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QUANTIFYING THE CONTAMINANT TOLERANCE OF HYDRAULIC SYSTEMS USING THE "CONTAMINANT LIFE INDEX"

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ABSTRACT

For years hydraulic equipment users have been asking "How clean should my fluid be?" Straight and well conceived answers to this question have not been available. This paper introduces the Contaminant Life Index as the definitive answer. The use and rationale of the Contaminant Life Index is explained.

INTRODUCTION

Users of hydraulic equipment need to know how clean their fluid should be. The information and procedure for determining this has not been readily available in the past. This has been largely due to the many factors that impinge on the decision. This paper introduces a new system called the Contaminant Life Index (figure 1) which deals with this question head on.

The Contaminant Life Index addresses each of the many issues involved in determining required system cleanliness. These factors are presented in a simple, easy to follow format. The CLI delineates only the most salient criteria with the objective to span the numerous diverse types of hydraulic equipment in use.

These criteria make up the Contaminant Life Index:

1. Pump Contaminant Sensitivity
2. Operating Pressure
3. Duty Cycle Severity
4. Fluid Type
5. Number of Servo Valves in Use
6. Presence of Water
7. Contaminant Abrasivity
8. Maximum System Flow Rate
9. Cost of Downtime
10. Safety Risk Upon Failure

WHY IS THE CLI NEEDED?

There is clearly a direct relationship between the contaminant level of a hydraulic fluid and the mean service life of the system. Some factors increase a system's sensitivity to contamination (e.g., pressure, presence of water, use of servo valves, design factors, etc.). Other factors influence the penalty associated with hydraulic failure. The Index tabulates the critical data affecting the system to arrive at a singular quantitative contaminant level value. This value, called the CLI rating, is used to interpret the required cleanliness level in terms of standard cleanliness classifications, e.g., particles counts or the ISO Code.

However, the real "why" for using the Contaminant Life Index stems from the increased demands and expectations we place on machinery. Some are purely economical. Consider these facts:

1. The Government says the cost of wear to the U.S. economy exceeds one percent of the Gross National Product.

2. The Military says the cost of contamination exceeds 60 percent of fuel costs on select marine and aviation equipment.

3. In Industry, the cost of downtime exceeds $15,000 per minute on select machinery and processes.

4. NASA says a single ten micron tramp particle can shut down flight control systems. Space shuttles have been delayed on the launching pad three times due to contamination.

Greater awareness of the need for contamination control comes simultaneous with the demand from many designers and users for:

1. Increased System and Component Life -- greater reliability (reduced downtime), longer service intervals, longer fluid life.

2. Increased Performance -- higher loads, higher speeds, higher pressures, and higher temperatures.

3. Improved Cost Efficiency -- in-

CONTAMINANT LIFE INDEX (CLI)

CONTAMINANT LIFE INDEX (CLI)	MACHINE I.D.:	DATE:	CLI SCORE:

For Determining Required Cleanliness Levels of Hydraulic Systems

Score Totals

A. Pump Contaminant Sensitivity:

Sensitivity	Unity	Insensitive	Mild	Average	High	Highest
Omega Rating	1-1.02	1.02-1.04	1.04-1.16	1.16-6	6-60	> 60
Score	3	10	35	175	350	450

A.______

B. Operating Pressure (under load): Score = Score Factor × Part A Score

Pressure (PSI)	0-500	501-1000	1001-2000	2001-3000	3001-4000	4001-5000	5001-6000	> 6000
Score Factor	0.12	0.16	0.35	1	3	10	50	100

B.______

C. Duty Cycle Severity:

Severity: (% time above 130% operating pressure)	MILD (0)	MEDIUM (1-4%)	ROUGH (5-10%)	SEVERE (above 10%)
Score	0	30	65	100

C.______

D. Fluid Type: Score = Score factor × [100−ISO Viscosity Grade (100 max)]

Type	Phosphate Esters	Mineral (Petroleum)	Other Synthetics	Water Glycols	High Water Based Fluids	Water Only
Score Factor	0.1	0.25	0.50	0.75	1.00	Score 150

D.______

E. Number Of Servo Valves In Use (Including Proportional Control & Solenoid):

Number	0	1-2	3-4	4-6	7-8	9 +
Score	0	40	80	120	160	200

E.______

F. Presence Of Water: Score = Score Factor × Part A Score

Amount (%)	0-0.01%	0.01%-0.05%	0.05%-0.15%	0.15%-1%	> 1%
Score Factor	0.05	0.15	0.4	0.75	1

F.______

G. Contaminant Abrasivity:

Description	HIGH abrasive & metallic particles	MEDIUM road dust	LOW industrial
Score	100	50	0

G.______

H. Maximum System Flow Rate:

Flow(GPM)	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	>90
Score	0	20	30	40	50	60	70	80	90	100

H.______

I. Cost Of Downtime:

Cost ($) Per Hour Downtime	< 100	101-500	501-2000	2001-5000	5001-10,000	10,001-50,000	50,001-100,000	> 100,000
Score	0	25	50	75	100	125	150	200

I.______

OR

Cost of Equipment ($)	< 5,000	5001-10,000	10,001-25,000	25,001-50,000	50,001-100,000	100,001-200,000	200,001-500,000	500,001-1,000,000	> 1,000,000
Score	0	25	50	75	100	125	150	175	200

J. Safety Risk Upon Failure:

Amount	None	Low	Medium	High
Score	0	150	300	400

J.______

Total .... Add Scores A-J To Obtain "Contaminant Life Index" (1000 Maximum Value) ______

CLI Translations:

CLI Value	Gravimetrics MG/LT (AC Fine Test Dust)	Particles Per Millilitre > 10 Microns	ISO Code	NAS 1638	Disavowed "SAE" Level
0-100	30	4350	21/18	12	9
101-200	15	2175	20/17	11	8
201-300	7.5	1088	19/16	10	7
301-400	3.75	544	18/15	9	6
401-500	1.88	272	17/14	8	5
501-600	0.94	136	16/13	7	4
601-700	0.47	68	15/12	6	3
701-800	0.23	34	14/11	5	2
801-900	0.12	17	13/10	4	1
901-1000	0.06	8	12/9	2	0

FIGURE 1

creased energy efficiency, reduced weight and size, decreased operating costs, greater productivity.

Truly, it is easy to accept the rationale that greater contamination control increases reliability of hydraulic systems. The cause-and-effect relationship between system life and fluid cleanliness levels is very well documented through both basic research and empirical analysis in the field. In fact, both users and OEM's have significantly stepped up the use and quality of filtration on most types of equipment over the past decade.

CLEANLINESS LEVEL CRITERIA

The cost of maintaining contamination control for a hydraulic system must not be overlooked. Obviously the benefit derived from improved contamination control must exceed this cost many fold. As a starting point, the CLI establishes the contaminant sensitivity of a system in terms of its design features, operating conditions, and application. Since these conditions vary widely from machine to machine, the CLI system customizes its assessment accordingly.

Next, the CLI considers fluid and contaminant related variables. Fluid types and fluid viscosities are rated according to their effect on contaminant wear and failure. Additionally, the presence of water and the hardness and angularity of solid contaminants are scored.

Finally, the cost of contaminant failure is quantified in terms of component replacement costs, downtime, and safety risks. The following is a delineation of the individual categories, the method of scoring, and rationale for use:

A. Pump Contaminant Sensitivity

The contaminant tolerance of a hydraulic pump varies from design to design and is a critical factor is assessing required cleanliness levels of system fluids. If a pump's contaminant tolerance is known, the contaminant service life of the pump is relatively easy to predict at known contaminant levels. In order to gain this information, a test procedure for pumps was established called the Omega Rating (NFPA RS T3.9.18 - 1976). This widely recognize standard rates a pump's contaminant sensitivity according to its performance under controlled conditions while subject to various levels of solid contaminants.

Many pump manufacturers publish their pump's Omega Ratings and can be found on spec sheets or in service manuals. Not all pump manufacturers have conducted these tests on their pumps and therefore have not made contaminant sensitivity data available to user groups. Nevertheless, some inferences relative to a pump contaminant sensitivity is necessary to predict its service life.

If the Omega value is available then the score for this category of the CLI is straight forward. However, for pumps having no published Omega Rating, the user should make a judgment based on normal or historical service intervals. Pumps requiring regular service or repair should be rated as high or highest depending on the frequency of failure. Further, pumps reaching normal or expected service intervals should be rated as average. Pumps experiencing longer than expected services lives should be rated as mild or insensitive.

Generally, vane pumps are more sensitive than piston pumps which are more sensitive than gear pumps. However, the experience of the user with the particular pump is a much more reliable. Once the score is determined it is registered in the right column.

B. Operating Pressure

Contaminant sensitivity of most all hydraulic components vary relative to the operating pressure of the system. Valves are more subject to silting and stiction. Actuators, motors, and cylinders loose efficiency and response relative to operating pressure and contaminant level. However, the pump clearly appears to be the most sensitive to pressure and is therefore weighted heavily by this category.

According to Omega tests on numerous pumps, the relationship between pump contaminant sensitivity, pressure, and contaminant level of Figure 2 (nomograph) was established. By juxtaposing CLI values next to the contaminant level scale an estimation technique was set up for scoring this category. Essentially, the objective was to achieve a combined score between pump sensitivity (A) and operating pressure (B) equal to their cumulative effect. This combined score approximates the empirical date represented by the nomograph. Note, although not originally intended, this category also considers the high component replacement costs associated with higher pressure systems by scaling the score in this manner.

To score this category, the operating pressure of the system under load is noted. This is the typical pressure experienced by the system during normal work cycles and can be estimated by observing

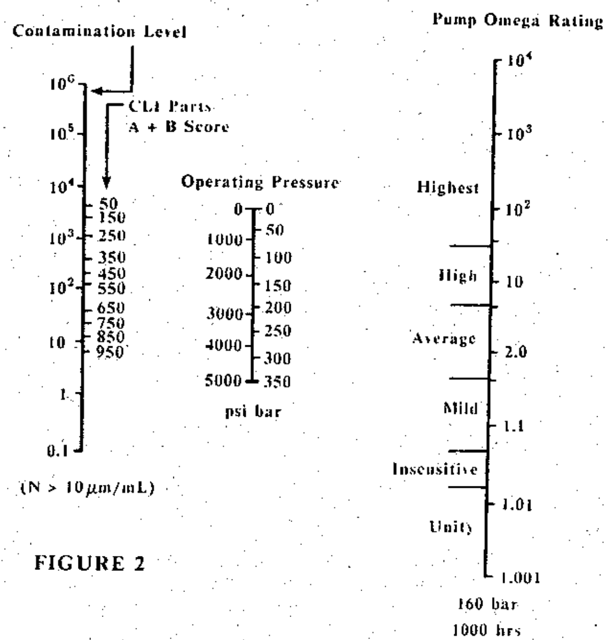


FIGURE 2

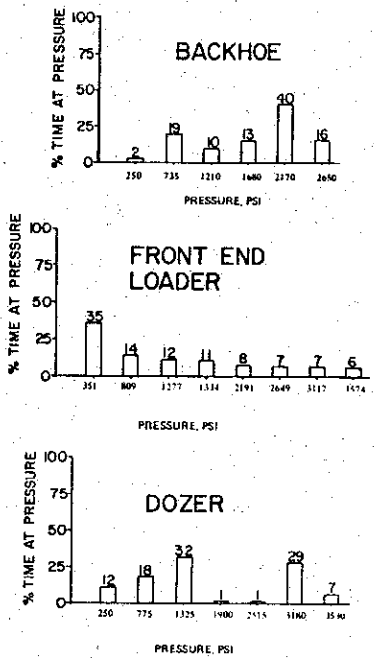


FIGURE 3

pressure gauges on equipment instrument panels. The Score Factor under the corresponding pressure range is multiplied by the score of part A to obtain the part B score. Similarly, it is recorded in the right column.

C. Duty Cycle Severity

In most field applications, the output pressure of a pump varies with its work cycle. Depending on the severity of this duty cycle, a pump experiences varying pressures and collects a certain amount of exposure time at these pressures. Since, as we have said, pressure directly effects the contaminant sensitivity of the system, information regarding duty cycle severity is necessary. Therefore, this category uses duty cycle to estimate the upward variance of pressure. Examples of pressure duty cycle effects is illustrated in field data obtain on a backhoe, front end loader, and dozer (Figure 3).

For simplicity, the CLI presents duty cycle as the percent time above 130% of operating pressure. Ideally, this information should be obtained from pressure gauges observed during peak work cycles. Equipment subject to rigorous performance requirements in the field (pump, motors, etc. are strained to operating limits), generally have higher duty cycle severity. When no information is available, this category should be score as "medium".

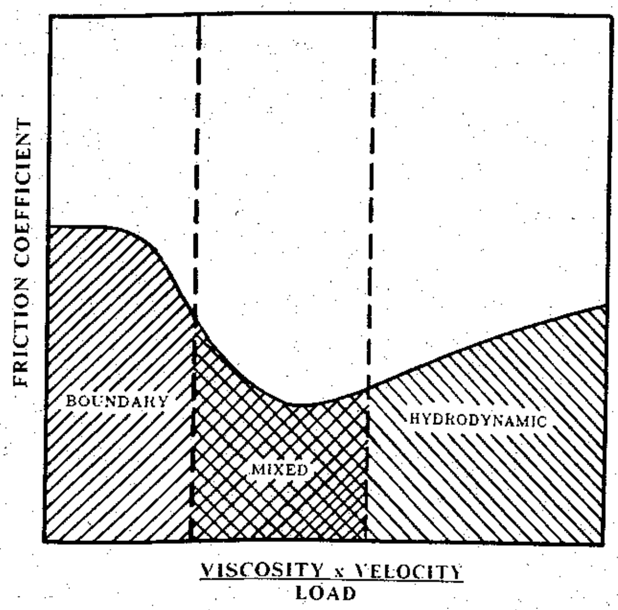
D. Fluid Type

A fluid's performance affects the system's contaminant sensitivity. Both viscosity and lubricity are involved. Tribological studies have shown that oils exhibit two basic forms of lubrication -- both of which appear to affect the rate of contaminant wear.

The first form, boundary layer lubrication, refers to the thin film which separates the asperities of sliding surfaces. These thin films are also effective in minimizing contaminant wear by producing a high lubricity coating on both the particle and the surface. Anti-wear and extreme-pressure additives play a key role in boundary layer lubrication.

The second form, hydrodynamic lubrication, produces a thick lubricating film between surface asperities. The viscosity of the oil, velocity of the moving surface, and the load determine the critical clearance produced (see figure 4). Since these clearances often exceed 20 micrometers in size, particles can gain easy entry to abrade critical surfaces. However, its the clearance size particles that do the greatest damage, i.e., those particles just smaller than the critical clearance.

In most hydraulic systems, over half of the particles found in the fluid are three microns or less. Therefore, the greater the hydrodynamic film the less damage cause by "clearance size" particles. This characteristic makes the vis-



STRIBECK CURVE AND LUBRICATION REGIMES

FIGURE 4

cosity of the oil important to the rate and extent of contaminant wear experience between critical surfaces. Meaning, higher viscosity fluids produce less abrasive and fatigue wear.

This category scores fluids according to their apparent lubricity and viscosity. The score factor under fluid type scales the lubricity effects of common fluids. As these are general categories, some exceptions exist. The user should rate the lubricity of his oil based on the best information available as opposed to rigidly conforming to the indicated scale. Finally, this score factor is multiplied by 100 minus the oil's ISO viscosity grade to obtain the score for the category.

E. Number of Servo Valves

A common failure mode on hydraulic systems is jamming/stiction of servo valves (including solenoid and proportional control). This type of failure is normally caused by silt size particles that become wedged between spool and bore. Obviously, the probability of failure from a servo valve increases relative to the number of valves in use. The score for this category is a function of this number.

F. Presence of Water

Most wear do to water contamination is cause by the combined "synergistic" effects of water and particulate matter. Figures 5 & 6 illustrate these effects at various water concentration levels for bearings and vane pumps. Further, the pump contaminant sensitivity also appears to play a key role. Therefore the Score Factor of this category (based on the water contaminant level of the fluid) is multiplied by the score of category one. Generally, oil that is hazy in color will have between 0.05 - 0.15% water. Oil will be milky or cloudy above 0.15% water.

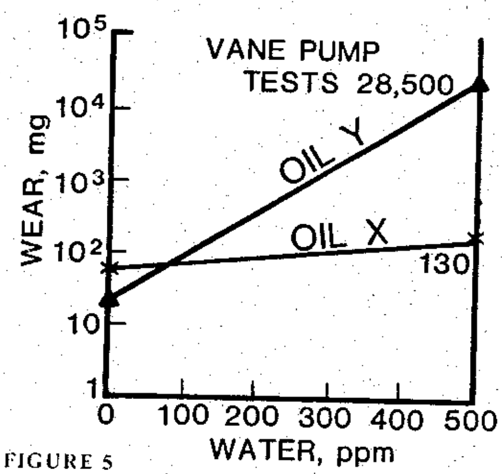


FIGURE 5

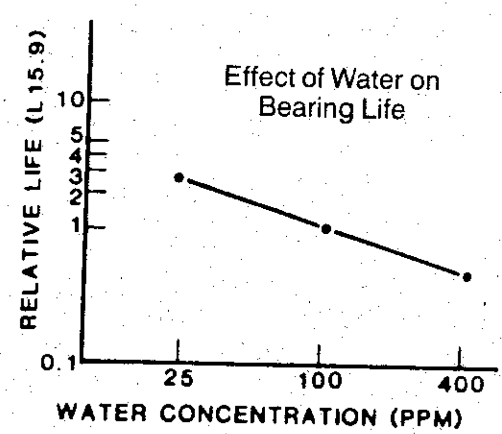


FIGURE 6

G. Contaminant Abrasivity

Particle hardness and angularity effect the amount of abrasive wear they cause. The abrasivity of the particles (dust) in the immediate area of the machine is needed to score this category. Generally, road dust has low angularity and therefore scores less than dust from gold mines, steel mills, glass factories, etc. Light industrial applications in indoor air-conditioned environments produce particles of lowest abrasivity.

H. Maximum System Flow Rate

Studies on pump contaminant sensitivity relative to maximum flow rate have not been conclusive. Nevertheless, system flow rate is a key cost factor and therefore must be considered. Generally, high flow rate systems have more expensive components, especially pumps, motors, valves and cylinders. Although this is strictly an economic consideration, it effects the desirability of extended service intervals as a function of component replacement costs. This category is scored according to the maximum system flow rate.

I. Cost of Downtime

Cost of downtime is also a key economic consideration. On some systems and equipment, these costs are phenomenally high. The penalty of failure due to downtime costs should certainly effect the cleanliness level decision, hence the inclusion of this category. Either known hourly downtime costs or approximate equipment costs are used to determine the score.

J. Safety Risk Upon Failure

Safety should also effect the cleanliness level decision. If a system presents a safety risk upon failure, much greater fluid cleanliness should be maintained. Although strictly judgmental in many cases, this category should be score according to risk level.

EXAMPLE HYDRAULIC SYSTEMS

Required cleanliness levels for four typical hydraulic systems are presented in Figures 7, 8, 9, & 10 using the Contaminant Life Index. The examples illustrate the versatility of the CLI system and the ease at which it can be used. Further, it will be difficult for any hydraulic engineer to argue the validity of the values obtained considering the all the individual facts.

SUMMARY

The primary objective of the Contaminant Life Index is to present a simple "user friendly" technique for assigning appropriate required cleanliness levels to the fluids used in hydraulic systems. Although not perfect, the CLI offers a comprehensive and complete approach to this increasing important subject.

The CLI is intended to be flexible and easily adapted the machine or equipment of concern. Improvements to the CLI including the addition of new categories are inevitable. As more and more cause-and-effect information is known these inclusions should be made. Further, the relative scores and weights given to each category will be refined in time to improve accuracy and usefulness of the CLI. Users are encouraged to contact the author to present such suggestions or contributions.

REFERENCES:

1) E. C. Fitch, An Encyclopedia of Fluid Contamination Control, FES, Inc., 1980.