**Air Pollution Control** 



# Separating and Filtering **Metalworking Fluids** A Guideline for Practical Use

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visions with complete accuracy.

This guideline serves merely as an aid and offers only an overview to assist in assessing the design of air handling devices and systems in metalworking fluid and lubricant separation. It does not claim to be exact, nor to interpret the existing legal pro-

It is no substitute for scrutinizing the relevant directives, laws and regulations. In addition, the particular features of the products in question and the different ways in which they can be used should be taken into account. A large number of other constellations are therefore conceivable for the assessments and approaches addressed in the guideline.

# **1** Introduction

In Germany, around 200,000 metalworking companies use metalworking fluids in both cutting and forming manufacturing processes. They are predominantly used for processing metals in machine tools. Most metalworking fluids are complex mixtures and can carry health risks for people working in the process if they are not handled with care. Their impact on the environment, especially in terms of safe disposal and threat to groundwater, shall also be noted.

With this "Guideline for Practical Use", the Working Group Aerosols (see cover page 3) at VDMA (Mechanical Engineering Industry Association) aims to enable quick and easy access to the complex subject matter of airborne metalworking fluids.

The information provided in the revised edition of the guideline ranges from statutory principles and definitions to extraction and fire and explosion protection, up to the selection and design criteria and feasibility calculations of extraction systems. Each chapter includes references to current standards and directives for further information. The guideline is also intended to explain possible hazards and to show responsible use of these airborne substances.

# **1.1** Terms and Definitions

### Aerosols

Solid or liquid substances dispersed very finely in a carrier gas, e.g. air

# Emulsion

A cloudy, milky liquid that is a mixture of two liquids (usually oil and water) that cannot be mixed (Source: Portal Kühlschmierstoffe: www.dguv.de/ifa/)

# **Metalworking fluid**

Mixed substance used for cooling, lubrication and transport of chips in the separation and forming of materials

### **Minimal lubrication**

In contrast to flood lubrication, minimal lubrication uses only low quantities of lubricant (approx. 5-50 ml/h) during cutting See DGUV Information 209-024 (formerly BGI/GUV-I 718) www.dguv.de

### Oil mist

Extremely fine dispersion of oil droplets in the air

### **Oil vapor**

Colloquial term for the hydrocarbons in the gaseous phase

### Oil smoke

Airborne solid particulate normally resulting from combustion processes

### Crude gas

Loaded airflow before entry into the separator

# **1.2 List of Abbreviations**

# Table 1 Abbreviations and Links

Abbreviation	Definition	Link
OEL	Occupational exposure limit (TRGS 900)	www.baua.de
BGR	Rule provided for by professional association	
DGUV	German Social Accident Insurance	www.dguv.de
DIN	German Institute for Standardization	www.din.de
Energy-related products/ Ecodesign Directive	Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products	http://eur-lex.europa.eu/ LexUriServ/LexUri Serv.do?uri=OJ:L:2009:28 5:0010:0035:de:PDF
GefStoffV	German Hazardous Substances Ordinance	www.baua.de
НЕРА	High-efficiency particulate air filter	
IFA	Institute for Occupational Safety and Health (previously BIA)	www.dguv.de/ifa
TA Luft	Technical Instruction on Air Quality Control	www.umweltbundesamt.de
TRGS	Technical Rule for Hazardous Substances	www.baua.de
VDI	Association of German Engineers	www.vdi.de

# 2 Legal Fundamentals and Guidelines

# 2.1 Occupational Safety

Where work with metalworking fluids is conducted, every business must ensure that hazards due to contact with the skin and eyes, emissions into breathing air, hazards due to absorption into the body, and fire and explosion hazards are eliminated or reduced to a minimum as far as technically possible. The workplace concentrations prescribed in TRGS 611, TRGS 900, TRGS 910, etc. must be adhered to regarding the emissions, based on the composition of the metalworking fluids, the technical conditions and the physical properties.

According to the state of the art (DGUV Rule 109-003, formerly BGR/GUV-R 143), the following concentrations of metalworking fluids in the air are achievable:

- Water-mixed metalworking fluids in metal, glass and ceramic processing, water-mixable and water-mixed forming lubricants: 10 mg/m<sup>3</sup>
- Non-water-soluble metalworking fluids with a flash point > 100°C in metal processing: 10 mg/m<sup>3</sup>
- Non-water-soluble forming lubricants: 40 mg/m<sup>3</sup>
- Non-water-soluble metalworking fluids with a flash point < 100°C in metal processing: 100 mg/m<sup>3</sup>

# 2.2 Environmental Protection

Devices and systems for extracting metalworking fluid aerosols and smoke in which the extract air is conveyed to the outside shall be assessed in accordance with the Federal Immission Control Act (Bundes-Immissionsschutzgesetz). Unless certain values for the respective site are exceeded, they do not usually require approval.

Pursuant to § 22 "Obligations for Operators of Installations not being subject to Permission" of the Federal Immission Control Act, however, those harmful effects on the environment which are avoidable according to the state of the art shall be avoided or, should they be unavoidable, they shall be limited to a minimum.

For this purpose, reference is made to the Technical Instruction on Air Quality Control [TA Luft] dated July 24, 2002, Chapter 5.2.5 as a basis for such state of the art.

"Organic substances in the exhaust gas, except for dust-like organic substances, shall not exceed

the mass flow rate of 0.50 kg/h or the mass concentration of 50 mg/m³, in each case indicated as total carbon,

in total. (...)

Within the mass flow or the mass concentration for total carbon those substances classified for Class I (substances according to Appendix 4) or Class II shall not exceed in total the following mass concentrations or mass flows in the exhaust gas, in each case indicated as mass of the organic substances, even if several substances of the same class are present.

### Class I

The mass flow rate of	0.10 kg/h
or	
the mass concentration of	20 mg/m³

# Class II

() The mass flow rate of	0.50 kg/h
or	
the mass concentration of	0.10 g/m³

Where substances from several classes are present, in addition to the requirements stated in Paragraph 4 Clause 1, the emission values of Class II not be exceeded in total if substances of both Class I and Class II are present in the exhaust gas."

# 3 Metalworking Fluids

# 3.1 What are Metalworking Fluids?

Metalworking fluids are non-water-mixable, water-mixable and water-mixed liquid preparations for cooling, lubrication and rinsing in production processes in cutting and forming processing.

For more information, see also DIN 51385 "Lubricants – Processing fluids for forming and machining of materials – Terms".

# 3.2 Maintenance and Disposal

Metalworking fluids are subject to various changes during their use, and may become contaminated. This can only be partially prevented in normal operations.

The operator is obligated to monitor the state of the metalworking fluids regularly (see DGUV Rule 109-003 and VDI 3397 Part 2).

The statutory regulations (see VDI 3397 Part 3) shall be adhered to in the disposal of metalworking fluids.

# 3.3 Emissions from Metalworking Fluids

Metalworking fluid emissions occur during cutting and forming processes. These emissions emerge as aerosols, vapors and smokes. The following examples are noteworthy:

- Mechanical emissions, by scattering in the case of spinning parts (e.g. in turning and grinding) or by blowing off work pieces
- Evaporation of metalworking fluids on hot surfaces (work pieces, tools or hot chips)
- Smoke generation through combustion processes, e.g. when insufficient metalworking fluid is used

The droplet size in case of mechanically created aerosols is significantly larger than in case of those emerging during thermal processes. Other emission sources that occur are the warm, processed work pieces stored in open receptacles. In principle, all surfaces wet with metalworking fluids (oily cleaning rags, wet floors, contaminated working clothes, etc.) are considered to be emission sources – the warmer they are, the more they emit. Further emission sources include bursting foam bubbles, solvents and detergents.

The cooling effect of the metalworking fluid plays a key role here (see Table 2). It has a direct impact on the evaporation rate (see VDI 3397 Part 1).

The flash point and the evaporation loss in accordance with Noack at 250 degrees Celsius have proved themselves as guide values for the selection of a low-emission lubricant; see also DIN EN ISO 2592 and DIN 51581-1.

# Table 2 Figures on cooling effect

Mineral oil	Water
approx. 1.9 J/gK	approx. 4.2 J/gK
approx. 0.1 W/mK	approx. 0.6 W/mK
approx. 200 J/g	approx. 2.300 J/g
	Mineral oil approx. 1.9 J/gK approx. 0.1 W/mK approx. 200 J/g

# 3.4 Hazards/Risks from Metalworking Fluids

"The toxicological assessment of the metalworking fluids depends on their material composition and on the properties of the components, the number and proportion of which differ significantly depending on the purpose. (...) Where metalworking fluids are used, high temperatures on the blade can cause vapors and high speeds can cause aerosols to enter the air at the workplace. There are very few findings from animal experiments or epidemiological studies regarding the long-term effect of absorption into the lungs under working conditions.

However, the toxic profiles of individual components indicate systemic toxic reactions after pulmonary or dermal resorption. Reactions in the respiratory tract and lungs after inhalation can be irritating or toxic. It can be assumed that the systemic toxic effects and the local effect on the skin and respiratory tract largely stem from the additives. (...)"

"The justification for systemically barely toxic metalworking fluid components that are assessed as being non-irritant to mucous membranes and for which no TLV value can be stated indicates that no health hazard due to the substance is anticipated at a concentration of up to 10 mg metalworking fluid per m<sup>3</sup>, which corresponds to the technology-based threshold in the BG rule (BGR/GUV Rule 143, 2011)." Excerpt from TLV and BAT value list 2016. DFG, Deutsche Forschungsgemeinschaft, see References.

The VKIS-VSI-IGM substance list contains the substances that should be used by manufacturers in metalworking fluids, those that are shall not be used, and those that are subject to mandatory declaration (www.vsi-schmierstoffe.de), see References.

# 4 Collection and Separation

# 4.1 General

Three primary measures shall be considered in order to prevent the hall air becoming contaminated with metalworking fluids:

- Avoiding the occurrence of aerosols, metalworking fluid vapors and oil smokes
- Full collection of unavoidable aerosols, e.g. through full encapsulation of the machine tool
- Hall ventilation (see Chapter 6)

Of major importance for the avoidance of the very fine metalworking fluid aerosols, oil vapors and oil smokes is the correct cooling and lubrication of the work piece during processing. Faults which might occur here include the following:

- Quantity and pressure of metalworking fluid not adapted to the processing process;
- Use of an unsuitable metalworking fluid.

Furthermore, secondary sources shall be avoided or reduced using the following measures:

- Maintain the machine tools regularly.
- Store warm, wet work items and avoid containers open to the atmosphere.
- Dispose of wet chips as quickly as possible.
- Bind spilled metalworking fluids using a binding agent and dispose of them.
- Cover collection and transport channels and the metalworking fluid treatment system.
- Avoid formation of foam in order to prevent emissions from burst foam bubbles.
- Do not allow metalworking fluids to spread into floor pans.

- Do not blow off wet work items; if this is unavoidable, then vacuum the workspace.
- Clean the workspace of metalworking fluids regularly; do not use any solvents.
- Do not leave cleaning rags and similar articles lying around.
- Keep the temperature of the metalworking fluid as low as possible.
- Reduce the amount of solvents and cleaning agents used.

# 4.2 Design Criteria for Separator Systems

One of the most complex issues for the handling of metalworking fluids is the design of a separator system for the metalworking fluid emissions that arise and for other production-related air pollution such as smoke, metal particles, grinding plate wear etc.

Because separator systems are process systems, expert advice is needed in order to prevent bad investments and guarantee operational safety. Incorrectly-designed separator systems lead to insufficient suction and separation performance as well as increased operating costs. In general, note the following:

- There must be underpressure in the encasing so that the movement of air is always into the processing space and not vice versa.
- It shall be possible to adapt the suction volumetric flow to the processing process, e.g. using a regulator valve or speed control.
- The air circulation inside the machine needs to be optimized.
- Where possible, the suction position inside the machine should be on the ceiling or wall opposite the machine doors and far away from the processing point, in order to achieve reliable suction of contaminated air.
- An impact plate should be installed in front of the suction nozzle so that larger particles cannot enter the separator system or the pipeline.
- A suitable separator system should be selected depending on the metalworking fluid used and the aerosol concentration; see Chapter 5.
- The suction speed in the pipeline for metalworking fluids should be in the range of approx. 12 m/s - 16 m/s; see VDI 3802 Part 2, Chapter 12.2.1. In the case of minimal lubrication, the suction speed is > 20 m/s (see VDI 3802 Part 2, Chapter 12.2.2).
- The suction speed in the collection cross-section at the collection inside the machine tool should be no more than 4 m/s; see VDI 3802 Part 2, Clause 8.2.2.2).
- The piping should be welded for tightness; folded pipes (spiral pipes) are not recommended. The pipes can be connected using beading and a clamping ring, or with flanges. An oil-resistant seal between the pipe connec-

tions is essential. All pipe components shall be designed for the maximum under-/overpressure. The piping should be installed with a gradient (1 % - 2 %) down to the separator. Where this is not possible, discharges shall be provided. Discharged water-mixed metalworking fluid cannot be returned to the metalworking fluid cycle.

- The piping network shall be designed for optimum flow in order to cause the lowest possible loss of pressure/resistance. When designed incorrectly, branches and elbows in particular cause an unnecessarily high loss of pressure (high noise level), which is reflected in higher operating costs. The piping system shall therefore be designed and installed by a specialist company.
- Cross flows at the collection point (e.g. due to drafts or compressed air) should be avoided in partially-encapsulated machines.

# These issues only represent a small extract from the assessment criteria.

Even when the suction point is correctly positioned, there is the risk that too much metalworking fluid will be taken in when the volume flow is too high. In addition, the choice of an unsuitable suction point and an incorrectly-set suction capacity can cause the emission discharge to change by a factor of more than 20 in the same separator system. This reduces the life span of the separator significantly.

# 4.3 Suction Volumetric Flow

Modern processing machines are usually fully encased. This shall be taken into account when determining the suction volumetric flow: if the volumetric flow is too high, an excessive quantity of the metalworking fluid itself will be extracted; if it is too low, metalworking fluid mist will escape from the machine encasing. The precise design of the air volumetric flow depends on the construction of the encasing and the processing process. General design specifications such as "200 air changes" should be assessed with caution.

# The suction volumetric flow is determined by the following factors:

- 1. Type of processing (turning, milling, grinding etc.);
- 2. Total open area such as joints, cracks, operating door and shaving discharge opening;
- 3. Volume of processing space;
- 4. Manual or automatic placement;
- 5. Type of metalworking fluid;
- 6. Pressure at which the metalworking fluid is brought in.

If the precise factors are not known, more generous design and subsequent adjustment, for example, are recommended.

# 4.4 Crude Gas Load

The crude gas load of the extract air from a processing center is one of the biggest cost drivers. It ultimately determines the design of the separator system. The higher the crude gas load, the more generous the dimensions of the separator in particular, not the volumetric flow, need to be. It is important to ensure that a filter system is chosen in which the liquid (in the case of emulsion and oil mists) can flow off quickly or in which independent regeneration (e.g. dust extractors) in minimal lubrication or dry processing enables acceptable life spans.

# Determining factors for the crude gas load include the following:

- Type of processing (high concentrations are achieved in grinding processes, for example).
- The material to be processed (wet-processed aluminum contributes little to the crude gas load; higher values are reached during dry processing).
- Energy input: The crude gas load is almost in proportion to the energy input required for direct processing, e.g. hard metal always has high values, as a great deal of energy is needed for processing.
- Spray-in pressure of the metalworking fluid: The crude gas load rises proportionately as the spray-in pressure of the metalworking fluid increases.
- The metalworking fluid temperature: The higher the temperature, the greater the proportion of gaseous components in the crude gas flow. This gas phase cannot be separated economically by any conventional system.



Figure 1 Cumulative frequency distribution in relation to the mass during external longitudinal turning

Source 1

# 4.5 Filtration Efficiency

There is no classification for air filters or separators when used in connection with metalworking fluids. The following standards are used for classification in practice: DIN EN 779 and DIN EN 1822-1. The current performance of the electric filters is comparable up to filter class E12 in accordance with DIN EN 1822-1 (see also VDI 3678 Part 2).

The goal is to adhere to the assessment value of 10 mg/m<sup>3</sup> at the workplace, set for technical reasons. The less metalworking fluid is returned into the factory hall, the lower the volumetric flow of outdoor air needed to adhere to the 10 mg/m<sup>3</sup>.

When assessing separator systems for metalworking fluid emissions, it is important to remember that both aerosols and metalworking fluid vapors (gas phase) are present. The separation level described above relates only to aerosols. For the typical distribution of aerosols, see Figure 1.

Interpretation example from Figure 1: 50 mass percent of the ester oil particles are smaller than 1  $\mu$ m.



Figure 2 Filtering separators



Figure 3 Filter media Source 3



# 4.6 Air Pollution Control Processes for Metalworking Fluids

# 4.6.1 Filtering Separators

In filtering separators, the extract air to be cleaned is directed through a filter medium, in which the dispersed solid or aerosol particles are retained by various mechanisms. For metalworking fluids, separators that clean the contaminated air using various filter materials, such as filter non-wovens, demisters, filter mats and HEPA filters are used here (see Figure 2). Using different filter qualities in series allows the extract air to be cleaned to the air quality required in each case (see also VDI 3677 Parts 1 and 2). When a certain degree of saturation is reached, the filters are cleaned or disposed of.

For more information on filtering separators, see the guideline VDI 3677 Parts 1 and 2.





Figure 4 Filtering separator

Source 4 Figure 5 Filtering separator



# **4.6.2 Coalescence Separators/Demisters**

In coalescence separators, various mechanical, physical and chemical processes cause the metalworking fluids to be deposited on the fibers of the coalescence element. The microscopic oil droplets join up in the fiber structure, coalescing into larger droplets and eventually an oil film. The enlarged droplets move to the surface of the filter element with the airflow, before the drainage effect and gravity cause them to fall to the encasing floor (see Figure 6).

The drainage effect means that the filter element constantly cleans itself.

The demister works in the same way as the coalescence separator. Demisters are usually characterized by knitted fabrics. Filter non-wovens, which have a high-quality oleophobic and hydrophobic surface, are increasingly used as an alternative to demisters. They can be used regardless of the volumetric flow.







Source 6 Figure 8 Demister



### Figure 9 Functional principle of electrostatic precipitator



Source 2



In electrostatic precipitators, the contaminated air is cleaned based on the physical principle of deviation of electrically-charged aerosols in an electric field. Here, the solid and/or liquid aerosols contained in the extracted carrier gas (air) are given a unipolar charge in the ionization zone. The aerosols are separated in the downstream separation zone (collector).

The collector usually consists of a series of vertical metal plates parallel to the air flow. Inside the collector, electrostatically-charged aerosols are deviated towards the earthed plates in an induced electric field and separated on the collector plates, where they can flow off by force of gravity (see Figure 9).

For more information on electrostatic precipitators, see the guideline VDI 3678 Part 2.







Figures 10-13 Electrostatic precipitators Source 8 Source 9 Source 2 Source 10



Figure 14 Functional principle of inertial or centrifugal separator

Source 2

# 4.6.4 Inertial or Centrifugal Separators

Centrifugal separators are members of the inertial separator family most commonly used in metal processing. Air pollution control here benefits from the fact that mass-proportional field forces i.e. centrifugal forces act upon the particles and aerosols. Due to their inertia of mass, the particles and aerosols thus move in a direction perpendicular to the airflow direction, separating them from the airflow (see Figure 14). Centrifugal separators are only suitable for separating larger particles and aerosols and are therefore often used for pre-separation of foreign substances (air pollutants).

Guideline VDI 3676 provides information on inertial and centrifugal separators.





Source 11 Figure 16 Functional principle of wet separator

Source 11

### 4.6.5 Wet Separators

Wet separators are used in metal processing to clean the air where it is contaminated with sticky, adhesive substances and especially explosive or flammable dry metal dusts.

In wet separators, the particles or aerosols to be separated are sprayed with scrubbing liquid or fed into a liquid bath, which deposits on the foreign substances (see Figure 15). In a subsequent step, the agglomerates formed here, consisting of drops and particles, are removed from the airflow. Depending on the cleaning process used,

wet separators are classified into different types such as self-induced-spray scrubbers, impingement scrubbers, wash bottle scrubbers, rotary scrubbers or venturi scrubbers.

Wet separators are described in the VDI 3679 series of guidelines.

# 4.7 Suitability of the Separation Principle

The correct selection of a separation principle depends on the metalworking fluid used. A rough selection matrix can be structured as follows.

Combined separator systems, which make good use of the benefits of the various systems, are often used in practice. In central systems, experience has shown that a high level of evaporation of the water content in water-mixed metalworking fluids and pre-separation of the oil content in the piping should be anticipated. This explains the different evaluations of de-centralized and centralized suction using individual separation principles in Table 3.

Recommendation: Due to the wide variety of application cases, individual advice is recommended.

	Oil	Emulsion	Min. lubrication*)	Smoke
Electrostatic precipitator (ESP)	А	C/A <sup>2)</sup>	С	А
Filtering separator				
Demister	С	В	D	D
Coalescence	А	B/A <sup>2)</sup>	D	D
Filter in accordance with DIN EN 779 Superseded by DIN EN ISO 16890	C/B <sup>2)</sup>	A	B/A <sup>2)</sup>	С
Filter in accordance with DIN EN 1822-1 (HEPA) <sup>1)</sup>	C/B <sup>2)</sup>	А	А	A
Dust extractor	D	D	А	С
Centrifugal separator	С	С	D	D

# Table 3 Technical suitability based on functional principlefor separator systems

A = suitable

B = mostly suitable

C = less suitable

D = unsuitable

Footnotes for table: \*) MQL (Minimum Quantity Lubrication) 1) as downstream filter 2) in centralized systems







Figure 18 De-centralized suction system with individual separation Source 2

# 4.8 Centralized and De-centralized Suction

For the removal by suction and subsequent separation of metalworking fluid aerosols, the decision has to be made in every individual case whether each emission source/machine shall be fitted with a separate individual device or whether the whole suction-relevant machinery can be covered by a centralized or group suction system. In each individual case, the optimal solution will always depend on various fundamental considerations and the individual marginal conditions present in the manufacturing plant.

In both suction-technical concepts all unavoidable emission sources (workspace, shavings conveyor, ejection box, metalworking fluid preparation plants, etc.) should be included into the collection concept. **4.8.1 De-centralized Suction (Recirculating Air)** Each de-centralized or individual suction device can extract and clean the extract air from just one machine with one or more emissions sources (see Figure 17). The suction device can be attached directly to the side or top of the machine, or positioned next to the machine on a frame or on the chip conveyor. The cleaned extract air is reversed out into the hall as recirculating air. The statutory provisions for recirculating air operation in accordance with Clause 2.1 "Occupational Safety" shall therefore be adhered to.

The suction volumetric flow is derived from the size of the workspace for which suction is to be provided and the processing process, see Clause 4.3.

# Assessment criteria for De-centralized Suction Devices

### Advantages

- Qualitatively and quantitatively clearly defined solution for a specific case of application.
- The suction of the remaining machinery is not affected when a separator is being main-tained.
- Very high flexibility in case of new arrangement of the machine park or in case of individual machines being omitted or added.
- Low assembly effort due to short pipelines.
- No interfering pipeline systems.

### Disadvantages

- Increased ventilation requirements, see Clause 2.1 "Occupational Safety".
- Unseparated metalworking fluid vapors are recycled into the production hall, see Clause 2.1 "Occupational Safety".



Figure 19 De-centralized suction system

Source 9

- Increase in extract air temperature due to energy input and increase in the relative humidity of the cleaned extract air due to evaporation cannot be influenced or reduced.
- The humidity in the hall can increase dramatically when water-mixed metalworking fluids are used (e.g. corrosion problems).
- When numerous separators are installed, the number of maintenance points and the maintenance effort increase accordingly.
- Exhaust air operation or alternative summer/ winter operation is only useful for large machines with high quantities of extracted air.





Figure 20 De-centralized suction system

Source 6 Fig

Figure 21 De-centralized suction system



Figure 22 Centralized suction system

Source 2

Figure 23 Centralized suction system

Source 8

**4.8.2 Centralized Suction Systems (Exhaust Air)** Instead of lots of individual suction devices, a centralized suction system can be installed for suction and air pollution control for multiple neighboring machines with one or more emission sources (see Figure 22).

The individual machines/emission sources are connected to central suction piping with multiple cross-connection pipes. They are extracted and the exhaust air cleaned with just one separator system. It is important to ensure that water-mixable and non-water-mixable metalworking fluids are extracted and separated in separate systems. It is best to design the suction piping with leakproof beading or flange pipes (not spiral ducts) connected in a modular system. This enables fast and easy assembly and any system conversions/additions later can be done easily. Pre-separators or impact plates respectively on the machine tools are recommended.

Options for heat recovery should be provided in the exhaust air line. This helps to save heating energy, especially during the cold winter months. One advantage of centralized suction systems with exhaust air operation compared to individual suction devices is the fact that not only particular contamination (aerosols, mist, smoke, dust) can be cleaned out, but a central suction system can also reduce the relative humidity in the hall air, the hall temperature and the odor pollution. Please see Clause 2.2 regarding emission values.



Figure 24 Centralized suction system

# Assessment criteria for Centralized Suction Systems

### Advantages

- Choice of recirculating air and exhaust air operation.
- In summer, the warm, humid, odorous extract air can be blown to the outside as exhaust air and replaced with incoming cold, fresh air from outside.
- In winter, the warm extract air can either be blown to the outside via a heat recovery system and the thermal energy transferred to the cold supply air, or the warm extract air can be blown back into the hall as part of the recirculating air (see VDI 3802 Part 2).
- The quantity of air extracted can be adapted to the actual demand of the machines for which suction is required using frequency converters (either manually or via underpressure control).
- Only one centralized maintenance point; thus lower maintenance costs compared to individual suction.

# Disadvantages

- Increased assembly effort due to installation of suction piping.
- Disruptive piping (e.g. in crane operation).
- The suction concept shall be planned with air capacity reserves in order to ensure sufficient suction if additional machines/emission sources are integrated.
- Increased energy consumption can occur due to increased pressure losses in extended piping systems.



Figure 25 Centralized suction system



Source 9 Figure 26 Centralized suction system

# **5** Selection Criteria for a Separator System

The selection of a separator system depends on many factors. The following key factors need to be considered:

1. Processing process

Metalworking fluid: oil, emulsion, minimal lubrication Process: turning, milling, drilling etc.;

### 2. Machine tool

Size of processing space minus installations and work piece, position of collection, size of loading doors, machine encasing, drive capacity;

- 3. Work piece material Steel, stainless steel, aluminum, titanium etc.;
- Metalworking fluid properties and composition Technical data sheet;
- Metalworking fluid supply Flush cooling, interior cooling, metalworking fluid pressure;

- 6. Crude gas concentration The crude gas concentration depends on points 1 to 5;
- **7. Spacial structure of the manufacturing hall** Space volume, height of hall, hall supply air and exhaust air, natural air supply via windows and doors;
- 8. Air re-circulation/exhaust air See Clause 4.8;
- 9. Suction system concept (centralized/de-centralized) See Clause 4.8;
- Heat recovery system (HRS) In exhaust air operation, an HRS can be useful (Energy Saving Ordinance does not apply);
- **11. Investment/operating costs** See Clause 10.

# 6 Hall Ventilation

The hall ventilation has a big impact on the air quality in manufacturing halls.

Due to different sources generating heat, such as processing machines, thermal flows that transport hazardous substances to the ceiling of the hall arise in an industrial hall (see Figure 27). The air circulation in the hall now has to ensure – apart from its task to create a bearable room climate – that such thermal flows do not reenter the breathing area of the employees. Furthermore, the hall ventilation has to ensure that the air deficit in case of extract air operation is compensated.

The principle of layered ventilation at the source is well suited to meeting these requirements (see Figure 28).







Figure 28 Layered ventilation

Source 2

An optimal ventilation system is presented, that includes air circulation as layered ventilation and discharges the extracted air to the outside as exhaust air (see Figure 29).

Important information and recommendations on the topic of air circulation can be found in the following sources:

- VDI 2262 Part 3
- VDI 3802 Part 1
- VDI 3802 Part 2

Source 2



Figure 29 Example of an optimal ventilation system

Source 10

# 7 Energy Efficiency/Management

# 7.1 Introduction

In general, process reliability needs to be guaranteed ahead of energy savings.

As well as the separation capacity, the energy efficiency is one of the most important criteria for a separation system. The energy consumption of a separation system is determined by the following factors:

- 1. Average pressure loss;
- 2. Average volumetric flow;
- 3. Extract air heat;
- 4. Compressed air (if applicable).

The energy consumption is clearly dominated by points 1-3.

# 7.2 Overview of Energy Consumption by Separation Performance

The next step is to check whether the right separator system has been selected. Table 4 below can act as a guide.

The energy consumption depends strongly on the design values, e.g. the filter face velocity, filter area, modes of operation. Assessment requires suitability in accordance with Table 3.

# As a general rule:

When selecting the right separator system for the application, it is always a matter of choosing a separator system with a high separation efficiency.

# Table 4 Energy consumption of separator systems

	Energy consumption	Separation capacity	Volume flow adjustable
Electrostatic precipitator	Low	High	Yes
Filtering separator			
Demister	Medium/High	Low/Medium	Yes
Coalescence	High	High	Yes
Filter in accordance with DIN EN 779	Medium	Medium/High	Yes
Filter in accordance with DIN EN 1822-1 (HEPA)	Medium/High	High	Yes
Dust extractor	High	High	Yes
Centrifugal separator	High	Low	No

# 7.3 Energy Costs (Separator System)

Consider the following example for how the separator pressure difference affects the energy costs:

The energy requirement is calculated by this equation:

$$E = \frac{Q \cdot \Delta p \cdot t}{\eta}.$$

Type of operation:	3 shift operation
Operating hours <b>t</b> :	6,000 h/a
Pressure difference $\Delta p$ :	100 Pa
Volumetric flow <b>Q</b> :	1,000 m³/h (correspond-
	ing to <b>Q</b> = 0.278 m³/s)
Efficiency <b>η</b> :	0.5 (fan)
Electricity costs:	€ 0.15/kWh
Energy consumption <i>E</i> :	333 kWh/a
Energy costs:	€ 50.00/a
CO <sub>2</sub> :	1.66 t/a (related to
	German energy mix
	2010)

That means: 500 Pa greater pressure difference at 2,000 m<sup>3</sup>/h corresponds to  $\in$  500.00/a energy costs and 1.66 t/a CO<sub>2</sub>.

The volumetric flow needed is determined by the process. Mist shall not escape from the machine at any time during processing. To achieve this, there shall always be underpressure in the machine.

# 7.4 Fans

When it comes to the system, the selection of the fan is the main priority here. As well as a fan with high efficiency, the option of adjustability should be selected here. This can be shown in two examples:

Figure 30 Characteristic curve for a system with regulated/ non-regulated fan

Source 10





Figure 31 Heat recovery

Source 11

As Figure 30 clearly shows, when a system has a non-regulated fan (blue arrow), the overall system starts up with a significantly increased separator pressure difference and an excessive quantity of air extracted. This results from the shift away from the target working point (red point) to the fan characteristic curve (blue point).

In contrast, in a system with a regulated fan (red arrow), adapting the fan capacity from the start allows the air quantity to be kept constant. The capacity is adjusted accordingly as the separator pressure difference increases (red arrow).

The adjustability of the fan thus ensures that work is always conducted at the optimum operating point. This also applies to the operation of the suction system itself. The use of regulated fans enables energy savings of more than 50%.

# 7.5 Heat Recovery

Heat recovery is generally a useful and necessary consideration. It is conducted via a heat exchanger system in the exhaust air. Up to 70% of the heat demand can be saved like this. For occupational safety reasons, no substances should be transferred from the exhaust air to the supply air when a heat exchanger system is used. Recuperative heat exchangers should be preferred (e.g. cross-flow heat exchangers, combined circulatory systems).

Where heat recovery is essentially useful, EnEV 2014 is not applied to process air systems.

# 8 Fire Protection

Today, non-water-mixable metalworking fluids are used when cutting work pieces in the metal processing industry. Flammable metalworking fluids are used. Thus increasing the danger of a fire during processing due to the occurrence of a reactive oil-air mixture.

Both the manufacturer and the operator of machine tools are subject to the following obligations regarding protection against fire and explosion:

- As part of a risk assessment (suitability of the machines for the intended metalworking fluid), the operator is obligated to check whether a risk of fire and explosion is present.
- The manufacturer takes this information into account when defining a suitable protection concept for the machine tool and adapts his operating and maintenance instructions to it.

More than 50% of fires on machine tools today are the result of tool breakage or an insufficient supply of metalworking fluid. In order to minimize the existing risk of fire and explosion, and thus protect employees and the machine tool, the following technical and constructive measures should be observed:

- Selection of a metalworking fluid with a low hazard potential;
- Extracting the oil mist in the workspace;
- Prevention of oil spills;
- Prevention of ignition sources;
- Cooling of the cutting point with sufficient metalworking fluid flooding, process monitoring;
- Installation of an automatic fire extinguishing system;
- a sufficiently pressure-resistance hood;
- Flame-arresting door labyrinths;
- Pressure relief valve where the hood is not sufficiently pressure-resistant.

The measures listed above shall be implemented individually or in combination based on the hazard assessment and checked regularly for effectiveness by the operator.

A detailed description of protection against fire and explosion, incl. checklist, can be found in the "Brand- und Explosionsschutz an Werkzeugmaschinen – DGUV Information 209-026" brochure published by the German Social Accident Insurance (DGUV).

The fire protection concept shall be coordinated in each case between all parties involved, operators, manufacturers of suction systems and machine tools.

# 9 Acceptance and Inspection of Air Handling Systems/Suction Systems

Air handling systems shall be checked for proper installation, function and arrangement by a person authorized in accordance with the German Industrial Safety Regulation (BetrSichV) before they are first commissioned, after significant modifications, and regularly – at least once a year. The requirements for the required expertise of an authorized person in accordance with § 6, Section 2 of the German Industrial Safety Regulation are specified in the Technical Rule for Operation Safety (TRBS) 1203. The results shall be documented.

An acceptance inspection before commissioning includes checks for completeness and function, in order to test the effectiveness of the system and ensure safe, uninterrupted operation.

The acceptance inspection should be conducted in the following steps:

- Check for completeness;
- Check for function (effectiveness);
- Measurement of function.

The scope of the measurement of function, the measurement process and the measurement devices should be discussed and specified in writing during the bid phase. The acceptance inspection shall be documented in writing.

# **Check for completeness**

- Comparison of scope of delivery with purchase order or order confirmation
- Delivery documentation includes the following:
  - Operating instructions (delivery documentation within the European Economic Area shall be provided in the national language. Outside the EEA, the language of the operating instruction is subject to negotiation);
  - Declaration of conformity/manufacturer's declaration;
  - Intended use of the system;
  - Safety information;

- Technical data sheet;
- Circuit diagram;
- Drawings;
- Spare parts list;
- Miscellaneous.

# **Check for function**

- Visual check for damage;
- Leak test of entire system; during and after commissioning;
- Comparison of technical information with manufacturer's information (target/actual).

### **Measurement of function**

- Measurement of the operating volumetric flow and the partial airflow:
  - Suitable testing instruments (e.g. vane anemometer, pitot-static tube);
- Measurement of power demand of the fan motor;
- Measurement of the pressure difference in mechanical filters for different operating times. The target volumetric flow should be reached throughout the entire life span of the filter elements in order to guarantee sufficient collection.

# Check of the effectiveness of the entire ventilation system

Workplace measurements in accordance with IFA Working Folder No. 0210 are recommended in order to examine the investments (www.ifa-arbeitsmappedigital.de). These workplace measurements are the only adequate check of the effectiveness of the entire ventilation system.

# **10 Cost Consideration/Economic Aspects**

# **10.1 Basic Information**

Separator systems for eliminating airborne metalworking fluids are a vital part of operational cost and risk management. For example, separator systems help to implement public or civil law requirements and provisions regarding air quality in the company. Liability cases with guaranteed amounts that are not insignificant (e.g. resulting from liability for environmental damage or from labor law) can thus be avoided.

Properly and professionally designed systems also help to reduce both direct and indirect costs. For example, oils can be recovered and maintenance costs caused by depositing aerosols can be reduced. More stable production processes are also possible (e.g. improved thermal behavior of a machine due to circulation of the heated air in the workspace).

Considering separator technology merely as a "cost driver" is often too simple; in the best case it leads "only" to bad investment, in the worst case, to a risk for the company. As with all business investments, investment in separator systems should be preceded by a detailed cost/benefit analysis as the basis for economic considerations.

# **10.2** Purchase Costs and Procurement

Separator systems are process-related systems, so the purchase or development costs depend on the process and manufacturer chosen. The main factors that influence the development costs are as follows:

- Design Electrostatic precipitators, for example, have a more complex structure than filtering separators and thus often a higher purchase price (albeit with lower operating costs when used as an oil mist separator);
- Size Sufficient technical dimensions require a specific size, which has a direct impact on the price;
- Configuration The decision whether machines should be extracted individually, in groups or completely centralized, for example, determines the design and size (emulsion and oil mists, for example, should not be extracted together via a centralized system);
- Specific features Manufacturers vary in terms of product features, project planning expertise and the services they offer, all of which have influence on a system and device calculation.

An assessment matrix can be created to enable the purchase or development costs of the various manufacturers to be analyzed. This allows specific points to be weighted individually. Table 5 here is intended as a reference and is based on the life cycle model in accordance with VDMA 34160.

	Weighting	Manufacturer A	Manufacturer B	Manufacturer C
Purchase price	20 %			
Initial equipment	10 %			
Spare parts package	3 %			
Extended warranty	10 %			
Installation costs	15 %			
Commissioning costs	5 %			
Freight costs	2 %			
Training costs	5 %			
Other procurement costs	5 %			
Construction and conversion costs	15 %			
Media supply/disposal	5 %			
Other infrastructure costs	5 %			
	100 %			

# Table 5 – Example of a reference model for an assessment matrix

The weighting shown above is an example and should be adapted individually. The development costs are a relevant aspect, but are not a main aspect when dealing with an investment project with a long life span. Over the entire life cycle of a separator system, the operating costs make up a large – under certain circumstances even the largest – proportion of the costs.

# **10.3 Example of an Operating Costs** Calculation

Table 6 can help to identify and clarify the relevant operating costs, as long as the the separation capacity is technically comparable.

# Filter system AFilter system BOperating time in h/yearIMotor capacity in KWIAverage load capacityIAverage filter life span in hIConsumption costs, e.g. spare filters throughout<br/>operating timeIMaintenance costsIOther costs over operating timeIElectricity costs over operating timeIDisposal costs for consumables over operating timeI

# Table 6 Comparison of operating costs

# 10.4 Cost Savings with Separation Technology

When considering costs, separation technology is often seen purely as a cost center, i.e. essentially as causing costs. Cost-saving effects are barely taken into account. However, these effects can be so significant that they enable shorter return-on-investment times, as the practical example of a suction system in the separation of oil mist in Table 7 shows: This does not include the costs saved or effects created by the suction technology with regard to the following:

- Insurance savings for premiums and claim settlement;
- Use of thermal energy from extract air;
- Simpler environmental audits;
- Savings due to improved employee health;
- Increased product quality due to improved thermal behavior of machinery.

# Table 7 Practical example of cost saving in oil mist separation

Purchase cost of suction system	approx. EUR 34,000
Savings through recovery of separated oil, Purchase cost of oil per liter approx. EUR 0.80:	200 liters x EUR 0.80 = EUR 160 per week x 52 weeks = approx. EUR 8,320
Indirect cost saving (saving on renovation, cleaning costs), approx. 4 working hours per week, EUR 45 per hour	52 weeks x 4 hours x EUR 45 = approx. EUR 9,360
Total saving per year:	EUR 17,680

# **11** List of Standards, Guidelines, German Regulations and References

BetrSichV	German Industrial Safety Regulation (2015)
BGIA Report 9/2006	Suction and separation of metalworking fluid emissions, Haupt- verband der gewerblichen Berufsgenossenschaften (HVBG) [Gen- eral Association of the Commercial Professional Associations], St. Augustin
BImSchG	Federal Immission Control Act (German Bundesimmissionsschutzgesetz)
Deutsche Forschungsgemeinschaft	TLV and BAT Values List 2016: Maximum concentrations and bio- logical tolerance values at the workplace, Copyright (2016) WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim ISBN: 978-3- 527-34218-1
DGUV Rule 109-003:2011 formerly BGR/GUV-R 143	Activities with metalworking fluids
DGUV Information 209-024:2010 formerly BGI/GUV-I 718	Minimum quantity lubrication for machining operations
DGUV Information 209-026:2012 formerly BGI/GUV-I 719	Fire and explosion prevention and protection at machine tools
DIN 51385:2013-12	Lubricants – Processing fluids for forming and machining of materials – Terms
DIN 51581-1:2009-11	Testing of petroleum products – Determination of evaporation loss – Part 1: Noack test
DIN EN 779:2012-10	Particulate air filters for general ventilation – Determination of the filtration performance
DIN EN 1822-1:2011-01	High efficiency air filters (EPA, HEPA and ULPA) – Part 1: Classification, performance testing, marking
DIN EN ISO 2592:2002-09	Petroleum products – Determination of flash and fire points – Cleveland open cup method (ISO 2592:2000)
EnEV	Energy Saving Ordinance
IFA Report 6/2015	Metalworking fluids (Hauptverband der gewerblichen Berufsgenossenschaften [Gen- eral Association of the Commercial Professional Associations])

IFA Folder No. 0210	Measurement of hazardous substances – IFA folder (Determination of exposure in the case of chemical and biological effects) (www.ifa-arbeitsmappedigital.de)
TA Luft	First general administrative provision on the Federal Immission Control Act (technical instructions on air qual- ity control)
TRBS 1203:2012	Technical Rules for Operational Safety – Authorized persons Edition: March 2010 Amended and supplemented: GMBI 2012 S. 386 [No. 21]
TRGS 611:2007-05	Restrictions on the use of water-miscible or water-mixed metalworking fluids whose employment can result in the formation of N-nitrosamines
TRGS 900:2006-01	Occupational exposure limits
TRGS 910:2014-02	Risk-related concept of measures for activities involving carcinogenic hazardous substances
VDI 2262 Part 3:2011-06	Workplace air – Reduction of exposure to air pollutants – Ventilation technical measures
VDI 3397 Part 1:2007-05	Metalworking fluids
VDI 3397 Part 2:2014-06	Maintenance of metalworking fluids for metalcutting and forming operations – Measures for maintaining quality, process improvement, and for reducing solid and liquid waste
VDI 3397 Part 3:2008-03	Disposal of coolants and cutting fluids
VDI 3676:1999-10	Inertial separators
VDI 3677 Part 1:2010-11	Filtering separators – Surface filters
VDI 3677 Part 2:2004-02	Filtering separators – Depth fiber filters
VDI 3678 Part 2:2010-12	Electrostatic precipitators – Process air and indoor air cleaning
VDI 3679 Part 1:2014-07	Wet separators – Fundamentals, waste gas cleaning of particle collections

VDI 3679 Part 2:2014-07	Wet separators – Waste gas cleaning by absorption (scrubbers)
VDI 3679 Part 3:2010-06	Wet separators – Mist eliminators
VDI 3802 Part 1:2014-09	Air conditioning systems for factories
VDI 3802 Part 2:2012-03	Air conditioning systems for factories – Capture of air pol- lutants at machine tools removing material
VDMA 34160:2006-06	Forecast model for the life cycle costs of machinery and plants
VKIS-VSI-IGM substance list	VKIS-VSI-IGM substance list for metalworking fluids in accordance with DIN 51385 for metal processing

# **12 Acknowledgment of Sources and Authors**

# **Further References**

BGETEM	Guideline on purchasing suction systems correctly
DGUV Rule 109-002:2004 formerly BGR 121	Workplace ventilation – Air handling measures
EAKV	EWC Regulation on the Introduction of the European Waste Catalog (EWC Regulation – EWC)
GefStoffV	Hazardous Substances Ordinance
KrWG:2012	Law for promoting life cycle management and ensur- ing that waste is managed in an environmentally friendly way
VDMA 24176:2007-01	Inspection of technical systems and equipment in buildings
WHG	Law on the Management of Water Resources

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# **Authors**

The following experts participated in drafting this guideline:

**Torsten Bell** VDMA Machine Tools and Manufacturing Systems Association Frankfurt am Main

**Olaf Bernstorff** DencoHappel GmbH Delbag® Air Filtration, Herne

**Holger Ernst** indusa Industrielle Umweltschutzanlagen GmbH, Neu-Anspach

J**ürgen Gollmer** KÖBO ECO>PROCESS GmbH, Wuppertal

**Peter Kolb** ESTA Apparatebau GmbH & Co.KG, Senden

**Marcus Kraus** Keller Lufttechnik GmbH, Kirchheim unter Teck

**Ulf Kruse** ILT Industrie-Luftfiltertechnik GmbH, Ruppichteroth

**Dr. Heinz Kuppinger, Kai Kuppinger** AFS Airfilter Systeme GmbH, Untermünkheim **Christine Montigny** VDMA, Air-Handling Technology Association Frankfurt am Main

Falco-Dominik Riemer ILT Industrie-Luftfiltertechnik GmbH, Ruppichteroth

**Denis Ruf** Filtration Group GmbH formerly MAHLE Industriefiltration GmbH, Öhringen

**Carlo Saling** UAS UNITED AIR SPECIALISTS, INC. Bad Camberg

**Karsten Schulz** Freudenberg Filtration Technologies SE & Co.KG, Weinheim

**Stefan Stehle** Mann + Hummel VOKES AIR GmbH & Co. OHG, Sprockhövel

**Reinhard Stockmann** Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA), Sankt Augustin

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### VDMA

Air Pollution Control Lyoner Str. 18 60528 Frankfurt am Main, Germany

# Contact

Christine Montigny Phone +49 69 6603-1860 Fax +49 69 6603-2860 Email christine.montigny@vdma.org Internet Ir.vdma.org **Editor** Christine Montigny (M. Sc.)

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# **13 Working Group Aerosols**

Manufacturers of aerosol extraction systems founded the working group Aerosols within the Department of Air Pollution Control of the Trade Association of Air-Handling Technologies at VD-MA (Verband Deutscher Maschinen- und Anlagenbau e.V., Mechanical Engineering Industry Association). Apart from representatives of VDMA member companies, representatives from the mineral oil industry, the machine tool industry as well as from the user industries, for example from the automotive industry, attend the meetings. The manufacturing companies of the group offer extraction systems and devices for various industrial processes where aerosols are released and separated for purposes of health and environmental protection.

The member companies address similar, topical and long-term issues of everyday business operations, discuss these and seek to find common solutions. With the support of the Association Air-Handling Technologies, the companies intend to be competent partners in the field of regulating authorities, testing authorities and users. The group considers a joint public relations work as a focus in their work, for instance providing information on the hazards of the metalworking fluids aerosols, smokes and vapours emerging from cutting manufacturing processes and their efficient disposal. Furthermore, the participants seek to contribute their experiences in the preparation of standards and technical rules. They benefit from their co-operation by the mutual exchange of information and experiences, by jointly discussing technical and scientific issues. They wish to extend their own knowledge through external speakers during their meetings.

Following a two year intensive review, the current, revised guideline ,Metalworking fluids – Separating and Filtering', is the latest product of this Working Group. The guideline is available in German and English for download at http://luftreinhaltung.vdma.org. The print version can be requested from the VDMA Air Pollution Control department.

# VDMA

Air Pollution Control

Lyoner Str. 18 60528 Frankfurt am Main, Germany

# Contact

Christine MontignyPhone+49 69 6603-1860Fax+49 69 6603-2860Emailchristine.montigny@vdma.orgInternetIr.vdma.org



Ir.vdma.org