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# THE IMPORTANCE OF AEROSPACE CONTAMINATION CONTROL

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## Summary

A recent technology "Contamination Control" is described with emphasis on its importance to aerospace missions. A number of incidents occurring at Cape Kennedy are described in which contamination played a part. How contamination may seriously affect an aerospace mission is also brought out. Various types of contamination are described. The importance of Management's role, carefully selected personnel, supervision, training, quality control, adequate facilities and working conditions are discussed.

## Introduction

A recent technology, "Contamination Control," has developed and expanded greatly within the last few years in the aerospace programs. Contamination is defined, for the purpose of this article, as foreign material that exists in a component or system in the form of small solid particles and liquid chemicals of various kinds. The small solid particles include particles of almost every type of material and those visible and not visible to the naked eye. This type of contamination usually adheres to the sides of a component or system and may eventually be picked up by fluid flowing through the system.

Contamination of this type, of course, is not new, and a certain amount of "control" has been exercised in the past. An example would be the filter on the fuel supply of an automobile or aircraft. However, with the development of the rocket and aerospace programs, the importance of contamination and its control has advanced greatly and elimination of all possible contamination is considered mandatory for a reliable system. The motto of one aerospace company is, "There is no second chance." Failure to maintain the proper level of "cleanliness" may result in mission failure or even destruction by explosion.

### How Clean is Clean

The word "clean" has been used to define a requirement. The question then arises, "How clean is clean?" Absolute cleanliness cannot be obtained and even a high degree of cleanliness or freedom from contamination may not be practical or feasible. Contamination is usually only a problem when it affects a function. Systems vary considerably in the degree of contamination that they will tolerate. This means that it is necessary for various limits of contamination to be detected, measured and defined.

## Detection and Measuring

There are a variety of ways in which contamination can be detected and measured. This article will not describe these methods except to give one example of how a certain procedure and requirement was established.

During the early testing at Cape Kennedy of the ballistic missile, propelled by liquid oxygen and RP-1 (kerosene), a question arose concerning the cleanliness of certain components that were to be used in contact with liquid oxygen. This brought about a situation that resulted in a "firing delay."

An ad hoc committee was established to study the problem. Liquid oxygen had been in use at the Cape for almost a year. It was decided that a large number of liquid oxygen ground support systems in use, i.e., piping, filters, spool pieces, valves, etc., should be removed and examined. This was done at different complexes. A procedure was developed to flush these components with a solvent that would remove the major portion of the particulate and chemical contamination. The particulate matter was then examined microscopically for amount, size and identification. The chemical contamination was determined in the form of "hydrocarbons" by use of the infrared spectrophotometer. "Hydrocarbons" were reported by weight per square foot of area.

A large number of different systems and components were tested and the results evaluated. It was considered that this was what we were "living with" as far as the contamination of liquid oxygen systems was concerned. We did not know then, and we still do not know the exact limits of contamination that should be allowed for the components of a system in contact with liquid oxygen. We do know that liquid oxygen is a potentially hazardous and explosive material and that its action in many instances has been unpredictable. Therefore, based on the results of this extensive study, and the known and unknown hazards of handling liquid oxygen, certain standard test procedures and contamination limits were established. These were later used for a number of standards and requirements for the control of contamination in liquid oxygen systems.[1,2]

## The Effect of Contamination on Function

In order to emphasize the importance and need for control of contamination, a description of a sensitive hydraulic valve and a few examples of malfunctions in which contamination was either directly responsible or strongly suspected, are given below.

### Servo Hydraulic Valve

A diagram of a servo hydraulic valve is shown in Figure 1. This hydraulic valve has small openings and orifices that are particularly sensitive to fiber "birdsnests" and other particles. Fiber "birdsnests" at the pilot valve reed, wedging of particles between the valve spool and body, or stoppage of flow at the orifice can cause malfunction of the valves.

The clearance between the valve spool and body is of the order of 1 to 2 thousandths of an inch (1 mil equals 25.6 microns). It can be readily seen that very small particles will seriously interfere with its movement and function.

Hydraulic servo valves are used to actuate various system controls including guidance. They are extremely important components. Contamination in the valve may cause the valve to become sluggish and respond slowly or it may become completely inoperative. Their malfunction may cause a missile or space vehicle to fail to meet its objective or bring about its destruction.

Failures or malfunctions due to contamination are obviously hard to determine. Such failures are often reported as mechanical failures. When one hears of failure due to a valve, switch or some other mechanical part, it is quite possible that some kind of contamination either contributed to or caused the failure.

A few examples are given below where contamination was related to a malfunction or failure.

### Vanguard Program

1. Scale formation that came from the surface of the second stage propellant tanks. This was suspected of having caused two malfunctions in Vanguard flights.

2. Breakdown of nylon seat in valve causing the valve to be inoperative. The nylon was identified in the laboratory.

3. Propellant deterioration of silicone grease in valve. This caused the silicone grease to break down and form abrasive material. The silicone was identified in the laboratory.

4. Explosion of hydrogen peroxide drum in storage. The drum is shown in Figure 2. Drum had not been cleaned properly. Hydrogen peroxide is highly active and is very sensitive to any surface contamination. The drum that exploded was to be used for the Vanguard program. The drum of peroxide if loaded into the rocket might have caused severe damage to the rocket or brought about a serious malfunction.

### Liquid Oxygen Accident, Figures 3 and 4

This explosion and fire destroyed a LOX storage system, pumps, concrete pad and several vehicles. High temperature and extreme heat were generated by gallons of LOX released when a transfer flexible metal hose exploded. Contamination (particles or hydrocarbons) may have caused the ignition that resulted in the explosion and fire in the LOX transfer system.

### LOX Explosion at Redstone Arsenal

An aluminum valve used for LOX exploded at Redstone Arsenal. The explosion was attributed to a fingerprint on the inside of the valve.

### Mercury Report

Contamination contributed to equipment malfunction on the Mercury Program. This was reported in Mercury Project Summary report for the Fourth Manned Orbital Flight.[3] This was reported as follows:

> Such matters of quality control as cleanliness, component limited shelf life, and limited operational life, and equipment failure, influenced the test philosophy. Technicians generally were not aware of the strict cleanliness required in handling components of the ECG and RCS systems. It became necessary to specify handling procedures for these highly dirt-sensitive components. Such items as gums, powders, lubricants, chips and hydrocarbons have appeared on components where they could not be tolerated

> for proper operation. Hydrogen peroxide systems have yielded some decomposables that could have caused extreme reaction. Breathing oxygen and drinking water also have been contaminated. As a result, all consumables were chemically analyzed before being put into their spacecraft containers, and a variety of equipment which was found to contain contaminating deposits was carefully inspected and cleaned before being used. This equipment included astronaut suits, valves, hoses and tubing.

Photographs of some of the contamination described are shown in the Mercury report. Gemini, Apollo, and more recent space probe programs are placing increased emphasis on a high degree of cleanliness for components and systems. As an example, for fuel cell gases a requirement has been placed for no particles to exceed 10 microns.

## Types of Contaminants

The examples given above illustrate that particulate and chemical contamination may not only lead to mechanical failure, but failure due to reaction with the fluids in the system. Many propellants are highly active chemicals and therefore react readily with contamination, sometimes violently.

Both particles and hydrocarbons have been mentioned. Particles, of course, may consist of hydrocarbons such as hair, skin, fibers, rubber, plastics, or they may be and often are metals, sand, soil, rust, sealing compounds and lubricants, etc. Very small particles tend to attract each other and agglomerate forming larger particles. An example is the "birdnest" effect of fibers that may occur in hydraulic systems.

Hydrocarbons are usually present as an oily, fatty, or waxy material that often forms a film or coating on the inside of the pipe, valve, or other component. It sticks to the surface and is not easy to remove. Body secretions are always present on the surface of the skin. When you handle an object with the bare skin, you transfer some of the secretion to the object. This is illustrated in the infrared curve shown in Figure 5. This curve shows the effect of adding the hydrocarbons rinsed from an approximate square centimeter of a finger to carbon tetrachloride. The amount added, as shown by the absorption point of this curve at 3.4 microns, can be readily detected. The amount represents a few micrograms of hydrocarbons. This is enough to cause trouble in an oxygen system if it's in the right place at the right time.

Liquid oxygen and hydrocarbons may ignite when subject to impact. For example, an impact type tester is used for the purpose of determining the impact properties of a material in contact with liquid oxygen. Petroleum materials such as RP-1 (kerosene), hydraulic fluids, lubricating oil, asphalt, etc. will explode readily in this test.

Particles and hydrocarbons have caused explosions and fire in high pressure gaseous oxygen systems. Small high velocity particles have been shown to generate sufficient energy to cause ignition and explosions of oxygen gas. Hydrocarbons (and this includes most common organic materials) will ignite with gaseous oxygen under suitable conditions.

## New Cleanliness Concepts Required

Contamination control, as applied to aerospace components and systems, requires a new concept for workers, operation supervisory personnel, and management. Old concepts of cleanliness must be drastically revised. Management must plan and select personnel carefully. The casual view of what constitutes reliability related to cleanliness, accepted by nearly everyone, must be discarded. This attitude has been brought about by our close contact with mechanical gadgets of varying quality so that we tend to accept equipment failure as a rule of life. Additionally, style changes and technical obsolescence come so fast that today's automobile, mechanical devices and household appliances are swept aside before their owners have a real opportunity to consider their reliability and durability.

In the aerospace field this concept is dangerous. Changing it represents a challenge that aerospace management must face.

Contamination control was found to be important in maintaining the reliability of rockets for missile use. It has become critical for space probes and manned rockets. "Trial and error" methods cannot be accepted.

## Management Responsibilities

Management plays an important role in this technology. The importance of selecting the right personnel has been mentioned. Operating supervisors in particular must be chosen with care for attitude, technical ability, and their capacity for adapting to both new and rigid requirements. All personnel working in this area must be conscientious and interested. Management must plan and organize effectively and provide adequate facilities and equipment. New techniques are employed along with the use of new equipment and tools.

A well-organized personnel training program should be established and kept up to date and manuals and other instructional material provided. Controls must be established, along with an organized and effective quality control program. Quality control personnel must be well trained and familiar with all phases of cleaning, clean room operation and specification requirements. All individuals working in contamination control should be periodically checked and follow-ups made on their work and effectiveness. This is an area in which errors of omission cannot be tolerated. Management must be responsible for providing adequate time to conduct proper work. There should be no pressure brought to bear on contamination control personnel that would affect the quality of the work. It has been demonstrated that with adequate facilities and trained conscientious personnel, reliable and effective cleaning and control can be accomplished.

A complaint frequently encountered is that specifications and requirements for contamination control are too rigid and too tight. In many cases this is probably true. But, one hesitates to tamper with a successful program, particularly in an area that is rather grey to start with. Obtaining a high degree of component cleanliness and maintaining freedom from contamination all along the way by special methods of packaging and handling, up to and including the finished system, is very expensive. Clean rooms are costly and they are costly to maintain. Adding to the expense are constant laboratory tests for contamination. It is very necessary that space personnel and the general public understand that while reliability is costly, it is still much cheaper than failure. After all, a rocket in flight cannot be sent back for repairs or to the drawing board. A failure may bring about a failed objective or destruction in flight. There is no second chance.

## References

1. AFBS Exhibit 61-3, "Permissible Contamination Limits and Inspection Criteria for Liquid Oxygen, Liquid Nitrogen, RP-1 Fuel, Gaseous Oxygen, Gaseous Nitrogen, Instrument Air and Helium, Components and Handling Systems."

2. Handbook for Contamination Control of Liquid Rocket Propulsion Systems, Revision 1, dated August 1961, issued by Aerospace Industries Association.

3. Mercury Project Summary, Including Results of the Fourth Manned Orbital Flight, dated October 1963, NASA SP-45, pp. 243-252.

4. Military Specifications:

   Mil-H-5606B, Hydraulic Fluid, Petroleum Base.

   Federal Standard No. 791 - "Lubricants, Liquid Fuels and Related Products; Methods of Testing."

5. American Society for Testing Materials, Test Method D-1257, 1961, "Particle Counting in Hydraulic Fluids."

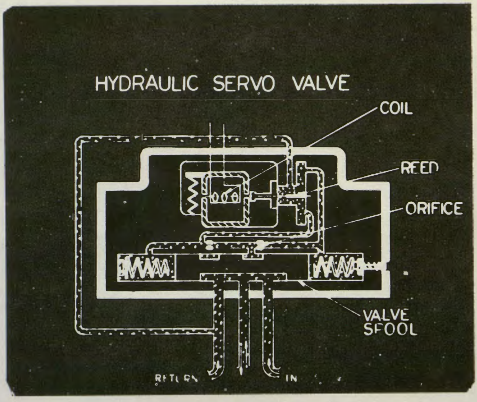

FIGURE 1. DIAGRAM OF HYDRAULIC SERVO VALVE

FIGURE 2. HYDROGEN PEROXIDE DRUM THAT EXPLODED IN STORAGE

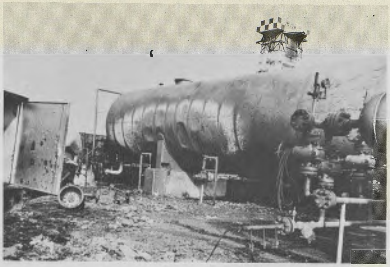

FIGURE 3. DAMAGE TO LIQUID OXYGEN STORAGE TANK AND EQUIPMENT DUE TO EXPLOSION AND FIRE

FIGURE 4. SAME AS FIGURE 3, ANOTHER VIEW

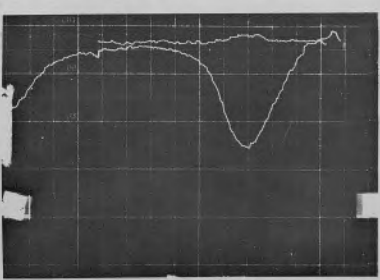

FIGURE 5. INFRARED ABSORPTION CURVE AT 3.4 MICRONS OF HYDROCARBONS FROM ONE SQ. CM. OF FINGER RINSED WITH CARBON TETRACHLORIDE. TOP CURVE BLANK, LOWER CURVE SAMPLE.