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Lubricant-Based Techniques for the Condition Monitoring of Non-Circulating Gear and Bearing Systems

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Introduction

The best maintenance techniques for mechanical machinery are condition-based techniques. Condition-based maintenance is maintenance prescribed by the real-time needs of the machine according to changes in specific operation conditions. These conditions fall into two categories.

The first set of conditions are those that present a risk to a machine's health if allowed to persist. These are operating and environmental conditions that precede failure, i.e., root causes of failure. They are not failure symptoms, which is after the fact. Examples of root cause conditions are misalignment, lubricant contamination, and overheating. The activity of detecting and correcting root cause conditions is referred to as proactive maintenance. Its singular purpose is to extend a machine's operating life.

The second set of conditions are early-stage failure conditions. Conditions that reveal the processes of failure are defined as "symptomatic conditions." Examples of such conditions are wear debris, certain abnormal vibrations, and corrosion products. The monitoring of symptomatic conditions is referred to as predictive maintenance.

Both proactive and predictive maintenance are condition-based techniques and are strategically critical to modern-day maintenance programs. When well applied they can significantly increase machine availability and reduce operating costs. The extent of the benefit is a matter of the quality and discipline of the implementation.

Role of Lubricant Contamination

Lubricant contamination plays a critical role in condition-based maintenance. First, the majority of wear related failures occur as the direct result of particulate contamination. A recent report published by Lubrication Engineering magazine leads to the conclusion that more than 82% of wear related losses are contaminant induced (Figure 1). And, the largest portion of this is abrasive wear; the direct result of particles wedged between rolling and sliding surfaces.

According to work done by SKF, bearings can have "infinite life" when the influence of particle contamination is eliminated. This point is illustrated in Figure 2 where it can be seen that more than a 75-times life extension can be achieved by maintaining exceedingly clean lubricating fluids. It is worth noting, from Figure 2, that the penalty associated with a contaminated lubricant equals that of a lubricant with just 25% of the recommended viscosity.

Figure 1 - Cost of Contaminant Wear*

Sector	Particle Induced			Non-Particle Induced			Total
	Abrasion	Erosion	Fatigue	Adhesion	Fretting	Other	
Pulp & Paper	217	93	13	36	4	19	382
Forestry	101	-	14	25	12	6	158
Mining	551	117	25	15	1	17	726
Agriculture	735	54	45	104	2	-	940
Transport.	799	-	202	240	17	68	1326
Power Generation	69	30	-	31	26	34	190
Total	2472	294	299	451	62	144	3722
Percentage	66%	8%	8%	12%	2%	4%	100%
Percentage by Category	82%			18%			
* Canadian Dollars			Ref: National Research Council of Canada				

There are few forms of internal machine failure that don't result in particles being released into the lubricant. Viewing increases in particle contamination as a predictive maintenance tool is indeed important. Figure 3 lists the range of failure types detectable using contaminant monitoring. The double-benefit of monitoring lubricant contamination for both proactive and predictive maintenance can not be overstated.

As a predictive maintenance technique, abnormal particle trends are the early symptoms of several non-particle induced conditions. Once the abnormal trends are recognized, a more precise assessment of lubricant condition or machine malfunction can be pursued. To be successful, a dutiful regiment must be followed.

First, all primary fluid sampling points must be upstream of filters. Filters, by design, will remove important signs of failure or abnormal particle ingestion. Dynamic changes in contaminant trends are obscured when samples are taken downstream of filters. The unfiltered particles are valuable data to a proactive and predictive maintenance program.

Monitoring frequency is also important to success. The frequency is influenced by several factors including the target cleanliness level and contaminant environment severity. When such a program is well implemented, even failures that are not directly caused by particles can be detected (using contaminant trend analysis), long before aberrant vibration signals are present. Examples are:

Failure Root Cause:	Revealed by Particle Generation From:
1. Moisture in Oil	Corrosion Debris
2. Additive Depletion	Wear Debris
3. Chemical Contamination	Debris From Corrosion and Wear
4. Viscosity Change	Wear Debris
5. Misalignment & Imbalance	Wear Debris
6. High Pump Inlet Vacuum	Cavitation Debris

In contrast, the proactive maintenance strategy targets the role of contamination on machine life and reliability. The approach needed to succeed can be reduced to three simple steps:

1. Set cleanliness targets for each fluid system, sufficient to achieve machine life extension.

2. Upgrade or add filtration, as necessary, to achieve and stabilize cleanliness to within target.

3. Monitor contaminant levels at frequent time intervals, based on target cleanliness and environment, to insure cleanliness is achieved.

A technique called the Life Extension Method (LEM) is used to set the target cleanliness level. The LEM upgrades the operating lubricant cleanliness (usually

Figure 2 - Influence of Contamination on Bearing Life

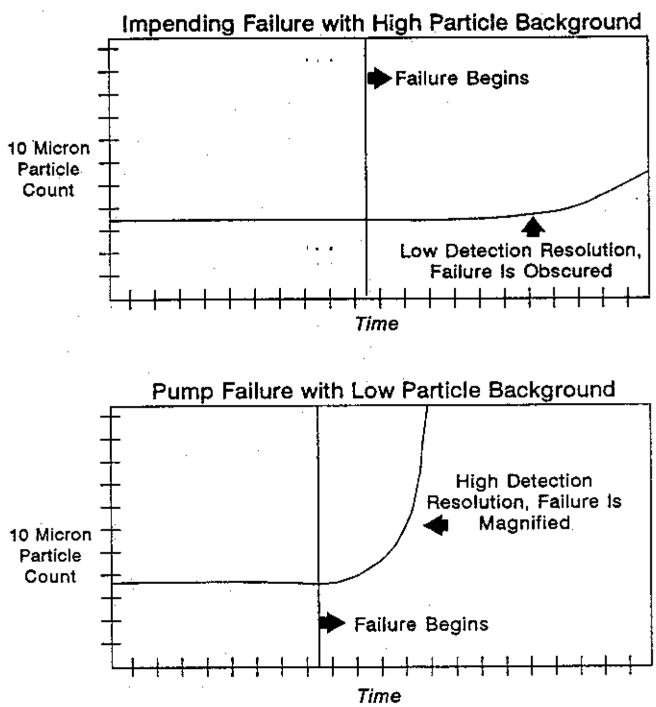
Bearing Type & Lubricant Cleanliness	Relative Bearing Life: Half The Recommended Viscosity	The Recommended Viscosity	Twice The Recommended Viscosity
Radial Ball Bearings:			
Very Clean	6	80	300
Normal	2.5	50	200
Contaminated	0.6	2.5	4
Radial Roller Bearings:			
Very Clean	0.6	5	15
Normal	0.3	1.8	3
Contaminated	0.2	0.4	0.5
Thrust Ball Bearings:			
Very Clean	1.3	18	48
Normal	0.7	5	9
Contaminated	0.3	0.7	1.2
Thrust Roller Bearings:			
Very Clean	0.3	1.5	3
Normal	0.3	0.7	1
Contaminated	0.15	0.3	0.35

Ref: SKF

dramatically) to extend the Mean-Time-Between-Failures (MTBF) by say 5 to 10 times. (Contact the authors regarding information on the LEM). In a gear box, this means that wear rates of gears, bearings, and other tribo-mechanical surfaces are reduced by 5 to 10 times.

The predictive benefit of high lubricant cleanliness is that the background particle levels that normally result in "noise" to a contaminant trending program is eliminated. The higher the particle concentration, the less sensitive and less "real-time" contaminant monitoring techniques can be (see Figure 3). When background levels are reduced or effectively eliminated, even minute changes in wear rates or particle ingestion are detectable.

Figure 3

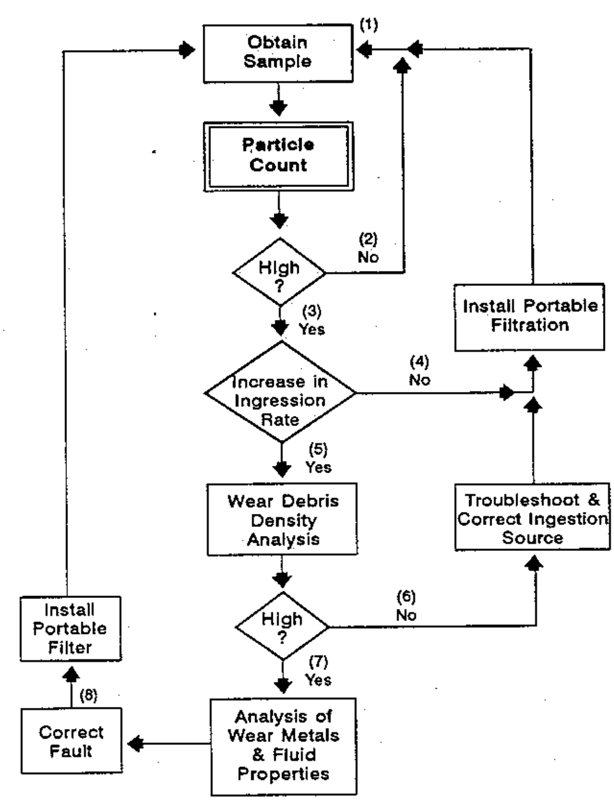


<u>Setting up a Contaminant Analysis Program for a Gear-Box</u>

With a splash-lubricated non-circulating gear-box, particles accumulate in the fluid until external filtration is applied or until the fluid is changed. A rate increase in particle level accumulation suggests a rate increase in wear/ingestion. The addition of wear debris analysis, at specific points in the process can help ferret out the specific root of the problem.

The flow chart in Figure 4 illustrates the approach for integrating contaminant monitoring into a combined proactive/predictive maintenance strategy. Starting at the top, (1) samples are taken and analyzed on a frequent basis using an inhouse particle counter (portable or benchtop). If the contaminant level is within the target (2), no action is taken and the next sample is scheduled. Note, if a significant level increase is noticed, even though the current

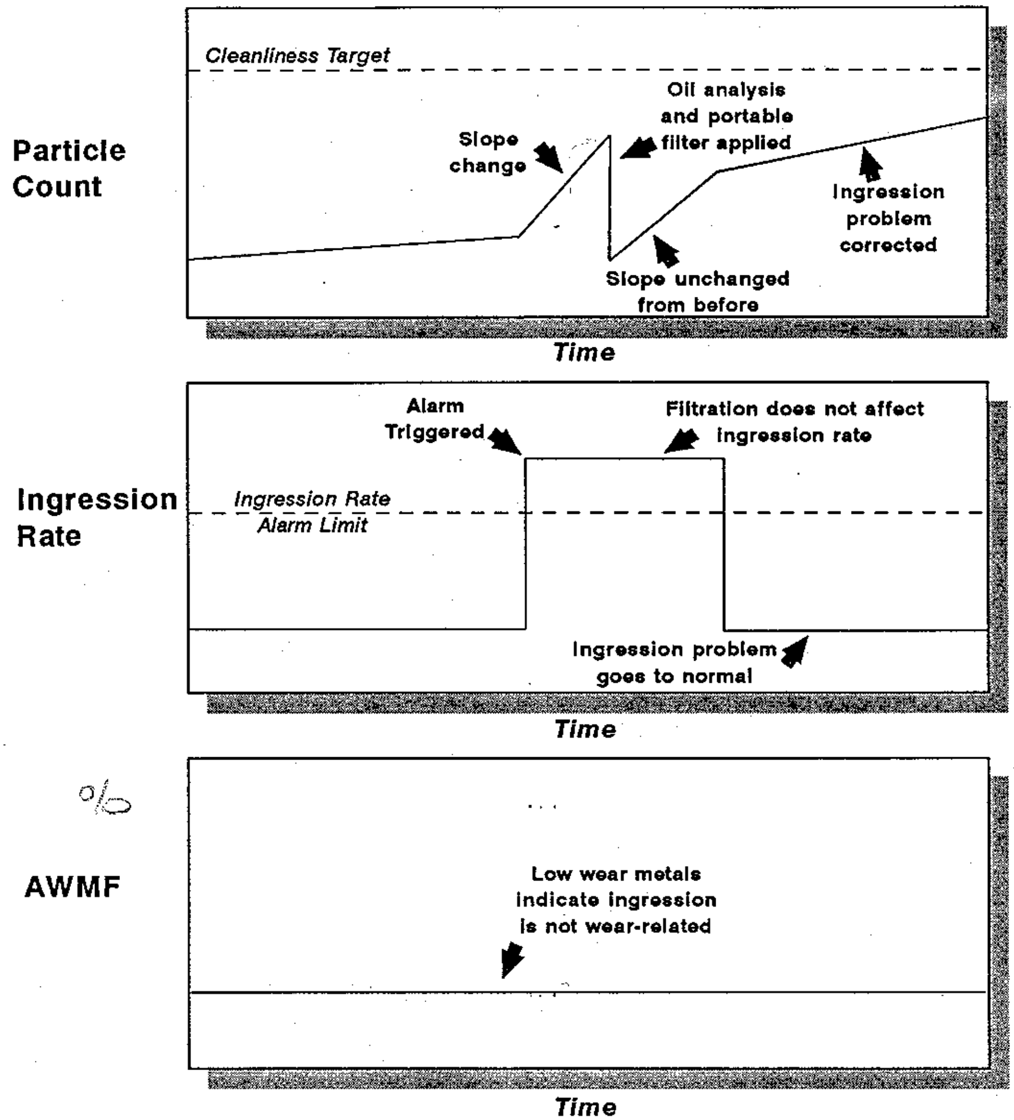
Figure 4



sample is below target, then this condition accelerates the time to the next sample. If the current sample is above the target, step (3) is triggered.

Step (3) analyzes the particle ingression rate. This is calculated by subtracting the particle count of the previous sample C(t1) from the current sample C(t2). This value is divided by the hours between the samples (t2-t1) to obtain the ingression rate in particles per hour of operation. If the ingression rate is not significantly increased from previous rates, then portable filtration is installed and the cleanliness is restored (4).

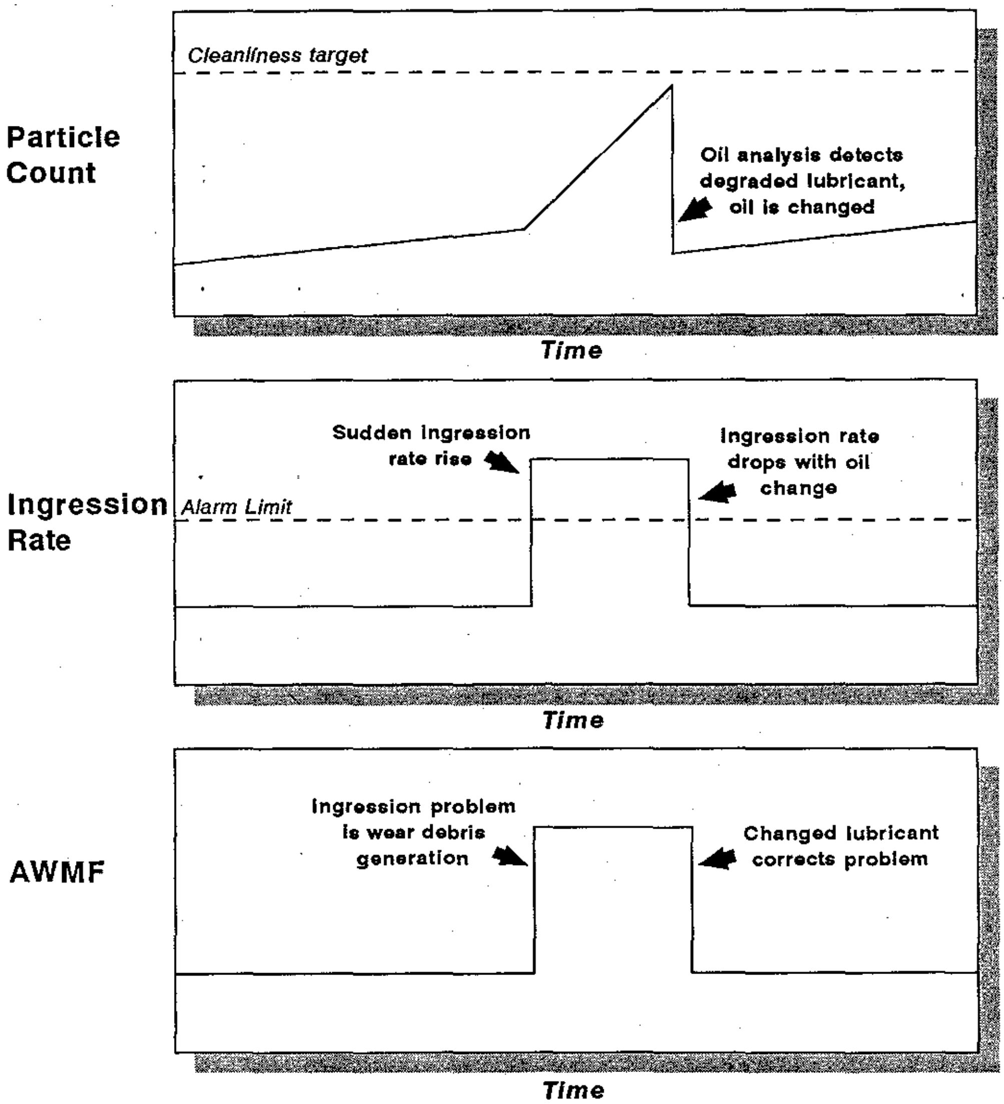
Figure 5 - Diagnosis of an Unfiltered Lube Oil System -- Particle Ingestion



If the ingression rates are measurably higher (5), the cause of the increase must be investigated. A wear debris density test can be conducted to determine the Apparent Wear Metal Fraction (AWMF). This is the approximate fraction of the total particles that is wear debris (metallic). Several laboratory techniques can be used to estimate this value. If a low fraction of the particles is metallic (6) then the rate increase in contamination is probably caused by a particle ingestion source, e.g., failed breather or seal. The source of the ingestion should be then located and corrected. The fluid is then filtered to restore cleanliness, see Figure 5.

A high fraction of wear metals (with respect to total particle concentration) suggests that wear is being induced by either the lubricant (e.g., loss of antiwear additive) or operating conditions (e.g., misalignment). To find the source of the problem (7) the lubricant is analyzed completely (unless done at step 5). If the quality of the lubricant is not satisfactory then the oil should be changed or restored (Figure 6). If the oil quality is good then other possible problems must be investigated. Vibration and shaft alignment instruments might be used to troubleshoot the problem source. After correcting the fault, the fluid cleanliness is restored (8). Future particle counts will confirm the remedy, Figure 7.

Figure 6 - Diagnosis of an Unfiltered Lube Oil System -- Lubricant-Induced Wear



*Moisture contamination, additive depletion, heat damage, viscosity change

<u>Hardware Installation for a Gear Box Contaminant Monitoring Program</u>

Without the proper connection hardware, an effective pro-active/predictive maintenance program for a gear box will be difficult. The following components can be retrofitted on standard industrial gear boxes with minimal cost and effort:

1. Male quick-disconnects with dust covers for the fill and drain ports.

2. T-Fittings with plugs between the casing and the quick-disconnects for optional fill and drain access.

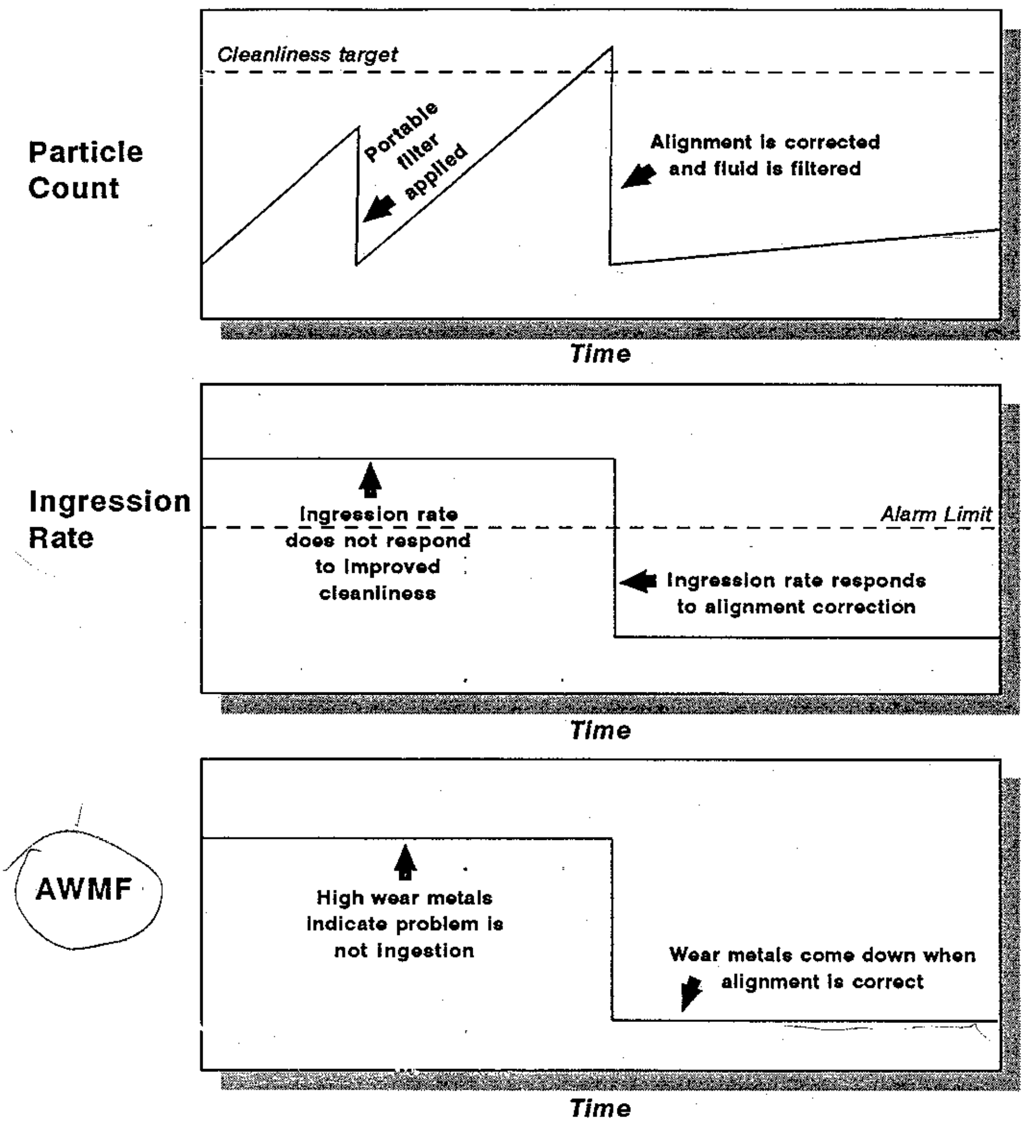
3. Positive retention breather filter on casing top.

4. Port identification tags.

Once the hardware is installed, a portable filter cart can be easily installed to; a) flush and restore cleanliness, b) transfer lubricant (or top off) to the gear box from a storage container, and c) to drain quickly by pumping instead of gravity drain, see Figure 8.

Additionally, the hardware makes the oil analysis process much simpler and more reliable. Figure 9 shows an off-line sampler (OLS) which attaches to the quick-disconnects. The off-line sampler has an internal pump and motor to circulate the fluid out of the drain port and back to the fill port. This circulation is necessary to achieve a uniform contaminant concentration in the fluid before sampling. After several minutes of circulation, oil can be sampled into a bottle from a port on top of the OLS. Alternatively, using a portable particle counter, the fluid can be analyzed at machine site.

Figure 7 - Diagnosis of an Unfiltered Lube Oil System -- Alignment or Load-Induced Wear



This is greatly preferred since questionable results can be double-checked without delay.

Conclusion

The price exacted by uncontrolled lubricant contamination can be enormous. While the processes of wear appear slow and almost unnoticeable, destruction and costly deterioration occurs. Incredibly, even the most sophisticated vibration monitoring techniques are known to be oblivious to abrasive contaminant-induced wear. Some experts have noted that vibration signals are actually attenuated when contaminants are added to lubricants (surface irregularities are smoothed out/lapped).

However, what the industry is generally not aware of is the symptomatic information revealed from contaminant trend analysis. And, that contaminant trends can point to the source of problems often unrelated to the fluid. The combined proactive/predictive maintenance approach can yield multiple payoffs only when effectively implemented. But new disciplines must be established and skills applied to succeed.

Figure 8

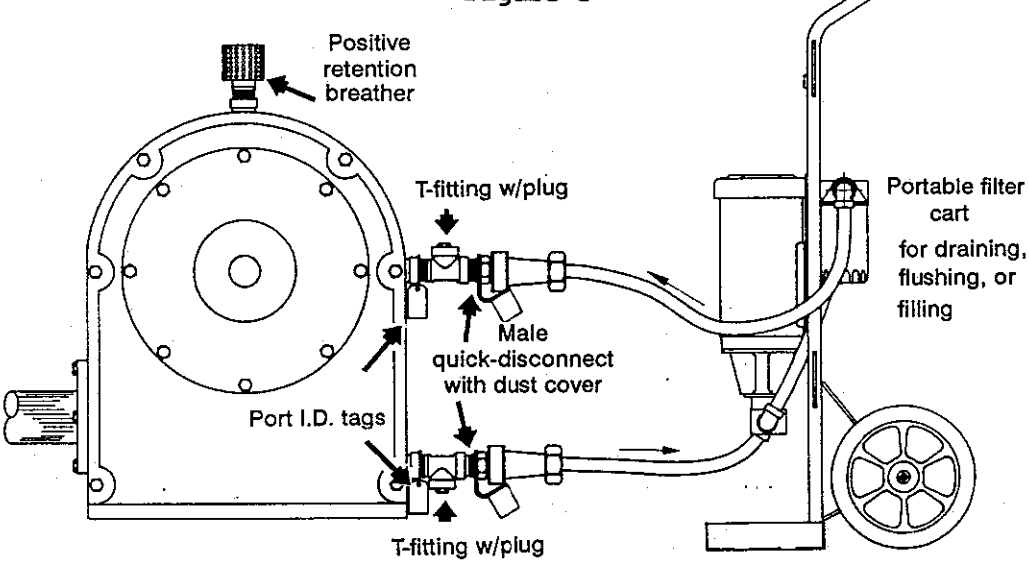
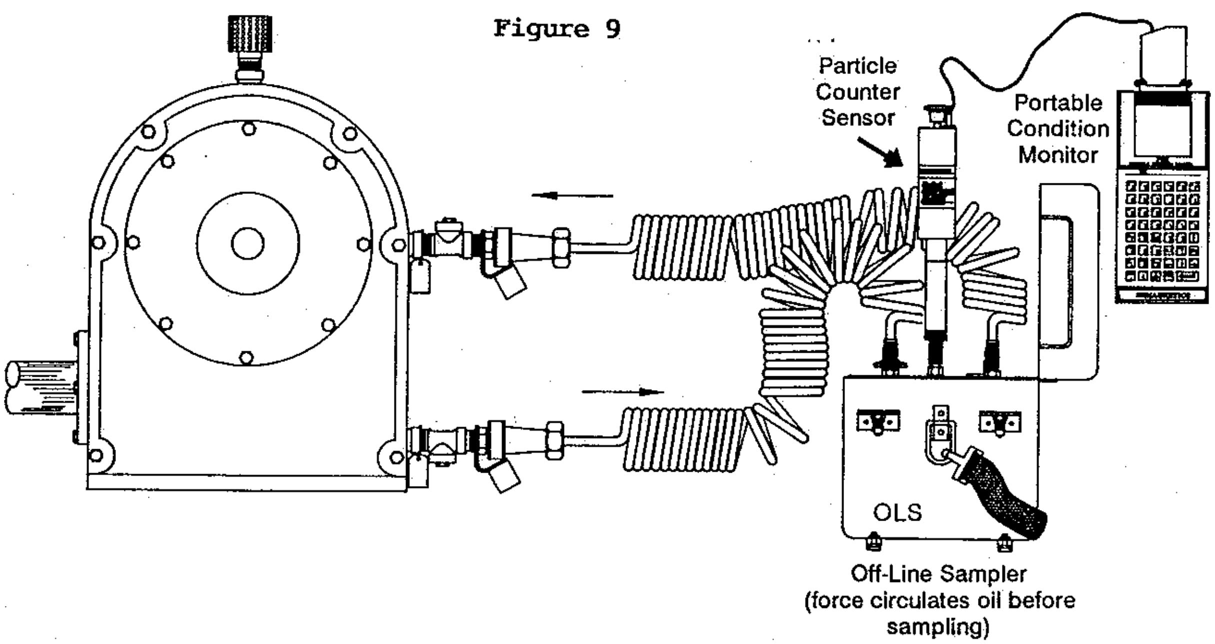


Figure 9



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