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ANALYSIS OF PROPOSED AIR DRYING PROCESS

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National Bureau of Standards

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Prepared for
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Greenbelt, Maryland 20771



U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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Abstract

NASA Proposal No. 7401-6-01A by the GCA Corporation describes a proposed air drying process which has been analyzed. The drying process, intended to reduce the water vapor content of a stratospheric sample to below one part per million by weight, is based upon the removal of the water as it passes through a phosphorous pentoxide absorber. Our analysis indicates that the method is feasible. Dependence on ram pressure to maintain flow through the absorber appears questionable and consideration should be given to other means.

Key Words: Absorption; drying; phosphorous pentoxide, water vapor.

Preface

GCA Corporation has made a proposal to the National Aeronautics and Space Administration for the development of a new technique with which to measure water vapor in the stratosphere. This technique is based on the discovery that ion plasma oscillations in coaxial corona discharges have a frequency dependence related to the presence of trace gases, including water vapor. The proposed technique is to determine the frequency difference between two separate discharges, one in which the stratospheric gas is present and the other in which the stratospheric gas with the water vapor removed is present. The frequency difference would then be related to the quantity of water vapor removed.

The National Bureau of Standards was asked to analyze the proposed method of water vapor removal with the purpose of determining its feasibility. Our conclusion was that the proposed method of drying was feasible within the required restraints, but that a mechanical blower or other positive means might be necessary to produce sufficient flow through the required absorber configuration.

Introduction

The GCA Corporation proposal does an analysis of a proposed air stream drying in situ in the stratosphere. Their proposal involves a P_2O_5 desiccant with a minimum flow rate of $10 \text{ cm}^3/\text{s}$ at pressure altitude equivalents up to 53 km. The goal is to achieve an effluent gas stream with a water vapor concentration of less than one part of water vapor per million parts of air by weight. Their proposal is to operate the drying system at -13°C . No discussion is given as to how the temperature would be maintained in the stratosphere.

Rather than doing a critique of their analysis, we did an independent worst case analysis (53 km pressure altitude equivalent) of our own. This is a worst case because for a given vapor content the parts per million are lowest at the highest ambient pressure. We used the -13°C temperature of their proposal in our analysis. Some parts of our analysis are the same as the GCA analysis and others differ considerably. Where appropriate, certain aspects of their analysis are referred to and commented upon.

Discussion

The subject proposal uses 0.25×10^{-10} g/cm³ as the equilibrium water vapor concentration for P₂O₅ at one atmosphere of air and 298 K. This is in agreement with results obtained by Morley⁽¹⁾ for a flow of three liters per hour through absorption tubes filled with P₂O₅ and is probably as good a value as is available. At this low flow rate, it is likely that vapor pressure equilibrium was achieved. This is equivalent to .02 PPM by weight at one atmosphere and 298 K. At a pressure altitude equivalent of 53 km this would be 37 PPM and at the 53 km pressure altitude equivalent and -13°C in lieu of 25°C this would be 32 PPM.

By means of calculations similar to those in the proposal, we calculate that lowering the temperature of the desiccant from 25°C to -13°C would reduce the equilibrium water vapor content by 256 fold resulting in an equilibrium vapor content of .125 PPM at -13°C and a pressure altitude equivalent of 53 km.

Since the water vapor equilibrium with P₂O₅ at 53 km altitude and -13°C appears to be considerably less than 1 PPM, it is of interest to determine what flow rates and absorber configurations are appropriate to dry air at the above condition to a level of less than 1 PPM. The best basis we have for evaluating such drying techniques is our own experience with a P₂O₅ absorption tube train.⁽²⁾

Our absorption train is composed of three tubes; the first one is filled with magnesium perchlorate and the second and third tubes are filled with phosphorous pentoxide. For purposes of this analysis we shall assume that the action of the magnesium perchlorate is not very different from that of the phosphorous pentoxide. We estimate that the gaseous volume associated with the desiccant in each tube is approximately 18.4 cm³ per tube. Our flow rate is 2 lpm giving us a residence time of 1.66 seconds.

Although we do not know how dry our effluent gas is, we have evidence that we can achieve an effluent with a level of less than 0.18 PPM by weight with an initial water vapor content of 7000 PPM by weight. Based on the premise that absorption of moisture is exponential with respect to the time the gas is in contact with an absorber, we obtain a time constant at normal temperature and pressure of less than 0.155 seconds.

The time constant should be a function of diffusion and/or chemical reaction rate. The diffusion, D, at any condition should be, approximately,

$$D = D_{NTP} \frac{P_{NTP}}{P} \left(\frac{T}{T_{NTP}} \right)^{3/2}$$

where D_{NTP} , P_{NTP} and T_{NTP} are the diffusion, pressure and absolute temperature respectively at normal temperature and pressure and P and T are the pressure and absolute temperature at the desired condition.

For -13°C and 53 Km pressure equivalent we have

$$\begin{aligned} D &= D_{NTP} \times \frac{1013.25}{5.5385} \left(\frac{260}{298} \right)^{3/2} \\ &= 1,491 D_{NTP} \end{aligned}$$

Therefore, if the time constant is less with increased diffusion, it will be greatly reduced at the new conditions. Let us assume the worst case, that the time constant is a function of the chemical reaction rate only. We use a method similar to that in the proposal for estimation of the reaction rate but our results are quite different from those in the proposal. For a decrease of 38 deg from 25°C to -13°C, we obtain a decrease in reaction rate of almost twelve fold as opposed to the eight fold in the proposal. This gives us a time constant of less than 1.8 seconds.

Table 1 is a table of residence times for various moisture levels of inlet gas, required to obtain an effluent of 1 PPM by weight based on a time constant of 1.8 s.

Table 1

Required Residence Times
for outlet levels of less than
1 PPM by weight of water

Inlet Moisture Level PPM by weight	Required Residence Time Seconds
2	1.4
5	3.1
10	4.4
20	5.6
50	7.3
100	8.5

Let us do a typical calculation using a relatively high level of 20 PPM. Providing a residence time of 5.6 seconds at $10 \text{ cm}^3/\text{s}$ flow rate requires a volume of 56 cm^3 and since about 65 percent of the volume occupied by the desiccant is gaseous volume, approximately an 86 cm^3 container of desiccant is required. There is probably a minimum length for effective desiccation necessary in order to prevent channeling (let us assume 3 cm) resulting in an area of 29 cm^2 .

Our experience has been that we obtain a pressure drop of about 30 dynes/cm^2 per cm length of desiccant per cm/s of air velocity. One might expect some reduction in pressure drop at the reduced pressure and approximately 12% reduction as a result of the lower viscosity due to the 38 deg temperature reduction. Let us, therefore, use the figure of 25 dynes/cm^2 per cm length of desiccant per cm/s of air velocity. With a 3 cm length and a 29 cm^2 area, a $10 \text{ cm}^3/\text{s}$ flow would give a pressure drop of 26 dynes/cm^2 which is greater than the pressure available due to ram pressure. Of course, reducing the length to 2 cm and increasing the area proportionately would reduce the pressure drop to $11 \frac{1}{2} \text{ dynes/cm}^2$. Preferably one would wish to increase absorber length for greater absorption assurance and reduced residence times might be desirable for faster speed of response, either condition would necessitate reductions of area. It would therefore seem that the use of ram pressure to provide the $10 \text{ cm}^3/\text{s}$ flow through the desiccant is marginal and that consideration should be given to the use of a blower on the downstream side in order to obtain the flexibility necessary to insure adequate flow through an optimum desiccant configuration.

Conclusions

A worst case analysis of the drying process indicates that a sample of 10 cm³/s of air at an altitude of 53 km maintained at -13°C can be dried to less than 1 PPM by weight by means of a P₂O₅ absorption tube. Such drying may require residence times considerably greater than one second. Use of a mechanical blower or other device with which to produce the flow through the desiccant appears desirable.

References

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