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Fluid Conditioning of Aviation Hydraulic Fluids

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Introduction

There has been a distinct market emergence in the field of fluid conditioning over the past ten years. This emergence has been due to several factors but the following have played the largest role:

A. User Education. There is a much greater awareness and understanding at the user level of the relationship between fluid health and system life.

B. Government Regulations. The EPA has passed rulings which have significantly increased the cost and inconvenience of waste oil disposal.

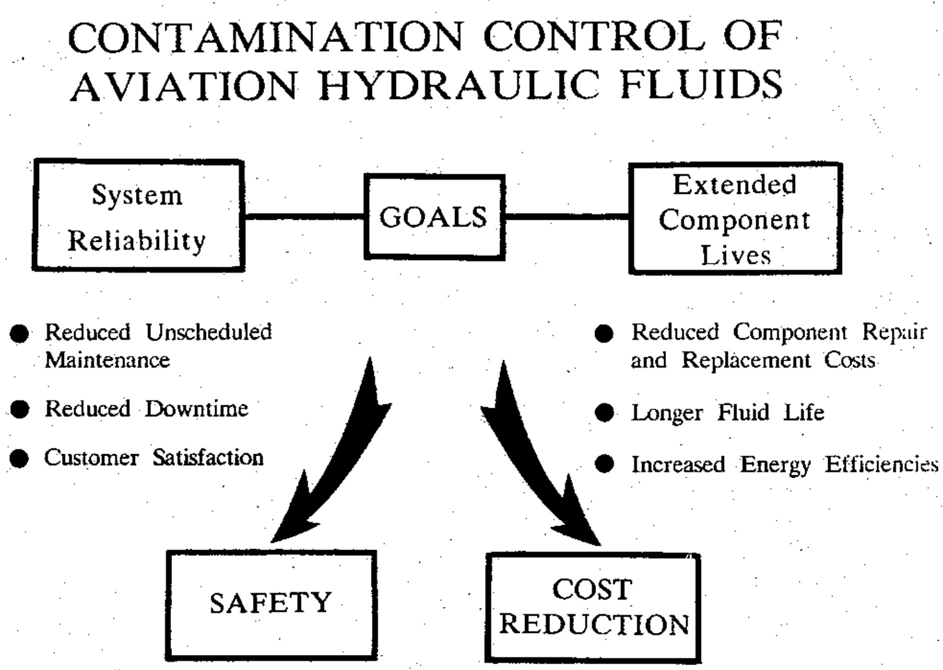
C. Product Availability. Only recently have reliable and effective fluid conditioning products been available.

Moreover, there is much greater awareness of the harm caused by water and volatile contaminants in lubricating fluids. New information on abrasive wear, erosion, corrosion, and silting confirms the contaminant synergy between water, air and solids. Since typical filtration products remove only solid particles from fluids, there is a specific requirement for vacuum distillation employed in fluid conditioning.

Synthetic phosphate ester fluids such as Skydrol are not excluded from the need for fluid reconditioning. In fact, considering the high cost associated with aviation hydraulic fluids, this requirement should instead be emphasized. We now know that contaminants such as water, chlorine, and solids do considerable damage to the base stock, additives, and system components.

This paper discusses the problems associated with hydraulic fluid contamination in aircraft as well as the benifits to be achieved by fluid conditioning. Also discussed is fluid conditioning prior art and the proprietary designed preferred by Diagnetics. Finally, it is propose that fluid condtioning be used to insure test

stand fluid health and cleanliness. This application, provided with routine oil analysis, might lead to much broader uses.



Failure Modes of Type IV Aviation Fluids

Contaminant induced failures of aviation hydraulic systems have been found to be indigenous to the base stock fluid, i.e., phosphate ester. Therefore, contamination control must be designed to deal with the specific failure modes present. An understanding of these failure modes leads to the clear conclusion that periodic fluid conditioning would offer more consistent performance of the fluid product over typical service intervals. The following is a brief discussion of the most common failure modes indigenous to aviation hydraulic systems and their relationship to the contaminant health of the fluid:

SERVO-VALVE EROSION

Electrokinetic erosion of metering edges in servo-valves and some pumps can be directly attributed to changes in fluid conductivity. Although the Type IV fluids have somewhat improved performance in this regard, a distinct problem still exist. The Monsanto Orifice Test Block pursuant to AS 1241-March 1974 can be used as a valve metering edge simulator to measure electrokinetic erosion as well as cavitation erosion under a variety of contaminant and fluid health conditions. Such tests have shown that abnormal moisture and chlorine levels may increase fluid conductivity thereby accelerating the erosion process.

One should also recognize that the products of thermal, oxidative, and hydrolytic degradation are acidic by nature and can be expected to reduce the resistivity of the fluid as well. This "aging" process is catalyzed by the presence of contaminants such as water, air, chlorine, certain wear metals, and excessive heat.

In some cases, resistivity has been restored using Fullers earth adsorption filters. However, with certain phosphate ester formulations, additive treatments interfere with the adsorption process producing ineffectual results. On the other hand, fluid conditioning units incorporating vacuum distillation, can effectively remove acid, chlorine, air, water, and wear metals.

SILTING

The effects of contamination on the performance of servo-valves for aerospace applications was first investigated during the 1950's and 1960's. However, these works were primarily committed to a specific program, such as selection of valves for an aircraft or missile, and were not based on standard procedure. Recent studies on the obliteration of close-tolerance surfaces and orifices have shown that greater attention needs to be paid to this problem. Specifically, these studies are showing a distinct synergism resulting from the presence of both water and particles in the fluid. Hence, as system pressures and performance requirements increase, fluid cleanliness must equally increase.

INTERNAL LEAKAGE

Volumetric efficiencies of pumps and motors degrade due to a number of factors and conditions. These degradation failures are gradual occurrences but are nonetheless costly to the airline company in terms of component replacement costs, downtime, energy losses, etc. Moreover, there has been a general failure among aircraft design and maintenance engineers to identify and deal with the root causes of internal leakage. Such an examination would clearly reveal contaminant induced surface wear to be the common source of most of these problems.

A. Lubricity Loss. Both boundary layer and hydrodynamic lubrication are essential to separating dynamic surface asperities. Fluid degradation resulting from the abnormal presence of water, air, chlorine, wear metals, and heat destroy a fluid lubricating properties. Boundary layer lubrication relies heavily on healthy antiwear properties while hydrodynamic lubrication depends on viscosity stability.

B. Abrasive Wear. Clearance size particles gouge and scrape sliding surfaces in a multitude of tribo-mechanisms. Loss of fluid antiwear protection accelerates this process. This loss is due to fluid aging (oxidation) and the presence of water and other catalytic contaminants. Of course, high performance filtration in the range of clearance size particles is essential.

C. Fatigue Wear. In recent studies the fatigue process has been identified a major and frequently occurring form of wear. The process involves particles being trapped under load between rolling

and sliding surfaces causing surface cracks and dents. The surface then fails releasing particles or spalls, forming surface cavities. The clearance size particles existing in the fluid are the cause of fatigue wear, particularly in high-load, high-pressure systems.

D. Cavitation Erosion. Cavitation erosion can be just as damaging to component surfaces as any other form of wear. This damage results from the hammering action caused by the implosion of cavitation bubbles in the flow stream. In the case of phosphate ester fluids, water contamination increases the fluid's vapor density and susceptibility to cavitation.

Fluid Conditioning, Prior Art

Numerous methods have been developed to selectively remove water and other volatile contaminants from hydraulic and lubricating fluids. These methods include absorbent filter media and regenerable adsorbent packings and the like. In many cases, it is not economical or practical to use disposable media and as a result continuous scrubbing processes have been developed.

The most common continuous scrubbers are derivatives of vacuum distillation processes where the oil is expanded to produce high specific surface area to facilitate the mass transfer of the liquid contaminants. Distillation involves heating, vaporization, condensation and cooling of vapors. Distillation separates components of a liquid mixture by partial vaporization of the mixture and separate recovery of the vapor and liquid residue. The more volatile components are obtained in increased concentration in the vapor, and less volatile components concentrate in the liquid. Completeness of separation depends on properties of the components and efficiency of the distillation process.

Vaporization is the change from a liquid to a vapor state. The change typically requires the addition of heat energy to the liquid. Condensation is the change in state from a vapor to a liquid and generally requires the removal of heat from the vapor in a condenser. Condensation is the reverse of vaporization.

Vacuum distillation is simply distillation at pressures below one atmosphere. Reduced pressure permits vaporization at reduced temperatures. This has two distinct advantages:

1. Thermal decomposition and degradation of the fluid and its' additives is avoided.

2. The energy requirement for both heating and cooling is reduced.

IN-PLANT APPLICATIONS

Thousands of industrial plants are reconditioning their own oils regularly with equipment that incorporates vacuum distillation. For in-plant reconditioning, each grade of fluid is treated (reconditioned) separately. Fluids are not mixed so they can be used repeatedly for the same purposes. Furthermore, mixing complicates the reconditioning process and increases its cost.

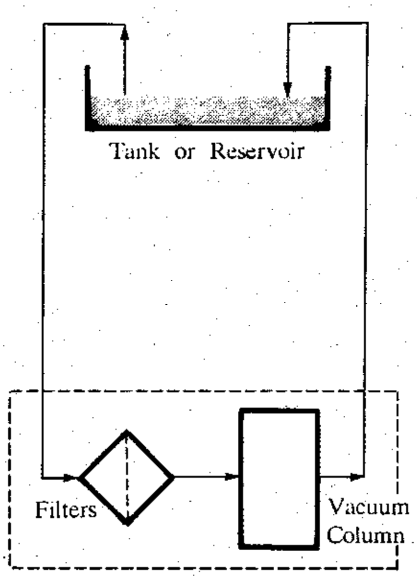
Vacuum distillation removes volatile contaminants from fluid in three basic ways:

1. The first application is simply just the transfer, in a single pass, through the fluid conditioner from one tank to another. Treated oil is not mixed with untreated oil. A vaporizer with 90 percent efficiency leaves 10 percent volatile contaminant in the effluent.

2. The second application involves the recirculation through a fluid conditioner from a tank or a reservoir of a non-operating fluid system with no contaminant ingression or generation. One pass is completed when the volume of fluid circulated through the fluid conditioner equals the total volume of fluid in the system. Continued recirculation provides many passes during which, theoretically, some fluid never passes through the fluid conditioner. Nevertheless, recirculation can provide adequate contaminant removal and control (see Figure 1).

3. The third application involves recirculation through a fluid conditioner in an operating fluid system during ongoing contaminant ingression. In many cases, the fluid conditioner may be dedicated to the machine for continuous contaminant removal. Such applications rarely require the addition of heat to the fluid as operating temperatures are often adequate to achieve distillation.

MULTIPASS FLUID CONDITIONING



Fluid Conditioning System

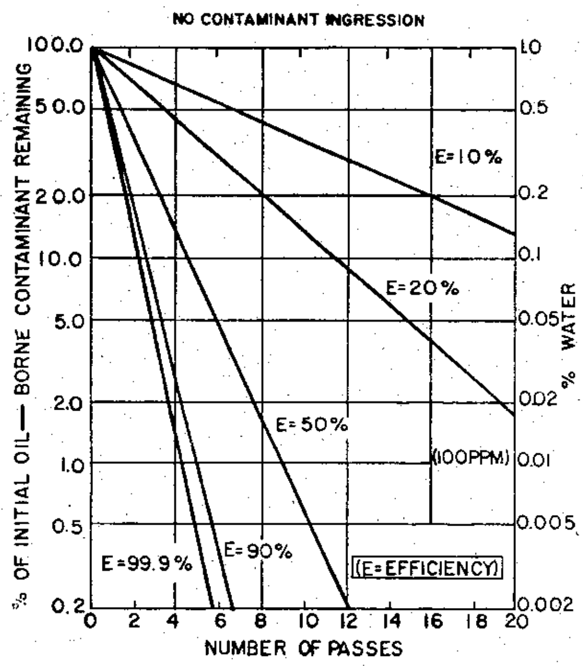


FIGURE 1

VACUUM DISTILLATION EQUIPMENT DESIGN

A typical vacuum distillation system for fluid conditioning includes the following basic components:

1. Positive displacement pumps are required to transfer fluid to and from the vaporizer. In some cases, vacuum is used to draw fluid into the vaporizer. While this eliminates the input fluid pump, it reduces the capability of flow control.

2. An incoming filter is needed to remove solid contaminants and to keep the distillation column clean.

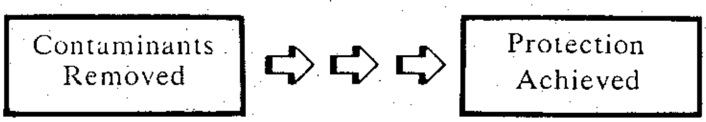
3. In some cases heat must be applied either electrically or by steam transfer to raise the fluid temperature to the boiling points of the volatile contaminants, and to vaporize the contaminants. However, the inlet fluid temperature may be high enough to eliminate further heating for vaporizing low boiling point volatiles present in small concentrations.

4. A distillation column or chamber is required to separate the volatile liquids and gases from the fluid. The primary objective of the distillation column is to create high surface area with the contaminated fluid, allowing ready effervescent vaporization of the contaminants. A number of different processes have been used including spraying the oil under pressure, passing the oil over a number of rings or saddles, thinly dispersing oil over a rotating surface, passing oil inside-out through glass-fibre filter cartridges, passing oil through a column of porous media, etc.

5. A condenser is used to convert the vapor to a liquid and for cooling the condensate so it will not reevaporate.

6. A vacuum pump is needed to exhaust trace amounts of noncondensed vapors and noncondensable gases to the atmosphere. A variety of rotary vacuum pumps are used to maintain absolute pressures in the vaporizer ranging from less than 1 to over 250 mmHg depending on the properties of the volatile contaminants.

7. Suitable gages for monitoring and control must also be provided to maintain efficient operation.



- Solids
- Water
- Acid
- Chlorine & Other Volatiles
- Air

- Viscosity
- Contaminant Wear & Erosion
- Additives
- Acid Formulation
- Corrosion

EFFECTS OF VACUUM DISTILLATION ON FLUID QUALITY

If the distillation system is designed properly for a given application, vaporization temperatures, applied for only a few minutes, cause no significant decomposition of fluid or additives.

The vapor pressures of fluid and additives normally are well below the absolute pressure in the vaporizer. There is no significant vaporization of additives or light fluid if processed in the pure state (for example, when new fluid is processed to remove air and traces of water).

Some vaporization of additives and fluid may also occur during evaporation of a dissolved solvent. Carryover of fluid is insignificant when vaporizing solvent with relatively low boiling points or high vapor pressures, such as pentane and benzene.

Oxidation of fluid additives is not a consideration because vacuum distillation occurs in the absence of air except for air present in the fluid, and this is removed in the vaporizer. Thermal decomposition of fluid and additives can be avoided by operating the vaporizer at a low absolute pressure. Vaporizing temperatures must be maintained below the maximum operating temperatures recommended by the oil suppliers.

Note although the fluid conditioning unit has no direct effect on additives or fluid qualilty, contaminants do. Hence, the condition of the fluid may have degraded during the time the contamiants were present. Therefore routine fluid analysis is essential.

Preferred Embodiment

Figure 2 shows a general schematic of a fluid conditioning unit available from Diagnetics, Inc. The circuits and features of the system are describes as follows:

THE FLUID INLET CIRCUIT

Contaminated fluid enters through a ball valve (1) and passes through a suction strainer (2). An inlet gear pump (3), which is protected by a relief valve (4), sends the fluid through an optional heater (5) and then through filters where particles are removed. The heater has a gage-switch to protect the fluid against over heating. The heater would be set to maintain an average inlet temperature of 140 degrees F to the vacuum chamber. To maximize filter life, both a coarse filter (6) and a fine filter (7) are used in series. These filters are the spin-on variety for ease of maintenance.

THE DISTILLATION CHAMBER

The fluid enters the distillation chamber (8) under pressure and is atomized by a special nozzle (9). The atomized fluid creates enormous surface area allowing almost instantaneous vaporization of free and emulsified moisture in the vacuum chamber. The atomized spray is directed into a proprietary reticulated metal foam

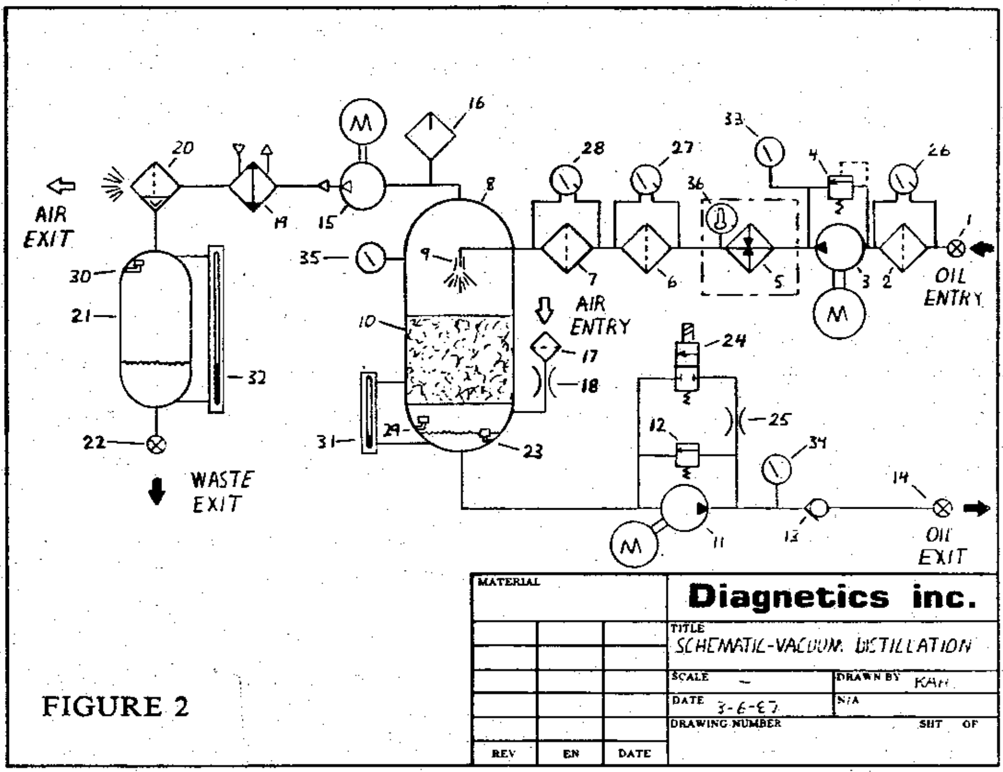


FIGURE 2

column (10). The droplets of fluid then coalesce in the foam column and gravity feed to the chamber bottom. The reticulated open-cell foam creates high surface area and fluid residence time owing to the foam's window-like porous structure. This second-stage separation facilitates the release of dissolved water from the fluid. The distillation chamber combines the unique elements of high surface area (at two stages), vacuum, raised temperature, and extended residence time.

THE FLUID DISCHARGE CIRCUIT

Fluid collecting at the bottom of the chamber is returned by a discharge pump (11) which is protected by a relief valve (12) through a check valve (13) and ball valve (14) to the system or tank being cleaned. The rate of fluid discharge is controlled by the high and low level switches in the chamber bottom. To prevent the exit pump from running dry, the float switch (23) is used for level control. When the fluid level in the bottom of the distillation chamber falls to the lower set point, a two-way valve (24) opens, allowing some of the exit pump flow to recirculate through the pump. When the level rises to the upper set point, the valve will close again. An orifice (25) prevents the valve from cycling rapidly.

THE VAPOR DISCHARGE CIRCUIT

Water and other low boiling point liquids are removed from the chamber by a vacuum pump (15), which maintains the chamber at a vacuum of between 24-27 inches of mercury. A lubricator (16) protects the vacuum pump from wear. Since

it is very difficult to remove vapors with vacuum alone, a small amount of air is allowed to enter through a spin-on air filter (17). A fixed orifice (18) controls the amount of air permitted to enter. The air influent insures constant movement of vapors up and out of the chamber. Further, as the air enters the chamber and expands in the vacuum, its relative humidity is reduced to less than 20 percent. This low relative humidity further encourages mass transfer of moisture by the absorption process (as oppose to boiling point vaporization).

Downstream from the vacuum pump is an air-cooled condenser (19) and a coalescer (20) to remove liquids from the exhaust stream. The coalescer automatically drains into a waste bowl (21). The bowl is manually emptied through a ball valve(22).

CONTROL & PROTECTIVE FEATURES

The system has several control protective devices. Relief valves (26,27) protect the pumps. Differential pressure switch-gages (28,29,30) on the suction strainer and filters automatically shut down the system if a filter becomes plugged. A float switch (31) in the distillation chamber shuts the system down if the chamber becomes flooded. Another float switch causes shutdown if the waste tank becomes full. Visual indication of these conditions are provided by the switch-gages and by sight gages (32,33) on the distillation chamber and waste bowl. Other indicators are pressure gages (34,35) on the pumps and a chamber vacuum gage (36).

Fluid Condition Monitoring

Monitoring the health of aviation hydraulic fluids, if done properly, can greatly improve maintenance, reliability, and system life; significant cost savings can result. The use of fluid conditioning equipment must be coupled with routine fluid analysis to insure the required result. Although the benefits of fluid conditioning equipment are many, fluid heavily damaged and altered by contaminants and operating conditions cannot always be restored. The following are examples of such conditions:

A. Fluid conditioning cannot restore thermally degraded and oxidized fluids.

B. Fluid conditioning cannot remove nonvolatile, liquid-phase contaminants.

C. Fluid conditioning cannot restore additives degraded or altered by contaminants.

D. Fluid conditioning cannot remove mineral-based oils from phosphate ester fluids.

Fluid analysis involves many technical and exact procedures. Any procedure that is compromised will generally destroy the integrity and accuracy of the results. The following are essential to a reliable fluid analysis program:

1. Bottles must be in a certified "ultraclean" condition before use. Bottles having original contamination above one particle greater than

ten microns per millilitre should be rejected.

2. Bottle caps should never be removed during sampling unless a protective cover is used. Probe-on style sampling bottles are ideal.

3. Fluid should be extracted from turbulent "live" zones and sample valves should be flushed thoroughly in advance. The system should be running.

4. The sample bottle should never be filled more than two-thirds full. Full bottles prevent adequate agitation and resuspension of contaminants by the laboratory.

5. Insist that the oil analysis laboratory provide expedient results. Any abnormalities should be clearly spelled out including the recommended corrective action.

Fluid Conditioning Applications

The use of fluid conditioning equipment should not be confused with fluid reclamation. Although many people use the words interchangeably, as previously mentioned, it is not always possible to return used fluid back to its orginal state of health, as fluid reclamation infers.

Therefore, fluid conditioning should not be considered a panacea for aged and damaged fluids. That is, fluid conditioning should not be used in place of replacing old fluid, especially in aircraft applications. The full effects of fluid conditioning need to be examined over time and usage. Ideally, applications should

Applications

Test Stand Fluid Conditioning

-Dedicated Systems
-Portable Systems

Used Oil Conditioning

-Unmixed Fluids
-Returned to Service After Analysis Only

Conditioning of Aircraft Fluids

-Not Recommended
-Establish Performance History

be limited to test stand fluid conditioning where normal learning-curve experiences have no severe consequences.

In time, after confidence and standard procedures have been established, fluid conditioning of the aircraft fluids may gain prominence. Until then, there is considerable savings to be gained from test stand and other non-critical applications.

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