Contamination Control in Hydraulic and Lubrication Systems of Paper Industries: An Overview

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ABSTRACT

The modern paper making process creates a very demanding environment for the hydraulic fluids and lubricants used on a typical paper machine, due to the inevitable presence of particulate contamination, water and steam throughout the mill, which can become ingressed in the hydraulic fluids and lubricants, through faulty seals, reservoir access ports, tank breathers, and other points of ingression. The presence of particulate contamination in hydraulic fluids and lubricants can cause wear of critical system components, such as bearings, valves, and pumps, and can lead to reduced product quality, reduced component life, reduced equipment uptime, and reduced productivity.

The presence of water in hydraulic fluids and lubricants can have wide-ranging effects on system components. Surface corrosion, probably the most obvious effect, is directly linked to the presence of free bulk water. Accelerated metal surface fatigue, such as in bearings, can be promoted even if all the water present in the fluid is dissolved. Furthermore, dissolved water can also adversely affect fluid properties, by accelerated oxidation of the fluid base stock and premature depletion of additives due to additive precipitation or chemical reactions involving additives. The detrimental effects of particulate and water contamination are compounded by the paper industry's development towards more power, more throughput, and longer service intervals.

In this paper, the author discusses the benefits of implementing a comprehensive approach to cleanliness control for hydraulic and lubrication systems typically used in the paper machine areas, coupling high efficiency filtration systems for the removal of particulate contamination with vacuum dehydration purifiers for the removal of free and dissolved water, and diagnostic instrumentation for measurement of levels of particulate and water contamination.

Introduction

Hydraulic and lubrication systems are at the heart of modern paper machines. The working fluids of those systems must be kept in good condition, at the lowest possible contamination levels in respect to particulates, and water. Maintaining good fluid system health is an often neglected practice that can prevent reduced product quality, reduced component life, reduced equipment uptime, and reduced productivity. The presence of water in hydraulic fluids and lubricants can have wide-ranging effects on the fluid system including accelerated fluid base stock oxidation and premature depletion and precipitation of fluid additives. The detrimental effects of particulate and water contamination are compounded by the paper industry's development towards higher throughput, and longer service intervals. In this work, the author discusses the benefits of implementing a comprehensive approach to cleanliness control for paper machine hydraulic and lubrication systems, coupling high efficiency filtration systems with vacuum dehydration purifiers and diagnostic instrumentation for measurement of levels of particulate and water contamination.

According to a study conducted by Dr. E. Rabinowicz of M.I.T [1], 70% of component replacements or "loss of usefulness" are due to surface degradation. In hydraulic and lubricating systems, 20% of these replacements result from corrosion, with 50% resulting from mechanical wear.

Particle and water contamination can damage systems through a variety of wear modes. The primary modes of wear are shown in the table below, along with the most common cause for that mode of wear. Each of these wear mechanisms result in the generation of particulate contamination capable of causing further component damage.

Contaminants Affecting The Performance Of Moving Equipment in Paper Machine Area:

Critical areas in the paper machine are as follows:-

Paper machine dry and wet end lube system

TABLE-1: TYPES OF WEAR AND PRIMARY CAUSES

Type	Primary Cause
Abrasive Wear	Particles between adjacent moving surfaces
Erosive Wear	Particles and high fluid velocity
Fatigue Wear	Particle damaged surfaces subjected to repeated stress
Corrosive Wear	Water or chemical

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Press Sections, Turbines and Powerhouse applications

Gearboxes, Winders, Roll handling equipment

Wood yard equipment, Conveyors / Truck Dump

Pulping equipment, Drive Systems, Contamination can be introduced into a fluid system from many sources, both internal and external to the system. The following lists common types of particulate contamination in the paper machine area:

(A) Built In (Manufacturing & Assembly)

Casting and machining debris

"Green Run" (break in) debris

(B) Routine Maintenance

Fibrous and other materials, Fluid top-off

Routine caustic wash downs

Dust and dirt during disassembly/reassembly (roll rebuild)

(C) Environmentally Ingressed

Dust and dirt from the mill environment

Residual process chemicals (fillers)

(D) Internally Generated

Wear debris from normal and abnormal wear of system components

Fluid degradation products (precipitated additives, varnish)

The presence of particulate contamination, including varnish, in hydraulic and lubrication systems can lead to:

(A) Accelerated wear of critical system components

a. Hydraulic control valves, Bearings
b. Press shoes, Pumps

(B) Deposits of varnish on system surfaces

a. Press shoes, Control valves
b. Bearings

When a hard particle > 5 micron is forced through the gap of around 0.5 micron, a dent is formed in the raceway. Even soft particles, if large enough, will produce dents in the very hard raceway. Following table represents the fatigue life reduction due to various amounts of contamination damage-

TABLE-2: FATIGUE LIFE REDUCTION RELATED TO TYPICAL NUMBER OF DENTS (Adapted from Ref # 2)

Typical Number of Dents	% Inner Race Covered By Dents	Calculated Life Reduction
19	1	2.73
37	2	4.25
56	3	5.82
75	4	7.30
94	5	8.76
112	6	10.13
150	8	12.94
189	10	15.62

Roller Bearings:

Roller bearings are most extensively used in paper machines and can be very large and expensive. There are two types; Spherical roller bearings, Toroidal roller bearings and the main characteristics are predominantly radial load, Self-alignment and Tolerance towards angular and axial displacement. Service life will be dependent on a number of factors including the amount of particulate, water contamination and entrained air they will see during commissioning and afterwards in operation. Roller bearings can be exposed to heat and high moisture content, especially in the drying section of the paper machine [3-5].

Theoretical considerations of rolling element bearing service life, e.g. SKF New Life Theory[2] has explicit parameters for taking into account lubrication, fluid cleanliness and other factors, e.g.

$$Ln = a1 \cdot a2 \cdot a3 \cdot ... \cdot (C/P)^p$$

n = number of millions of revolutions, typically 10 million

C = basic dynamic bearing load rating, per ISO 281 [6]

P = equivalent dynamic load, per ISO 281 [6]

p = 3.333 for roller bearings per ISO 281 [6]

'ai ' are factors that account for operating conditions like lubrication, cleanliness, etc.

Significant increases in bearing life and reliability are predicted with improved lubricant cleanliness. SKF uses a combined coefficient, a_{SKF}, to account for the combined effects of fluid contamination, and lubrication conditions:

$$Ln = a1 \cdot a_{SKF} (C/P)^p$$

a1 = life adjustment factor for reliability (see table below)

n = number of millions of revolutions, typically 10 million

C = basic dynamic bearing load rating, per ISO 281

P = equivalent dynamic load, per ISO 281

p = exponential factor for bearing geometry, per ISO 281

(p = 3.333 for roller bearings)

TABLE-3: LIFE ADJUSTMENT FACTOR FOR RELIABILITY (Adapted from Ref # 2)

Reliability %	L_{na}	a_1
90	L_{10a}	1
95	L_{5a}	0.62
98	L_{2a}	0.33
99	L_{1a}	0.21

The a_{SKF} factor represents a very complex relationship between various influencing factors including contamination, lubrication, dynamic bearing load and mechanical design parameters [1].

Values of a_{SKF} can be obtained from the Diagram for different values of η_c(Pu/P) and k.

- η_c = adjustment factor for contamination
- Pu = bearing fatigue load limit, design parameter
- P = equivalent dynamic bearing load, determined by operating conditions
- k = viscosity ratio

TABLE-4: CLEANLINESS CONDITION AND ADJUSTMENT FACTOR FOR CONTAMINATION (Adapted from Ref # 2)

condition	η_C (d > 100 *mm*)	
	min	max
extreme cleanliness (debris size of the order of lubricant film thickness)	1	1
high cleanliness (extremely fine fluid filtration)	0.8	0.9
normal (fine fluid filtration)	0.6	0.8
slight contamination (slightly contaminated)	0.4	0.6
typical contamination (coarse fluid filtration, wear debris, external ingression)	0.2	0.4
severe contamination (heavily contaminated, inadequate sealing)	0	0.1

For any specific bearing, at given operating conditions, the level of contamination in the fluid can affect bearing life significantly and values for η_c are theoretical guidelines [2].

Cleanliness Measurement:

The key to successful fluid condition monitoring and trending is consistency in sampling and analysis techniques. Primary Sampling points are where routine oil samples are taken to trend fluid condition, contamination and machine condition. Secondary Sampling points are used for non routine samples, to monitor particular components or when tracking down the source of a problem indicated by primary sampling. Flushing of sampling points is required where sample contamination can affect results, such as for particle counting and spectrographic analysis. If lines supplying the sample point can't be guaranteed to be clean & representative, then they need to be flushed before sampling. All sample valves need to be flushed. Be aware that they can release contaminants when operated, leave them open during sampling. Vacuum pump sampling tubes should be flushed if the tube can become contaminated during storage, handling or insertion [7].

Automatic mesh blockage partlcle Counting:

It is a method for determination of cleanliness code in which a standard volume of fluid is passed through a mesh filter. As particles in the fluid block the pores in the filter, the flow through it is restricted (at constant pressure) or the pressure drop across it increases (at constant flow). The rate of flow decay or pressure increase is measured & converted to a cleanliness code. A separate mesh size filter is used for each particle size range. Cleanliness class [8-10] is determined as per ISO 4406 with a diagnostic program. A cleanliness monitor is best suited for Paper Machine applications due to its insensitivity towards suspended additives, water or foam.

Water Contamination: States, sources & effects of Water

Water, in addition to particulate contamination, is the second most important contaminant in paper machine fluid systems. It can be present in hydraulic fluids and other lubricants as dissolved or free water depending on the fluid's ability to hold water. The point at which the fluid cannot hold any more dissolved water is called the saturation point. If more dissolved water is present than the fluid can hold, the excess water can be present either as a separate bulk water phase or as an emulsion. Typically, oversaturated fluids appear cloudy. How much water a fluid can hold at saturation strongly depends on the fluid base stock type, the additive package, temperature and pressure. Typical paper machine fluids saturate at 200 ppm to 400 ppm at 40 deg C. Water can originate from a variety of sources. Examples of environmental ingression are rain leakage into external reservoirs, seepage through reservoir covers, access panels, breathers or worn seals, and condensation from air in reservoirs and other system areas. Water can also enter the fluid system from the process side, from leaky heat exchangers or coolers, or direct ingression of process water, such as cooling water, wash down water or steam. Water ingression can be minimized with clever system design and good housekeeping, but it is difficult (and costly) to eliminate all sources of water entirely. The presence of water in hydraulic fluids and lubricants can have wide-ranging effects on system components. Surface corrosion, probably the most obvious effect, is directly linked to the presence of free bulk water. Accelerated metal surface fatigue, such as in bearings, can be promoted even if all the water present in the fluid is dissolved. This was studied by Cantley[11] in 1977, who investigated the effect of dissolved water on the fatigue life of tapered roller bearings. Cantley developed an equation linking the relative bearing life and the water content of the lubricant used in the tests, an SAE 20 fluid containing rust- and oxidation-inhibiting additives. He showed that the bearing life could be extended by a factor of five, if the bearing lubricant contained only 25 ppm dissolved water compared to 400 ppm, close to the saturation level at the test temperature of 65°C[12].

A water sensor offers real-time monitoring and can be used as a control

FIGURE-1. CAPACITIVE WATER SENSOR TECHNOLOGY [13] device. This instrument is a development of the air moisture sensor. It consists of a capacitive cell formed by sandwiching a dielectric polymer between electrodes (Figure 1).

Precautions To Control The Water Contaminants: Water Removal Technologies for Paper Machine Area Applications

1. **Absorption** - Free & dissolved water, in-line & quick mainly low removal rates so high operating costs
2. **Vacuum dehydration** - Free & dissolved water, any gases, good for unit & bulk processing.

Vacuum Dehydration Purifiers:

Vacuum dehydration purifiers are used to dry hydraulic fluids and lubricants by exposing them to a partial vacuum. Two technologies are available, flash distillation vacuum dehydration and mass transfer vacuum dehydration. While both processes utilize the concentration gradient between the fluid and the evacuated air to evaporate the water from the fluid, the flash distillation technology also applies heat to further boil off more water and operates at a higher vacuum. This makes flash distillation more efficient, as it quickly removes more water from the fluid than a mass transfer device. However, the high temperature and vacuum employed in flash distillation devices can lead to loss of lower boiling base stock fractions and volatile additives, and can result in thermo-oxidative fluid degradation - serious drawbacks if fluid integrity needs to be preserved. Mass transfer purifiers are recommended due to their minimal impact on fluid chemical and physical properties (Figure 2). The fluid is fed into the vacuum chamber where it is spread into a thin film to reduce the path length for the water to reach the free surface and so be transferred to the air. When combined with a water sensor, mass transfer purifiers can be utilized to control water in hydraulic and lubrication systems continuously[13].

FIGURE-2. SPRAY NOZZLE MASS TRANSFER PURIFIER [13]

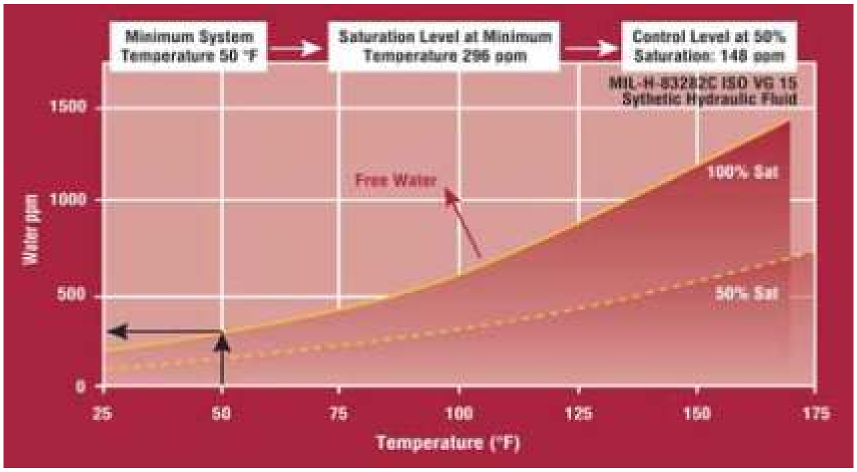

FIGURE-3. SELECTING PROPER CONTROL LEVEL [13]

Reservoir breathers can be attached to prevent airborne particulate contamination from entering a fluid reservoir. It minimizes ingression of external particulate contamination into fluid system.

An air Blower can be mounted on top of the fluid reservoir close to where the fluid pumps draw fluid from the reservoir. The motor drives the blower and delivers clean, dry air across the top of the oil reservoir, displacing moist air that collects there. The slight positive pressure created by the blower prevents dirt ingression through poorly sealed hatches and access ways. The continuous stream of clean air minimizes contamination and condensation within the reservoir and ultimately protects the components within the hydraulic and lube system in paper machine applications.

Water content control Limits:

A properly set control level, typically recommended at 50 % to 70 % Saturation at the lowest possible temperature in the fluid system (such as during an outage), will minimize the detrimental effects of water contamination, as this safeguards against the formation of free water, at all operating conditions. A purifier can be employed to maintain consistently low water content of the fluid. The reduction of absolute water content will slow all chemical reactions, which depend on water as one of the reactants (i.e. fluid and component surface degradation). In addition, the inhibition of the formation of free water will safeguard against surface corrosion or loss of fluid properties (i.e. lubricity, compressibility)[13-14].

Conclusions:

The removal of particulate contamination, undesired gases, and water is important in reconditioning the fluids to meet or exceed pulp and paper hydraulic & lubrication specifications.

The use of on-line diagnostic devices such as mesh blockage cleanliness monitor (PCM 400) and water sensor provides the solution for measurement of cleanliness level and % water saturation level in paper machine hydraulic and lubrication systems and provides cost effective solution. Mass transfer vacuum dehydration purifiers are recommended for water removal from hydraulic fluids and lubricants because of the minimum impact on fluid properties.

Particulate contamination should be removed through appropriate grade filters as 5 micron, 12 micron and 7 micron (i.e Fluid Compatibility, Flow Rate, Viscosity, Micron Size) for pressure line filtration, return line filtration and off line filtration respectively for paper machine application systems.

Thin film polymer capacitor technology based water sensor provides output corresponds to water saturation level at a given fluid temperature and this water saturation levels can be related to absolute water concentration in PPM.

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