40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit
11 - 14 July 2004, Fort Lauderdale, Florida

AIAA 2004-4147

State of the Art High Performance Hydrogen Peroxide Catalyst Beds

Eric J Wernimont* and Dick Durant†
General Kinetics Inc., Lake Forest, CA, 92630

In the last decade, many parties have become interested in Hydrogen Peroxide for monopropellant applications. This has increasing lead to the need to decrease the mass of the catalyst bed. Hence this has led to a desire to drive the catalyst beds to higher mass fluxes than the prior state of the art. This paper examines an effort which methodically increased the flux level to more than three times that of the prior state of the art in the 1950-1970s. Test data showing catalyst bed performance (Cat bed pressure drop, decomposition efficiency and roughness) versus flux are provided for design purposes.

Nomenclature

*C** = Characteristic Exhaust Velocity (ft/s)

I. Introduction

THE use of a catalyst bed for decomposition of hydrogen peroxide both in monopropellant and bi-propellant applications has been the preferred method. Because the catalyst bed is an essential part of such an application increasing the power density or thrust to weight ratio is a highly desired thing to achieve. For catalyst beds systems increased power density or thrust to weight is directly correlated to the mass flux or mass per unit area of catalyst bed cross section. General Kinetics has developed a catalyst bed system which greatly increases the mass flux state of the art over prior technology at equivalent chamber pressure and decomposition efficiencies. This will help enable the use of hydrogen peroxide for higher performance applications where the favorable properties of hydrogen peroxide (i.e. "green", storable, easy handling, monopropellant, high density, etc) are desired. As an example of this the intended application is for a missile defense system.

II. Test Apparatus

In order to demonstrate the General Kinetics Inc. advanced catalyst bed system a flux test series are performed on a single test article. The flux test consists of a series of steady state tests at a fixed flow rate (fix flux for a fixed test article) and fixed chamber pressure. From test to test the chamber pressure and or flow rate is adjusted by either changing the throat size (several nozzles with fixed throat were manufactured for this test) or changing the hydrogen peroxide venturi and or feed pressure to the venturi. For the data provided in this paper the test article is a heavy weight 1.125" diameter catalyst bed with a flanged entrance and exit for ease of ground testing.

A. Test Setup

A catalyst bed per ID032-201-002 (PD032-201-002, SN 001) is mounted horizontally in a test stand which provided hydrogen peroxide from a pressure fed system. The feed system and test schematic is shown in Fig. 1 which because it is a hydrogen peroxide system also provides methods for remote venting and relief. To date General Kinetics Inc. with more than 10,000 hot fire test of hydrogen peroxide has never needed to dump hydrogen peroxide from its test stand because of undesired decomposition. The test skid hydrogen peroxide feed system is constructed from class 2[1] or better materials properly pickle-passivated along with procedures to maintain system cleanliness. Figure 2 shows the test skid at the test location and contains a 14 gal 2800 psig ASME coded tank for the H2O2. The test article is mounted such that the plume shoots off the page to the right about mid-photograph. The main fire valve is a 6000 psi ¼" ball valve. A valve position indicator is not present on the test apparatus but an oxidizer valve command electrical signal is recorded. Because the catalyst bed was new a wear-in test was

* Chief Operating Officer, 22661 Lambert St, Suite 205, AIAA Member.
† Senior Test Engineer, 22661 Lambert St., Suite 205.

performed prior to the flux tests. A wrap-on heater was used to preheat the cat bed prior to the wear-in pulses and was then subsequently removed for the flux testing. For all flux test runs, a pulse preheat of the catalyst bed was employed using 3 pulses 0.25 sec long, 1 sec off with 1 sec off before the steady state portion of the test. A typical test includes pulse preheat followed by 10 sec steady state operation of catalyst bed. Data sample rate was 1k sps with a low pass analog filter with 250 Hz cut off frequency. Test procedures where written and followed to ensure a safe test series.

Figure 3 shows a close up photograph of the catalyst bed mounted in the test stand. On the right is the flanged interchangeable nozzle. On the catalyst bed exit flange can be seen temperature ports (out and into the page) to measure the catalyst bed exhaust temperature. Also on the exit flange are #2 pressure ports (top and bottom) used to measure the chamber pressure, the bottom being capped. Also can be seen the catalyst bed inlet flange (the aft face of the fastners can be seen) which is mounted to the forward adaptor. The forward adaptor contains an inlet for the purge (can see the check valve mounted directly into the adaptor), pressure measurement ports for the venturi inlet and catalyst bed inlet pressures (on the back side, not visible). Also contained inside of the adaptor is the flow control venturi and the inlet of the adaptor directly mounts to the oxidizer fire valve exit.

B. Instrumentation

To determine performance of the catalyst bed during each of the tests 5 pressures were measured at varios locations in the system. Pressures were measured with tabor pressure transducers that were calibrated end to end against a NIST traceable standard dial gauge. The following pressures and temperatures were measured:

- Pressure Oxidizer Tank (POT) – On the top of the oxidizer tank, measures gas over the oxidizer in the run tank.
- Pressure Venturi Inlet Oxidizer (PVIO) – Measured just upstream of the venturi and downstream of the oxidizer fire valve. This device is wetted with H2O2.
- Pressure Inlet of Cat Bed (PIO) – Measured just downstream of the venturi and at the inlet to the catalyst bed. This device is wetted with H2O2.
- Chamber Pressure (PCH) – Measured on the downstream side of the cat bed.
- TOT– Temperature measured thru a wetted probe on inside the H2O2 tank.
- TVIO– Temperature measured at the venturi inlet. This 1/16” type K is the H2O2 temp just prior to entering the venturi.
- TCH – Temperature measured at the downstream flange of the cat bed

The pressure transducers were calibrated in an end to end configuration against a NIST traceable mirror gauge over the range of expected operating pressures. This set of instrumentation is sufficient to monitor the test system for safety and to determine performance.

C. Propellant

The propellant 90-91% weight percent H2O2 purchased from FMC which is shipped in 30 gal all aluminum drums. The hydrogen peroxide is purchased against a General Kinetics Inc. specification for purity, etc. The propellant is also filtered (10 micron or better) at the fill valve at the time of loading into the run tank. The pressurant and purge gases are high purity gaseous nitrogen and are also filtered at 10 micron or better before being used in the test stand.

III. Test Results

A total of 21 tests were performed on the catalyst bed at various flux and chamber pressures, which resulted in approximately 225 seconds of life accumulated. At the end of the testing there was *no* indication that the catalyst bed had reached the end of life. As previously mentioned each test consisted of 3 warm-up pulses and then a 10 second steady state run. The performance was calculated from the last 25% of the steady state portion of the run. In not all cases but in most the catalyst bed had cooled to approximately ambient temperature from the prior test and as such the pulses were used to heat the catalyst bed. Because of this starting method the efficiency is lower on the first pulse and in some cases a little liquid is seen in the exit plume. It was also discovered approximately 1/3 through the testing that the ambient temperature of 55F (although propellant was conditioned to 75-100 F) was reducing the efficiency because the hardware was cooling the propellant before being decomposed. This problem was corrected with a small conditioning building built around the hardware and then conditioned to 85-100 F. A typical measured chamber pressure trace is shown in Fig. 4 where the preheat pulses can be seen and the smooth operation in steady state. Note the purge comes back in at about 50 psia during shutdown. This trace is for a test at the highest flux level tested of 1.4 lbm/(in^2-s) at 725 psia chamber pressure and the measured C* efficiency as compared to theoretical therochemical[2] values of 95%.

The measured chamber pressure decomposition roughness for all of the tests is shown in Fig. 5 versus the tested catalyst bed flux level. The roughness value reported is the zero-to-peak 3 sigma deviation compared to the mean chamber pressure. Although it can be seen that some of the values are between 3% and 5% in actuality all roughness was less than ~3% with the remained being 60 Hz electrical noise that was not eliminated until part way through the testing. These results are quite exceptionally good given that so great a range of chamber pressures (200-970 psia) and fluxes (0.2-1.4 lbm/(in^2-s)) were tested. In all cases the venturi used for hydrogen peroxide flow control was in caviation.

The measured C* efficiency for all of the tests is shown in Fig. 6 versus the catalyst bed flux level. It can be seen from the figure that the general trend is that higher chamber pressure has higher efficiency. Also the expected result of higher flux leads to lower efficiency. The data that runs counter to this is the 450 psia chamber pressure data at the lower end of the fluxes tested. The reason that this data does not conform to the expected trend is that the three lower flux levels tested at this pressure were tested before a thermal conditioning building was made to condition the hardware as well as the propellant. As a consequence of the hardware being exposed to the ambient temperature of ~55 F results in a reduction estimated at 5-10%. Additionally, the 200 psia tests at flux of 0.75 lbm/(in^2-s) & the two at 1.0 lbm/(in^2-s). were also at the lower hardware temperature.

The measured catalyst bed pressure drop versus flux level for all of the tests is shown in Fig. 7. As can be seen from this figure the expected trend of decreased pressure drop for increased chamber pressure is seen. Another expected trend is that of increased pressure drop for increased flux. The data doesn't completely conform to these trends for the same reason as that for the C* efficiency in that the cold ambient tests had low C* efficiency and lower catalyst bed pressure drop. Also shown in the Fig. 7 is the performance envelope of prior state of the art for 90% H2O2 catalyst beds[3]. It can be seen that the General Kinetics Inc catalyst bed tested completely outperforms the prior state of the art both in the lower end of the pressure drop and approximately 3 times the capability in flux. This is a huge step forward in increasing the power density of hydrogen peroxide systems.

IV. Conclusion

General Kinetics Inc. has successfully pushed the state of the art in 90% H2O2 catalyst beds as determined from flux testing. A few of the major conclusions are drawn from the measured test data:

- A total of 21 tests performed on one catalyst bed tested between flux levels between 0.2-1.4 lbm/(in^2-s) and chamber pressures 200-940 psia.
- C* efficiency quite exceptional, which pushed the state of the art from a maximum flux level of 0.4 lbm/(in^2-s) to 1.4 lbm/(in^2-s).
- The roughness is < 3% for all test flux and chamber pressures tests, which is quite low.
- It was found that low hardware temperatures of ~55 F had an adverse effect on the performance.
- The flowing trends were noted in the data:
    - Increase in catalyst bed pressure drop for increased flux.
    - Decrease in catalyst bed pressure drop for increase in chamber pressure.
    - Increase in C* efficiency for increase in chamber pressure.
    - Decrease in C* efficiency for increases in flux

Acknowledgments

General Kinetics would like to thank Lawrence Livermore Laboratories (LLNL) for funding the flux testing. Specifically, the LLNL members: Doug Dobie, Ken Skulina, Arno Ledebuhr, Don McMahon, Elon Ormsby, Lee Pittinger, & Jeff Robinson.

References

[1]Rocketdyne, North American Aviation, "Hydrogen Peroxide Handbook," Air Force Rocket propulsion Laboratory Technical Report AFRPL-TR-67-144, July 1967.

[2]Gordon, S. and McBride, B.J., "Computer Program for Calculation of Complex Chemical Equilibrium Compositions, Rocket Performance, Incident and Reflective Shocks; and Chapman-Jouguet Detonations," NASA SP-273, NASA Lewis Research Center, 1971.

[3]Wernimont, E. and Mullens, P., "Capabilities of Hydrogen Peroxide Catalyst Beds," 36th AIAA Joint Propulsion Conference and Exhibit, AIAA-00-3555, Huntsville, AL, 2000.

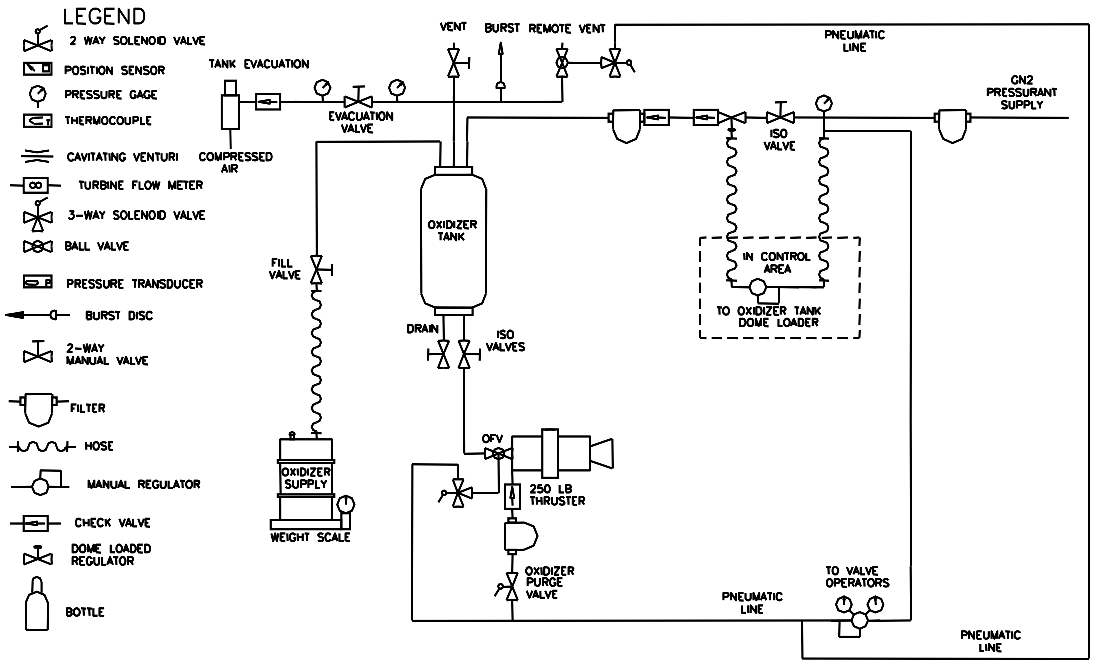

Figure 1. Schematic of Test Stand and Article

Figure 2. Picture of Test Stand

Figure 3. Picture of Test Article

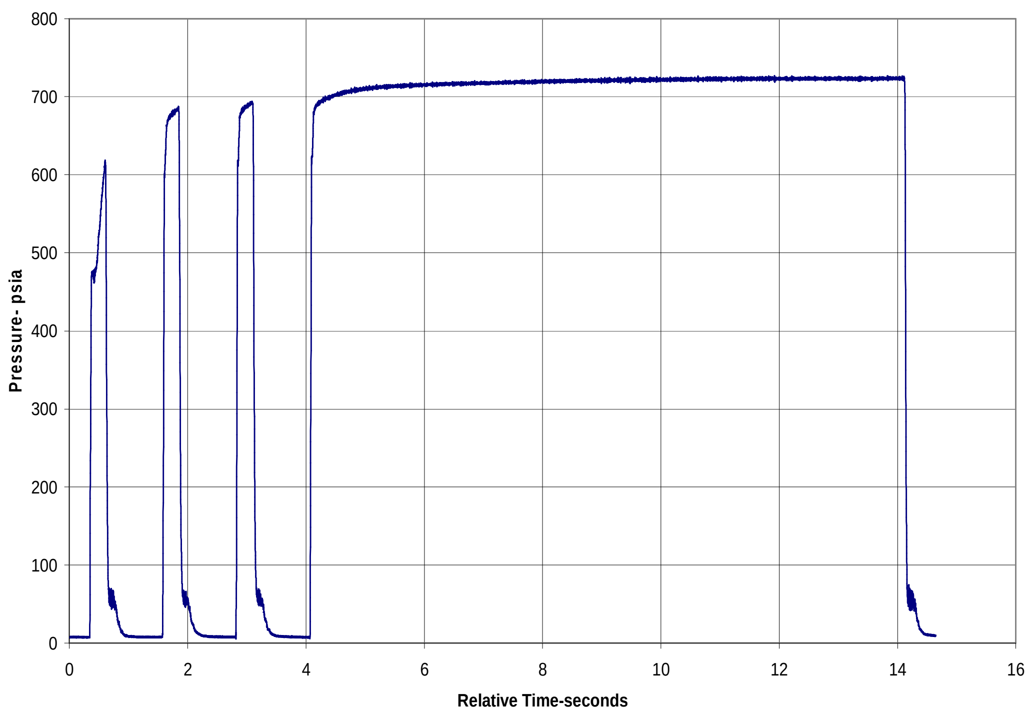

Figure 4. Example Measured Pressures for Flux ~ 1.4 lbm/(in^2-s), Pc ~ 725 psia, C* Efficiency 95%

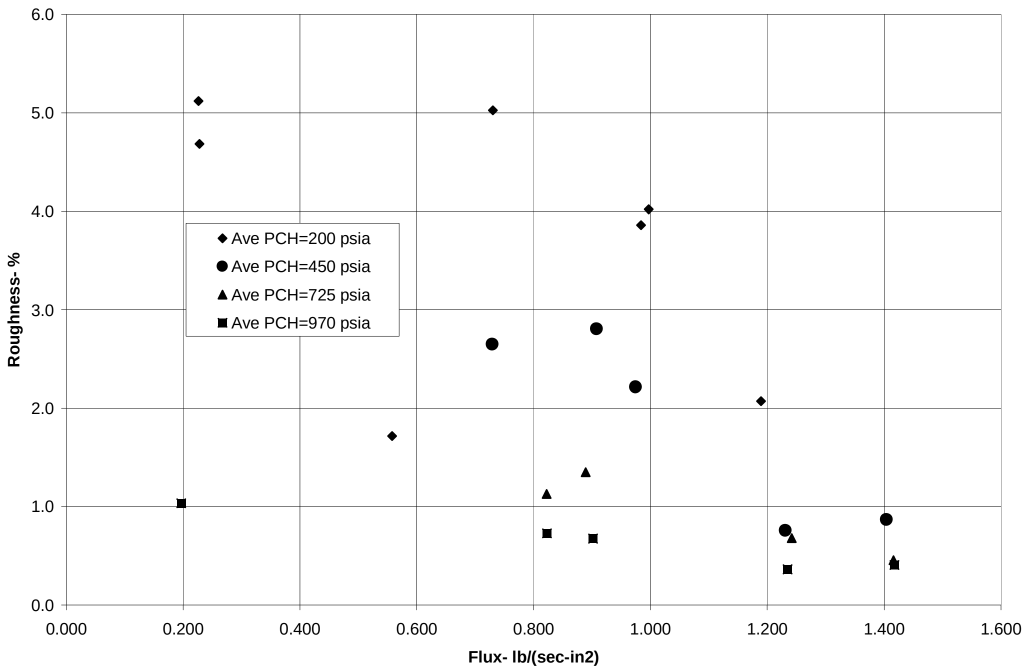

Figure 5. Flux Test Roughness Data Comparison

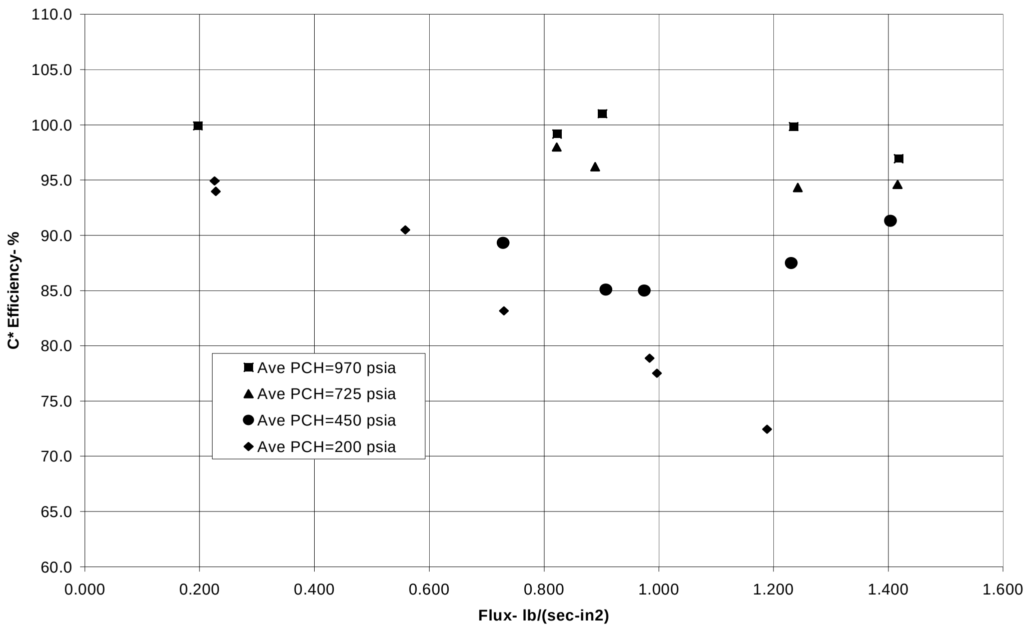

Figure 6. Flux Test C* Efficiency Data Comparison

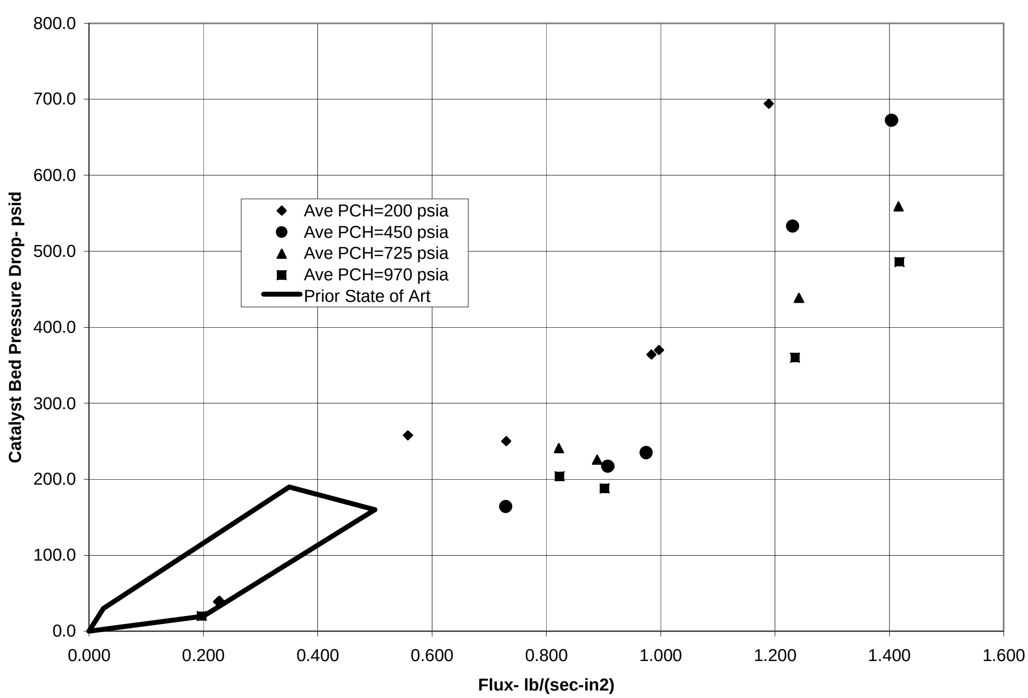

Figure 7. Flux Test Catalyst Bed Pressure Drop Comparison