Condensation control – The main task of low-temperature insulation

Parameters influencing the insulation thickness

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Whereas hot installations (heating and hot-water pipes, for example) are mainly insulated to save energy, cold systems (such as the chilled-water pipes of air-conditioning systems or the suction lines of commercial freezers) also need protection against condensation. On refrigeration systems, i.e. in applications where the line temperature is lower than the ambient temperature, water vapour can condense on the cold surface. Condensation on building equipment can result in considerable costs. Apart from the expense of repairing the damage, there may also be costs due to wet ceilings, spoilt goods or disruptions to production processes. Moreover, as the insulation effect of a material deteriorates greatly when it becomes damp, energy losses may rise dramatically and the risk of corrosion also increases sharply. Condensation control must therefore be the primary aim of any low-temperature insulation.

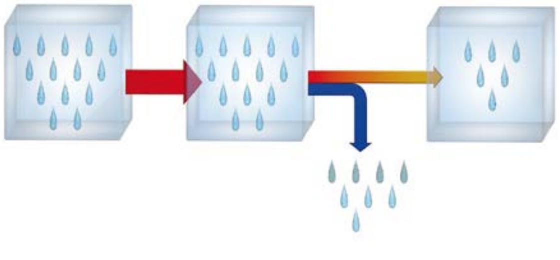
Why condensation occurs: air cannot absorb an infinite amount of water vapour
The air contains water in its gaseous state. At a given temperature and with a given relative humidity, the air contains a defined amount of water vapour. If air is cooled down, it will be 100 % saturated with water vapour at a certain temperature. This temperature is known as the dew point. If the air were cooled further, some of the water could no longer be held in the form of invisible water vapour but would turn into liquid droplets. So warm air can absorb more water vapour than cold air (Figure 1).

Figure 1: Air cannot absorb an infinite amount of water vapour

The respective water vapour content of the air can simply be taken directly from tables provided in typical specialist literature. These show to what extent air of a certain relative humidity can cool without the relative humidity of 100 % being exceeded and thus condensation forming.

Normally air only contains a certain percentage of the maximum possible moisture. It is expressed as relative humidity and can be defined in two ways:

1. as one hundred times the value of the ratio of the existing moisture content to the maximum possible moisture content.
2. as one hundred times the value of the ratio of the water vapour partial pressure and the saturation pressure.



The temperature must not fall below the dew point
Applying this physical law to insulation in refrigeration applications means that the insulation thickness must be designed so that temperatures are never lower than the dew point anywhere

on the surface of the insulation material. In the example in Figure 2, the insulation thickness must be at least 11 mm in order to prevent condensation forming (ambient temperature 22° C, line temperature 6° C, relative humidity 80 %, pipe outer diameter 33.7 mm). In practice, it is seldom possible to obtain a product with exactly the insulation thickness calculated. Therefore, the next largest insulation thickness is usually selected.

Figure 2: The temperature must not fall below the dew point

In order to prevent condensation it must be ensured that the surface temperature on the insulation is always at least as high as or higher than the dew point temperature under defined ambient conditions.

Only correctly dimensioned insulation thicknesses provide optimal protection against condensation
To calculate the surface temperature or the insulation thickness needed to ensure that the surface temperature is at least as high as the dew point, not only the line temperature but also the ambient conditions – ambient temperature and relative humidity – must be known or defined as expected maximum values as part of the planning process. In addition, it is necessary to determine the thermal conductivity of the insulation material, the object (pipe/duct, etc.) to be insulated and the heat transfer coefficient of the surface of the insulation.

These formulae are probably well-known. However, it is crucial to know how the individual factors influence the dimensioning of the insulation and its future serviceability.

The influencing factors

The ambient conditions
In order to determine the minimum insulation thicknesses for low-temperature insulation, assumptions must be made about typical ambient conditions. The maximum values listed in Table 1 were given by insulators, specifiers and plant operators. They reflect the conditions typically used when dimensioning low-temperature insulation.

Table 1: Typical ambient conditions for low-temperature insulation

	maximum ambient temperature [°C]	maximum relative humidity [%]
Plant rooms	32	75
Pipe shafts/ pipe ducts - ‘dry’ - ‘damp’	 24 22	 65 85
Cellar corridors	22	85
Ceiling cavities (suspended ceilings)	24	65
Rooms in offices, schools and hospitals	28	70
Underground car parks - badly ventilated - ventilated	 22 26	 85 89
Food manufacturing	20	90

A common mistake is to underestimate the impact of the relative humidity on the insulation thickness needed to prevent condensation. For example, in some areas a 10 per cent increase in humidity can mean that the insulation needs to be twice as thick.

The thermal conductivity of the insulation material

The thermal conductivity values of materials typically used for technical insulation range from 0.030 to 0.060 W/(m·K). One parameter which influences the thermal conductivity is the mean temperature. In the case of elastomeric insulation materials such as Armaflex Class O, the thermal conductivity increases as the temperature rises. This has a decisive influence on the insulation thickness, because the lower the thermal conductivity, the thinner the insulation thickness. Reputable suppliers of insulation materials only declare the thermal conductivity of their materials in combination with the mean temperature.

The heat transfer coefficient
The heat transfer coefficient depends on the type of flowing medium, the flow speed, the character of the wall surface (rough or smooth, shiny or dark) and further parameters. The heat transfer coefficient usually consists of heat transfer through convection and heat transfer through radiation.

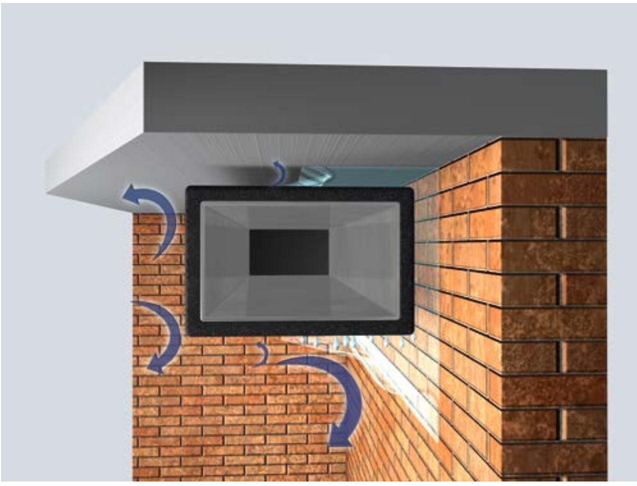
Convection makes a substantial contribution towards improving the heat transfer coefficient. The faster the ambient air flows, the more heat is transported. Therefore, in practice and when designing plant, it is essential to ensure that pipes and ducts have sufficient clearance to each other, walls and other installations. If this is not the case, it is not only difficult to install insulation material professionally, there is also the danger of a build-up zone being created. In such areas, the air circulation (convection) needed for a sufficiently high surface temperature is prevented, i.e. in such build-up zones the heat transfer coefficient is lower (Figure 3). As a result, the risk of condensation forming increases significantly.

Figure 3: Build-up zones prevent convective heat transfer

Therefore, clearance of 100 mm between the insulated pipes and from the pipes to the wall or ceiling is required. In the case of vessels, equipment etc. the distance should even be 1000 mm. Further details can be found in the appropriate standards.

Thermal radiation is a type of heat transfer where the heat is transferred by electromagnetic waves. The transfer of energy through radiation is not restricted to one transfer medium. Unlike thermal conduction or convection (heat flow), thermal radiation can also spread in a vacuum. In the case of thermal radiation, the mechanism of heat transfer consists of two sub-processes:

- Emission: on the surface of a body with a high temperature heat is transformed into radiation energy.
- Absorption: the radiation which strikes the surface of a body with a lower temperature is transformed into heat.



Dark-coloured bodies emit more radiation energy than light-coloured ones; on the other hand, dark-coloured bodies also absorb more thermal energy than light-coloured ones

The measure for the emissive power of a material is the emission coefficient ε. The measure for the absorptive power is the absorption coefficient a. The emissive power of a body of a certain colour is as great as its absorptive power. A vessel which is completely black has the greatest absorptive or emissive power. Table 2 shows the emission and absorption coefficients of some surfaces of insulation systems. As the table shows, it is largely the nature of the surface of the insulation material or its jacket – apart from the influence of other radiating bodies – which determines the contribution of radiation α_S to the heat transfer coefficient. A synthetic-rubber-based insulation material absorbs much more thermal energy than, for example, an aluminium foil. This has an extremely positive effect on the insulation thickness required to prevent condensation, i.e. the higher the absorptive power, the lower the insulation thickness.

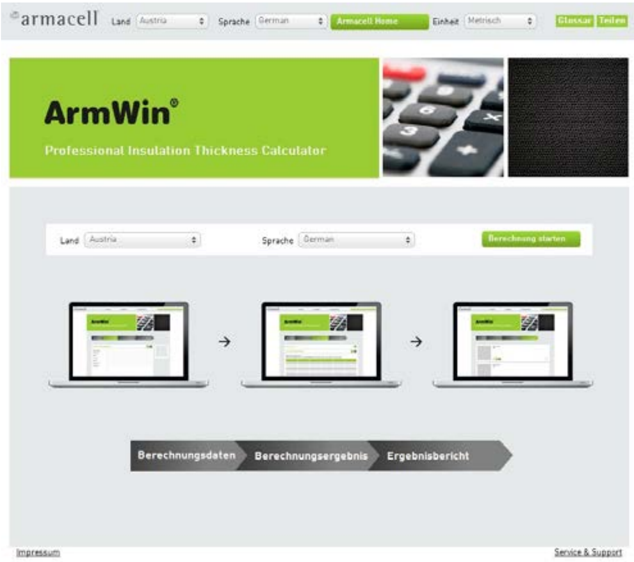
Table 2: Emissivity (ε) of various surfaces

Material and surface condition	ε = a
Aluminium foil, shiny	0.05
Aluminium, oxidized	0.13
Steel, galvanized, shiny	0.26
Steel, galvanized, dusty	0.44
Stainless austenitic steel	0.15
Alu-zinc, smoothly polished	0.16
Arma-Chek Silver	0.83
Paint-coated sheet metal	0.90
Plastic covering	0.90
Flexible elastomeric foam	0.93
Arma-Chek R	0.93
Arma-Chek D	0.94

Determining insulation thicknesses
A crucial factor when calculating the insulation thickness needed to prevent condensation is whether a flat surface or cylindrical object (pipe) is to be insulated. In the case of cylindrical objects, not only the ambient conditions, but also the logarithmic ratio of the diameter of the insulated pipe to that of the uninsulated pipe must be included in the calculation. The consequence is that on pipes thinner insulation thicknesses are sufficient to achieve the same effect, i.e. to obtain the same surface temperature as on flat surfaces. The solution can only be determined iteratively.

To avoid having to carry out this complicated procedure, a calculation program such as the new ArmWin program provided by Armacell can be used. Apart from the minimum insulation thickness required for condensation control, this program can be used to carry out all the typical calculations both in the refrigeration and air-conditioning sector and in the heating and plumbing sector. Armacell has completely revised its calculation program and now offers ArmWin as a particularly user-friendly aid in on- and offline mode and also as an app. Compared to the previous version, technical calculations can be carried out much more easily and quickly. The input required has been reduced to a minimum. New features include the possibility of entering individual data on the project in question and storing calculations as a pdf. Furthermore, ArmWin provides various interactive functions: calculations can be mailed directly, the program is linked to product information on the Armacell website and key terms are explained in a glossary.

Preventing condensation on the surface is a minimum requirement which all low-temperature insulation must fulfil in the long-term, even under critical conditions. To achieve this the correct insulation thickness must be used. Another crucial factor is the quality of both the material and the workmanship. Particularly in cold applications, it is worth having insulation work carried out by an expert. Specifiers and installers often take an incalculable risk if they accept inferior quality for low-temperature insulation, for example by using unsuitable materials or specifying and installing inadequate insulation thicknesses.



Minimum insulation thicknesses which prevent condensation are usually not optimally designed for reducing energy losses. As the results of a study carried out by Armacell show, much higher energy- and CO_2-savings are possible if greater insulation thicknesses are used. Higher levels of insulation – i.e. insulation thicknesses exceeding those required for condensation control – require slightly higher investments, however these pay off over the operating time and allow substantial financial savings after a few years.

Armacell is a world leader in flexible insulation foams for the equipment insulation market and also a leading provider of engineered foams. In the year 2013, the company with more than 2,200 employees worldwide generated net sales of EUR 415.7 million. With its 20 manufacturing plants in 13 countries on four continents, Armacell follows a strategy of internationalization. The company operates within two main businesses: The Advanced Insulation business develops flexible insulation foam products for the insulation of mechanical equipment. The Engineered Foams business develops and markets light foams for use in a broad range of end-markets.

In addition to ARMAFLEX, the world's leading brand for flexible technical insulation, Armacell offers thermoplastic insulation materials, covering systems, fire protection and noise control solutions as well as special foams for a multitude of industrial applications. In recent years, Armacell has developed new insulation systems for the oil and gas market, core foams for composite materials, and low-smoke products that are setting new standards in the industry.