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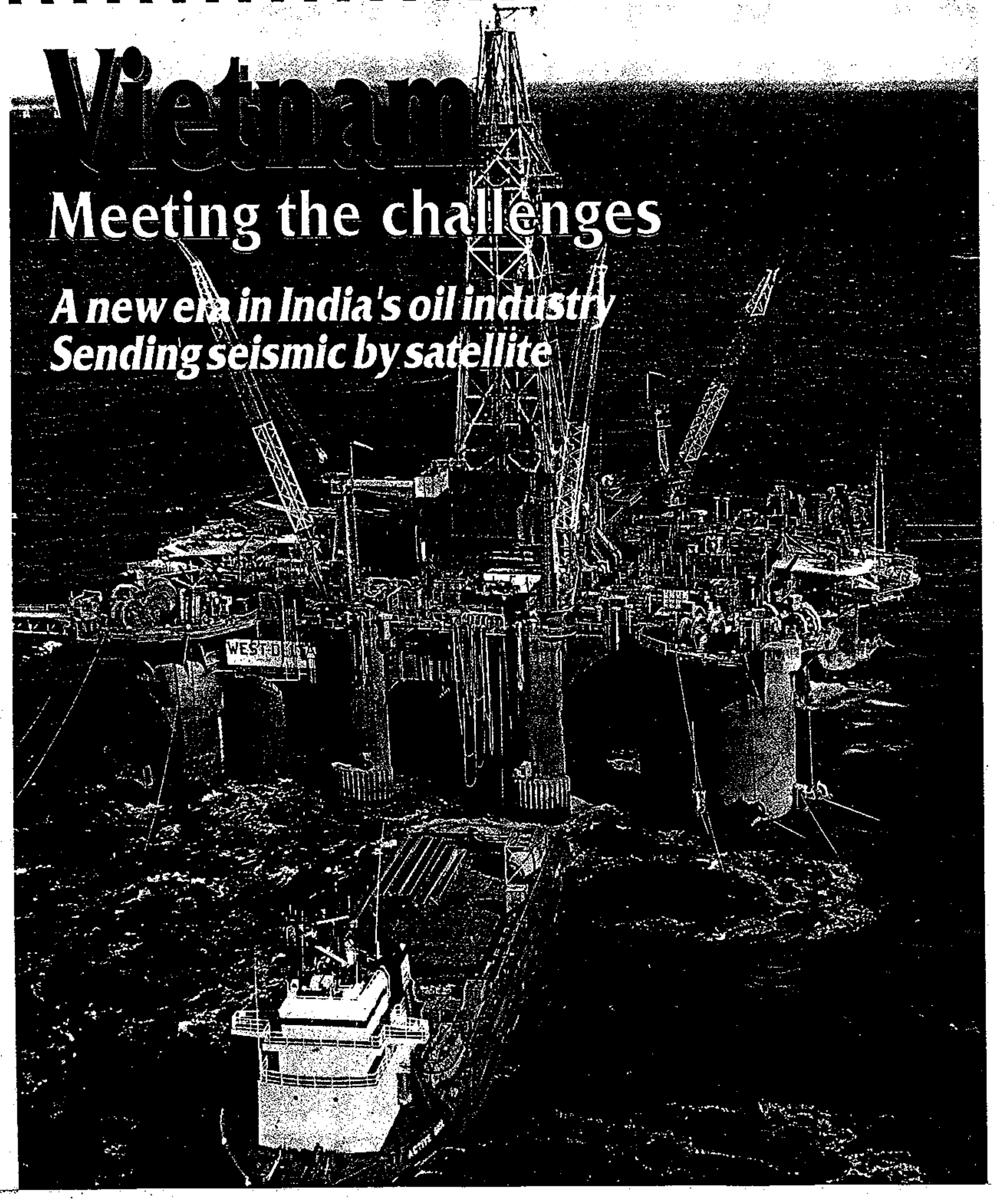

Fluid contamination analysis as a maintenance tool

Analysis of hydraulic fluids, if done correctly, can indicate maintenance procedures designed to improve hydraulic equipment reliability and extend system life. Conducted properly and in a timely manner, significant cost savings can result.

Oil contamination can be defined as any foreign material found in the lubricant which is not added by design. Usually, contaminants are not beneficial and may even be detrimental to the performance of the oil and/or operating machinery. Contamination is the root cause of a high proportion of machine and lubricant degradation and failure. Often overlooked as a source of failure because its impact is usually slow and imperceptible, contamination is both a significant threat to reliability and quality efforts but at the same time also an opportunity, because improvements are very attainable. Research on an array of fluid dependent machinery, such as bearings and rotating equipment, hydraulic systems, gearboxes, diesel engines, turbines, clearly supports the idea that very often machine reliability is a function of contamination control.

Particles, moisture, heat, air, glycol and fuel are all contaminants found in industrial lubricants. Particles and moisture are especially common and typically present the greatest risk to machine reliability and lubricant performance. Particles and moisture, either acting alone or in unison, lead to fluid oxidation, additive depletion, viscosity failure and loss of lubricity, especially where heat is present. Once the fluid's lubricating qualities are degraded they no longer provide the 'cushion' between moving machine surfaces. Because the fluid can no longer perform as it was designed, wear and ultimate failure ensue.

Perhaps more devastating than fluid degradation however, particles and moisture act directly upon the machine to cause wear and deterioration. Research has shown that more than 50% of wear related failures are due to particle and moisture contamination. Their presence leads to abrasion, cavitation, erosion, rusting and corrosion of operating surfaces. While it might be thought that tiny particles are no match for a heavy-duty gearbox or pump, once the surface material of the gearbox or pump deteriorates, the machine is on the short list for either the scrap heap or an expensive refit.

Proactive maintenance

As a root cause of wear and fluid degradation, control of particle and moisture contamination can be seen as a proactive maintenance activity, focused on failure avoidance. Particle content is also a very early warning indicator of component wear caused by other root causes such as misalignment, mechanical loading or fluid degradation. Particle counting can provide field level screening of problems to assure that when oil and wear analysis are needed for diagnostics, the user is already in an aggressive, information seeking mode. Contaminant monitoring as a predictive maintenance tool is especially effective when paired with vibration analysis and other condition monitoring tools. Correlation between two or more separate measurement systems lends greater confidence to the maintenance decision when trouble is suspected.

Particle detection instruments and methods generally fall into one of three categories: pore-blockage automatic techniques; light extinction or light scattering (optical) automatic techniques; or subjective visual techniques. The automatic techniques provide a quantitative particle count which can be calibrated to a known standard and translated into the universally accepted ISO 4406 Cleanliness Code (see table). The ISO Code simplifies the complexity of particle count and distribution by assigning a range code to the particle counts at the > 5 micron and > 15 micron sizes. ISO Code ranges double as the range number increases. This is an effective approach because a servo-hydraulic system with a cleanliness level of ISO 13/10 should not be afforded the same tolerance of variation as a farm tractor with a target cleanliness level of ISO 20/16.

Number of particles per ml.		R
>	≤	Range number
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5,000	10,000	20
2,500	5,000	19
1,300	2,500	18
640	1,300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	5
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.02	1

ISO 4406 Conversion Chart

$R_{5\ microns} / R_{15\ microns}$

Example 1:

400 particles > 5 μm/ml

65 particles > 15 μm/ml

ISO 16/13

Example 2:

16,030 particles > 5 μm/ml

2,490 particles > 15 μm/ml

ISO 21/18

Selecting equipment

Contamination monitoring, as with any maintenance activity, has to be cost driven. Cost can be incurred when a machine fails because of contamination: lost production, repair cost (parts & labour); human safety related to equipment failure; and operational quality. Failure costs, except for human safety costs, can be quantified using available information, to determine which machines should be monitored for contamination and, how often.

Whenever costs are quantified, decisions surrounding condition monitoring become easier to make and, more importantly, easier to sell within the organisation. The cost of poor reliability, the Machine Reliability Cost (MRC), can be calculated, using the formula:

$$MRC = \frac{(DC * FD) + RC}{MTBF}$$

Where:

MRC = Daily Machine Reliability Cost
DC = Downtime (lost production) cost, per hour
FD = Average duration of failure (hr)
RC = Average cost of repair (parts + labour)
MTBF = Mean time between failure resulting in lost production

For example, a machine which carries a $10,000/hr downtime cost and fails, for any reason, every 123 days on average, with the machine's average repair costs at $17,000, usually taking 23 hours to get the machine back up and running, the MRC would be as follows:

$$MRC = \frac{(10{,}000 * 23) + 17{,}000}{123} = \$2{,}008.13/day$$

This means that this machine's daily costs, for imperfect reliability, is more than $2000, excluding human safety and quality costs. Each day that this machine is involved in operations it incurs this cost as part of doing business. It is no different than buying energy, paying the operator, or any other cost associated with running the machine. Reducing the MRC should be the focus of the maintenance activities, including contamination analysis and control.

The MRC can be reduced by either improving efficiency or by improving effectiveness. Efficiency improvements come from reducing downtime, duration and repair costs. It is difficult to achieve more than incremental improvements when efforts are basically focused on efficiency improvements. Effectiveness improvements come from extending the mean time between failures. It is here that significant improvements can be made through identification and control of root causes of failure. Controlling contamination through an aggressive monitoring program provides one option for achieving significant improvement.

The formula falls short of considering human safety and quality costs, which are more difficult to quantify, but these can still be factored into the numerator of the MRC formula. An aggregate daily plant reliability cost (PRC) can be then calculated by summing the MRCs for all individual machines or systems. An annual MRC and PRC can subsequently be calculated by multiplying the daily costs by the optimal number of operating days per year.

Clearly, the majority of one's contamination monitoring resources should be directed towards those machines with the highest MRC number, with the aim of minimising the PRC. Once the costs have been assessed, rely on a technical analysis to further define the machines which warrant aggressive contamination monitoring. Some technical factors to consider are:

Mechanical sensitivity to contamination - Some mechanical systems, and some fluids, are more sensitive to contamination than others. For instance, electro-servo-valves are very sensitive to particle contamination. They will jam and lock, causing production shutdowns and quality defects.

Rolling element bearings experience extreme momentary loads when the roller contacts the race. Moisture in oil reduces the fluid's resistance to compression, resulting in wear caused by poor surface separation. Also, water and particles in fluid increase additive depletion and oxidation. Zinc-based additives are especially sensitive. These sensitive systems need to be monitored with greater frequency.

Environment severity - In dusty environments and environments with high relative humidity, machines are more apt to ingest contamination. Monitoring should be more frequent in such circumstances.

Application severity - Machinery operating at, or exceeding its upper operating range is more likely to be affected by contamination. Some examples include severe hydraulic duty cycles, frequent starts and stops and variable speed operation of rotating equipment. These systems should be monitored more closely for contamination.

Recent case histories

Actual cases serve best to illustrate the power of contamination monitoring as a proactive and predictive maintenance tool. An aluminium plant in the US relies heavily on hydraulic systems during production. Within three years of opening, it became clear to the management that a substantial improvement in maintenance costs could be achieved through aggressive contamination monitoring.

To confirm this hypothesis, two machines, representative of the machines in the facility, were isolated. The machines had annual parts maintenance costs of $11,000 and $15,000 respectively. Only material component costs were considered in the case study because other costs such as downtime and labour are 'soft' or variable, the price of a pump or valve being relatively fixed.

An aggressive programme was started to eliminate contamination from the system. High performance filters were installed and in-house particle count technology implemented. A technician performed routine counts on-line, minimising variances in the readings. Any high counts encountered were dealt with immediately before it became a problem.

Component replacement costs for the two systems in the study were reduced from an average of $13,000 per system to under $500 per system! Based on these findings, the programme was extended to the rest of the facility, giving a conservatively estimated annual savings in material component costs alone of more than $200,000 per year. When downtime, labour and other costs are included, the savings become substantial to say the least.

In another case, a piece of rotating machinery in a paper mill showed, from vibration analysis, that a problem was developing. However, the signal to noise ratio was rather unfavourable and left the production manager in some doubts as to whether to shut down the plant. A high particle count confirmed the problem with further investigation of the return line fluids from individual bearings revealing that one component was failing. A catastrophic failure and inevitable shaft damage was thus avoided.

On a separate occasion in the same plant, a high particle count was observed in the machine. A ferrous particle count revealed that there was 86% ferrous material in the contamination. A wear level that high is usually indicative of a lubricant or mechanical stress related failure. In this case, high moisture content was detected, along with an increased copper count. The problem was identified as a heat exchanger failure. The fluid was dehydrated, contamination levels returned to normal and excessive damage avoided. If the user had been using on-site particle and moisture monitoring systems the problem could have been identified even before the increase in particle count.

Forcing a change

In-house monitoring of particles and moisture, the primary cause of machine degradation, should be a key component of any aggressive condition monitoring programme. A contamination monitoring programme should include target cleanliness levels, monitoring frequencies determined by machine criticality with special attention to sampling and analysis.

Many major industries, the oil industry, in particular, have in the past failed to recognise the quality added value and significant cost savings of proactive maintenance, almost universally practising a run to failure philosophy on plant and equipment. Industry economics are now forcing a change of view towards maintenance, from being primarily a repair function to a reliability function that provides cost effective increases in production capacity.

As a dedicated maintenance company specialising in proactive maintenance management programmes, Singapore based Rayco Engineering is pioneering the use of preventive maintenance systems, fluid analysis and other condition-based monitoring techniques in the industry. The company can provide either a service or act as consultant to establish a customised programme for anyone considering contamination monitoring as a proactive maintenance management programme. Rayco is distributor for Diagnetics (Tulsa, USA) condition monitoring equipment and has offices and representatives throughout the Middle and Far East. Rayco's core business, apart from maintenance management and condition monitoring systems, includes the manufacture, assemble and installation of major oilfield equipment, procurement and distribution of oilfield products through any of its more than 1500 principals and tool maintenance/ warehousing facilities. The company has a highly qualified and experienced support team including specialist mechanics, 6G coded welders, drilling tool maintenance technicians and logistics experts.

With more than 20 years experience in the design and supervision of maintenance programmes, Rayco feel confident in being able to provide a maintenance management and condition monitoring programme tailor-made to fit the needs of any industrial application.

PET

Product Number 12-01

Particle Life Extension Method

Life Extension Factor (LEF)

Current Machine Cleanliness (ISO Code)

	2	3	4	5	6	7	8	9	10
26/23	23/21	22/19	21/18	20/17	20/17	19/16	19/16	18/15	18/15
25/22	23/19	21/18	20/17	19/16	19/15	18/15	18/14	17/14	17/14
24/21	21/18	20/17	19/16	19/15	18/14	17/14	17/13	16/13	16/13
23/20	20/17	19/16	18/15	17/14	17/13	16/13	16/12	15/12	15/11
22/19	19/16	18/15	17/14	16/13	16/12	15/12	14/11	14/11	14/10
21/18	18/15	17/14	16/13	15/12	15/11	14/11	14/10	13/10	13/10
20/17	17/14	16/13	15/12	14/11	13/11	13/10	13/9	12/9	12/8
19/16	16/13	15/12	14/11	13/10	13/9	12/9	12/8	11/8	11/8
18/15	15/12	14/11	13/10	12/9	12/8	11/8	-	-	-
17/14	14/11	13/10	12/9	12/8	11/8	-	-	-	-
16/13	13/10	12/9	11/8	-	-	-	-	-	-
15/12	12/9	11/8	-	-	-	-	-	-	-
14/11	11/8	-	-	-	-	-	-	-	-
13/10	11/8(1)	-	-	-	-	-	-	-	-
12/9	11/8(1)	-	-	-	-	-	-	-	-

(1) Life extension factor = 1.8

Example : By reducing particle levels from ISO 20/17 to ISO 14/11, machine life can be extended by a factor of 5

Moisture Life Extension Method

Life Extension Factor (LEF)

Current moisture level

PPM	2	3	4	5	6	7	8	9	10
50,000	12,500	6,500	4,500	3,125	2,500	2,000	1,500	1,000	782
25,000	6,250	3,250	2,250	1,563	1,250	1,000	750	500	391
10,000	2,500	1,300	900	625	500	400	300	200	156
5,000	1,250	650	450	313	250	200	150	100	78
2,500	625	325	225	156	125	100	75	50	39
1,000	250	130	90	63	50	40	30	20	16
500	125	65	45	31	25	20	15	10	8
250	63	33	23	16	13	10	8	5	4
100	25	13	9	6	5	4	3	2	2

1% water = 10,000 ppm

*Estimated life extension for mechanical systems utilising mineral-based fluids.

Example : By reducing average fluid moisture levels from 2500 ppm to 156 ppm machine life (MTBF) can be extended by a factor of 5.

The accompanying tables are examples only of the life extension method first devised by James Fitch of Diagnetics in the late 80s to determine the cleanliness levels required according to the life extension expected. These tables are based on a wide array of mechanical systems, the ones illustrated being for hydraulic systems. Tables for roller bearings, diesel engines and others are available.