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CONTAMINATION IN HYDRAULIC SYSTEMS

by

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S U M M A R Y

The background of contamination control in hydraulic control systems is discussed, with some results showing the effects of oil borne contamination on system performance. Measurement of contamination levels, techniques of contamination control, and system sensitivity to contamination levels, are discussed.

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Particle Size Range Micron	Particles per Litre of Oil		
	Missile System	Mil.Aircraft System	Industrial System
<5	NOT COUNTED		
5-15	35,000	200,000	2,000,000
15-25	6,000	100,000	300,000
25-50	3,000	25,000	100,000
50-100	500	1,000	5,000
>100	0	0	500
Gravimetric Equivalents	<3 mg/L	10 mg/L	100 mg/L

TABLE 1

Typical Particle Distributions in Hydraulic Systems

Contamination Level		Pump Life
SAE Class	No. of Particles > 5μ per Litre	Hours of Operation
0 - 1	30,000 - 60,000	40 - 55
3 - 4	300,000 - 450,000	17 - 30
5 - 6	1,100,000 - 1,800,000	7 - 10

TABLE 2 (Ref. 4, 5)

Effect of Contamination Level on Pump Life

INTRODUCTION

It is inevitable that the oil in a hydraulic system will contain contaminants in particle form. The sources and types of oil-borne contaminants are well known. Commonly contamination will include particles of silicas, metals, elastomers, and fibres of textile meterials. Sizes and concentrations of particulate contaminants are indicated in Table 1.

Modern high-pressure piston components such as pumps, motors, and spool valves, operate at pressures up to 5000 psi. To keep leakage down to reasonable levels, the diametral clearance between the pistons and cylinders of such components is of the order 2.5 to 25 micron per inch diameter, depending on the quality of the component. Such clearances demand almost geometrical perfection of the pistons and bores, and hence the components are expensive. Contaminated oil not only can impair the performance of a component, but also can cause it to wear rapidly. The contamination problem becomes increasingly serious as clearances are reduced towards the size of the very large numbers of very small particles which cannot be removed from the system by conventional filtration.

There is considerable interest among manufacturers and users of hydraulic systems in establishing acceptable limits of contamination in which particular systems will operate satisfactorily. Such information would be used to

a) specify the degree of filtration required in the system
b) specify the contamination sensitivity of the system
c) define the contamination tolerance level of the system.

To this end, it is necessary to gather reliable data on the performance of system components under controlled contaminated oil conditions. Information is needed as to the size, quality (material), shapes, and concentrations of contaminants which will affect performance.

In this paper, some results and practices associated with oil-borne contamination of hydraulic systems will be discussed.

SOME EXPERIMENTAL RESULTS

Earl (1954)[1] carried out experiments to demonstrate the effect of filtration on the performance of a spool valve. The hardened steel piston lands were 0.318 in diameter x 0.03 in long, with a diametral clearance of 5 micron in the hardened steel bore. The spool was held stationary under pressure for 15 seconds, and then the force required to move it axially was measured. Fig. 1. shows the measured break-out force at pressures up to 3000 psi, when (a) coarse filtration and (b) fine filtration was used on the system oil. The finer filtration reduced contamination lock dramatically.

Wells (1961)[2] conducted experiments on an aircraft spool valve and found that both the continuous motion operating force, and the break-out force after a stationary period, depended on the size, concentration, shape, and material properties of the contaminant matter in the oil. It was apparent that the critical particle size was in the region of the diametral clearance.

Dransfield (1967)[3] examined experimentally the contaminant sensitivity characteristics of a small electro-hydraulic spool valve operating at 3000 psi. The valve was operated in a number of controlled contamination conditions. The degree of impairment to the valve's operation due to contamination in the oil was assessed by measuring the stroking force which was required to move the spool after it was left stationary for a period of time. Fig. 2 shows the results of one experiment, with stroking force expressed as a percentage of the maximum force available for stroking the spool (100% infers a seized valve). The effect of contaminant level is clearly indicated. The valve will operate reasonably well at a level of 1.75 mg/L of the contaminant used, but deteriorates rapidly if the level is increased to 3 mg/L.

Hollinger (1964)[4] and (1966)[5] conducted tests on axial piston pumps at 3000 psi in systems having different levels of contamination. AC test dust was used as the artificial contaminant. Table 2 summarizes some of the results obtained. Pump life was considered to end when the case drain leakage in the pump exceeded a pre-determined value. Tests

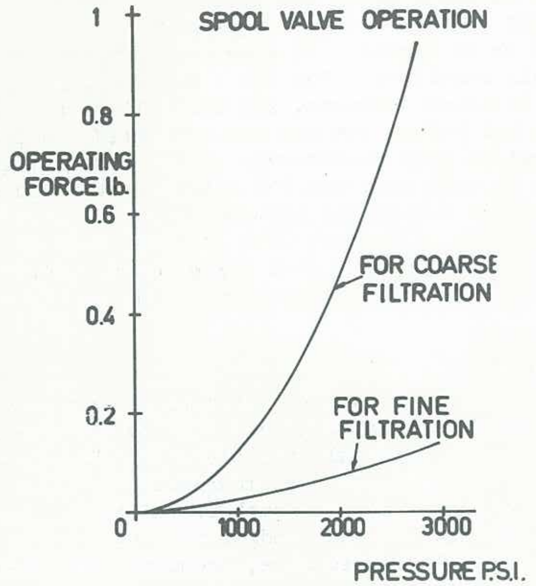

FIG. 1.
The Effect of Contamination Level on Spool Valve Operation[1].

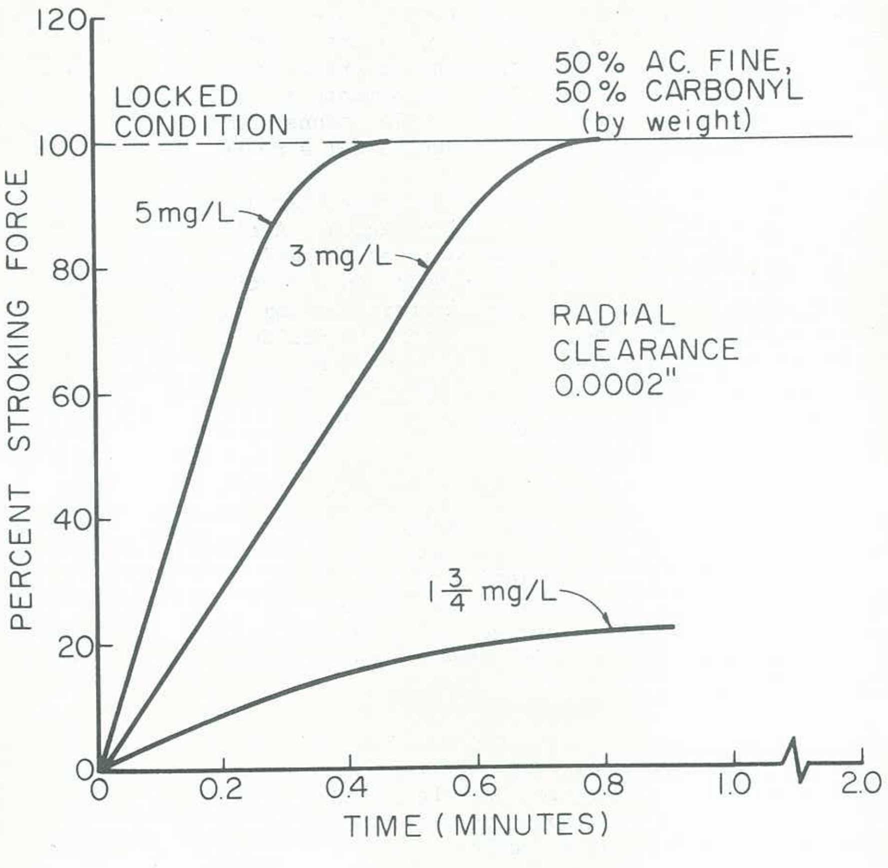

Fig. 2.
The Effect of Contamination Level on Spool Valve Performance [3].

were conducted on the same type of pumps using contaminants of controlled particle size ranges. Three 50 hour tests were carried out with particles in the respective ranges; less than 3 micron; 3 to 5 micron; 5 to 10 micron. In each case the concentration was 35 mg/L, which is industrially a clean oil condition. For the 2 smaller size ranges, pump performance remained satisfactory for 50 hours. However, for the 5-10 micron size range, leakage increased to over 2 gpm at 3000 psi before the run was completed. Hollinger also introduced tests to examine the effect on pump performance of the material qualities of contaminants. The size range used in each test was 3-5 microns, at a concentration of 35 mg/L. It was found that cotton lint fibres did not affect pump operation. Nor did rouge. Iron filings had only a minor effect. A.C. test dust (silica) however produced excessive leakage in less than 3 hours. The author felt that the abrasive quality of the contaminant was the controlling factor in determining pump life in the particle size ranges used.

THE MECHANISMS OF CONTAMINATION LOCK

Fig. 3 shows some of the situations by which contamination can lead to interference in the actuation of piston components. Figs. 3(a) and 3(b) illustrate that particles of sizes equal to the diametral clearance, and half the diametral clearance are likely to be particularly effective. Pressure expansion of the clearance, Fig. 3(c), allows particles to enter a clearance annulus which cannot pass through in the flow. Any reduction in pressure allows the cylinder to jam down on such lodged particles. Fig. 3(d) illustrates how particles can cause a piston to tilt in its bore, inducing the unbalanced axial pressure profiles which cause hydraulic lock.

MEASURING CONTAMINATION LEVELS

Accurate assessment of the contamination level in a hydraulic system has proven to be difficult and time consuming. Data required includes the size spectrum and concentration (i.e. the particle count), the weight of contaminant per unit volume of fluid (i.e. the gravimetric reading), and the geometric and material properties of the contaminants. It is not possible to make accurate in-line assessments of contamination levels, and fluid samples must be taken for laboratory analysis. The manner in which fluid is taken from the systems must be closely controlled in order to get a representative sample.

Standard procedures have been developed[6] whereby flat slides can be produced for optical counting of particles in specified size ranges. A fluid sample is drawn through a membrane under vacuum leaving the contaminants on the gridded surface of the membrane. The particle count is then made using a microscope on a statistical area basis, yielding data as shown in previous Table 1. The gravimetric reading is obtained by drying and ashing the contaminant-loaded membrane, and weighing the residue. The whole operation should be carried out in a surgically clean space by highly-trained technicians. It takes an experienced operator about 1 hour to make one particle count. An experienced operator can also make a broad qualitative assessment of the shape and quality of the contaminants present on the membrane slide, classifying the particles as fibres, silica, metallic, and elastomers.

A number of electronic particle counting devices exist, for both laboratory and inline use. Tests carried out by the author and others at Oklahoma State University in 1966 showed them to be useful in giving a relative measure of contamination level. Their absolute correlation with the optical particle count method was poor. Latest model particle counters are believed to be greatly improved in accuracy. The need for automated contamination level measuring equipment is high, due to the precision, cost, time delay, and tedium involved in manual optical methods.

Neither optical methods or electronic particle counters can assess the very large numbers of particles below 5 micron. With modern high-pressure high-precision orifices and clearances, particles below 5 microns are becoming significant to component and system performance. A number of simple go no-go portable devices exist for getting a qualitative idea of the cleanliness level of a hydraulic system.

CONTROLLING CONTAMINATION LEVELS

Potential trouble due to oil borne contamination can be minimized by proper initial cleaning, flushing, and wear-in procedures, and by carefully designed system filtration.

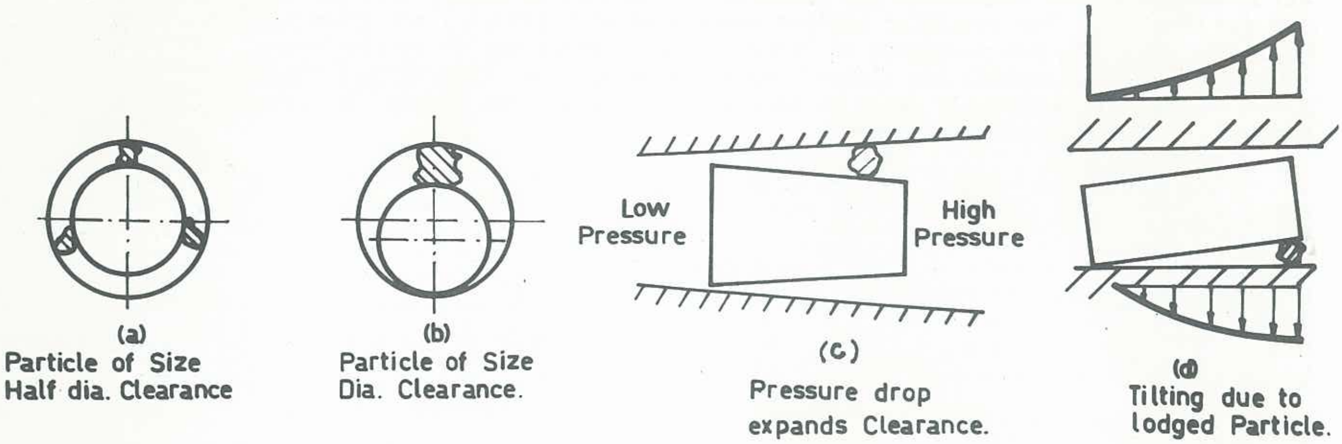

FIG. 3

Oil Contaminant Effects.

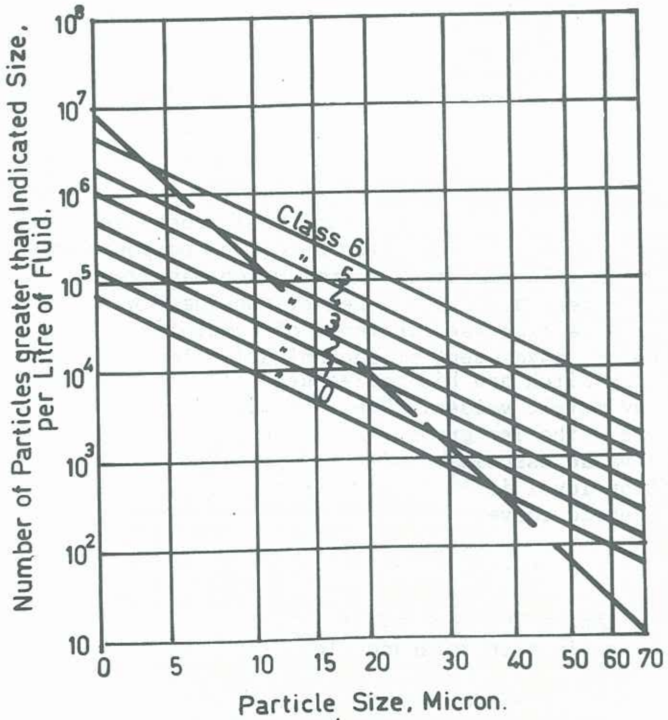

Fig.4. **SAE Cleanliness Levels for Hydraulic Systems.**

—— ——Observed Military Aircraft System.

All hydraulic system components are potential contamination generators, particularly when new and when old. For sensitive systems associated with military and space aircraft, all assembly, cleaning, and packaging of components is carried out in "clean" rooms. Commonly, aircraft hydraulic systems are cleaned routinely using large fine filters mounted on a ground cart. The relatively small filters in the aircraft can handle the contamination generated between routine clean ups.

A filter is required to provide maximum restriction to the passage of contamination, while offering minimum resistance to flow of the system fluid. Specification of the performance of filters must encompass these conflicting characteristics. Rating of filter performance has been notoriously vague. Filter efficiency distribution curves, and absolute cut-off ratings are both highly dependent on the test procedures used. Both British and American groups are seeking to improve the "standard" requirements of filter rating procedures. It seems desirable that the filter media be tested separately, followed by tests on the assembled filter to examine manufacture, design, and assembly qualities.

CONTAMINATION TOLERANCE LEVELS

Hydraulic components and systems will have to operate with the oil contaminated to some degree. It would be most useful to be able to describe the sensitivity of a component or system to particular contaminants - i.e. how much of contaminant x of size y can the component tolerate and still perform satisfactorily? This concentration of contaminant can be thought of as a contaminant tolerance level. More generally, contamination tolerance level can be defined as the concentration of multisize contamination which cannot be exceeded in order that a component or system fulfills its specified performance, reliability, and life.

SAE committees concerned with fluid power systems for aircraft and spacecraft have produced the family of cleanliness levels shown on Fig. 4 ranging from ultra-clean (Class 0) to dirty but satisfactory for some systems (Class 6). The objective is that a system is designed to operate at one of these specified levels, and that filtration be provided to maintain this level in an environment of continual generation of contamination within the system. It has been shown that the distribution and slopes of the SAE cleanliness levels are good for new oils but are not always appropriate to working systems. Fig. 4 shows the actual operating band levels of cleanliness obtained from controlled sampling from military aircraft over a period of 18 months.

For contamination control to become a meaningful procedure at the system design stage, system contamination level, filtration performance, and component sensitivity to contamination, must all be expressed in compatible terms which have general recognition. Fitch (1970)[7] made significant headway in this area by showing how the functions involved in contamination control can be expressed in terms of cumulative particle size distributions correlated with gravimetric assessment of contamination levels. Fig. 5 shows a Contamination Chart, developed by Fitch and his colleagues, on which particle size distributions are correlated with gravimetric values. The contamination level of a particular system is described by two numbers - the iso gravimetric line to which the distribution is tangent plus the particle size value associated with the point of tangency. Thus, for the case on Fig. 5, the contamination level is 10-40; 10 for the particle size at the point of tangency with the 40 mg/L gravimetric curve.

Fitch proposes that the chart be used

1. to describe contamination levels, as illustrated above;
2. to describe contamination tolerance levels of critical components in a hydraulic system;
3. to describe the performance capability of filters.

Thus, contamination levels for systems could be specified, filters selected should achieve this, and periodic tests made to ensure that the levels are being maintained.

CONCLUSION

Hydraulic control systems must operate with their fluids contaminated to some degree. Components must be designed to operate in realistic levels of contamination. The accepted levels of contamination must be achievable by available filtration.

The measurement of contamination levels existing in systems is reasonably straight forward. The measurement of filter performance is receiving attention in order to standardize procedures and produce unambiguous results. This leaves assessment of the contaminant sensitivity of system components as the area in which increased research is required.

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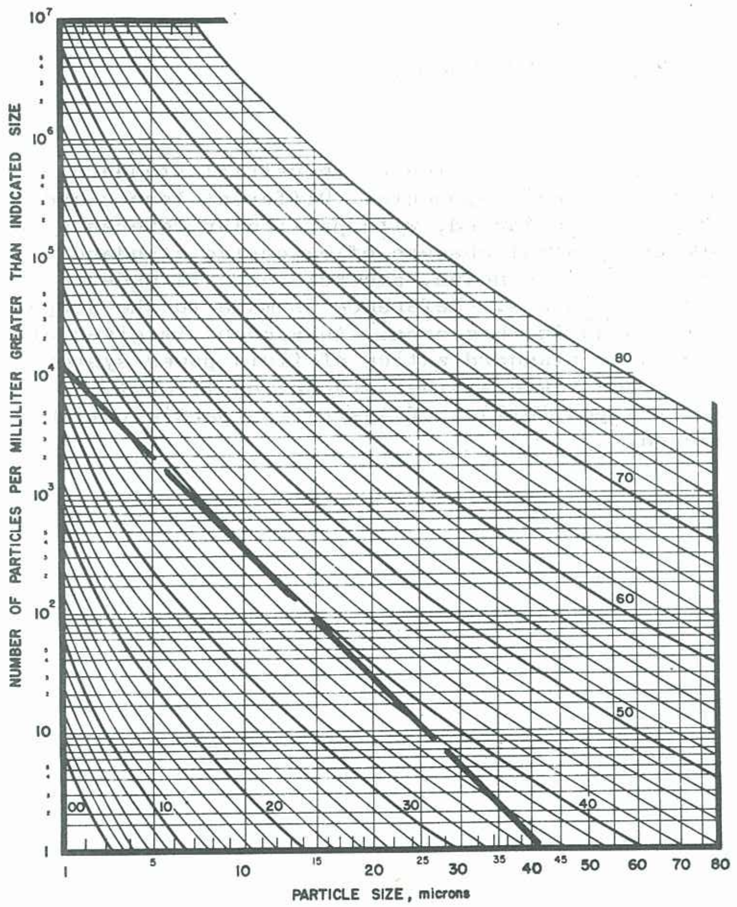

FIG. 5.
CONTAMINATION CHART (Fitch, Okla. State Univ.)[7]
Showing a 10-40 Distribution.