

Service guide

MicroChannel Heat Exchangers

MCHE

Corrosive environments

Selection guide for alloys and coatings



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1. Introduction

1.1 General

This manual is a guide for material selection in corrosive environments and maintenance of Danfoss Microchannel Heat Exchangers (MCHEs). The manual also describes the causes of corrosion and the identification of corrosive environments.

We recommend that you read this manual carefully before commencing any work. Danfoss is not responsible or liable for any damage caused by failure to comply with the instructions in this manual and/or due to incorrect installation, operation and maintenance of MCHEs.

2. Corrosion

2.1 Corrosion - What is it?

Corrosion is a slow, progressive and/or rapid deterioration of a metal's properties such as its appearance, its surface aspect, or its mechanical properties due to the reaction with the surrounding environment: air, water seawater, various solutions, organic compounds, and the like.

2.2 Typical types of aluminum corrosion

Different types of corrosion, more or less visible to the naked eye, can occur with aluminum, such as uniform corrosion, pitting corrosion and, galvanic corrosion. The predominant type of corrosion depends on a certain number of factors that are intrinsic to the metal, the medium and the conditions of use.

Uniform Corrosion

This type of corrosion develops as very small diameter pits, in the order of a micrometer, and results in a uniform and continuous reduction in thickness over the entire surface area of the metal.

Pitting Corrosion

It is a localized form of corrosion that is characterized by the formation of irregularly shaped cavities on the surface of the metal. Aluminum is prone to pitting corrosion in a media with pH out of neutral range, which basically covers natural environments such as surface water, seawater, and moisture in ambient air.

Unlike other metals, aluminum corrosion is always visible because the corrosive pits are covered with white, voluminous and gelatinous protrusions of alumina gel $Al(OH)_3$. These protrusions are much bigger than the underlying cavity.

Pitting corrosion occurs when the metal is put into continuous or intermittent contact with aqueous media: water, seawater, rain water, and humidity.

Galvanic Corrosion

Galvanic corrosion, also called bimetallic corrosion, is an electrochemical process in which one metal corrodes preferentially when it is in electrical contact with another, in the presence of an electrolyte. A similar galvanic reaction is exploited in batteries to generate a useful electrical voltage to power portable devices.

2.3 What defines a corrosive environment?

Atmospheric corrosion is the attack of a metal, or an alloy, by the atmospheric environment to which it is exposed. This corrosion is caused by

the simultaneous influence of rain or condensing water, oxygen contained in the air, and atmospheric pollutants. Atmospheric corrosion is a special type of corrosion because the electrolyte is represented by a thin film of moisture, where the thickness does not exceed a few hundred micrometers. It can be assumed that such a film is always saturated with oxygen, and its diffusion is not hindered. Atmospheric corrosion may be intermittent because it stops when the surface of the metal is no longer humid. When immersed in water or in a salt solution, the metal is in permanent contact with the electrolyte. However, corrosion may be slowed by the weak diffusion of oxygen to cathodic sites.

A corrosive environment can consist of many different corrosive elements. Not all corrosive pollutants are found in a single corrosive environment. It is rare that a corrosive environment consists of only one corrosive pollutant.

Therefore, a corrosive environment must be clearly identified and understood before proper coil protection can be determined.

Coastal/Marine



Large industrial power plants and chemical refineries tend to locate in coastal areas. This presents a challenge for air conditioning equipment that must operate in potentially corrosive environments.

Coastal or marine environments are characterized by the abundance of sodium chloride (salt), which is carried by sea spray, mist or fog. Most importantly, salt water can be carried several miles by ocean breeze. It is not uncommon to experience salt-water contamination as far away as 10 km (6.2 miles) from the coast. Even if the location is at a substantial distance from the ocean, corrosion from salt-water contamination can still occur if the equipment is not properly protected.

Line-of-sight distance from the ocean, prevailing wind direction, relative humidity, wet/dry time, and coil temperature will determine the severity of corrosion in a coastal environment.

Industrial



Industrial activity, particularly power generation plants and chemical refineries, create environmental conditions with the potential of producing various air-borne emissions. Sulfur and nitrogen oxide contaminants are the most common. Depending on the manufacturing processes, other contaminants may include ammonia, acid fumes and hydrocarbons. Power generation involving coal and fuel oils releases sulfur oxides (SOx) and nitrogen oxides (NOx) into the atmosphere. These gases accumulate in the atmosphere and return to the ground in the form of acid rain or low pH dew. Industrial emissions are not only potentially corrosive, the emitted dust particles can be laden with harmful metal oxides, chlorides, sulfates, sulfuric acid, carbon, and carbon compounds. These particles, in the presence of oxygen, water, or high humidity environments can be highly corrosive.

Combination: Marine/Industrial



Salt-laden seawater mist, combined with the harmful emissions of industrial plants, poses a severe threat. The combined effects of salt mist and industrial emissions can accelerate corrosion. This environment requires superior corrosion resistant properties for air-conditioning equipment to maintain an acceptable life-time and level of cooling performance.

Urban



Highly populated areas generally have high levels of automobile emissions and increased rates of building heating fuel combustion. Both conditions elevate sulfur oxide (SOx) and nitrogen oxide (NOx) concentrations. Corrosion severity in this environment is a function of pollution levels, which in turn depends on several factors including population density. HVAC equipment installed adjacent to and/or in the vicinity of diesel exhausts, incinerator discharge stacks, fuel burning boiler stacks, or areas exposed to fossil fuel combustion emissions (truck station, heliport, airport) should be considered an industrial application.

Rural



Rural environments far from the city also may contain high levels of ammonia and nitrogen contamination from animal excrement, fertilizers, and high concentrations of diesel exhaust. These environments should be handled much like industrial applications.

3. Categories of atmospheric corrosion

Atmospheric corrosion is divided into six categories of corrosivity level, as shown in Table 1.

Corrosivity	ISO 9223 Category	Corrosion rate for aluminum ¹⁾ g/m ²
Very low	C1	negligible
Low	C2	$r_{\text{corr}} \leq 0.6$
Medium	C3	$0.6 < r_{\text{corr}} \leq 2$
High	C4	$2 < r_{\text{corr}} \leq 5$
Very high	C5	$5 < r_{\text{corr}} \leq 10$
Extreme	CX	$r_{\text{corr}} > 10$

¹⁾ Mass loss of aluminum (g/m²) after one year to exposure to atmospheres with different corrosivity categories (Ref. ISO 9223)

- Classification criteria is based on methods for determining the rate of corrosion by using standard specimens to evaluate the degree of corrosion (Ref. ISO9226)
- Measurement method of corrosion rate (Ref. ISO9225)
- The aluminum corrosion can be uniform and/or localized. Corrosion rates shown in table 1 are calculated as uniform corrosion. Maximum pit depth or the number of pits can be a better indicator of potential damage, depending on the final application.
- Corrosion rates exceeding the upper limits in Category C5 are considered extreme. Corrosivity Category CX refers to specific maring and marine/ industrial environments (see Annex 1).

4. Corrosion protection

To prevent corrosion, proper material selection, surface modification and field maintenance are necessary. There are several corrosion preventions and retardment options that can be adopted to brazed aluminum alloy MCHE, such as materials selection, surface modification, macro/micro-structural optimization after controlled atmosphere brazing (CAB) metallurgical evolution, coating implementation, and regular surface cleaning.

4.1 Material selection

Aluminum MCHE have been used in the automotive industry for over three decades. Due to their balanced comprehensive performance in weldability, mechanical properties, formability, and general corrosion resistance, 3000 series aluminum alloys are the structural materials of choice. Accordingly, 4000 series Al-Si alloys are used as filler metals in the form of cladding layers and sealing rings due to their ability to melt, flow and provide wettability to fresh Al-Mn alloys surface just renovated by applying flux under an inert atmosphere. In addition to benefits such as light weight, low refrigerant charge and, competitive raw material costs, these materials combinations were used intentionally to develop a total aluminum MCHE resolving the problem of galvanic corrosion that occurs in conventional round tube-fin heat exchangers using dissimilar metals.

Today, aluminum MCHE are being applied at an increasing rate to residential and commercial HVAC&R applications, demanding continuous improvement in materials to enhance anticorrosion performance in various environments and operating conditions.

The current Danfoss MCHE Materials Portfolio includes well-recognized aluminum alloy bases and clad fillers that are well-suited for brazing in tunnel furnaces where the atmosphere is controlled. The result is a MCHE with consistently high-quality levels and low field failure rates. It is worth noting that respective diversities of designated 3000 series aluminum alloys for the combination of multiple ports extruded (MPE) tubes, high frequency (HF) welded headers (also called manifolds), and louvered fins, is expected to follow a desired sequence of chemical reactivity for each component, thereby optimizing corrosion resistance. These fine-tuned material configurations are characterized by a few millivolt differences of electrochemical potentials in electrolyte solutions, which dominate the tendency for corrosion and the thermodynamic susceptibility of a metal-environment. In other words, electrochemical potential differences manifest as driven forces and determine the possible sequential order of processes that initiate corrosion. Accelerated corrosion tests also demonstrates that electrochemical factors influence the overall level of corrosion damage encountered by relevant components.

Danfoss MCHE structural material specifications
Table 2.

Components	Tube	Fin	Header
Standard Life Alloy	3102 ZAS	3003	3003
	3102 ZAS	3003	3005Mod
Long Life Alloy	9153 ZAS	3003	3003
	9153 ZAS	3003	3005Mod

4.2 MPE Tube surface modification with Zinc Arc Spray (ZAS)

ZAS for MPE tubes has long been proven as a relatively mature technique for positively utilizing corrosion to alter pitting (one of the most hidden and fast developing localized corrosion), into a laterally spread general corrosion pattern over the surface of the tube. This, in turn, increases the time for a leak to occur.

Danfoss continues to monitor its tube suppliers to ensure that the zinc diffusion depth (measured after CAB), delivers MPE tubes with stable zinc loading and coverage, 1 wt.% Zn @ min depth of 65 μm as measured from a transverse section of the tube is recommended.

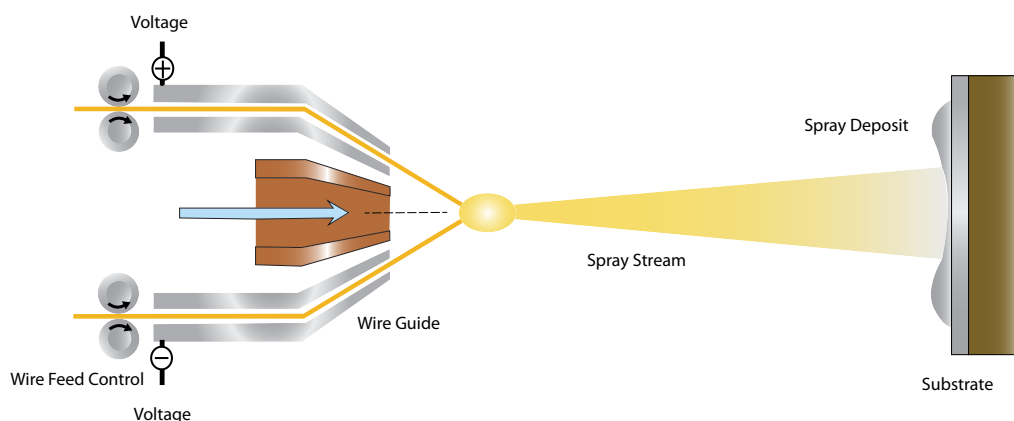
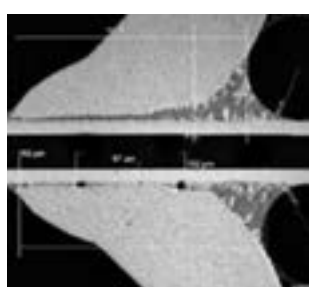


Figure 1 - Illustration of ZAS applied onto MPE tube surface

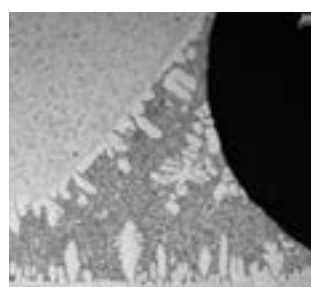
4.3 Macro/micro structure optimization

Besides regulating brazing defects, material texture (either for substrate alloys or braze joints) need to be monitored as metallurgical evolutions could deviate from normal status during controlled atmosphere brazing, especially when an inappropriate CAB profile is applied.

After years of investigation, Danfoss has established a systematic way for evaluating metallurgical results. For example, within the welding pool of a brazing joint, intermediate developed primary aluminum dendrites are desired along with a moderate tube filler dissolution / fuse level.



Longitudinal cross-section of a typical header-to-tube joint profile



Primary aluminum (dendrite) pattern



Eutectic structure in a welding pool

5. Coating implementation

For fixed metallic materials, corrosion deterioration almost always occurs on surfaces that are exposed to corrosive environments. Creating a physical barrier over the surface to protect it from outside attack is instinctively one of the major considerations to prevent corrosion. Years of hands-on experience, starting with heat exchangers consisting of round copper tube and aluminum fins, has been proven that a waterborne cationic epoxy resin based electrophoretic, also known as e-coating, under cathodic conditions at which the MCHE is maintained as a cathode, is an effective anticorrosion solution for the following reasons:

- A uniform coating thickness can be readily applied to metal surfaces under well controlled direct current (DC) parameters
- Without bridging and other non-desired outcomes, a uniform coating coverage can be achieved that encompasses all exposed surfaces, including fin edges and confined louvers
- Excellent penetration of the coating, the ability to seal minor brazing voids (i.e. pores by shrinkage) and the ability to create smooth surfaces and entrain any flux residue

In addition, e-coating is often used with a compatible topcoat to prevent ultraviolet (UV) irradiation from decomposing the polymer's molecular chains. This must be taken into consideration especially when considering outdoor applications that are exposed to direct sunlight.

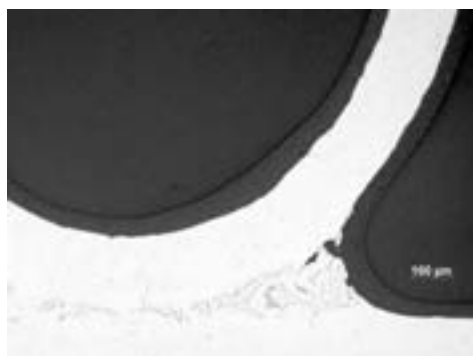


Fig. 2 - Cationic epoxy electrophoretic coating coverage over the tube-to-fin-joint

The successful implementation of an e-coated aluminum MCHE also depends on proper surface treatments (stripping, pH balancing, chemical conversion films) prior to the coating process. Phosphating and passivating are two prevailing processes for creating aluminum conversion films over entire surfaces that are subjected to phosphate anion or chromate-based solutions. Anodizing, using various acid-based electrolytes to create electrochemical reactions, is another process for generating anodic oxide films for corrosion protection. In addition, various types of molecular deposition films are being developed thanks to advancements in nanotechnologies.

When applied after the required surface treatments, e-coating has demonstrated the following results:

- Less than 3% degradation on thermal performance, when first applied, due to the low thermal resistance
- Good adhesion to substrates
- High physical stability and chemical durability under conditions such as handling, packing, transportation, installation and servicing
- Reasonable flexibility to accommodate customized shapes or unexpected macro/micro deformation
- Minimum permeability of gaseous/moisture (or high anti-blistering in aqueous mediums)

Corrosion-resistant coatings applied to aluminum MCHE must be qualified by using a recognized accelerated corrosion test, such as ASTM G85-A3 and/or ASTM G85-A2 and/or ASTM B117, and successfully passing a minimum of 3,000 hours of exposure without leaking. Danfoss' fully and conditionally qualified MCHE e-coating suppliers are available in Asia, North America and Europe. All Danfoss qualified e-coating suppliers must maintain consistent quality, a sufficient e-coating capacity and an agile lead time.

Unauthorized applications include, but are not limited to, MCHE that are in direct contact with incompatible chemicals and/or continuously immersed in water, condensate or aqueous solutions. Manufacturers and end-users of refrigeration units / systems are cautioned against using e-coated MCHE in applications.

Where elevated ambient temperatures, frequent thermal shocking and/or severe fouling exist. Where the extent of environmental corrosion needs to be determined for a given job site, an assessment can be performed by a third-party provider. A good practice for assessing atmospheric corrosion is to record and evaluate the type and extent of corrosion appearing on metallic structures in the surrounding area.

**Better coating system selection
(based on laboratory experiments)**

+

**High standard application practices
(design, transportation, installation,
maintenance)**

↓

Reliable corrosion protection

Danfoss requires that both uncoated and e-coated aluminum MCHE be maintained through frequent servicing. When properly maintained, factory applied e-coating protects MCHE efficiently from corrosion. However, e-coating degradation caused by physical damage to the coil, may render the protection useless. Polyurethane varnish is occasionally used for cosmetic renewal on limited areas of the coil, but it is not an effective form of corrosion protection.

In addition, e-coated MCHE may experience premature failure in coastal areas with prolonged rough seas and/or heavily polluted industrial areas where the accumulation of dust and corrosive chemicals degrades the coating. Preventive measures such as cleaning the entire e-coated areas of the MCHE to remove crystallized salt deposits as well as the accumulation of dust and chemicals play a significant role in extending the life of the MCHE.

6. Selection guide

6.1 Corrosion resistance

Danfoss suggest the following guideline to be follow when applying the Danfoss products.

Product options	Corrosive atmosphere ²⁾ equivalent aluminum corrosion rate				
	Very Low to Low (C1, C2) Negligible	Medium (C3) 2 g/m ²	High (C4) 5 g/m ²	Very high (C5) 10 g/m ²	Very high to Extreme (CX) >10 g/m ²
MCHE SLA ³⁾	✓	✓	✗	✗	✗
MCHE LLA ⁴⁾	✓	✓	✗	✗	✗
LLA Tube & LLA Fin ⁵⁾	✓	✓	✓	✗	✗
TCP Coating	✓	✓	✓	✗	✗
E-Coating	✓	✓	✓	✓	✗
Double Coating	✓	✓	✓	✓	✓

²⁾ Defined corrosivity categories refer to ISO9223

³⁾ Danfoss Standard Life Alloy (SLA)

⁴⁾ Danfoss Long Life Alloy (LLA)

⁵⁾ Danfoss Long Life Alloy (LLA) tube and Long Life Alloy (LLA) Fin

Refer to ISO 9225 for the measurement methods involving environmental parameters.

✓ Recommended

✓ Acceptable, product life may be reduced

✗ Not recommended

This guide is intended to provide general information regarding corrosive environments and the mechanisms for corrosion. Although recommendations are provided, details regarding real-world application of Danfoss products cannot be fully addressed in this document. Other factors, including cost, should be considered in making final selections. For further clarification, contact Danfoss Heat Exchangers, MCHE Product Management.

7. Maintenance of MicroChannel Heat Exchangers (MCHE)

Frequent servicing is essential to maintaining the required MCHE performance. For every installed Danfoss MCHE, service records must be documented.



CAUTION

Prior to servicing MCHE, be sure to disconnect the power supply and use lock-out methods to prevent the power from accidentally being turned on.

Filters

Danfoss recommends the use of air filters on the frontal face of the MCHE to lower the deposition of rain water and other contaminants that can collect on the surface of the tubes.

Shut down periods

During periods when the MCHE is not operated for longer than a week, the MCHE must be completely cleaned following the cleaning procedure. This practice must also be performed during short shut-down periods where corrosive deposits accumulate on the MCHE.

Reversible fan motor

Danfoss recommends the function to reverse the direction of condensing fan motor for several minutes every day. It could help to blow off excess dust, dirt, debris and remaining water from the condensing coil.

Cleaning Procedure

Refer to "Danfoss MicroChannel Heat Exchangers(MCHE) Installation and Maintenance Guide", Document Number **AX292455807588en-000201**



WARNING

Field applied coatings are not recommended for brazed aluminum MicroChannel heat exchangers. Danfoss MicroChannel heat exchangers must NOT be coated using any other coating, but the ones specifically approved by Danfoss, such as certain qualified e-coating (epoxy based electrophoretic coating) suppliers or similar high-quality coating technologies. Coating of a coil using a supplier or coating process not approved by Danfoss voids the product warranty. It may also reduce the lifetime and/or the performance of the MicroChannel heat exchanger. Consult your Danfoss Sales & Application representative for more information

8. Annex 1

Description of typical atmospheric environments related to the estimation of corrosivity categories.

Corrosivity Category	Corrosivity	Typical environments - Examples	
		Indoor	Outdoor
C1	Very low	Heated spaces with low relative humidity and insignificant pollution, e.g. offices, schools, museums	Dry or cold zone, atmospheric environment with very low pollution and time of wetness, e.g. certain deserts, Central Arctic/Antarctica
C2	Low	Unheated spaces with varying temperature and relative humidity. Low frequency of condensation and low pollution, e.g. storage, sport halls	Temperate zone, atmospheric environment with low pollution ($SO_2 < 5 \mu g/m^3$) e.g. deserts, subarctic areas
C3	Medium	Spaces with moderate frequency of condensation and moderate pollution from production process, e.g. food-processing plants, laundries, breweries, dairies	Temperate zone, atmospheric environment with medium pollution (SO_2 : $5 \mu g/m^3$ to $30 \mu g/m^3$) or some effects of chlorides, e.g. urban areas, coastal areas with low deposition of chlorides Subtropical and tropical zone, atmosphere with low pollution
C4	High	Spaces with high frequency of condensation and pollution from production process, e.g. industrial processing plants, swimming pools	Temperate zone, atmospheric environment with high pollution (SO_2 : $30 \mu g/m^3$ to $90 \mu g/m^3$) or substantial effect of chlorides, e.g. polluted urban areas, industrial areas, coastal areas without spray of salt water or exposure to strong effect of de-icing salts Subtropical and tropical zone, atmosphere with medium pollution
C5	Very high	Spaces with very high frequency of condensation and/or with high pollution from production process, e.g. mines, caverns for industrial purposes, unventilated sheds in subtropical and tropical zones	Temperate and subtropical zone, atmospheric environments with very high pollution (SO_2 : $90 \mu g/m^3$ to $250 \mu g/m^3$) and/or significant effect of chlorides, e.g. industrial areas, coastal areas, sheltered positions on coastline.
CX	Extreme	Spaces with almost permanent condensation or extensive periods of exposure to extreme humidity effects and/or with high pollution from production process, e.g. unventilated sheds in humid tropical zones with penetration of outdoor pollution including airborne chlorides and corrosion-stimulating particulate matter	Subtropical and tropical zone (very high time of wetness), atmospheric environment with very high SO_2 pollution (higher than to $250 \mu g/m^3$) including accompanying and production factors and/or strong effect of chlorides, e.g. extreme industrial areas, coastal and offshore areas, occasional contact with salt spray

9. Annex 2 (informative)

Danfoss e-coating is chemically resistant to chemicals, in the table below, at ambient temperature. It is not intended for liquid-to-liquid (immersion) applications. Elevated temperatures can have an adverse effect on the corrosion durability of the coating product, depending on the specific environment.

The following table is intended as a guide for general reference.

Acetates(ALL)	Ethyl Ether	Nitrobenzene
Acetic Acid	Ethylene Oxide	Nitrogen Fertilizers
Acetone	Fatty Acid	Oils, Mineral & Vegetable
Acetylene	Fluorine Gas	Oleic Acid
Acrylonitrile<10%	Formic Acid <10%	Oxalic Acid
Alcohols(ALL)	Formaldehyde 27%	Ozone
Aldehydes(ALL)	Formic Acid <10%	Perchloric Acid
Alum	Freon	Phenol 85%
Amines(ALL)	Fructose	Phenolphthalein
Amino Acids	Fuels(ALL)	Phosgene
Ammonia	Gasoline	Phosphoric Acid
Ammonium Hydroxide	Glucose	Potassium Chloride
Ammonium Nitrate	Glycol Ether	Potassium Hydroxide
Aniline	Glycols(ALL)	Propane
Benzene	Hydrazine	Propyl Alcohol
Benzoic Acid	Hydrocarbons(ALL)	Propylene Glycol
Benzol	Hydrochloric Acid <10%	Salicylic Acid
Borax	Hydrofluoric Acid(NR)	Salicylic Acid
Boric Acid	Hydrogen	Salt Water
Butyl Alcohol	Hydrogen Peroxide 5%	Sodium Bisulfite
Butyl Cellosolve	Hydrogen Sulfide	Sodium Chloride
Butyric Acid	Hydroxylamine	Sodium Hydroxide <10%
Calcium Chloride	Iodides(ALL)	Sodium Hydroxide >10% (NR)
Calcium Hypochlorite	Iodine	Sodium Hypochlorite 5%
Carbolic Acid	Isobutyl Alcohol	Sodium Sulfate
Carbon Dioxide	Isopropyl Alcohol	Starch
Carbon Monoxide	Kerosene	Stearic Acid
Carbon Tetrachloride	Ketones(ALL)	Sucrose
Carbonates (ALL)	Lacquers	Sulfate Liquors
Carbonic Acid	Lactic Acid	Sulfates(ALL)
Cetyl Alcohol	Lactose	Sulfides(ALL)
Chlorides(ALL)	Lauryl Acid	Sulfites(ALL)
Chlorinated Solvents(ALL)	Magnesium	Sulfonic Acid
Chlorine Gas	Maleic Acid	Sulfur Dioxide
Chloroform	Menthol	Sulfuric Acid 25-28%
Chromic Acid(NR)	Methanol	Surfactants
Citric Acid	Methyl Ethyl Ketone	Tannic Acids
Creosol	Methyl Isobutyl Ketone	Tetraethyl Lead
Diesel Fuel	Methylene Chloride	Toluene
Diethanolamine	Mustard Gas	Triethanolamine
Esters(ALL)	Naphthol	Urea
Ethers(ALL)	Nitric Acid(NR)	Vinegar
Ethyl Acetate	Nitrides(ALL)	Xylene
Ethyl Alcohol		

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