Metalworking fluids – pocket guide

Basics for best process stability

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Relevant documents and sources
BGR / GUV-R 143 "Technical rules for cutting fluids" (DGUV)
VDI Guideline 3397, sheets 1,2 and 3
UKLA Guideline “Good Practice Guide for Safe Handling and Disposal of Metalworking Fluids”

1 Introduction

1.1 Purpose of metalworking fluids

Metalworking fluids (MWF) are used in metal removal processes for a variety of reasons:

- Improving tool life and surface quality
- Reaching work piece tolerances
- Flushing away chips from the cutting zone
- Increasing metal removal rates and thereby reducing cycle time

1.2 Three basic types of metalworking fluids

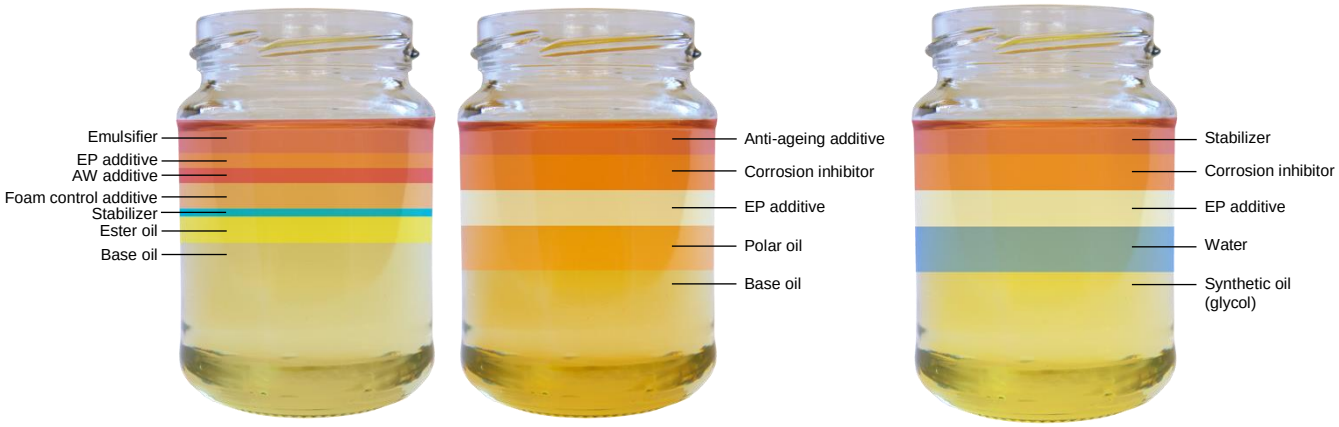
Water-miscible fluid **Neat oil** **Synthetic fluid**

Water-miscible fluids form an emulsion when mixed with water. The concentrate consists of a base oil (mineral oil or ester oil). The emulsifier help produce a stable emulsion. Additives are added to protect from corrosion, boost lubricity or ensure long-term stability. Water-miscible fluids are used in diluted form, with concentrations ranging from 3 to 15%. They provide good lubrication and heat transfer. They are widely used in the industry.

Neat oils are non-emulsifiable and are used in metalworking operations in undiluted form. They mainly contain a base oil (mineral or ester oil) and additives. Neat oils provide excellent lubrication but limited cooling characteristics.

Synthetic fluids do not contain mineral or ester oils. They are formulated from synthetic oils, pH-boosters and additives for corrosion inhibition. They are generally used in a diluted form (usual concentration between 3 and 10%). Synthetic fluids often provide very good cooling performance.

1.3 Main components of metalworking fluids



1.4 Choosing the right metalworking fluid

Consider the following when choosing the most suitable MWF:

- Material or material mix to be machined
- Type of machining (which operation)
- Water quality
- Specific qualifiers/disqualifiers of the industry segment
- MWF system
- Health and safety aspects

The following picture shows the main materials used in metalworking. It also shows whether they are easy or tough to machine.

2 Storage of metalworking fluids

2.1 Avoid direct sunlight

When storing MWF, the drums should not be exposed to strong sunlight for longer periods. On the surface of the drum, temperatures can exceed 70 °C (158 °F) and alter the properties of the fluid inside.

2.2 Avoid cold temperatures

The behavior of MWF during transportation and storage at low (cold) temperatures is very important. Some fluids are susceptible to freezing because of their water content. In order to maintain their quality, these MWF must be protected from freezing when transported on trucks or rail containers, and they may only be stored in heated premises.

If frost-insensitive MWF are stored outside, drums should be allowed to warm up at room temperature for at least 24 hours.

For shelf life and storage temperature of a MWF, consult the Safety Data Sheet (SDS).

3 Mixing of metalworking fluids

Water-miscible MWF are normally diluted with water. The typical concentration ranges between 3 and 15%. The recommended concentration depends on the operation and material and varies from MWF to MWF. This information can be found in the Product Information Data Sheet (PIDS).

3.1 Water quality

The main component of MWF emulsions is water. The water quality varies widely by source, region and country. It has a significant effect on emulsion quality and sump life.

Water hardness determines the foam behavior of many MWF emulsions
- In soft water (water hardness <8° dH/140 ppm), increased foaming may occur.
- Very hard water (well above 20° dH/350 ppm) may have negative effects such as formation of lime (calcium) soaps, weakened corrosion protection, reduced emulsion stability and shorter sump life.

Water hardness can be adjusted
- Calcium acetate can be added to increase the hardness of water that is too soft.
- Hard water can be treated by ion exchange. This means hardness is reduced and the water becomes soft. Other water treatment procedures like reversed osmosis (RO) or de-ionization (DI) removes all salts and leads to salt free water.

In most cases, normal tap water can be used for initial filling of the machine. Treated water is recommended for preparation of the daily top-up emulsion. However, some MWF need soft or even RO/DI water for a good long-term stability.

Chloride concentration
Another important quality parameter is the chloride concentration. Chloride should not exceed 25 mg/l, as it accumulates in the MWF over time.[1] High chloride concentration may lead to corrosion on machines and work pieces. Water treatment with RO/DI also eliminates the chloride in the water.

How to check water quality
Water hardness and chloride concentration can be checked on site with strips. In many cities and regions information on water quality is also available on the Internet.

[1] In Americas, upper limits of 40 ppm for emulsions and 20 ppm for synthetic coolants are recommended.

3.2 Correct mixing ensures a stable emulsion

A correct mixing procedure ensures a stable emulsion with fine dispersed oil droplets.

Automatic mixing
Best results are obtained by using an automatic mixing equipment like the Jetmix or Mini-Jetmix. When connecting to the drinking water supply, it must be ensured that emulsion cannot enter the drinking water system (installation of a backflush valve) per local regulations.

Jetmix

Mini-Jetmix

Manual mixing
For manual preparation, always add the concentrate to the water while stirring. Small quantities can be mixed in a clean separate container. The concentration must be checked with a refractometer.

Check concentration with a refractometer
It is recommended to check the concentration with a refractometer, even if the mixing unit has preselected concentration scales. Please note that the product-specific refractometer factor must be taken into consideration. The real concentration can be calculated by multiplying the refractometer reading in %brix with the refractometer factor. The refractometer factor of each MWF can be found on the product-specific PIDS.

4 Monitoring of water-miscible coolants

4.1 Why monitoring is important

Water-miscible MWF get contaminated during their use by dirt, guideway and hydraulic oil, by metal fines and even some unknown substances. This may directly influence quality aspects like performance, foam or the skin tolerance of the product. For process stability and minimizing health and environmental risks, a regular monitoring of the MWF is strongly recommended.

4.2 A stable concentration is a prerequisite for a stable process

The most important parameter to monitor is concentration of the emulsion. It should be checked whenever the tank gets filled up. The emulsion concentration is relevant for cutting performance, corrosion protection, foam and skin compatibility. Running the MWF with a stable concentration is a prerequisite for a stable process and long sump life. Several countries such as Germany, United Kingdom and USA request a periodical monitoring of the MWF.

4.3 Daily visual checks

Liquid level
The first check is the fluid level in the coolant tank. This is a prerequisite for proper MWF use. In machining centers with low fluid level, insufficient supply of the feed pump may lead to higher emulsion temperature, air suction and foaming. Additional possible consequences can be insufficient cooling of the work piece, reduced tool life or reduced performance (e.g. burn marks, excessive wear or built-up edges).

Color and stability
The second check is the visual check of the color and stability of the MWF. If visual changes can be detected (color change or floating oil layer on the surface), this could be an early warning for a quality change of the emulsion. Tramp oil can also form a floating oil layer. This layer must be removed continuously by an effective method (e.g. with an oil skimmer).

Since it is often difficult to reach the MWF in the tank, it is advisable to take a sample from the nozzle. Changes in the MWF can have many causes. Therefore the corrective measures may not always be the same.

4.4 Measuring the concentration

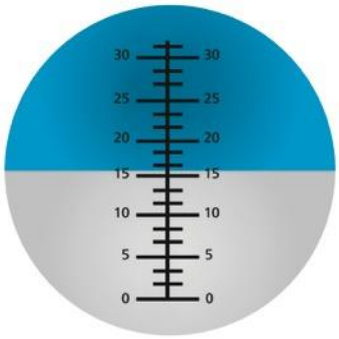
The concentration of the emulsion is the most important parameter to check on site. Check the concentration whenever the tank gets filled up. At least once a week the concentration must be recorded in a monitoring sheet.

Simple and cost-effective with a refractometer
The concentration measurement is simple and cost-effective with a handheld refractometer. The reading on the measuring scale, recognizable by a clear color-separation on the scale, indicates directly the concentration level.

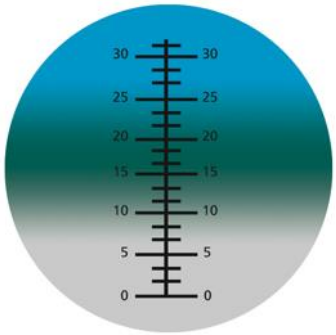
Refractometer factor
For some MWF, this reading must be multiplied with the product-specific “refractometer factor”. The result is the actual concentration of the emulsion.

Calibrating the refractometer
It is important to calibrate a handheld refractometer with water. Do this zero-point setting with good quality water before measuring the emulsion concentration.

Diffused reading
An emulsion heavily loaded with tramp oil or an unstable emulsion leads to a diffused reading (see picture).



Fresh and clean emulsion



Contaminated emulsion

4.5 Checking the pH value

The second on site measurement is the pH value. Check and record the pH value once a week with test strips. No calibration of these test strips is needed. Just be aware that they have an expiration date.

pH indicates the health of a metalworking fluid
The pH value trend over a certain time period gives valuable information. A consistent trend in one direction can be seen as early warning indicator.

Sharp drop of pH value: may be caused by low emulsion concentration or high tramp oil leaking.

Sharp increase of pH value: may indicate possible chemical contamination with an alkaline cleaner.

4.6 Determining the emulsion hardness

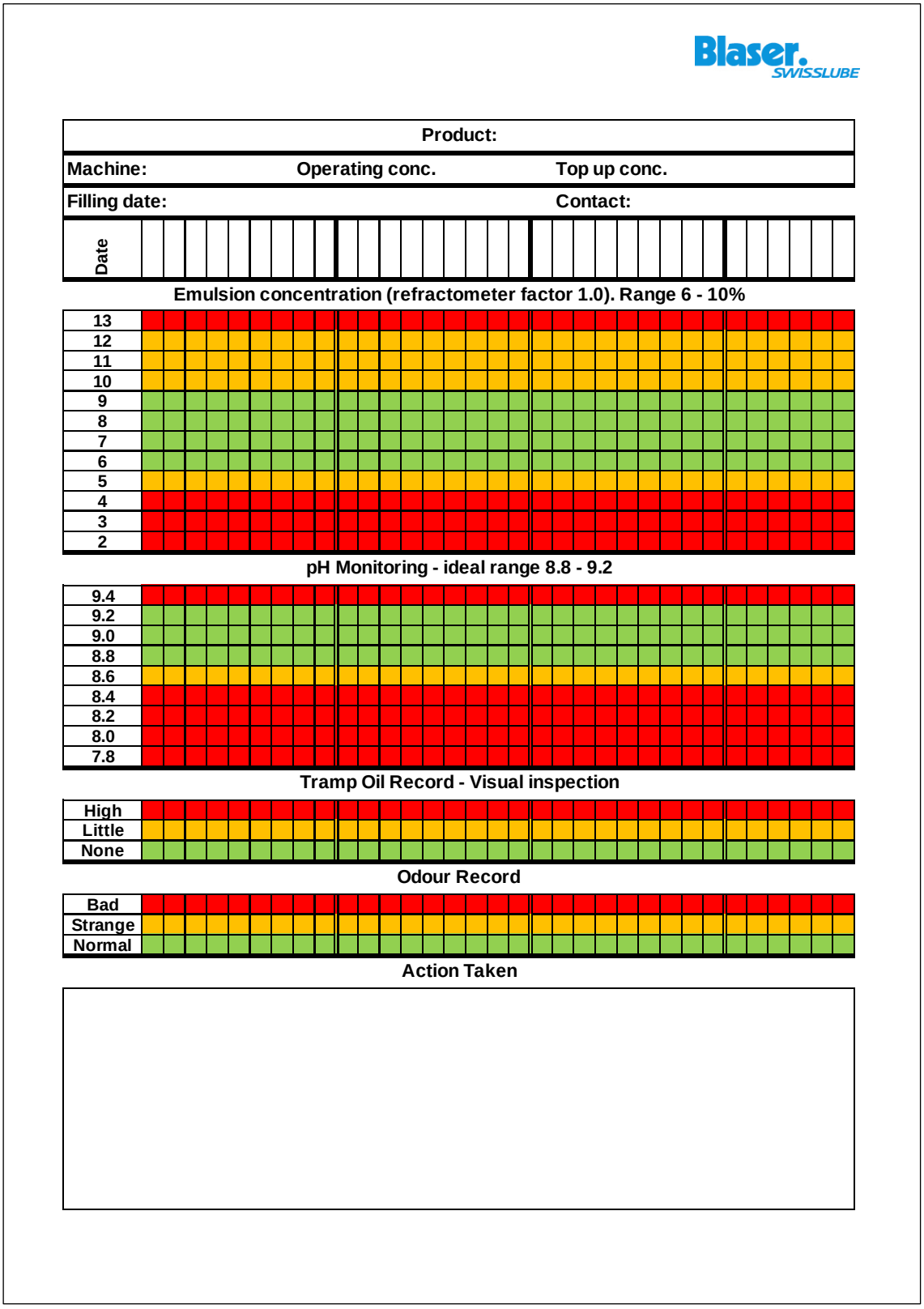
Another check that may be helpful is the determination of the hardness of the emulsion.

A consistent hardness ensures a consistent emulsion quality. Especially in applications with hard water and high water evaporation, a fast accumulation of hardness may occur. This can lead to an unstable emulsion or residue formation.

When RO or DI water is available, the hardness level can be managed by switching from hard water to RO or DI water based on the hardness level in the emulsion.

4.7 Monitoring sheet

The results of the on-site tests can be tracked with a simple Excel sheet. This sheet shows the current state and the trend over a certain time period at a glance.



Example of a monitoring sheet

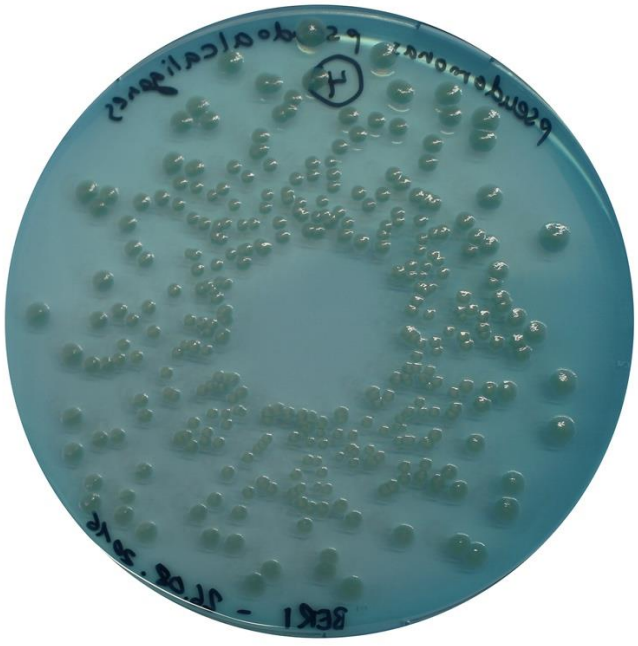
4.8 Additional on-site tests

Nitrite
In Germany, the technical guideline TRGS 611 requests a weekly check of Nitrite in water-miscible MWF. There are Nitrite test strips available. The upper limit for Nitrite is 20 mg/l. The background for this additional on-site test is the risk of Nitrosamine formation.

Microbial growth
In the United Kingdom, the UKLA guideline requests a monitoring program for checking microbial growth in water-based MWF by means of a dip slide test. The main reason for this additional test is to ensure the safety of the fluid. However, microbiologists and safety officers question the value of this test. Only colony-forming microorganisms are detected and the treatment with biocide is not always the best corrective measure under the aspect of safety for operators. Good housekeeping in combination with monitoring and maintaining the concentration and pH are considered as efficient and effective to maintain the quality and safety of a water-based MWF.

4.9 Dip slide tests with Bio-concept fluids

The Swiss coolant expert Blaser Swisslube offers the water-miscible MWF called “Blasocut”, which do not contain any bactericides and which foster the natural growth of benign bacteria. These coolants, which are gentle to operators’ skin, do not need biocide treatment. Dip slide tests do not make sense, as bacterial growth is desired.



Bio-concept coolant: Growth of primary (benign) bacteria is desired.

5 Monitoring of neat oils

Non-water-miscible MWF, also known as neat oils, are based on mineral and/or ester oils. Selected additives such as corrosion inhibitors, anti-mist, extreme-pressure and anti-wear additives improve the application properties.

Unlike water-miscible MWF, neat oils have an almost unlimited life. Bacterial contamination does not occur due to the absence of water. Important for the application is an oil temperature below 40°C (104°F), the optimal temperature is below 30°C (86°F).

Metal fines should be removed continuously by an efficient filtration system. A disadvantage of neat oils is the irreversible mixing with hydraulic, spindle and guide way oil. Such contaminations may change the viscosity and/or reduce the performance.

6 Lab tests

In addition to on-site tests, MWF can also be tested in the laboratory. The procedure is as follows:

- Take a representative sample of the MWF in use.
- Send it together with the sampling report to the customer service lab.
- After a few working days, you receive a lab report.
- Never send a sample without a sampling report. Without this document, the lab does not know the reason and goal of the lab test.

7 Maintenance of metalworking fluids

7.1 Ensure good starting conditions with a system cleaner

Thorough cleaning and rinsing of the machine or central system is crucial for good starting conditions. A long sump life can only be achieved with professional cleaning before refilling a system. While the emulsion tank, the chip conveyor, the filtration system and the machine room can be cleaned with a high-pressure cleaner, the cleaning of the piping system with mechanical methods is only possible with great effort.

System cleaners are therefore used to clean the non-accessible areas. They have special wetting agents that help wash off residues from areas that are hard to reach. Ensure correct concentration and duration of use. The technical data sheet shows the detailed procedure.

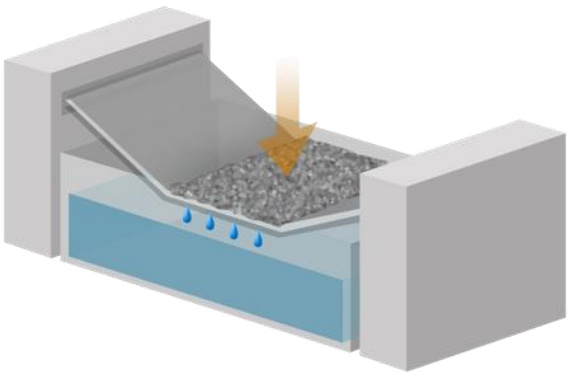
7.2 Other service products (Additives)

In most applications, there is no need for additional service products (additives). In some cases it may be economical to boost the pH value with an additive or eliminate stains on critical aluminum alloys. Calcium acetate may also be used as foam control additive.

7.3 Remove solid contamination

Filtration is the most frequently used method as mechanical separation process. The vast majority of processing machines are already equipped with a filtration system. All types of solid contamination are removed depending on the filter mesh (micron size).

The filtering process depends on the type of MWF (emulsion, neat oil or synthetic fluid). The required cleanliness of the MWF depends on the manufacturing process and the acceptable residues on the work pieces.



Band filters
Many machines have a filtration system with a paper filter. The filter cake is the real filter and filter paper is indexing as soon as the filter is blocked. The used filter paper is disposed of.

Some of these filter papers are covered with surfactant, meaning the fluid may start to foam due to the residues on the filter paper. This can be checked with a simple test: Put a piece of filter material in a glass of water for up to 1 hour. Then perform a shake test.

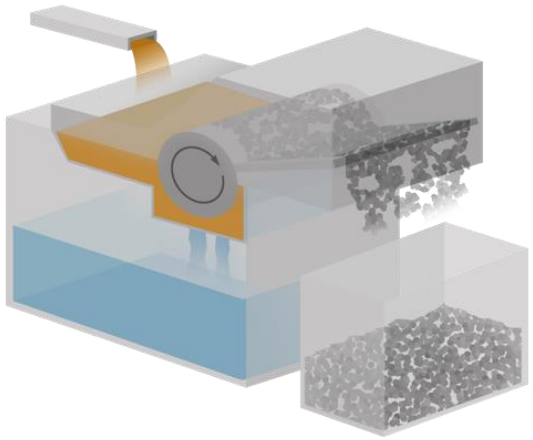
Due to increasing disposal costs, more and more filtration systems clean the filter and re-use it many times. As a result, the disposal costs for used filter material are considerably reduced. These so-called endless-belt plastic or metallic filters are a widely used filtering method in metal removal processes.

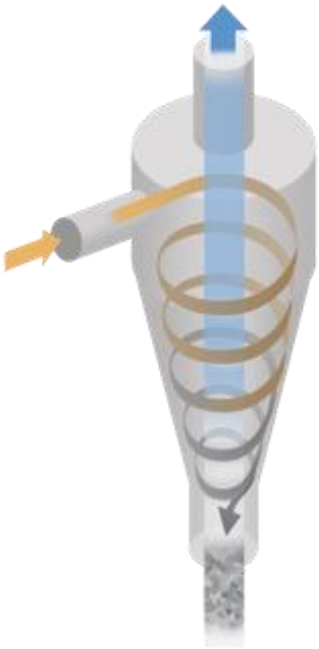
When filtering water-miscible MWF, there is a certain risk that too fine filters do not only separate solid particles from the emulsion, but also components of the MWF like hardness soaps or defoamers. As a result, the MWF may start to foam because of the filtration.

Magnetic separators
This technology is limited to ferromagnetic metal particles. It is used as continuous or discontinuous system.

A discontinuous system uses a permanent magnet that needs to be cleaned from time to time.

More economical are continuous band or drum magnetic separators, in which the metallic particles are permanently removed via scrapers from the belt or the drum.





Hydrocyclones
By setting the MWF into a rotary motion, the solids are pressed to the cyclone wall by the centrifugal forces, where they accumulate and leave the system as sludge. The sludge has a high moisture content and must be treated before disposal. This method is used exclusively with emulsions and synthetic fluids.

7.4 Remove liquid contamination

There are many types of permanent installations and mobile devices available. When selecting the equipment, also the subsequent maintenance must be taken into consideration, as there is a certain risk that components of the emulsion are removed together with the tramp oil. In order to prevent this, it is recommended to test the equipment in advance under real conditions.

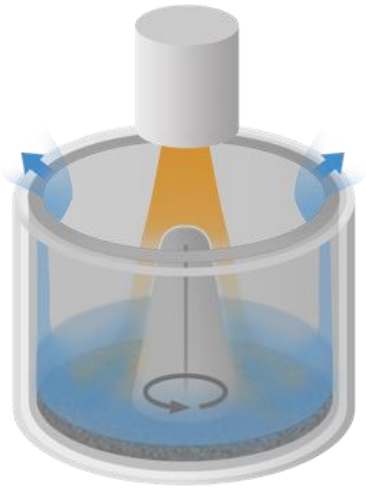
Oil skimmer
The oil skimmer is a relatively simple and economical way of removing unwanted oils. The tramp oil sticks to a moving disc or belt that is immersed into the emulsion. Important for this procedure is a zone without turbulence so that the tramp oil can separate from the emulsion. Otherwise the oil does not float on top of the emulsion and the oil skimmer also removes emulsion. In this case, only run the oil skimmer when the machine is turned off.

Emulsion without skimmer

Emulsion with skimmer

Coalescer
This equipment is intended for use in a bypass. Part of the MWF is removed from the system and calms down in the coalescer, causing the tramp oil droplets to accumulate and separate from the emulsion (coalescence). There are a variety of different types on the market, both as permanent installation and mobile device. Mobile devices are particularly suited for stand-alone tanks.

Centrifuge – 2-phase fluid separator
The MWF is brought to high acceleration (G-force) in the 2-phase separator. Due to the difference in density between MWF and oil, a separation takes place. For emulsions with bigger droplets, there is a risk that part of the emulsion separates as well and leaves the system. Therefore, a test under real conditions should be carried out in advance. The relatively high initial costs only pay off if the device is used most of the time.



7.5 Simultaneous removal of tramp oils and metal fines

The removal of solid and liquid contaminants can be combined by using a mobile cleaning unit. A permanent centrifuge can also be used if it is designed for this purpose.

Mobile emulsion cleaning unit (Freddy, Ecovac, MKR)
For a large number of machines with stand alone tanks, it can be economical to use a so-called emulsion cleaning unit, which is a maintenance system that can be used flexibly on all machines. It can be equipped with filter (candle filter) or centrifugal separation technology. It can be used with a bypass while the machine is running or during idle time of the machine. Mobile emulsion cleaning units must be cleaned regularly. In particular, in the case of discontinuous use, uncontrolled bacterial or fungal growth may happen during standstill.

8 Health and safety

8.1 Skin issues

Thousands of operators work with MWF without any health issues. Good housekeeping and the use of safe fluids is important. However, some operators may develop dermatitis on their hands, arms and face caused by frequent contact with MWF. This is similar to the effects of frequent contact with soapy water, which causes the skin to lose its natural lipid and barrier oils. An early indication of dermatitis is itching and red patches on the skin.

Possible preventative or corrective measures
- Minimize skin contact with the MWF.
- Wear gloves when appropriate to prevent direct contact of the MWF with the skin.
- Do not hold the parts in your hand during cleaning with compressed air.
- Wash hands, arms and any other exposed skin before taking a break and at the end of a shift. It is essential to dry the skin well.
- Use a good skincare regime: liquid gloves or barrier creams at the beginning of the shift and moisturizing cream after cleaning the hands.

8.2 Respiratory issues

There is a risk of respiratory problems for operators exposed to MWF mist, due to hazardous substances such as biocides and volatile chemicals contained in the mist.

Possible preventative or corrective measures
- Where practicable, enclose machining processes.
- Leave machines closed until the mist inside has sufficiently cleared before you open the door.
- Ensure that the MWF variables are appropriately set (nozzle position, flow rate, operating temperature).
- Avoid using compressed air when removing MWF residues without mist collector.
- Check air filters regularly.

9 Conclusion

It is crucial to invest time and money in monitoring and maintenance of your MWF. This does not only lead to longer sump life, which reduces consumption and disposal costs. It also ensures a more stable process as a whole, including more consistent tool life, better surface quality of the work pieces and lower risk for health issues.

10 Trouble shooting

Even with the best MWF and good housekeeping it can happen that the process stability is at risk. Most of the issues can be corrected by professional trouble shooting. See the separate booklet on-site trouble shooting for details.

11 Glossary

Aluminum casting	Multi-component alloy consisting of aluminum, silicon, magnesium, titan und zinc.
Aluminum wrought	Soft and gummy aluminum alloys. Prone to staining. Alloyed with Magnesium, copper, zinc and other elements.
Amines	Most widely used pH booster in metalworking fluids. They have a buffer capacity and keep the pH value in the alkaline range. Indirect corrosion protection.
ASTM	American Society for Testing and Materials. Institution that sets up the American mineral oil test standards among other things.
Bacteria	Microorganisms. One-cell organisms. Individually or in groups. The primary bacteria colonization of a metalworking fluid is the principle of the Bio-concept coolants by Blaser Swisslube.
Base oil	Mineral or ester oil. The main component of a metalworking fluid. Highly refined or stabilized for long sump life and with a good safety profile.
Biodegradable	The ability to be degraded by microorganisms in a given time. There is an official OECD method (OECD 302B).
Biocide	A chemical that is added to metal working fluids/concentrates in order to prevent microbial growth. The term biocide covers bactericides and fungicides.
Built-up edge	A piece of melted material that is formed at the cutting edge of a tool.
CAS-Number	Chemical Abstract Services Registry Number. A number that identifies a chemical. The number is assigned by the Chemical Abstract Service.
Cast iron	An alloy of iron, silicon and carbon. The first differentiation between cast iron and steel is the carbon content of the metal. Steels contain less than 2% carbon. Grey cast iron, ductile and white iron are types of cast iron.
Centrifuge	A machine with a rotary chamber, in which substances of different densities can be separated by centrifugal forces.
CFU/ml	Colony Forming Units per milliliter. Measuring unit for viable microbial populations.
Copper, brass, bronze	Copper: main alloy copper Brass: copper/tin alloy (more than 10% tin) Bronze: copper/zinc alloy (more than 40% zinc)
Creamy layer	A concentration of emulsion oil drops at the surface after the emulsion has been standing still for a certain time.
Emulsifiers	A molecule, which contains a polar and a non-polar group in the same molecule. The polar group is hydrophilic (water-soluble) and the other is lipophilic (oil-soluble). It emulsifies two liquids, which are not mixable.
Flash point	The lowest temperature at which oil ignites if it comes in contact with an ignition source. This is a standardized test.
Fungus	Multi-cellular aerobic microorganisms. Fungus may grow on the machine surfaces, inside pipes (areas outside the bulk fluid), on or beside the filters.
Fungicide	Biocide specifically for fungus. Fungicide is added to most water-miscible concentrates. Can also be used as sump side additive.
Galvanic corrosion	A corrosion process that attacks the surface by potential differences of two different metals with the help of electrolytes.
Hardness	Measurement of the calcium and magnesium salts specified as hardness degrees or ppm. The sum of all calcium and magnesium salts is the total hardness.
PPM	Parts per million. Corresponds to the unit mg/l.
Softened water	Exchanges cations (Ca2+ and Mg2+) with sodium ions. Ca2+ and Mg2+are responsible for the water hardness.
Stress-crack corrosion	Corrosion that is caused by stress due to high internal tensions of the metal.
Ultrafiltration	A separation technology in which a liquid is cleaned by a semi-permeable membrane. The cleaned liquid is called permeate and the waste stream, the effluent, contains the concentrated salts and impurities.
Water quality	For metalworking fluids the water quality plays an important role. Its quality varies with the region and the source. It can contain salts and microorganisms.

12 Notes

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