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Thermal Insulation Materials for Building Applications

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resulting in disruption of biological signalling. Styrene was identified as a possible human carcinogen in 2002 by the IARC and in 2014 by the US NTP.

2.12. Polyethylene (PE) insulation

Introduction

Polyethylene insulation is also known as PE foam. It is not commonly used for insulating building walls, roofs etc., but it is widely used for insulating pipes and for soft packaging. It is made from polymerised ethylene and various catalysts, and is extruded. Polyethylene was used in the thin aluminium composite panels that were used on the cladding attached to Grenfell Tower. Manufacturers of this material are found in the Philippines and Australia, where it is promoted as a building insulation material (Thermotec E-Therm).

Constituents and manufacture

PE foam is produced by polymerising ethylene obtained from crude oil. PE foam is manufactured using isobutane as the blowing agent.

Form, dimensions and application

Thin sheets

PE foam is a low-density closed-cell foam material and can be produced in quite thin sheets ranging from 25 to 50 mm in thickness. It is claimed to have good acoustic properties. It is waterproof and has been used in flotation devices. It is lightweight and flexible, difficult to break or tear, but easy to cut. The key physical and hygrothermal properties of PE insulation is presented in Table 2.13.

Environmental attributes

There are claims in product literature that polyethylene is made from recycled foam, but no evidence for this could be found. Manufacturers say that it can be recycled, but again there is

Table 2.13 PE insulation properties

Property (units)	Value
Thermal conductivity (W/m·K)	0.033–0.039
Specific heat capacity (J/kg·K)	–
Density (kg/m^3)	19–144
Porosity	–
Compressive strength (kPa)	48–317
Reaction to fire (EN 13501-1)	B
Moisture buffer value, MBV (kg/m^2·% RH @ 8/16 h)	Negligible
Moisture adsorption at 98% relative humidity	Negligible
Water absorption, long-term (kg/m^2), EN 1609	< 0.3
Water absorption coefficient	–
Vapour diffusion resistance factor, μ	7000

Chapter 3
The science of insulation

The purpose of thermal insulation materials for building applications is to control heat transfer through the building envelope in order to maintain thermal comfort inside buildings. The mechanisms for sensitive heat transfer are conduction, convection and radiation. These mechanisms are briefly discussed below.

3.1. Heat transfer mechanisms

Conduction

Conduction is the mechanism of heat transfer through solids, liquids and gases, from a region of higher thermal energy to one of lower thermal energy. For solids, conduction takes place by means of the vibration of molecules and the movement of free electrons. In the case of liquids and gases, conduction occurs by collision or diffusion of molecules.

Convection

Convection is the transfer of heat between a solid surface and a liquid or gas that is in motion. In convection, heat transfer and mass transfer occur together. Convection can be either natural or forced. Natural convection is buoyancy-driven, that is, when fluid motion is the result of a difference in temperature and concentration. Forced convection is caused by a mechanically induced pressure difference.

Radiation

Radiation is the emission by surfaces of thermal energy in the form of electromagnetic waves when the surface temperature is higher than zero kelvin. Electromagnetic radiation includes ultraviolet, visible light and infrared radiation. Electromagnetic waves can travel through a vacuum, and thus no intervening medium is required for heat transfer by radiation. Since the radiant heat travels at the speed of light, it is the fastest mechanism of heat transfer between two visible surfaces.

Other mechanisms

Latent heat, another mechanism of heat retention and release, is transferred by a carrier, and the heat is converted to sensitive heat when the carrier changes its phase.

3.2. Thermal conductivity

Thermal conductivity can be defined as the rate of heat transfer through unit thickness and area of a material, in the direction normal to the surface of the material, for a unit temperature difference. Thermal conductivity is a material property and indicates the ability of the material

4. a comparative method with concentric samples of known and unknown thermal conductivity and a central heat source or sink
5. electrically self-heating cylindrical samples where the temperature distribution is analysed to measure the thermal conductivity of the sample.

In the radial heat flow method, heat is generated along the axis of a cylinder; when the steady state condition is reached, the radial temperature isotherm is measured at two different radii. If there is no longitudinal heat loss, the thermal conductivity λ is given by Equation 12.

$$\lambda = \left\{ \frac{Q}{2\pi l \Delta T} \left[\ln \left(\frac{r_2}{r_1} \right) \right] \right\} \tag{12}$$

In practical applications, the central heat source is of finite length; therefore, an end guard is used and a correction is applied. This method is also used as a comparative method by having concentric cylinders of known and unknown conductivity with a central heat source.

Transient methods

The principle of the transient methods is to transmit a signal to the specimen to generate a small amount of heat and an acceptable temperature difference in time and to analyse the feedback response to determine the thermal conductivity (see Plate 15). Since a steady state is not required, the result can be obtained within a few minutes. Due to the short time required for measurements, the problem of measuring the thermal conductivity of moist materials without creating a moisture gradient is overcome by this method. However, the transient method is not very suitable for anisotropic martials due to directional heat distribution. Some of the transient methods discussed here are hot-wire and transient plain-source methods.

Hot-wire method for measuring thermal conductivity

The transient hot-wire method measures the thermal conductivity of a sample by monitoring the temperature rise at a known distance from the linear heat source inserted into the sample at known time intervals. In general, the method is used to measure the thermal conductivity of solids and powders by creating one-dimensional radial heat flow inside isotropic samples.

Here, the conductivity can be obtained as a function of temperature, time and heat flow without knowing the diffusivity and the distance. The mathematical model of the hot-wire method is based on the assumption that hot wire is a continuous line source, and, by providing constant heating power through thermal impulses, it generates cylindrical coaxial isotherms in an infinite homogenous medium with initial equilibrium conditions. The transient temperature can be expressed by Equation 13.

$$T(r,t) = \left\{ \frac{Q}{4\pi\lambda} \left[\ln \left(\frac{4\alpha t}{r^2} \right) + \frac{r^2}{4\alpha t} - \frac{1}{4} \left(\frac{r^2}{4\alpha t} \right) - \cdots - y \right] \right\} \tag{13}$$

where λ is the thermal conductivity (W/m·K), Q is the power supply per unit length (W/m), α is the thermal diffusivity of the conductive material, r is the radial position where the temperature is measured, t is the time between heat generation and measuring the temperature, and y is Euler's constant.

Box 7.1 Membership of the Building Regulations Advisory Committee (England and Wales) 2019

Chair
Emma Clancy – Consultant (CEO of Certsure LLP 2013–2018)

Members
Anthony Burd – Head of Built Environment Sector, British Standards Institution
Gavin Dunn – Chief Executive of the Chartered Association of Building Engineers
Julia Evans OBE – Chief Executive of the Building Services Research and Information Association
Rachel Smalley – President of the Access Association
Neil Smith – Head of Standards, Innovation and Research, National House-Building Council
Paul Timmins – Managing Director of Approved Inspector Services Ltd
Dr Hywel Davies – Technical Director of the Chartered Institution of Building Services Engineers
Lorna Stimpson – Deputy Managing Director of Local Authority Building Control
Michael Sansom – Head of Building Control, Brighton and Hove City Council

(UK Government (2019), as of June 2019)

7.2. Classification of flammability and insulation materials

Despite pressure to increase thermal standards and the changes made to improve safety in cladding systems, the building regulations and guidance documents still fail to discriminate clearly between different kinds of insulation materials. For example, it would seem appropriate to distinguish between non-flammable and flammable insulations, but instead the regulations continue to support the questionable concept of semi-combustible or limited combustibility materials. Martin Brown, in an article in *The Construction Index*, raised questions about limited combustibility.

> I suppose it depends on what the UK definition of 'limited combustibility' is but on the face of the information publicly available it is hard to have any confidence in their results. I'd expect at least some cladding tested to have been FR or A2 by now (and samples of them should be tried as a control to show that they do pass this test). I think unnecessary worry is being generated by a testing regime that fails everything that it tests because the methodology is fundamentally flawed. (Brown, 2017)

For instance, the use of the term Class 'O', which was primarily introduced to restrict the spread of flame *internally* over non-combustible surfaces is now being used to classify some insulation composite products. The European fire classification system (Box 7.2), on the other hand, is different, and this also leads to a great deal of confusion. There are significant differences in standards and practice between different EU countries (Fire Safe Europe, 2018).

The Euroclass definitions are referred to in the Appendix to the English Building Regulations Approved Document B.

There has also been a shortage of nitric acid, which appears to be another reason for the insulation shortages. Further investment to resume production is being considered.

> The major application of 4,4’-MDI is the production of rigid polyurethane. Typically, one tonne of polyurethane foam needs 0.616 tonne of MDI and 0.386 tonne of polyol, with 0.054 tonne pentane as a blowing agent. These rigid polyurethane foams are good thermal insulators and used in nearly all freezers and refrigerators worldwide, as well as buildings. Typical polyols used are polyethylene adipate (a polyester) and poly tetramethylene ether glycol (a polyether). (Serra, 2017)

Transporting MDI is subject to Hazchem procedures, as with many other volatile chemicals. Most factories using these materials are located in rural areas of England and Wales and Ireland so that the chemical has to be transported from various ports (Cargo Handbook, 2013; ISOPA, 2016).

Figure 9.1 MDI warning label

Methyl isocyanate
Hazchem Class 6.1

Hazchem Class: 6.1
Emergency action code for this hazard class 6.1
UN Number: 2480

3WE

Material:	Methyl isocyanate
Hazard class:	6.1
UN number:	UN2480
Packing Group:	I
Label Codes:	6, 1, 3
Special Provisions:	1, B9, B14, B30, B72, T22, TP2, TP13, TP38, TP44
Exceptions:	None
Non bulk:	226
Bulk:	244
Passenger aircraft rail:	Forbidden
Cargo aricraft only:	Forbidden
Location:	D
Other:	40, 52
sku:	HZ051