Improving metalworking fluid performance and service life through cleanliness

By SKF RecondOil in Partnership with Noria Corporation


50mL
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Cleanliness is key

Clean fluid is fundamental for insuring product quality and that machines run properly, reliably and with low operating and maintenance costs over time. But in-service fluids do not stay clean for long in most work environments—especially in metalworking applications.

As lubrication knowledge and technology have advanced, we have learned new ways to care for and extend the life of vital metalworking fluids (MWF). With the right technology and practices, achieving ultra-clean fluids is possible even in dirty environments. The right solution can help make this a reality, bringing transformative performance benefits, product quality, cost savings, less waste, less downtime, and significant reductions in environmental impact.

These benefits are especially pronounced in metalworking applications where product quality can be severely impacted by contamination. However, since controlling contamination can help improve machine reliability, reduce wear and component failure and more, they apply to most industrial applications.

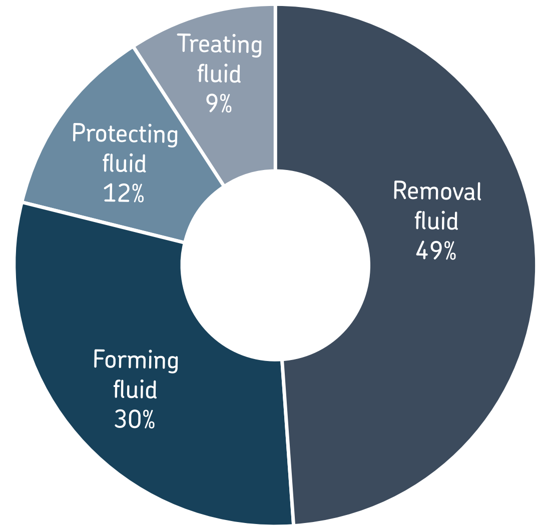
Metalworking fluids' role in production

Cutting, shaping, and finishing metals is thirsty work. Every year, the world's factories consume more than 3.7 million tonnes of metalworking fluids. The specialised oils and emulsions that flow through machines account for almost 20% of the $61 billion global market for industrial lubricants.

That is a huge cost for products that end-users never see, but without metalworking fluids, manufacturers could not achieve the levels of quality, performance, and productivity that their customers expect.

Metalworking fluids perform a variety of essential functions in manufacturing: they cool tools/dies and workpieces, remove chips and swarf, lubricate highly loaded shaping and cutting surfaces and protect parts from corrosion and wear. These critical lubricants and fluids must be kept clean enough to maintain product quality and machine reliability—a task that is not always simple, especially in metalworking applications where contaminants abound. The fluids must be continuously filtered to remove metal chips, wear debris, dirt and organic matter. They also need frequent monitoring and analysis to ensure oxidation and contamination is not affecting essential functional properties.

MWF consumption by category



Removal fluids

Removal fluids, such as grinding fluids and cutting fluids, are used in metalworking operations to remove chips, swarf, and particles from the workpiece, as well as to cool and lubricate. They are present in a wide variety of machining operations. Operations where removal fluids are in use include: Boring; drilling; gear shaping; grinding; honing; milling; sawing; shaving; threading; turning and more.

Protecting fluids

Protecting fluids temporarily shield metal surfaces from air, water, and other corrosive substances. The common protecting fluids are rust preventives applied to iron and steel. Protecting fluids are also used on such nonferrous metals as copper, aluminium, and brass. In addition to providing corrosion protection, protecting fluids have a dual function when used as a pre-lube for stamping operations.

Forming fluids

Forming fluids are used in metalworking operations that do not produce chips. In these operations, the shape or contour of metals is being altered by bending, squeezing, stretching, or pounding the metal. Forming fluids are classified into rolling oils, drawing and stamping fluids, casting compounds, hydroforming fluids, and forging compounds.

Treating fluids

Treating fluids are used in thermal processes in which the physical properties of the metal are changed to meet various application requirements. A metal can be made hard, soft, elastic, or brittle by heating or cooling it under controlled conditions. Heat-treating fluids are an essential part of this process, as they act as a thermal transfer medium.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Metalworking fluid: composition and requirements

Metalworking fluids come in two basic types: emulsions (or "soluble oils"), which are made up of small droplets of oil, emulsifying agents and other additives suspended in water, and neat oils (or "straight oils").

Emulsions are less expensive than neat oils, and they offer superior cooling properties in some applications. On the downside, they need much more care. Users must carefully monitor the properties of the fluid for concentration level (oil/water ratio), pH and microbial contamination (bacteria). The entire fluid system must also be drained and carefully cleaned during planned production shutdowns.

Neat oils, by contrast, are far more stable (although volatility and flammability are important factors to consider, especially for low viscosity oils). They require little routine maintenance beyond filtering to remove contaminants. They also offer better performance in demanding applications involving high forces. But despite the advantages neat oils offer, users with high-precision applications still need to replace the oil in their systems on a regular basis. If they use the same oil for too long, process performance can be significantly impaired, leading to quality issues, scrap material (product rejects) and low productivity. In fact, even in facilities without high-precision metalworking needs, an over-extended use can lead to an assortment of problems.

Dirty fluids wreak havoc in metalworking applications, and even with the best possible care, all metalworking fluids have a finite life. Eventually, they must be discarded and replaced. Safe, environmentally benign disposal of old fluid is expensive, and every litre adds to an organization's overall carbon footprint. As companies begin the transition to a low-carbon and circular economy, these waste disposals and emissions are coming under increasing regulatory scrutiny.

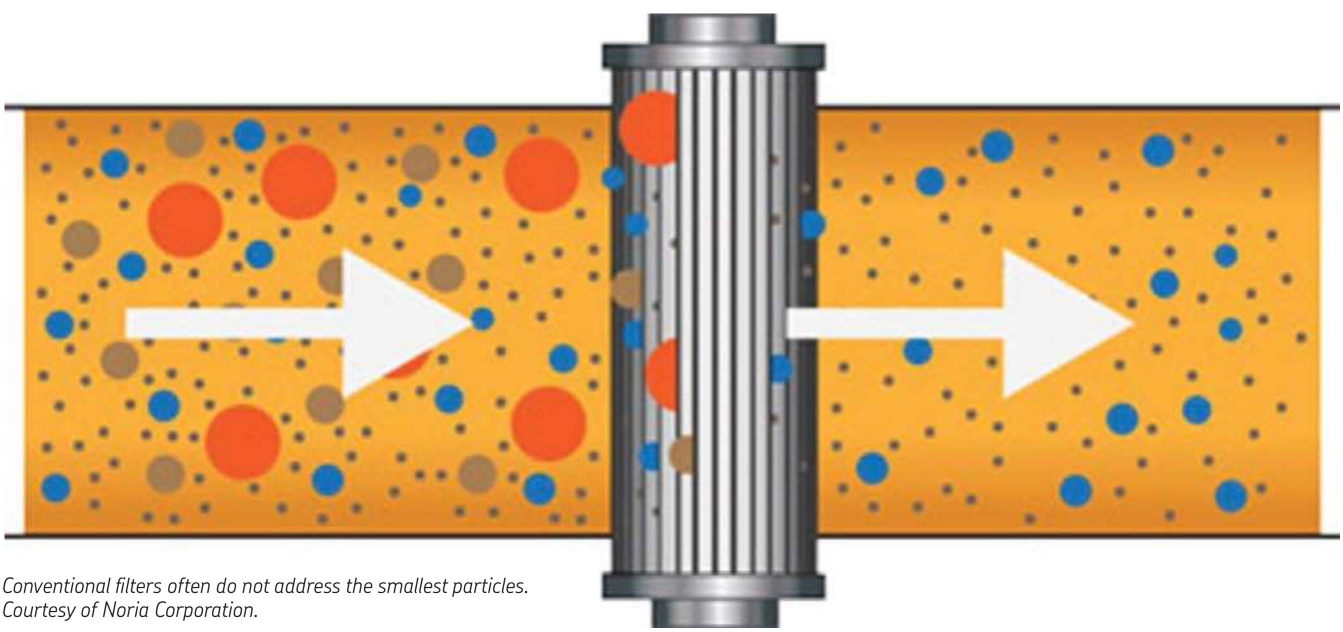
Controlling contamination

The hazardous effects of contaminants have been well-documented. No fluid in metalworking applications can optimally perform in the presence of contaminants, but at the same time, no machine or lubricant can be defined as contaminant-free. Even in the cleanest manufacturing environments, metalworking fluids normally become contaminated while in use. The fluids pick up metal chips, particles of airborne dust and floor dirt from the work environment, and they are also exposed to moisture ingress from the atmosphere.

Contaminant particles come in many sizes, shapes, hardness, and compositions. And although conventional filtration is efficient for removing larger particles from the fluids, not all contamination is as easy to remove. Most of the particles that enter the oil will be extremely small, only a few microns in size - too small to be seen with the naked eye. They are even difficult to detect using conventional oil analysis techniques. And they are small enough to pass through the pores in a conventional filter, remaining suspended in the oil as it returns to use.

The vast number of particles continuously produced in metal working processes also limit the types of filtration systems that can be used. Many filter systems use a back-flushing sequence to renew the filters capacity. This produces a volume of fluid with a high concentration of particles and contamination, which must be taken care of correctly to avoid fluid losses and recontamination of the metal working fluid.

Since these miniscule particles are not easily removed, they will accumulate over time, eventually reaching concentrations that can degrade the performance of the oil, or even destroy it. Experts refer to these particles as “ghost rider particles”.



Conventional filters often do not address the smallest particles. Courtesy of Noria Corporation.

The problem with ghost rider particles

To solve the problem of ghost riders in metalworking fluids, we first need to understand what they are and how they affect lubricants and machines.

The longer a lubricant remains in service, the longer it is subject to contamination ingression. And most lubricant contaminants are nearly microscopic; since small particles enter more easily than large particles, for each 10-micron particle that ingresses into the oil, there may be ten 3-micron particles present.

This small-particle dominance is compounded further by filtration. Most production processes using metalworking fluids include conventional filters that remove particles based on size exclusion. This means that particles above specific micron sizes are filtered out. For simplicity, this will be referred to as the filter's particle size cut-off.

Particles larger than the filter's size cut-off are trapped and eliminated from a system with each filter change. But particles smaller than the filter's size cut-off remain in the process fluid, lines and tank. These particles are the ghost riders in a system, and their size is really dependent on the filters size cut-off. If a filter's size cut-off is 10-micron, all particles smaller than 10 microns are "ghost riders" in that application – simply because they are not addressed by the filtration system.

Over time, the fluid accumulates an increasing number of ghost rider particles. Most of these particles may be submicron, and can consist of organic matter (soft, insoluble contaminants that can lead to sludge and varnish) as well as inorganic hard particles from environmental dust, process particles, and wear debris. Due to their miniscule size, these ghost riders also are not prone to settling (Stokes' law[1]) but rather embed tightly into the fluid, held by viscosity, circulation and Brownian motion (like food dye in water).

Certain depth filters remove particles well into the submicron range. If the filters are used throughout the life of the fluid, it is possible to achieve a high level of control over contamination. However, the effectiveness of these filters varies depending on the particle size and composition. With most conventional filtration technologies, ultra-small ghost rider particles will often remain in the oil, causing further damage down the road.

Eventually, the total surface area of millions of small particles aggregates to represent a much larger area; in a typical sample of oil, nano-sized ghost rider particles can account for 80 percent of the total contaminant surface area. The presence of the ghost riders can cause a vast array of issues.

Courtesy of Noria Corporation.

[1] *Stokes' law describes the rate at which objects fall in viscous fluids. An object's fall rate is affected by (1) its size, (2) its density, (3) the viscosity of the fluid in which the object is falling, and (4) the density of the fluid — the lower the density of the fluid, the faster an object will fall.*

[2] *Brownian motion is the name given to the random movement of particles suspended in a liquid or gas.*

Small particles cause large concerns for metal working fluids

The presence of ghost riders in metalworking applications causes a whole range of problems. The type of fluid and application greatly determine the concerns and risks associated with these small particles:

Polishing and increased mechanical friction

Exposure to periodic or continuous boundary lubrication is a common occurrence in many machines, including certain metalworking applications. Due to slow speed and/or high unit loading, the lubricant is unable to maintain a fluid film between moving surfaces. This can result in surfaces that rub mechanically in sliding frictional zones.

To control wear, extreme-pressure and anti-wear additives are often used. However, these additives cannot always prevent the abrasive damage caused by small particles, leading to polished and honed surfaces under common boundary conditions. As the population of these small particles increases, more wear damage follows. Unfortunately, where there is wear there is excessive friction. This can lead to higher energy consumption and negative environmental consequences, not to mention higher costs and unplanned downtime.

Additive tie-up

A high density of small particles exposes the fluid to an extensive amount of surface area (the collective outer-shell surfaces of all particles). Due to their polarity, many lubricant additives are naturally attracted to both machine and particle surfaces. Common examples include friction modifiers, emulsifying agents, rust inhibitors, metal deactivators, detergents, anti-wear, and extreme-pressure additives. When these additives stick to particles, their functional value is lost to the oil, the process and machine. The particles occupy this role instead, catalysing additive depletion. This results in lost or impaired corrosion protection, oxidation stability, film strength, and deposit control.

Restricted flow and silt lock

Small particles, commonly referred to as silt-sized particles or just silt, can work their way into narrow oil ways, glands, and orifices. This can cause restricted oil flow, leading to lubricant starvation and impaired mechanical movement.

High air hang time

Significant levels of dissolved air, invisible to the naked eye, can be found in all lubricants. If fluid pressure and temperature changes, the air can shift from a dissolved state to a bubbly state (Henry's law[3]). Small particles aid the transition by providing nucleation sites for emerging air bubbles. Highly pure lubricants have a greater tendency to produce large, buoyant air bubbles (rapid air release). Conversely, highly contaminated fluids, including those rich with organic solids, lead to the formation of small air bubbles, which impair buoyancy and result in slower air detrainment (Stokes' law effects). There are many negative consequences to bubbly, aerated fluid.

Oxidation by metal catalysts

Metal particles (especially iron and copper) promote or catalyse base oil oxidation, especially for neat oils. Abnormal levels of heat and water contamination contribute to this phenomenon. If not quickly filtered out, the metal particles can be crushed into smaller particles. And if these particles break down, a greater nascent metal surface area becomes exposed to the fluid and its additives.

Eventually, the oxidation inhibitors are fully depleted, and the base oil reaches its breaking point, followed by a runaway state of oxidation. At this point, the only solution is a complete drain, flush, and fluid change.

In conclusion, there is a wide range of issues caused by ghost rider particles. And the first step for manufacturers to mitigate the situation is acknowledging that they are there. But since the ghost riders are so small and difficult to detect, they often go unnoticed by maintenance staff, and unmeasured and unreported by oil analysis labs.

[3] *Henry's law describes the proportionality of a dissolved gas in a liquid to its partial pressure above the liquid.*

Fluid analysis to expose ghost riders

Fluid analysis is commonly used to determine the remaining useful life (RUL) of circulating fluids in applications. Once the end of the fluid's useful life is imminent, it is changed in the application. This is referred to as a condition-based fluid change. This approach is effective if all factors that define the fluid's health and condition are taken into account by the laboratory performing the analysis. Performing a comprehensive assessment of all the important factors and attributes of lubricant health and performance is key to upholding the integrity of the fluid. Some labs understand the importance of this holistic approach, while others fail to consider the big picture.

Unfortunately, most laboratory methods have substantial blind spots when it comes to particle counting (especially the smallest particles), elemental spectroscopy, ferrous density, analytical ferrography, and other means and aspects of measurement. Table 1 provides a list of common fluid analysis tests and the ability of these methods to quantify or even roughly indicate the presence of ghost-rider-size particles in fluid.

One test is capable of reporting a single numerical value for total solids (hard and soft), making it particularly useful: gravimetric analysis. Toluene and hexane are solvents used to enhance the accuracy of this test by isolating and measuring the soft insoluble particles and hard particles separately. Other tests in this table can also effectively determine particle count, especially in tandem with additional testing methods. For example, data from two or more of the following tests can provide a practical understanding of small particle contamination: ultracentrifuge, MPC, blotter spot testing, elemental spectroscopy, and submicron patch testing.

Regardless of the method, or combination of methods, used to detect the particles, if left unchecked the particles will eventually cause the fluid to degrade to a point where it no longer performs as intended in the application. In smaller applications, when all else fails, the most practical solution may simply be to perform an oil change. But in machines holding thousands of gallons of oil, new technology can offer a more financially and environmentally sound solution.

Common fluid analysis tests

	Basic match test	Match ferrography	Microscope particle count	Gravimetric analysis	Particle micro patch imaging (PMPI)	Filterability	Pore blockage particle co–unt	Membrane patch colorimetry (MPC)
Related Standards	SAERP 4285	ASTM D7684	ISO 4407	ISO 16232-6	16232 788	ISO 13357	BS 3406	Pending ASTM Standard
	ASTM D7670		ASTM F312-08	ASTM D4898			ISO 21018	
	FTM 3012/3		FTM-3009	ISO 4405				
Non-quantitative Indication of Total Solids	No	No	No	Yes	No	No	No	Yes
Submicron Particles	No	No	No	Yes	No	Yes	No	Yes
Quantification of Total Solids	No	No	No	Yes	No	Yes	No	No
Soft Insolubles Quantifications	No	No	No	Yes	No	No	No	Yes
Wear Debris	No	No	Yes	Yes	Yes	Yes	Yes	No
Elemental Composition	No	No	No	No	No	No	No	No
Visual Indication of Solids	Yes	Yes	No	Yes	Yes	No	No	Yes
Availability of Test Method (Commercial Labs and Vendors)	Yes	Yes	Limited	Limited	Limited	Limited	Limited	Yes

	SEM/EDX	ICP Spectroscopy	RDE Specrtoscopy	Sediment content	Optical particle counting methods	Blotter spot test	Ultra-centrifuge	Ferrous density tests
Related Standards	ISO 16232-8	ASTM D5185	ASTM D6595	ASTM D2273	ASTM D7647	NONE	NONE	None
					ISO 11500			
Non-quantitative Indication of Total Solids	No	No	No	Yes	No	Yes	Yes	No
Submicron Particels	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Quantification of Total Solids	No	No	No	Limited	No	No	Limited	No
Soft Insolubles Quantifications	No	No	No	Yes	No	No	Yes	No
Wear Debris	Yes	Yes	Yes	No	Limited	Limited	No	Yes
Elemental Composition	Yes	Yes	Yes	No	Yes	No	No	No
Visual Indication of Solids	Yes	No	No	Yes	Limited	Yes	Yes	No
Availability of Test Method	Limited	Yes	Yes	Limited	Yes	Limited	Limited	Yes

Table 1: Oil analysis tests for indicating the presence of ghost-rider particles in oil. Source: Noria Corporation

Extending the service life of metalworking fluids

Without a doubt, conventional filters do effectively mitigate the exposure and risks of particle contamination. When larger particles are quickly filtered from the fluid, they cannot harm work surfaces, products, or machines, nor can they be crushed into small ghost rider particles that continue doing damage. Consequently, conventional filtration is still essential for contamination control. But taking contamination control a step further can yield transformative results. An option for those looking to extend their metalworking fluids' service life is offered in the form of a new process technology from SKF RecondOil: Double Separation Technology (DST).

DST is a two-stage combination of chemical and mechanical separation. The technology uses principles originally developed in the world of biochemistry, which have been adapted by SKF RecondOil for industrial applications. Compatible with a wide range of metalworking fluids and other industrial oils, the technology is capable of removing contaminant particles in all size ranges, all the way down to nano-size.

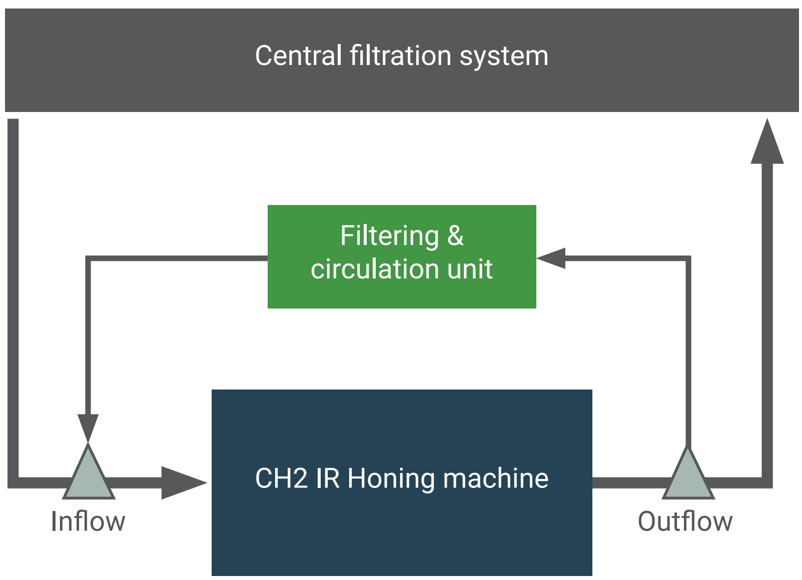
At its heart is a special separation booster; a chemical component that is added to the contaminated fluid in precisely metered amounts. Under carefully controlled conditions, the booster acts like a chemical magnet, attracting contaminant particles, water molecules and degraded additives and causes them to coalesce into larger clusters. These eventually settle in the fluid and can be extracted from the bottom of a reaction chamber as a concentrated contaminant sludge. In the second stage of the DST process, the fluid or oil is passed through a specialized mechanical filtration system that extracts any remaining separation booster, leaving behind ultra-clean fluid ready to re-use.

Solving the ghost rider problem in SKF factories

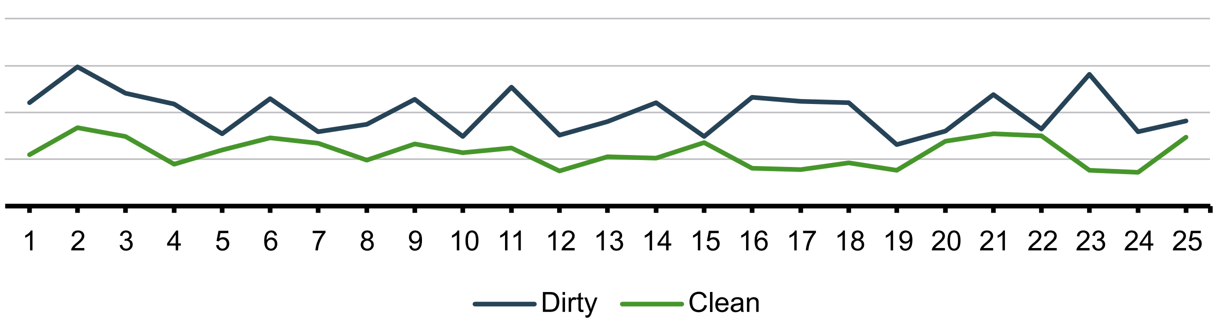
It is clear that ghost rider particles can cause many problems over time: poor production quality, lubricant oxidation, performance impacts, and even machine or component failure due to increased wear. By removing them completely, and continually, DST can be a highly effective way to maintain "reliably clean" metalworking fluid or oil.

To investigate the exact impact of clean oil in metalworking, SKF decided to test the technology in real-life conditions in their own manufacturing facilities. One area where clean oil was expected to contribute positively was in honing of bearing rings. Honing is a very important process for the bearing. In the honing step, final surface parameters which influence the quality and function of the bearing are set. A poorly honed surface contributes to higher noise and vibration, and it also affects the life of the bearing negatively.

The test was conducted in SKF's deep groove ball bearing factory in Cassino, Italy. Reference data was collected from the production by measuring components and fully assembled bearings. Then, in one of the channels, an inner ring honing application was isolated from the central honing oil feed to a separate filtration unit. In this filtering unit, clean oil was filled and circulated in the honing machine. No other parameters were changed.



After running the production with one machine supplied with clean oil, data was gathered for surface and general quality parameters. The first parameter analysed was the arithmetical mean deviation (Ra) of the raceway of the inner ring. This value is highly important for the bearing raceway, especially for deep groove ball bearings. Below is a graph showing the results from the Ra value sampling



In the above graph, the blue line represents the baseline of the channel, and the green line represents the production with the clean oil. Clearly, having clean oil circulating in the application affected the Ra value in a positive manner. The average difference of the Ra value was calculated to 25%.

Further parameters were examined in order to determine the full impact of clean oil in the honing of deep grove ball bearings. One major parameter that was analysed was the noise and vibration levels of the assembled bearings. This parameter is crucial for the end-quality of the bearing and how much customers are willing to pay. Noise and vibration are measured for all assembled bearings in the channel. Those out of the specified standard range are considered scrap.

A reference value was taken in the channel prior to the oil change. New values were then taken when production was run with clean honing oil. SKF discovered that simply by having clean oil in the application, and not changing any other parameter, the scrap figure decreased with approximately 40%.

Expanding the scope for DST

In the Cassino test, SKF determined that by having clean honing oil in the production of bearings, quality and performance increased. Besides expected savings on fluid purchase and disposal (calculated reduction is $55m^3$/year), SKF is also expecting an improved environmental footprint (around 150 tonnes of CO_2 emission avoided). And since ultra-clean oil improves the surface parameters significantly, SKF estimates a 40% scrap reduction at final noise and vibration inspections. What's more, since the oil used in the honing process is so clean, SKF is expecting to be able to remove an entire washing step from the manufacturing process.

At another SKF factory in Airasca, Italy, production is focused on hub bearing units, primarily for the automotive industry. The factory has installed a DST unit that is connected to the central honing oil supply system, where it is continuously regenerating the oil and creating a stable flow of super-clean oil. The system was installed in November 2020. Unfortunately, due to Covid-19, the site experienced some supply shortages during December and January. However, the system has been working as intended from February, maintaining record oil cleanliness levels. What's more, the DST system has provided increased stability. The exact monetary effect on SKF Airasca is still to be calculated, but with a more stable quality of the honing oil supplied to the machines SKF can trim the honing machines to be more effective and productive, resulting in exponentially increased benefits.

Double Separation Technology could have a big impact on the quality of the bearings, as well as the production performance, throughout SKF's manufacturing footprint. SKF has therefore decided to deploy the technology in a majority of its honing applications. In addition, DST is rolled out to SKF factories for quenching oil regeneration.

Industrial oils can be treated with DST again and again. And since the same fluids can be regenerated to their original state, the need to produce, purchase, and dispose of used fluids are significantly reduced. In fact, when combined with carefully selected oils, clean manufacturing procedures and the right know-how, DST can create a completely circular use of oil.

And metalworking applications are just the beginning for this technology. DST has proven to be excellent for removal of varnish and varnish potential, a major issue in hydraulic applications. DST can also be used to regenerate oil in gearboxes, turbine-generators, paper machines, and many other applications where reliable, efficient operation is required.

Zapp precision metals scrap rate drops by 80 percent

At Zapp Precision Metals AB, SKF RecondOil's Double Separation Technology has kept the same oil operating for more than nine years. Zapp makes high-precision fine wire, a product with high requirements on surface tolerances. Consequently, fluid cleanliness plays a significant role for their production output. Before DST, Zapp was changing the oil used in its drawing machines every 12 weeks.

A DST system is now integrated within the fine wire production line. The system processes around 5 percent of the total oil in circulation at any one time before returning it for use. Because the DST treatment removes contamination particles faster than they accumulate, the company has a constant supply of ultra-clean oil.

The approach saves Zapp money, eliminating the need to buy large volumes of new oil and dispose of contaminated material; however, the most significant benefit for the company has been in higher process performance.

Because the continually DST-treated oil always works like new oil – or even better – the drawing process runs more reliably and consistently. Zapp has seen scrap rates drop by 80 percent, productivity has increased by a quarter and the service life of wire drawing dies has doubled.

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