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Use of Field-Applied Polyurethane Foams in Buildings

by M.T. Bomberg and M.K. Kumaran

This Update reviews the use of spray-polyurethane-foam insulation in buildings and discusses how their characteristics influence their field performance.

Spray-polyurethane foams (SPFs) were introduced some forty years ago and have met with good success in the construction industry. While not used as extensively as the prefabricated board material, they have properties that can be used to advantage in certain applications. They adhere well, for example, to clean, dry surfaces and are readily applied to complex shapes. They are also thermally efficient and can be sprayed to any thickness to provide the desired thermal resistance. In addition, polyurethane foams are effective as air barriers, and the medium- and higher-density products can be used as vapour retarders. Their availability in various densities means they can provide increased mechanical resistance, such as compressive strength and impact resistance, where desirable.

Figure 1. Typical spray-polyurethane foam used as insulation in buildings

In addition to being used in buildings, SPFs have also been used successfully for insulating storage tanks, ducts and pipes in district heating; providing the high bonding strength needed in sewer line renewal projects; and in mining operations to consolidate ground strata.

Despite the extensive use of these foams through the years, some questions related to performance remained unanswered, specifically

1) What are the reasons for loss of thermal resistance? and
2) How does the foam cope with the diffusion of water vapour when it is used as a vapour retarder in accordance with the National Building Code?

Findings from research conducted at NRC's Institute for Research in Construction in conjunction with the Canadian Plastics Industry Association to help answer these questions are presented and discussed in this Update.

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Types of Field-Applied Polyurethane Foams

The typical spray foam consists of two components: a polyisocyanate compound and a polyhydroxyl compound. The latter contains blowing agents, which allow the foam to expand, and other additives, such as stabilizers, to keep the foam from decaying. The two compounds are pumped separately to a spray gun. Depending on the reactivity and the delivery mechanism of the material, it may reach the substrate as one of the following:

- a poured foam (liquid)
- a spray foam (liquid droplets)
- a froth foam (droplets containing gas bubbles).

The foam products are usually applied directly to the surface to be insulated or sealed.

There are also one-component moisture-cured foams, often called polymeric sealants. This type of foam is discharged by a propellant gas through a plastic tube, allowing the sealant to be deposited where required.

Polyurethane foams are classified according to their compressive strength. Table 1 gives the approximate density taken from the middle part of the foam (core) that is likely to provide the desired strength for various applications.

The super high-density (SHD) and the high-density (HD) foams are used primarily as thermal insulation in roofing applications with a recommended minimum thickness of 40 mm (1.5 in.). These foams are sufficiently strong and durable to withstand typical service conditions. Making the right choice between "super high-density" and "high-density" foam will depend on the climate, such as temperature extremes and the anticipated traffic conditions on the roof.

The medium-density (MD) foams are used in both masonry and frame construction. Although the foam is protected from the elements in these applications, it must nonetheless be able to withstand all or part of the wind load as well as structural movements. When these loads are expected to be small, the low-density (LD) type can be used. The LD foam is more vapour permeable than the MD type and does not qualify as a vapour retarder.

Good quality bead-applied foam sealant (BSF) should have the following properties:

- density ranging between 27 kg/m^3 and 50 kg/m^3
- percentage of closed cells between 60% and 90%
- compressive strength between 40 kPa and 80 kPa.

Some bead-applied foam sealants available in the marketplace have densities as low as 16 kg/m^3 and unspecified mechanical performance.

The Aging Process of Foams

The mixing of the compounds during spraying causes an exothermal (heat-producing) reaction, which brings the blowing agent to the boiling point. As the gas expands, it forms small bubbles trapped in the polymeric matrix. The polymer must then be allowed to cure (harden) in order for the foam to support itself.

Table 1. The minimum compressive strength and approximate core density of SPF for various applications

Types of SPF	**Main use**	**Compressive strength, kPa (psi)**	**Core density, kg/m^3 (lb/ft^3)**
SHD – super high density	Thermal insulation in roofs	380 (55)	56 (3.5)
HD – high density	Thermal insulation in roofs	280 (40)	45 (2.8)
MD – medium density	Thermal insulation in walls	170 (25)	37 (2.3)
LD – low density - machine applied - pressurized container	Thermal insulation in walls	 100 (15) 100 (15)	 20 (1.3) 27 (1.7)
BSF – bead-applied foam sealant	air sealing	35 (5)	16 (1.0)
OCF – open-cell foam	air sealing	N/A	8 (0.5)

As the foam cools, the gas pressure within the cells falls below atmospheric. The pressure within the cells is further reduced, as some of the blowing agent is absorbed by the polymeric matrix. This allows ambient air to enter into the foam, quickly restoring the atmospheric pressure at the surface of the foam. The diffusion of air from the surface to the interior of the foam occurs more slowly, however, resulting in a pressure gradient within the foam as the cells at the surface are at a higher pressure than those further in.

This diffusion of air into the cells dilutes the gas remaining in the cells, which has a higher thermal resistance than the air. Thus, as the air progresses further into the insulation, its presence results in a gradual reduction of the thermal resistance of the foam, a process called thermal drift or foam aging. Other factors affecting the thermal resistance of these foams include the absorption of some of the blowing agent by the matrix and the outward diffusion of the blowing agent.

The aging process can be explained using a computer model developed by IRC.[1] The effect of aging on SPF is shown in Figure 2. Curve 1 shows that a 25-mm-thick polyurethane specimen fully encapsulated (all surfaces are sealed with a coating of epoxy) is not affected by aging. Encapsulation prevents the entry of air into the foam, but has no effect on the internal movement (redistribution) of the blowing agent. Despite the change in pressure due to the absorption of some of the blowing agent by the matrix, the thermal performance remained the same.

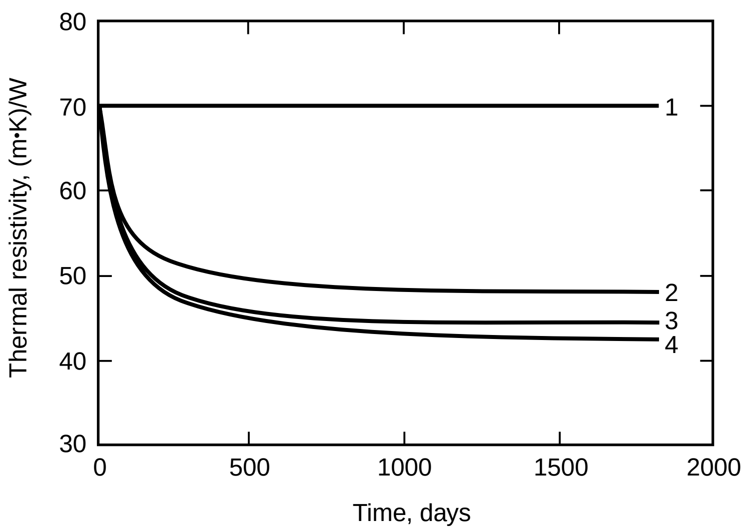

Figure 2. *Thermal resistivity versus aging time for a 25-mm-thick, typical polyurethane-foam specimen*

Curve 2 shows the aging of the polyurethane specimen when air is allowed to enter. The redistribution of the blowing agent is eliminated for this specific phase. Curve 3 shows the previous case plus the effect on the aging process of the absorption of the blowing agent by the polymeric matrix. Curve 4 shows the previous case plus the effect of the outward diffusion of the blowing agent, thus illustrating the change that occurs in the thermal resistance of the foam over the course of its service life.

These model calculations show that the greatest loss of thermal resistance results from the diffusion of air into the cells. Contrary to previous belief, the loss of blowing agent from outward diffusion is not a major factor in the reduction of the thermal resistance of the insulation.

Design Thermal Resistance of Polyurethane Foams

The thermal drift (aging) of polyurethane insulation creates a problem for designers in that they cannot use the initial thermal resistance of the material in their calculations, as it is not representative of the thermal resistance that the insulation will deliver during its service life. What is required for design purposes is a value that reflects the gradual loss of thermal resistance.*

A two-year field study (IRC/industry consortium project) looking at the thermal resistance of a medium-density product used in an exterior house basement insulation system found that the effect of weathering occurred mainly during the initial period of exposure.[2]

* Several research projects were undertaken by IRC to examine the R-value of spray-polyurethane foams using various blowing agents. Researchers compared measured and predicted long-term R-values.[1] In one project, the thermal resistance of an SPF exposed for five years in the exterior wall of an IRC building was found to agree within 3% with the results obtained in the laboratory using medium-density samples manufactured with CFC 11 as the blowing agent. Another project involved a two-and-one-half-year exposure of several medium-density SPF products (blown with HCFC 141b).

The thermal resistance of any gas-filled foam insulation varies with time; therefore, the heat loss (or gain) calculations should be based on the thermal properties of the material averaged over its service life. As the change in the thermal resistance of spray foams is not linear (see Figure 2), or constant through the material over time, it is necessary to determine the value that reflects the average thermal resistance of the insulation over the course of its service life.

The Canadian Standard ULC-S770 defines the long-term thermal resistance (LTTR) of a foam product as the value measured at standard laboratory conditions after a five-year storage period in a laboratory. The value is determined by an accelerated laboratory test and used in lieu of the five-year waiting period.

> Thermal resistivity (r-value) is the inverse of the k-factor. It defines the resistance to heat flow through a slab with unit thickness. Thermal resistance (R-value) is the resistance to heat flow offered by a foam layer of a specific thickness. R-value is obtained by multiplying r-value by foam thickness.

The aging process of polyurethane foams is dependent on a number of factors such as the chemical and morphological characteristics of the foam, the type and interaction of the blowing agent(s) and the thickness of the material. The retention of the initial thermal performance of the foam depends to a large extent on its thickness, since ambient air requires more time to reach all the cells of a thick insulation. If the product has not been tested and its LTTR is not available, the values given in Table 2 are applicable to SPF products manufactured in accordance with current standards.

Table 2. Thermal resistivity values by thickness of foam

Thickness, mm (in.)	Thermal resistivity, (m•K)/W [(ft^2 h F)/BTU in.]
40 (1.5)	39.5 (5.70)
50 (2)	39.9 (5.80)
75 (3)	42.4 (6.15)

Moisture Performance of Polyurethane Foams

When a polyurethane foam at constant temperature is exposed to water, in either liquid or vapour form, little moisture will accumulate in the foam, since 90 percent of the cells are closed and hence bound by continuous membranes that the water cannot penetrate. However, if exposure to water occurs under a thermal gradient, as is generally the case for building insulation where one face (the interior) of the insulation is warm and the other (the exterior) cold, water vapour can migrate through the foam cells towards the cold side (as a consequence of diffusion, condensation and evaporation, which occur sequentially) and accumulate in the insulation.

The force behind the accumulation of water is the vapour pressure differential, or “vapour drive.” Water vapour exerting pressure on the cell walls creates the pressure differential, which is dependent on the vapour concentration (relative humidity) and the temperature of the air on both sides of the cell walls. The pressure differential is greatest on the warm side of the insulation; it decreases with temperature. To balance the pressure, the vapour gradually moves towards the cold side where the vapour pressure is lower, flowing continuously through the insulation if there is nothing to prevent it from escaping. This approach to dissipating water vapour is sometimes referred to as flow-through design.

Because the rate of moisture transport decreases as the thickness of the insulation increases, it is important to specify a thickness that will minimize the accumulation of seasonal moisture in the foam. Thin layers of spray-foam insulation (less than 15 mm) are not recommended (for this and other reasons); thicker layers (40 mm or more) are generally satisfactory and perform well.

If the cold side of the insulation is in contact with an impermeable material, such as metal siding, the water that condenses in the cells will not be able to escape. As a result, the amount of water absorbed by the insulation will be greater than it would be if the water were free to escape. If the temperature on the cold side of the building envelope warms up, as it does during the spring and summer, some of the moisture contained in the insulation will diffuse back towards the inside.

Table 3. The average design values of water vapour permeance for SPF systems

SPF and substrate	**Total thickness, mm (in.)**	**WV resistance, (Pa•s•m^2)/μg**	**Permeance ng/(Pa•s•m^2) (perm)**
50 mm (2 in.), exterior gypsum board	63 ($2^1/_2$)	19	52 (0.91)
75 mm (3 in.), exterior gypsum board	89 ($3^1/_2$)	25.7	39 (0.68)
50 mm (2 in.), concrete blocks	74 ($2^7/_8$)	33.9	29.5 (0.52)
75 mm (3 in.), concrete blocks	98 ($3^7/_8$)	40.6	24.6 (0.43)

Under typical service conditions, if a reasonable thickness of material is specified and the flow-through design approach is used to deal with water vapour, the thermal performance of spray-polyurethane foams will not be significantly affected by the presence of water in the cells. The presence of air and blowing agents inside the cells also protects the insulation from damage due to freeze-thaw cycling.

Water Vapour Permeance

Table 3 gives typical water vapour permeance design values for spray-polyurethane foams applied to gypsum board and concrete block walls.

The lower permeance of the SPF-concrete block system is due to the fact that when the insulation is applied to a material such as a concrete block, the surface layer forms a “skin” that has good resistance to water vapour diffusion. The skin, however, does not form when the foam is sprayed on a capillary material such as gypsum board.

Practical Recommendations

- When using medium-density (MD) foam in walls as both insulation and vapour barrier, a minimum thickness of 40 mm is recommended.
- When placing a foam product in an exterior wall assembly, ensure that the moisture flowing through the foam will not affect other materials. This could happen when moisture is trapped in a moisture-sensitive material, such as plywood or OSB, and drying is prevented by the layer of SPF. It could also happen when moisture accumulates in the outer layer of the spray foam, which could damage moisture-sensitive materials such as sheet metal.
- When foam products are used behind the exterior cladding of a rainscreen wall to provide water-resistant protection to the back-up, or structural, wall, ensure that an air cavity is provided between the insulation and the cladding (typically, the minimum width of the air cavity is 25 mm).
- When used as an air barrier, polyurethane foam may crack on joints subjected to differential movement caused either by shrinkage or by structural deflection. To maintain the integrity of the air barrier, attach a strip of peel-and-stick membrane to both sides of the joint.[3]
- When used in a roofing system, spray-foam insulation must be sprayed onto a dry surface; otherwise the heat generated by the chemical reaction during the foaming process may create gas pockets that contain an air/vapour mixture, leading to loss of adhesion.
- When spray foam is used as roof insulation it should have a smooth finish and be protected by a liquid-applied protective coating. Most of these coatings have a vapour permeability coefficient of the same magnitude as (or higher than) that of the spray foam.
- Proper design and construction of flashing details are both important to the long-term performance of SPF roofing. Industry recommendations should be followed.
- A spray-foam insulation roofing system must be adequately protected whenever maintenance work is done on the roof. Puncturing of the insulation and the spilling of liquids (e.g., oil or gasoline) should be reported immediately.

Conclusion

A number of field-applied polyurethane foams have been in use for many years as insulation and/or air barriers and their properties and application are covered by Canadian standards. Some products intended for use as air barriers are still in the developmental stage and undergoing durability testing. Finally, there are some products — specifically, open-cell foam (OCF) products — for which no rigorous testing has been done. It is therefore important for the designer or specifier to require the results of testing and evaluations carried out for those materials they propose to use.

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Drs. M.T. Bomberg *and* ***M.K. Kumaran*** *are senior researchers in the Building Envelope and Structure Program of the National Research Council's Institute for Research in Construction.*

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**For more information, contact Institute for Research in Construction,
National Research Council of Canada, Ottawa K1A 0R6
Telephone: (613) 993-2607; Facsimile: (613) 952-7673; Internet: http://irc.nrc-cnrc.gc.ca**