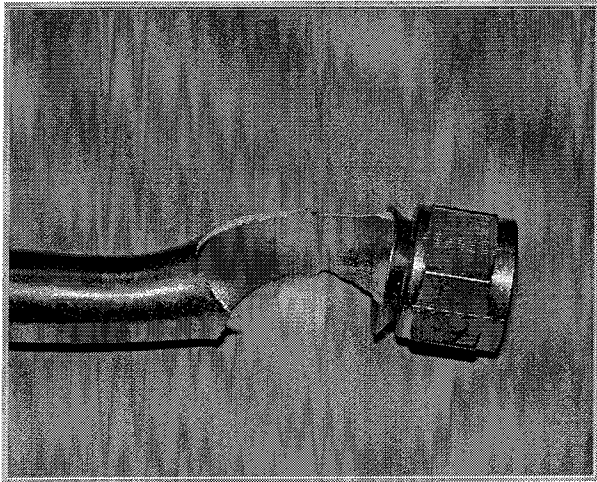


Figure 2: Run Line

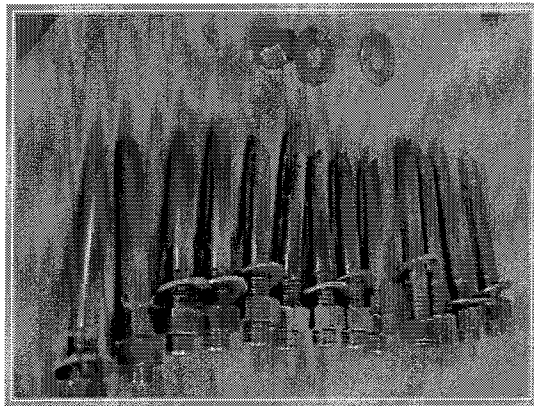


Figure 3: Flange Bolts



Figure 4: Valve Body Plate

CAUSE OF EVENT

Figure 5 shows a sketch of the hardware pertinent to this discussion. It is known from the video/audio tape that the pre-valve was leaking after the previous successful test and prior to the incident. The leaking pre-valve provided a supply of peroxide to the catalyst, which in turn generated vapor and heat. Opening the supply valve with high-pressure fluid triggered the rapid decomposition of hydrogen peroxide vapor trapped in the supply line and test article at the start of the final test. From an energy analysis of the event, it is apparent that the liquid phase of the peroxide also participated in the event [5]. Liquid participation in the reaction is consistent with documented test results for high concentration (>95%) peroxide [2]. The following paragraphs offer supporting evidence for this conclusion.

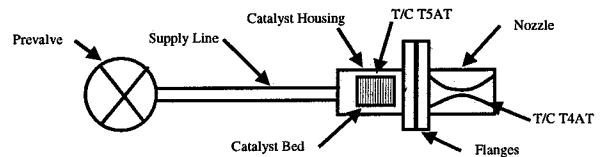


Figure 5: Sketch of Test Hardware

Figure 6 shows the initial temperature of the hardware for all of the tests in the series. At 121°C (250°F) the initial temperature for the final test was approximately 28 °C (50 °F) higher than previous tests. Figure 7 shows the transient response of the test article three minutes prior to the start of test. As shown in the figure, the test article is heated by the decomposing peroxide as it leaks from the valve and comes in contact with the catalyst. Additionally, peroxide vapor is created as a product of the liquid in contact with the hot test hardware.

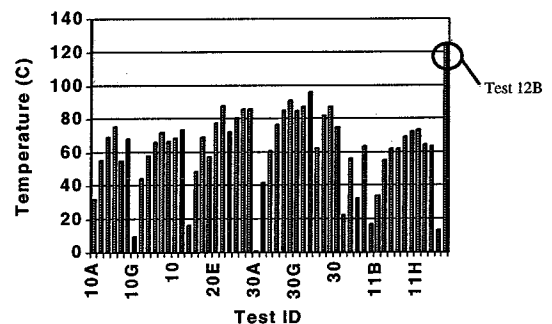


Figure 6: Test Article Initial Temperature

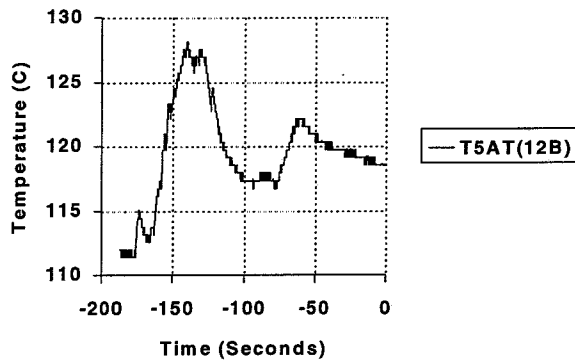


Figure 7: Temperature Response Pre-Test

Figure 8 shows the thermal response of the temperature sensor in the test article over a period of 70 seconds including one minute prior to the start of the test. The temperature sensor is located to measure the fluid temperature of the peroxide in the test article and the nominal test response is shown in test 12A. As shown in the figure, for test 12A the test article and fluid temperature were at ambient temperature prior to the start of the test. In contrast, the temperature at the start of test 12B increases over 110 °C (200°F) over a period of approximately one second. Heat is a byproduct of the peroxide decomposition reaction and the data show that there was a large amount of heat generated in a very short period of time.

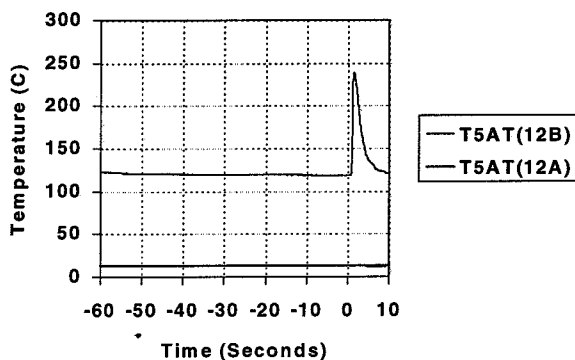


Figure 8: Thermal Response Data

Rapid decomposition describes the process that is often referred to as vapor ignition or detonation in the peroxide literature. Ignition and detonation are terms correctly used to describe combustion events. Ignition in the context of this paper refers to the initiation of rapid decomposition, not a combustion event. Data supporting detonation measurements with hydrogen peroxide are limited and conflicting [2].

Given a sufficient vapor concentration a spark, heat source, or catalyst is all that is required to initiate an exothermic reaction that can generate pressure rise rates of 62 MPa/Sec (9000 PSI/Sec) [2]. Although not suspected in this event, rapid decomposition can be triggered by gross contamination as well. Peroxide decomposition is accelerated by a factor of 2.3 for each 10 °C (18 °F) rise in temperature. Hydrogen peroxide is not classified as an explosive. Explosions that occur with the use of peroxide are a result of the rupture of the containment vessel.

Critical vapor concentrations are well defined as a function of concentration and pressure [2]. Figure 9 shows the critical temperature range for generating potentially dangerous levels of peroxide vapor at ambient pressure. As shown in the figure, the critical temperature range increases as the concentration increases, thus, 98% concentration is more sensitive to temperature than 85%. For the case at hand, it is known that peroxide vapor/liquid was present and that the temperature was approximately 121°C (250°F) at the start of the final test. These conditions are sufficient to create a dangerous vapor concentration at the start of the test. In addition, Figure 10 shows the critical vapor concentration as a function of pressure. As shown in the figure, the relationship is logarithmic with respect to pressure and concentration and the critical concentration decreases as the pressure increases. A high but less than critical vapor concentration in the system at low pressure can translate into a dangerous level by increasing the pressure from ambient to normal operating pressures of 3.4 MPa (500 PSIA).

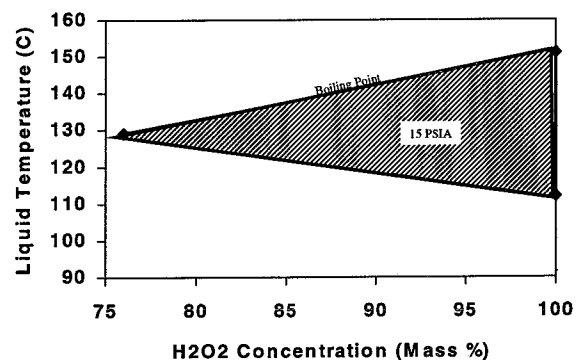


Figure 9: Critical Temperatures for Peroxide at Ambient Pressure

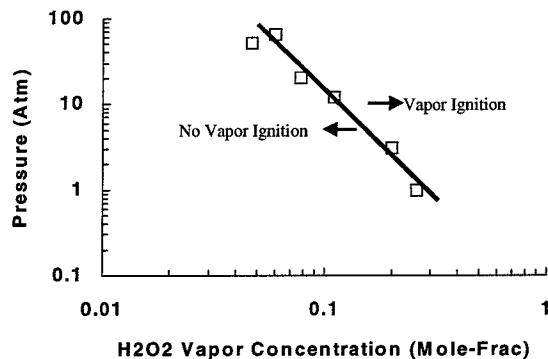


Figure 10: Critical Vapor Concentration as a Function of Pressure

CORRECTIVE ACTIONS FOR PREVENTION

To insure that incidents such as this do not reoccur, specific recommendations have been made as a result of this incident and the investigation that followed. The items listed below are recommended to insure safety of personnel and prevent over pressurization of test hardware.

- Train all test personnel on the danger of hydrogen peroxide vapor
- Maintain technical expertise in the combustion/chemistry aspects of peroxide to supplement the storage & handling expertise on site for test operations
- Eliminate or minimize areas where fluid may collect and come in contact with heated surfaces
- Measure hardware temperatures at specific locations where fluid may collect
- Review test Go/NoGo parameters with respect to facility hardware
- Improve reliability of facility valves

LESSONS LEARNED

- Hydrogen peroxide can decompose at an explosive rate
- The combination of peroxide vapor, heat, and catalyst material is hazardous
- Leaking facility valves present a hazard that require special attention and test aborts should be considered
- Test personnel and customers need to be aware of vapor rapid decomposition
- Valve position indication would provide useful information to characterize start-up
- High speed video would provide useful information in determining the sequence of events in this incident

CONCLUSION

An incident occurred at NASA's SSC using HTP where no personnel were injured and minimal damage occurred to the test hardware. This incident serves as an important reminder of the energy available in HTP and the dangers that users must be aware of. The purpose of this disclosure is to prevent incidents of this nature from occurring at other facilities and laboratories. As stated by Andrews [6] "the greatest danger in the use of HTP is likely to arise from the fact that it appears to be so safe".

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6. Andrews, David, "Advantages of Hydrogen Peroxide as a Rocket Oxidant", Journal of the British Interplanetary Society, Vol 43, pp319-328, 1990.

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