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(UNCLASSIFIED)

(10) J. L. CARNES

POWER PLANT LABORATORY

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Fuming Nitric Acid Oxidizers For Liquid Propellant Rocket Engines(U)
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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

WADC-TN-55-781
February 1956

Power Plant Laboratory
Directorate of Development
Project No. 3058-30338

FUMING NITRIC ACID OXIDIZERS FOR LIQUID PROPELLANT ROCKET ENGINES

A. PURPOSE:

To set forth data and conclusions of a Power Plant Laboratory study presented to the Laboratory Staff (June '55) on the use of fuming nitric acid oxidizers in liquid propellant rocket engines on development contracts. (Unclassified)

B. FACTUAL DATA:

1. Inhibited red fuming nitric acid (Type III A, IRFNA) has a number of advantages which make it more desirable than white fuming nitric acid (Type I, WFNA) for use in liquid propellant rocket engines. These advantages are:

a. Lower freezing point
b. Greater stability during storage
c. Less corrosion. (Unclassified)

2. The use of Type III A Acid has some disadvantages which are as follows:

a. Higher vapor pressure
b. The inhibitor now used attacks in varying degrees materials such as cermets, ceramics, and glass.
c. The compatibility of all the materials in engines under development has not been proved.
d. The cooling capacity is approximately 30% less than WFNA. (Unclassified)

3. The physical and chemical properties of Type IIIA and Type I acids are very similar so that the change to Type IIIA from Type I on engines under development results in a minimum of redesign and testing of the engine. Design principles used in gas generators, pumps, thrust chambers and injectors appear to be equally adaptable to Type IIIA Acid. (CONFIDENTIAL)

4. Nine rocket engines using fuming nitric acid as the oxidizer are in various stages of development. Two of these engines, the XLR77-RM-1 (IM97) and the XLR81-BA-1 (XB-58), were designed and developed to their present status with Type IIIA Acid. (CONFIDENTIAL)

The Title of this Report is "Unclassified."

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5. A discussion of special tests, other data, and individual engines will be found in Appendix A. (Unclassified)

C. CONCLUSIONS:

1. The advantages of Type III A over Type I acid are sufficient to warrant a change to Type III A in those engines which are scheduled for operational use. (Unclassified)

2. The future status of engines under development will be as follows:

a. The LR63-AJ-1, YLR63-AJ-3, and XLR67-BA-5 engines will continue to use Type I acid.

b. The XLR81-BA-1 and XLR77-RM-1 engines will continue to use Type IIIA acid.

c. The XLR67-BA-9 engine should be converted from Type I to Type IIIA Acid for all component improvement and engine qualification testing. (This recommendation has been made to the GAM-63 project office).

d. The XLR73-AJ-1 will be converted to Type IIIA Acid. Any radical design changes that differ from Type I practices shall be brought to the attention of Power Plant Laboratory by the engine contractor.

e. The XLR59-AJ-9 engine should be converted to Type IIIA Acid at the appropriate time so as to utilize full benefit of flight approval testing and flight scheduling.

f. The XLR59-AJ-5 engine should be converted to Type IIIA Acid if major development effort is considered for this engine (CONFIDENTIAL)

D. RECOMMENDATIONS:

It is recommended that material and storage evaluation programs be continued with Type IIIA Acid to support the rocket engine programs. (Unclassified)

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COORDINATION:

R.B. Robinson WCRTH-3

PREPARED BY:

J. L. CARNES

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PUBLICATION REVIEW

This report has been reviewed and is approved.

APPROVED BY:

for E. Phillips

C. APPOLD, Colonel, USAF
Ch Power Plant Laboratory

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APPENDIX A

A. BACKGROUND

1. Fuming nitric acid has been used by the Air Force as the primary oxidizer for applications involving stand-by time such as assist take-off, aircraft super-performance, interceptor aircraft and air-to surface missiles. Three types of fuming nitric acid have been used; acid with a nominal 0% nitrogen dioxide, acid with a nominal 6% nitrogen dioxide, and acid with a nominal 14% nitrogen dioxide. (CONFIDENTIAL)

2. Type I Acid was selected as the standard oxidizer for major engine development work, primarily because of its lower vapor pressure. Although the freezing point of Type I Acid is about -43°F, it was thought that an additive could be obtained which would lower this value to a -65°F. A completely satisfactory additive has not been found which lowers the freezing point but at the same time maintains the other desirable characteristics of vapor pressure and water content. (CONFIDENTIAL)

3. Type I Acid decomposes during storage liberating oxygen which prohibits the storage in sealed containers without periodic venting. A further result of the decomposition is an increase in water and nitrogen dioxide content. (CONFIDENTIAL)

4. The extreme corrosion tendencies of the fuming nitric acids led to investigations of materials and additives which would decrease the corrosion attack. Aluminum and the stainless steels emerged as the primary materials of construction and very small amounts of hydrofluoric acid (.5%) is effective in reducing corrosion to most metals in both Type I and Type III Acids. (Unclassified)

5. The decomposition and corrosion of Type I Acid did not appear to be a major problem in the earlier rocket engines since they could operate with acid which had accumulated some iron products through corrosion processes and would tolerate water content of 2% to 5% without seriously affecting performance. However, with engines having gas generators for turbine drives and firing durations greater than 60 seconds, troubles were experienced with iron deposits in thrust chamber and carbon-iron deposits in the gas generator systems which caused severe limitations on the procurement and storage of the oxidizer. Repeated use of shipping and storage containers aggravates the situation since residual corrosion products contaminate the fresh acid unless a cleaning process is invoked.

6. Experience with Type III Acid indicated that this acid was much more stable and therefore could be stored in sealed containers with only very small changes in composition for relatively long time periods. A freezing point of -65°F could be obtained with the judicious selection of nitrogen dioxide and water content without adverse effects on rocket engine systems. The use of the inhibitor, hydrofluoric acid, and selected materials substantially decreases corrosion rates for long term storage and therefore is beneficial in decreasing

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(APPENDIX A - Continued)

the metallic content of the oxidizer at the time it is used. (CONFIDENTIAL)

B. POWER PLANT LABORATORY STUDIES

1. In view of the known advantages of Type IIIA Acid, the Rocket Propellant Section of Power Plant Laboratory, WCLPT, and the Chemical Branch of Materials Laboratory, WCRTH, recommended that Type IIIA Acid be used for new engine development programs and that consideration be given to changing the existing engines to Type IIIA Acid. These recommendations were followed and the design of XLR77-RM-1 and XLR81-BA-1 engines were initiated with Type IIIA Acid. Studies and special tests were then conducted to determine the feasibility of converting the existing engines. The following paragraphs relate test data and general information relative to the conversion of existing engines. (CONFIDENTIAL)

2. Reports on the progress of the Corporal and Nike missiles developed by Army Ordnance were reviewed for applicable data.

a. The Corporal is a 20,000 lb thrust unit operated for 60 seconds. The thrust chamber material, including the injector, is 1020 mild steel and the chamber is regeneratively cooled with fuel, a 50-50 mixture of aniline and alcohol plus 7% hydrazine. The tanks are aluminum with a stored gas pressure feed. The major development effort was done with RFNA (6% NO_2) and a change was made to IRFNA (14% NO_2) without any changes in the system.

b. The Nike is a 2800 lb thrust unit (cruise) with a ceramic-lined chamber and nozzle. The chamber produced by the Bell Aircraft Corporation uses a niafrax convergent section and throat, a graphite chamber section with a silicon carbide coating, a graphite diverging section and a zirconium and sodium silicate insulating cement. Development work was conducted with RFNA (6% NO_2) and the unit was converted to IRFNA (14% NO_2) without design changes. (CONFIDENTIAL)

3. The Bell Aircraft Corporation has conducted a number of tests with Rascal hardware (XLR67-BA-9 engine components) in support of the Hustler program with Type IIIA Acid. These tests are summarized below.

a. Approximately 150 thrust chamber assembly runs were made over a temperature range of -65°F to +160°F with the mixture ratio varied from 3.8 to 5.7. The fuel was JP-4 with UDMH as the start fluid. The runs averaged 15 seconds in duration and the chamber was fabricated of stainless steel tubes with cast aluminum, steel injectors, and a ceramic heat barrier on the combustion side. Fifteen different chambers and eleven (11) injectors were used; many having previous firing time with Type I Acid. No endurance or life tests were conducted. Performance appeared to be equivalent to that obtained with Type I Acid.

b. Three Rascal pump and drive assemblies were tested with Type IIIA Acid and JP-4. Assembly No. 1 was tested in five (5) runs totaling 1.5 minutes,

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(APPENDIX A - Continued)

assembly No. 2 was operated 27 times totaling 21.5 minutes, and assembly No. 3 was run 89 times for a total of 37.5 minutes. Other than rapid oxidizer seal wear, there were no difficulties attributable to the Acid.

c. An oxidizer pump on the pump test rig completed 12 tests totaling 10 hours of operation for calibration and endurance tests. One seal (teflon-glass) endured the complete tests.

d. Tests with a gas generator package have indicated no additional problems with carbon, performance, or controls.

e. In addition to the above tests, some testing has been accomplished with prototype Hustler components (21 June 1955). The drilled aluminum chamber configuration has been fired 93 times with 43 full duration runs. The steel tube - cast aluminum design, has had 193 firings with 93 full duration runs. Injectors have been fired over the temperature range of -65°F to +140°F. One injector has achieved 54 full duration runs for a total endurance of 3517 seconds. A pump and drive assembly has accomplished 175 minutes of functional testing. (CONFIDENTIAL)

4. Of primary importance to the fabrication of liquid propellant rocket engines are the materials of construction. Programs to use less critical elements include those on ceramics and 17-7PH for 1605 and 347 steels. Previous data with 17-7PH indicated that the inhibitor caused a scale formation which if allowed to dry and then exposed to moisture, would separate from the parent metal. The Materials Laboratory ran some quick tests with 17-7PH and available ceramics with Type IIIA Acid. The tests were inconclusive because of the time element. Results of these tests indicated the following:

a. At a temperature of 175°F a scale will form on 17-7PH in liquid IRFNA in something less than 4 hours.

b. At ambient temperatures, the time required for scale formation on 17-7PH in liquid IRFNA is greater than three (3) days.

c. A one-time scale removal from previously corroded specimens did not adversely effect the corrosion rate of 17-7PH when re-subjected to the corroding medium.

d. Two of the twelve samples tested in IRFNA at 175°F indicated rather severe pitting beneath the scale.

e. IRFNA attacked all ceramics subjected to the tests in a closed system at 175°F. In an open system the presence of HF did not affect the materials at ambient temperatures. Different ceramic formulations exhibited different characteristics. While IRFNA attacked all ceramics subjected to the test more vigorously than WFNA, the applicability of the test procedure for those ceramics

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(APPENDIX A - Continued)

destined for thrust chamber use is questionable. Ceramic filters and rotating seal elements may not be usable in IRFNA. Development of the XLR77-RM-1 engine and other ceramic investigations sponsored by the Power Plant Laboratory has indicated that ceramics are now available for thrust chamber liners with IRFNA as the oxidizer.

5. The Aerojet-General Corporation conducted some special tests on a 17-7PH regeneratively cooled chamber and injector with Type IIIA Acid. This chamber was fired 26 times in seven days. There were 25 - 60 second runs and 1 - 15 second runs with 48 hours maximum interval between runs. Periodic examination of the filter downstream of the chamber coolant jacket did not reveal any differences than with Type I Acid. The performance was equivalent to that obtained with Type I Acid. Teardown of the chamber revealed severe erosion of the injector face and combustion chamber wall adjacent to the injector. The erosion may have been caused by HF, NO_2, or injector design (spray pattern). There have been no other indications that either HF or NO_2 would be the primary cause for such erosion; however, past experience shows that the injection pattern can cause erosion by the circulation of combustion gases within the chamber. (CONFIDENTIAL)

6. Other problems of installation and servicing have been examined. For superperformance type aircraft, the higher vapor pressures of Type IIIA Acid will require higher tank pressures to prevent boil-off. More stringent requirements will be placed on booster pumps because of the higher vapor pressure and greater suppression head required by the rocket engine pumps. (It was calculated for the F-86 rocket engine installation that the oxidizer tank for a 10 psi pressure would weigh 81 lbs. whereas the present tank with only 3 psi weights 71 lbs. A further increase to 28 psi would bring tank weights to about 100 lbs.) Filtration equipment has, in general, used glass elements for filter material. However, metallic strainers have been used almost exclusively in operations to date. The design of the B-2 servicing trailer has considered the handling of Types I, III, and IIIA Acids. (CONFIDENTIAL)

C. SUMMARY

1. The primary advantages of Type IIIA Acid; storage stability, low freezing point, and less corrosion, are sufficient to justify its use in rocket propulsion systems which are to be developed for tactical use. ~~(Unclassified)~~

2. The use of the material 17-7PH with Type IIIA Acid is questionable and further investigations should be made to substantiate or refute existing data. ~~(Unclassified)~~

3. Adequate ceramic materials are available for use in engine combustion chambers. ~~(Unclassified)~~

4. The majority of rocket engine construction materials are equally adaptable to Type I or IIIA Acid. ~~(Unclassified)~~

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(APPENDIX 4 - Continued)

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5. Design criteria (combustion, injection, pumps, and cooling) appear to be equally adaptable to Type I or IIIA Acid. The differences in vapor pressure, density, and heat capacity must be considered in systems design. ~~(UNCLASSIFIED)~~