# Design of Cold Insulation to Prevent Formation of Condensation

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Content

## 1. Introduction

The most frequent requirement for the design (determination of insulation thickness) of cold insulations is the prevention of condensation formation on the surface.

The whole discussion in this document is based upon the recommendations of FESI Document 08 “Principles of cold insulation” which describes the physical principles leading to the formation of condensation when temperature differences occur in gases carrying water vapour. Rules for the construction which result from these physical principles and are independent of the conditions of the individual design are discussed there.

## 2. Condensation on insulation surfaces

Condensation on the surface of cold insulation systems generally does not impair the effect of the insulation. Nevertheless, the prevention of condensation on the surface of an insulation is a frequent criterion for the determination of the insulation thickness, since condensation is undesirable for several reasons:

- Dripping condensed water could for example adversely affect neighbouring production areas.
- Condensation water could lead to corrosion at the surface of the insulation and, subsequently at other parts of the installation reached by it.
- The formation of condensation leads to general dirtiness of the installation.

## 3. Relevant factors

To calculate the insulation thickness sufficient to prevent condensation formation on the surface, the factors given in Table 1 must either be known, be assumed, or agreed with the operator of the installation.

**Table 1: Check list – Information required for the design of cold insulations**

Information to be provided by client or contractor

| | | | | Unit | CL | CO | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | Medium temperature (normal service conditions)[1] | constant | | °C | X | | |
| | | flexible/ changing | Min. | °C | X | | |
| | | | Max. | °C | X | | |
| 2 | Ambient air | Temperature | | °C | X | | |
| | | Relative humidity | | % | X | | |
| 3 | Insulation material | Type/product | | | X | A | |
| | | Service thermal conductivity according to VDI 2055 | | W /(m·K) | | X | |
| 4 | Surface heat transfer | Geometry/drawing | | | X | A | |
| | | Convection/ radiation | Wind[2] | m/s | X | A | |
| | | | Casing material/ - coating | | X | X | |
| | | | Other factors[3] | | X | A | |
| 5 | Insulation thickness | | | mm | | X | |
| 6 | Fire protection | Requirement: | | | X | A | |
| 7 | Sound insulation | Requirement: | | | X | A | |
| 8 | Hygiene | Requirement: | | | X | A | |

CL = Client
CO = Contractor
} Information { X = provides; A = advises

1) The significance of occasional temperature excursions must be agreed upon
2) In buildings: free convection.
3) e. g. neighbouring radiating surfaces (see also FESI Document 05, chapter 2)

(Specimen for this list at Annex 1).

The table shows which data is to be provided by contractor or client (X = provides) and where the contractor is supposed to advise the client (A = advises).

In case of deviations from the recommendations of this table, the settlement found is noted in the “Remarks” column.

### 3.1 Medium temperature

The medium temperature must be known to allow for the selection of the insulation material. For variable service conditions and for service conditions with changing temperatures, the respective minima and maxima must be given.

### 3.2 Ambient air

The information concerning the condition of the ambient air is especially important. The insulation needs to be calculated so as to prevent condensation formation on the surface of the insulation, provided the agreed conditions of the ambient air prevail.

The relative humidity and temperature of the ambient air, upon which the design shall be based, must be decided by the client and agreed upon in the contract. Whilst taking that decision, it must be remembered that a relative humidity of > 85% leads to very high insulation thicknesses and should, therefore, be considered with great care.

If – as is recommended – the design condition is **not** based upon extreme ambient conditions, it will be temporarily exceeded during the actual operation of the installation. This may lead to condensation on the surface of the insulation. Normally, This is not critical in the open air.

However, if in buildings the dripping of condensed water on products or other installations must be prevented under any circumstances, this can only be achieved by taking additional measures (see chapter 4).

### 3.3 Insulation materials

The insulation material is selected on technical and economic grounds. Where the client decides on a specific insulant, the contractor has to be consulted regarding the suitability of that insulant.

The determination of the service thermal conductivity is according to VDI 2055 (available in English).

### 3.4 Surface heat transfer

The surface heat transfer from the ambient air onto the insulation surface is expressed numerically in the form of the surface coefficient of heat transfer $\alpha$. In determining $\alpha$, the following must be considered:

- For the calculation of insulation thicknesses, designed to maintain a given surface temperature, it is of decisive influence and
- smaller surface coefficients of heat transfer lead to larger insulation thicknesses.

Therefore, smaller surface coefficients of heat transfer must be selected to be on the safe side.

To gauge the surface heat transfer conditions, knowledge of the geometry of the installation and the positioning of its different components is required.

Assumptions must be made especially regarding the radiation conditions of cold insulation surfaces in radiation exchange with other radiating surfaces and regarding the influence of convection.

It must be taken into account that close spacing and neighbouring cold surfaces considerably decrease the surface heat transfer.

Reliable conclusions are possible only in rare cases, even if the entire installation geometry is known precisely.

In many specifications for external installations, it is required to determine the surface coefficient of heat transfer at a wind speed of 5 m/s. This applies – following the above reasoning – to heat loss calculations.

#### 3.4.1 Convection – radiation

The surface heat transfer from the ambient air to the insulation surface consists of the components $\alpha_C$ for convection and $\alpha_R$ for radiation.

$$\alpha_{total} = \alpha_C + \alpha_R$$

Convection is the movement of air by which heat is transferred onto the insulation. This movement can be caused by wind or an artificial ventilation or it can occur naturally as free convection, as colder and therefore heavier air in the immediate vicinity of the insulation flows downward.

If the air movement is hampered through close spacing conditions, e. g. in lowered ceilings and room corners, the surface heat transfer through convection decreases.

The thermal radiation absorbed by the insulation surface depends upon its absorption coefficient a. A black surface with $a \approx 1$ absorbs the major part of the incoming radiation, whilst a bright surface with $a << 1$ reflects the major portion.

Surfaces with low absorptivity, therefore, possess a lower surface heat transfer. This leads to high temperature differences, and to larger insulation thicknesses being required.

The absorption coefficient a is rarely mentioned in the literature. However, in many cases the rule applies that the absorption coefficient a equals the emissivity $\varepsilon$ which is given for insulation surfaces in VDI 2055, table 6 and copied in Table 2.

### 3.4.2 Total surface coefficient of heat transfer $\alpha_{total}$

Table 2 shows the total surface coefficients of heat transfer for different casing materials. Underlying is the assumption of a convection part of the surface coefficient of heat transfer of $\alpha_C = 2\ W/(m^2 \cdot K)$, which applies to horizontal pipes with a temperature difference of 4,5 K.

**Table 2: Surface coefficients of heat transfer**

| Casing | $\varepsilon$ | $\alpha_R$ $W/(m^2 \cdot K)$ | $\alpha_{total}$ $W/(m^2 \cdot K)$ | No. in diagram |
|---|---|---|---|---|
| Aluminium, bright | 0,05 | 0,27 | 2,27 | 1 |
| Aluminium, oxidised, stainless austenitic steel | 0,13 | 0,70 | 2,70 | 2 |
| Steel, galvanised, bright | 0,26 | 1,50 | 3,50 | 3 |
| Steel, galvanised, dusty | 0,44 | 2,50 | 4,50 | 4 |
| Paint-coated sheet metal, foam glass, elastomeric foam, plastic casings | 0,90 | 5,00 | 7,00 | 5 |

One can see that the total surface coefficient of heat transfer $\alpha_{total}$ increases with increasing emissivity. This means that the temperature difference between the ambient and the surface of the insulation decreases, and that a smaller insulation thickness suffices.

The consequence of the varying radiation behaviours of these surface materials for the insulation thickness required for condensation prevention is shown in the diagram below depending on the prevailing relative humidities.

## 3.5 Insulation thickness

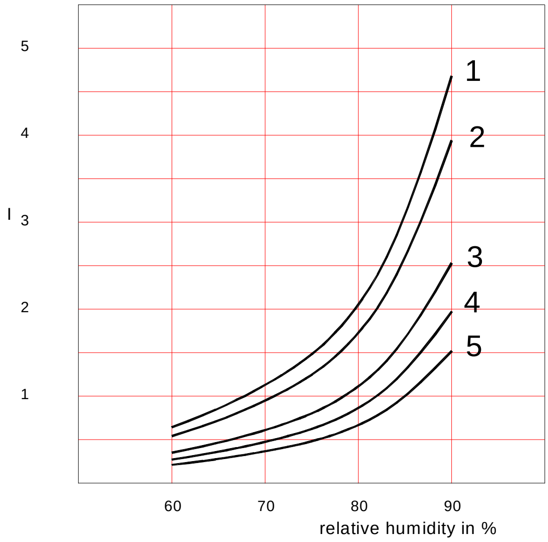
The discussion above leads to the important result:

> **The insulation thickness required for condensation prevention is dependent upon the radiation conditions at the insulation surface and thereby upon the casing material chosen.**

This is shown in an exemplary way in the diagram below.

**Diagram: Insulation thickness to prevent condensation formation**

In relation of the relative humidity and different casings according to Table 2




Some consequences of this result are:

- If using galvanised steel sheet or paint-coated steel sheet, lower insulation thicknesses are required than if using aluminium casings.
- If an insulation of foam glass or elastomeric foam is cased with an uncoated sheet metal, the insulation thicknesses required are increasing.
- In some cases, condensation on an insulation surface with sheet-metal casing can be prevented by the later application of paint. Each non-metallic paint (e. g. **not** silver bronze) can be used, including white.

It may appear strange that even white shows a high emissivity since on the one hand a high absorptivity is required for this, on the other hand, white is characterised by the fact that it does not absorb oncoming light, but instead almost totally reflects it.

The explanation for this is that white paint – in the same way as snow, ice or haw frost – behaves differently in the area of visible light and the area of infrared radiation, which is decisive for surface heat transfer. Whilst in the area of visible light, the radiation is reflected, the infrared radiation is absorbed almost completely so that white and also other colours behave in this area almost like a black surface.

As a general conclusion, it can be summarised:

- The brighter a surface, the “colder” it is.
- Paint coatings, oxidation layers, dust and dirt result in “warmer” surfaces.

### 3.6 Fire protection

In cases where the cold insulation needs to be installed in fire-risk areas or other hazardous zones, for example:

- fire safety zones in nuclear power plants,
- control rooms in chemical plants,
- escape routes in public buildings,
- mines,
- marine and off-shore installations

fire protection takes precedence over lower insulation thickness.

Not only must be fire classification of the insulation material itself, e. g. according to DIN 4102 or other relevant standards, be heeded, but additionally the behaviour of the entire cold insulation system and its contribution to the total fire load, and possibly its fire resistance class. Details should be taken from the relevant fire protection directives.

Points for the consideration of fire behaviour are:

- insulation material (building material classes A1, A2, B1, B2 according to DIN 4102),
- casing material (metallic materials, plastics, gypsum, mastic),
- adhesives (gap fillers, sealing compounds, erection aids),
- vapour retarder, abrasion protection and other coatings,
- mechanical fastenings (wire, bands, adhesive pins),
- stockpiling on the building site (increasing the fire load through ignitable components).

Only when all components mentioned are brought into harmony in fire-protection aspects, and when all safety directives and requirements have been met, can the selection of the insulation material and with that the calculation of the insulation thickness required for condensation prevention take place.

### 3.7 Sound insulation

Additional requirements of sound insulation are critical for cold insulations. The closed-cell insulation material necessary for prime thermal reasons (see FESI Document 08) possess bad acoustically protective properties.

Examples for the composition of cold insulation systems with simultaneous acoustic-protective requirements are given in DIN 4140 and in AGI working document Q 03.

### 3.8 Hygiene

For insulated installations, e. g. in the food industry, special requirements for hygiene may be required. Especially where parts of the installation need to be cleaned or disinfected, the compatibility of the casing with cleaning agents used is of decisive importance for the operating safety of the installation. Special attention is needed for the sealing of the casing where wet cleaning, e. g. with high-pressure cleaning machines, occurs, to keep the danger of moisture ingress into the insulation as low as possible.

Materials used must not be toxic. For plastic materials, paints, metals or alloys, special directives apply. Prior to their employment, manufacturers must be consulted.

Materials must be resistant to disinfecting agents and against corrosion. It is therefore recommended, for installations such as milk-processing machines, to use casings of e. g. stainless austenitic steel with designation codes 1.4541 or 1.4571.

## 4. Additional precautions when leaving service conditions assumed for the design

These additional measures must be taken in cases where the conditions assumed have been left “unfavourably”, that means in direction of increasing risk of condensation.

### 4.1 Gutters and troughs

Gutters can take away the dripping water along the length of a piping. They require a minimum inclination of 10 mm/m and an exit to an existing drainage. Axes of pipe and gutter must be in alignment. The width of the gutter should equal the diameter of the casing. The minimum should be 2/3 of that diameter.

To remove dripping water in critical areas, troughs are used below the dripping points. They need a means of drainage.

Gutters and troughs should have a distance of at least 50 mm from the lower surface of the insulation.

When installing gutters and troughs, the accessibility of operating appliances must be taken into account.

### 4.2 Enforced ventilation

Wherever gutters and troughs cannot be employed, enforced ventilation is an alternative to prevent formation of condensation when the design conditions are being left.

Enforced ventilation is only effective in a limited area. Heating the ventilating air can improve the drying effect.

### 4.3 Additional insulation

If one realises during operation that the conditions assumed are being left permanently, it must be taken into consideration to increase the existing insulation thickness.

Whilst mounting an additional insulation layer, it must be determined whether the vapour retarder and the metal casing need to be disassembled to arrive at defined insulation conditions. The additional insulation needs to be equipped with a vapour retarder in any case and if needed also with an mechanical protection.

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Annex: Specimen check list

| | | |
|---|---|---|
| Literature: | VDI 2055 | Thermal insulation for heated and refrigerated industrial and domestic installations – Calculations, guarantees, measuring and testing methods, quality assurance, supply conditions; |
| | DIN 4140 | Insulation of industrial installations; |
| | AGI Q 03 | Thermal insulation – Execution of thermal and cold insulations – Insulation work on industrial installations |

**Table 1: Check list – Information required for the design of cold insulations**

Information to be provided by client or contractor

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | **- CHECK LIST – COLD INSULATION –** | | | | | |
| Building project: | | Contract No.: | | Date: | | | |
| Responsible engineer: | | Personal contact: | | Sheet No.: | | | |
| | | | | Unit | CL | CO | Remarks |
| 1 | Medium temperature (normal service conditions)[1] | constant | | ℃ | X | | |
| | | flexible/changing | Min. | ℃ | X | | |
| | | | Max. | ℃ | X | | |
| 2 | Ambient air | Temperature | | ℃ | X | | |
| | | Relative humidity | | % | X | | |
| 3 | Insulation material | Type/product | | | X | A | |
| | | Service thermal conductivity according to VDI 2055 | | W /(m·K) | | X | |
| 4 | Surface heat transfer | Geometry/drawing | | | X | A | |
| | | Convection/radiation | Wind[2] | m/s | X | A | |
| | | | Casing material/-coating | | X | A | |
| | | | Other factors[3] | | X | A | |
| 5 | Insulation thickness | | | mm | | X | |
| 6 | Fire protection | Requirement: | | | X | A | |
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