

N-52-2-1453-1

TECH. NOTE
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ROYAL AIRCRAFT ESTABLISHMENT

FARNBOROUGH, HANTS

Inv. 83
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TECHNICAL NOTE No: R.P.D. 11

**FURTHER CONSIDERATIONS
ON SELECTION OF AN
OXIDANT FOR ROCKET MOTORS**

by

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ROCKET PROPULSION DEPARTMENT

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Technical Note No. R.P.D.11

February, 1949

2 ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Some further considerations on the selection of
an oxidant for rocket motors

by

A.D. Baxter

SUMMARY

The note calls attention to the relative state of development and experience on hydrogen peroxide (HTP) and nitric acid as rocket motor oxidants. It is shown that some of the fears regarding storage and handling difficulties with HTP have not been justified and that development of nitric acid motors in this country requires at least 12 months to bring it up to the present stage of HTP motors.

Some unfavourable consequences of the higher combustion temperature of nitric acid are also discussed.

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Comparative performance of hydrogen peroxide and nitric acid with n-decane Table I

Loss of concentration of hydrogen peroxide with time Figure 1

1 Introduction

Considerable thought has already been given to the selection of the best oxidant for rocket motors and the general conclusion has been reached that, for guided missile operation in the near future (say up to 1957), the decision rests between nitric acid and hydrogen peroxide. (HTP). Several assessments^{1,2,3} of their relative merits and special features have been made, but they have failed to establish a definite and clear advantage in using either of these oxidants. Consequently a decision as to which to use must, in the last resort, be made by an aggregation of comparatively secondary considerations. The present note has been written to draw attention to some of these points which may have been overshadowed by the more prominent technical arguments. Some of them are established facts and others are still matters of surmise, which our ever-increasing experience indicates as likely to be justified by events.

2 Present knowledge

Our knowledge of liquid propellant rockets has extended rapidly since 1945. It has been largely built on the foundation of German work prior to the end of the war and supported by American results. A review of the practical progress made in this country reveals that nitric acid systems are much less advanced than HTP systems. This can be seen by a brief consideration under two headings, viz.

- (1) technical development
- (2) storage and handling.

2.1 Technical development

Developments in this country have been influenced by the German scientific teams brought here. Considerable work was done in Germany on nitric acid systems, but these were not so far forward as the HTP units. Furthermore, fewer good scientists with nitric acid experience were available for carrying out work in this country. This is reflected in the German staff at Westcott, where only two out of a total of fifteen were engaged primarily for their experience of nitric acid and nine for their work on hydrogen peroxide. In consequence, the progress on HTP systems has been much greater and, therefore, the design of motors operating on HTP can be undertaken with a fair degree of confidence.

On the other hand, our experience with nitric acid is still restricted and many of the development problems remain to be solved. Some knowledge has been gained by the Armament Design Establishment, Fort Halstead, with a British version of the German "Taifun", an unguided rocket.⁴ This has a total propellant weight of 24 lb and burns for only $2\frac{1}{2}$ sec; consequently the problems met in this design are not the same as those of a long burning guided missile motor. Work is being undertaken at the Explosives Research and Development Establishment, Waltham Abbey with small scale test bed motors; investigations are also proceeding at Westcott with a view to larger motors, but they have not yet advanced very far. There is, of course, a large volume of experience in America on nitric acid motor design, but it is chiefly in the form of practical "know how", not easily transmitted to others except by personal contact. Little basic data are available here and, in addition, most of the work has been carried out with red fuming nitric acid and self-igniting fuels such as aniline

or furfuryl alcohol. In this country the policy has been to avoid self-igniting fuels except, possibly, for starting.

It has been argued that theoretically there is little difference between the two oxidants on technical and thermodynamic grounds but it is a very dubious point whether this is true in practice. There is, for example, the marked difference in combustion gas temperature. The possible influence of this on future development is discussed in a later paragraph. In other respects also it is clear that at the present time the development of nitric acid systems still remains a long way behind in such features as mechanical ignition, gas generation for pressurising or driving pumps, combustion chamber cooling by oxidant, variable thrust control, etc. These problems can be solved, although the methods may not be so neat as those for HTP. However, the work still remains to be done and it is reasonable to estimate that a period of 12-18 months will be necessary to bring them to a state comparable with the present on hydrogen peroxide.

2.2 Storage and handling

Both oxidants have unpleasant features from the operators point of view, but it is not considered that either will present any unacceptable limitations in a final assessment. The important point is that the nature of the limitations is fully realized by the personnel handling them. Such limitations are accepted as a normal hazard in other fields as, for instance, the handling of petroleum fuels, explosives, etc., and no exceptional ability is called for in the personnel.

The limitations, in the case of HTP, have been greatly exaggerated and were the subject of much early ill-founded criticism, probably due to the very slight knowledge of the oxidant in this country at the end of the war. Since then a great deal of experience in storage and handling has been accumulated and much research and development work has been carried out on the compatibility of materials by the various establishments.⁵

It is now reasonable to say that HTP can be transported safely by road or rail without the very elaborate precautions visualized at one time. It is also true that the rigid conditions originally assumed necessary for bulk storage are not at all essential. The storage vessels at Westcott, for example, consisted of aluminium tanks of 20-50 tons capacity completely exposed to all types of weather, extremes of wind, sun, high and low temperatures, etc. German hydrogen peroxide, manufactured prior to the end of the war was stored in them at concentrations between 80% and 85%. It was found that the loss in concentration was only of the order of $1\frac{1}{2}\%$ per annum at 85% concentration, $2\frac{1}{2}\%$ at 80% concentration and increased to 4% per annum at 75-77% concentration. The figures relate to storage in the exposed conditions already mentioned, with tanks only partially filled and the contents subject to frequent agitation by pumping off requirements for use, etc. It thus appears that, starting with an initial concentration of 85%, an operational storage life of at least three years is possible before re-concentrating is necessary.

The commercial use of nitric acid has provided a large bulk of experience on its normal handling, transport and storage problems, and it has been generally assumed that the information available would be quite adequate. Because of the small scale use of nitric acid for rocket motors up to the present, the aspects peculiar to guided missile work have only just begun to be appreciated and, in fact, a surprising

lack of data on them is revealed. Among subjects which need investigation, are the use of inhibitors to reduce corrosion, the compatibility properties of materials for storage, combustion chambers, pumps, etc., the development of respirators having a life in nitric fumes much longer than the present one of 20 minutes, the development of quick and effective treatment for burns, etc.

Answers to all these problems will be forthcoming in due course, but at the present time they are not available and in this case, as in motor design and development, it is probable that a period of at least twelve months will elapse before a stage will be reached comparable with that of HTP.

3 Other technical considerations

It is well known that for equivalent performance, HTP operates at a gas temperature 300-400°C. lower than that for nitric acid. This difference has been dismissed as unimportant in a regeneratively cooled combustion chamber. Ultimately, when research on heat transfer and cooling techniques has progressed far enough, this criticism will be true, but with existing knowledge it is not correct. Present performance of motors running for more than a few seconds is limited almost entirely by the maximum safe combustion temperature, which is far below the optimum value for nitric acid. A comparison between HTP and nitric acid at equal temperatures shows the latter to have an inferior performance both on a weight basis and a volume basis. This is illustrated in Table I which has been compiled from the results of Ref.3. It shows the nitric acid performance to be between 4 $\frac{1}{2}$ % and 5 $\frac{1}{2}$ % worse than that of HTP.

Whilst considering volumes of propellant, it may be pointed out that nitric acid has a 20% greater volume coefficient of expansion and this will necessitate a larger ullage space in the propellant tank, especially if the tank is sealed. This will produce a further small detraction from the performance.

Efforts to raise the combustion temperature are likely to involve higher rates of heat transfer and larger quantities of heat absorption by the coolant. It is already apparent that the limits of regenerative cooling by circulating the fuel will soon be reached, as the flow is insufficient to deal with higher rates of heat transfer. This is of particular significance for HTP systems where the fuel/oxidant ratios are low. For nitric acid systems the ratios are higher, but the limit is still close. There is a further danger, if the cooling fuel is paraffin, as cracking may occur and carbon blockage of the burner orifices or other small passages may be produced. Cooling by oxidant will, therefore, almost certainly be necessary in future if actual specific impulses much greater than 200 sec. are to be achieved. Cooling by HTP has already been partially developed, but it has not yet been tried with nitric acid.

A further consequence of the higher temperature gases produced by nitric acid may be an increase in the attenuation of control signals. It is well established that attenuation increases with exhaust gas temperature, though it does not follow that it will reach a significant level in a non-luminous gas. Recent work⁶, however, suggests the possibility of nitrogen being a serious attenuator. This work is still incomplete and no definite conclusions can be drawn as yet, but there is a likelihood of nitric acid causing trouble.

If it is necessary to limit the temperature, it can be accomplished by using either a fuel rich mixture or an excess oxidant mixture. If the former is used there is considerable risk of attenuation arising from the after-burning which may occur in the exhaust gases. If the latter method is adopted, the nitrogen ions may play a part.

4 Conclusions

Of the points discussed, the most important is that development and design experience with nitric acid systems in this country is still some way behind that with HTP systems, particularly with reference to such features as fuel expulsion by self-generated gases, variable thrust control, oxidant cooling and compatibility of materials. Thus, any decision in favour of nitric acid motors for operational use will involve accepting a delay in availability of at least twelve months.

Other disadvantages may accrue from the higher combustion temperatures of nitric acid, required in order to give the same performance as HTP, by introducing additional heat transfer problems and by the possible greater risk of attenuation.

The handling and storage of HTP has not proved to be as difficult as was originally anticipated, and there appears to be no reason why unskilled labour should not be trained to handle it as safely as petroleum is handled. A minimum storage life of three years at normal operating concentrations seems certain before re-concentration need be considered.

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TABLE I

Comparative performance of hydrogen peroxide
and nitric acid with n-decane

Gas Temp. °K	Specific Impulse			Specific Impulse x Rel. Density		
	HTP	HNO ₃	Difference %	HTP	HNO ₃	Difference %
2000	207.3	198.4	4.4	242	231	4.75
2400	219.6	210.6	4.3	265	252	5.1
2600	224.7	215	4.5	276	261.5	5.5
Comparison by Weight				Comparison by Volume		

HTP = 88.3% concentration

HNO₃ = 100% "

Fuel = n-decane

Combustion chamber pressure = 20 atms.

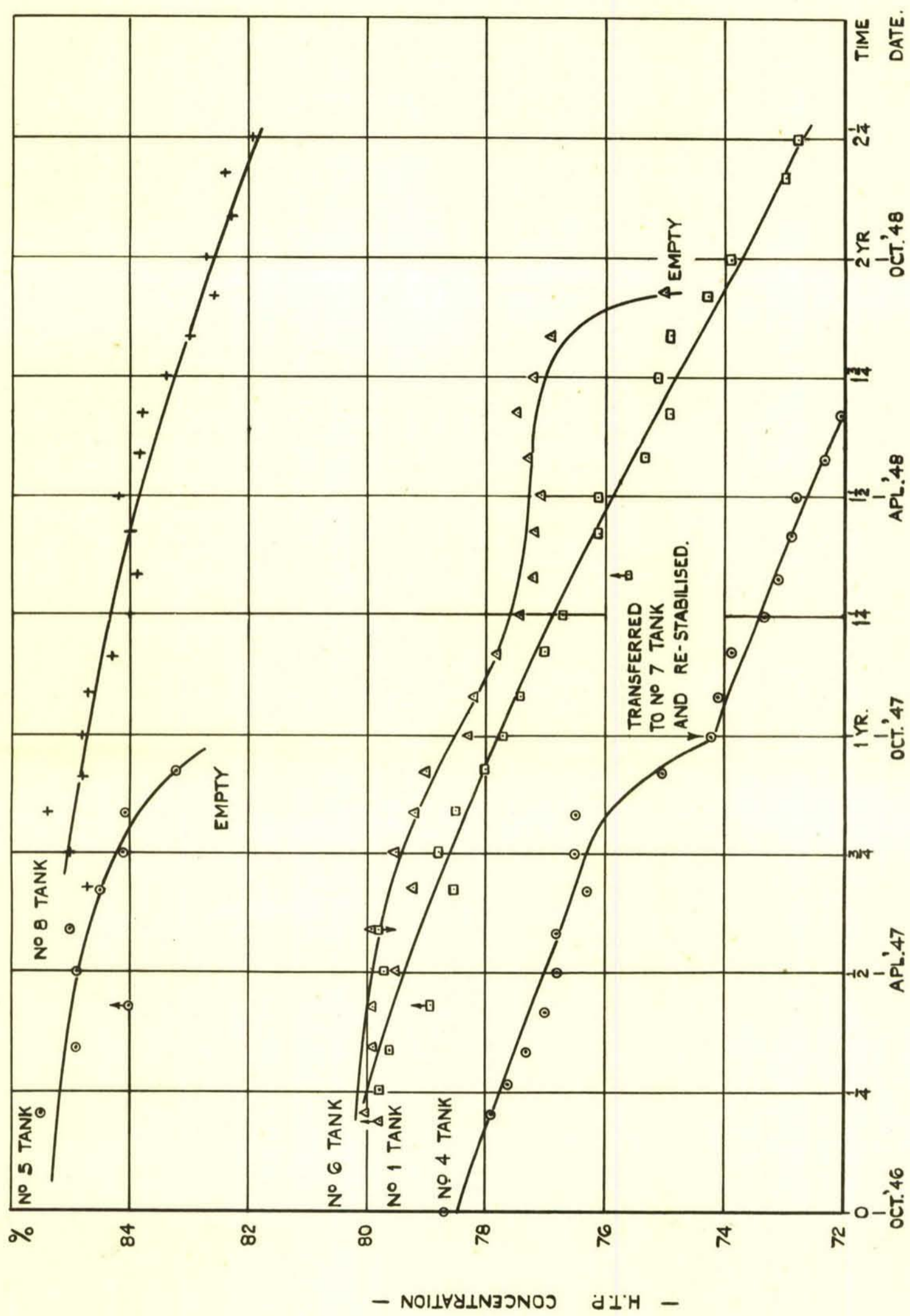


FIG. I. PERIOD OF STORAGE LOSS OF CONCENTRATION OF HYDROGEN PEROXIDE WITH TIME.