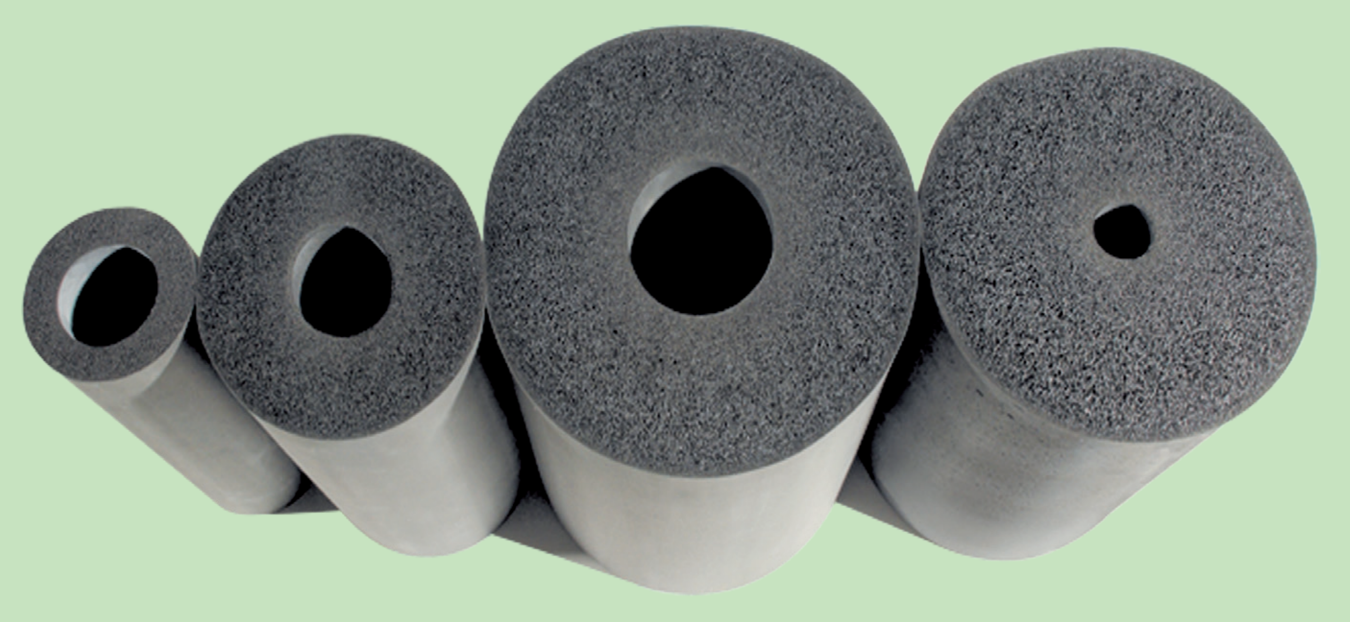
EPDM rubber closed cell elastomeric pipe insulation



Selecting the Right Insulation Material – for Mechanical Systems

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Introduction

Though thermal insulation is a vast topic, the discussion in this article is limited to thermal insulation for mechanical systems.

Thermal insulation is a material or combination of materials primarily used to limit heat gain and loss from surfaces operating at temperatures below and above the ambient temperature.

About the Author

Shahab Ahmad is an MBA from IIT Delhi and mechanical engineer from JMI, New Delhi with over 20 years of experience in the field of HVAC&R, including technical sales and marketing, design and operations of products and systems. He has worked with leading companies such as Blue Star, VTS Group, Voltas International (KSA), Thermax, ETA Engineering, Desiccant Rotors International (UAE) and Mekar LLC (UAE). He is ISHRAE and ASHRAE member. He is currently Associate Vice President at ALP Aeroflex India, Gurgaon, responsible for all India sales and marketing of thermal and acoustic insulation products and accessories.

Benefits of Insulation

The main benefits of insulation are:

Energy Conservation

To minimize unwanted heat gain or loss from HVAC&R systems and thereby protecting natural and financial resources.

Condensation Control

To minimize or avoid surface condensation by keeping the insulated surface temperature above the dew point of the surrounding air. This is usually applicable for cold applications.

Controlling Surface Temperature

To maintain a specific surface temperature, thus preventing any burning or damage of the skin. This is mainly applicable for hot insulation.

Freeze Protection

To prevent or delay the freezing of liquids in sub-zero applications in case of system failure, and to reduce the energy for heat tracing in cold storages.

Classification of Insulation Materials

From the microstructure point of view, insulation materials can be classified as open cell, interconnected cell, semi-closed cell and closed cell.

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Open Cell

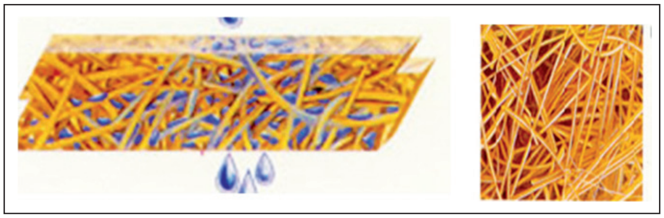

Figure 1: Open cell insulation

As the name suggests, this insulation material has no cell walls and is made from compacted fibers with air entrapped in the spaces between fibers. Examples of such materials are glass fiber, mineral wool and ceramic wool. They are characterized by low K (thermal conductivity) values and low µ (water vapor diffusion resistance) values, making them less suitable for cold applications, in which both heat and water vapor flow from the ambient side (hot side) to the cold side (see *Figure 2*). In the absence of an effective vapor barrier, the migrating vapor comes in contact with a cold surface whose temperature may be below the dew point of air, leading to condensation. If the surface temperature is below 0°C, it will lead to ice formation, drastically increasing the K value of the material, resulting in large energy loss. (K value of water is 0.58 W/mK at 25°C, and of ice is 2.18 W/mK, i.e. 30 and 70 times respectively the K value of dry material, which is 0.03 W/mK). Further, a water absorption test as per ASTM 1056 shows that glass fiber will absorb 400% water by weight after 20 minutes.

Open cell material is excellent for hot applications. In a hot application, both heat and vapor flow from the hot surface to the ambient side. If there is any entrapped water vapor, it will move outwards and make the material drier, thereby improving the K value of the material and reducing energy loss. (See *Figure 3*.)

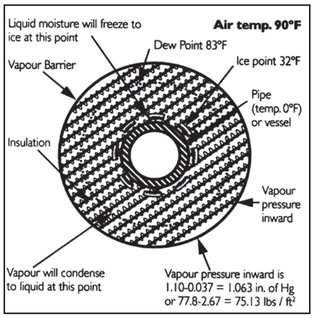

Figure 2: Cold application

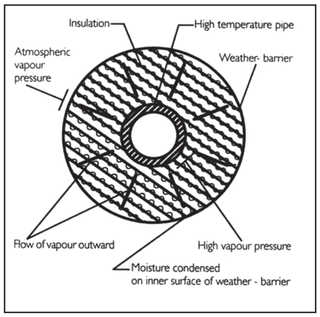

Figure 3: Hot application

Interconnected Cell

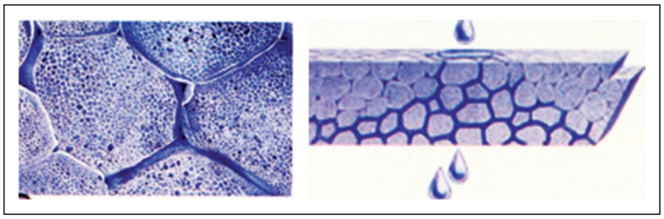

Figure 4: interconnected cell insulation

This insulation material is made by compressing tiny styrene pellets into foam sheets under high temperature and pressure. The cells are interconnected with air gaps between the pellets. Examples are expanded polystyrene (EPS), commonly known as thermocole, and extruded polystyrene (XPS). EPS is a lightweight material used for making household items – trays, cups, bowls, fish boxes, etc. EPS is also widely used as the packing material for cushioning of fragile items. It has a low K value in the range of 0.032-0.036 W/mK, and is used for cold applications below 100°C. It is available in pipe sections and sheets. However, it has low µ value of 30-70. Due to its low water vapor diffusion resistance, moisture can pass through its annular spaces, leading to condensation. In cold applications, it is necessary to use it with a moisture barrier. Hot bitumen can be applied to the metal surface and EPS, and the two stuck together. Joints can be sealed with bitumen and finished with sand cement plaster or metal cladding. Bitumen has water content, which allows the vapor to permeate the insulation, leading to increase in the K value.

Semi-closed Cell

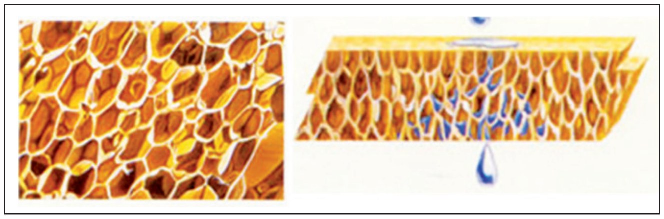

Figure 5: Semi-closed cell insulation

This type of insulation material has small independent cells, with walls of each cell shut from each other but imperfectly. Examples are lightweight polythene (PE) foam and low-density polyurethane foam (PUF). PUF can be used over a wide temperature range, from 80 to 110°C. It has low thermal conductivity of 0.025 W/mK due to the presence of HCFC gases within its cells, but is ozone depleting in nature. The density of semi-closed insulation used for HVAC systems is in the range of 30-45 kg/m^3, keeping in mind adequate price and quality. This is the reason why the cell walls are weak and high in moisture permeability. During expansion and contraction of the material due to temperature variations, these cell walls break and hence the thermal conductivity becomes higher than closed cell material over a long period of time. Due to its weak cell wall structure, it is recommended to use vapor barrier for all cold applications. As regards flame spread, it complies with Class 1 standard as per BS 476 Part 7. However it produces highly toxic gases such as HCN, which can prove fatal even if inhaled in a very small quantity. Research shows that there are more fatalities in building fires due to smoke than due to the fire itself. Further, in a 20-minute water absorption test as per ASTM 1056, low density PUF will absorb 40% water by weight.

Closed Cell

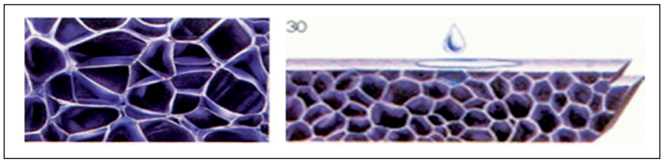

Figure 6: Closed cell insulation

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Closed cell elastomers consist of a large number of tiny well-defined singular cells containing dry inert gases (such as N_2 and CO_2) emitted by a blowing agent in a honeycomb matrix structure. These elastomers are made of synthetic rubber or a combination of synthetic rubbers such as nitrile and EPDM rubber. The cell walls are impenetrable, and therefore prevent any moisture ingress. They are produced in the density range of 40-60 kg/m³ for both hot and cold applications. Water absorption is less than 10% by weight when tested as per ASTM 1056. Because of their closed cell structure, they have a very high µ value above 8000. The K value is in the range of 0.032-0.035 W/mK at 10°C, which remains stable during the service life of the material.

Factors Affecting Condensation Control

In areas of high humidity, especially where cold insulated ducts and pipes run through non-ventilated shafts and voids, condensation problems are frequent. Condensation damages the false ceiling, carpets and furniture and creates water logging, rendering the space uninhabitable. It also results in energy wastage and financial losses. Condensation problems can be avoided in three simple ways:

Determining Proper Insulation Thickness

Minimum insulation thickness is a function of Relative Humidity (RH) of a space at constant dry bulb (DB) temperature. *Table 1* shows that for a fixed DB, increasing the RH increases the required insulation thickness to prevent condensation. The required insulation thickness increases 6-8 times when RH increases from 50% to 90%. During the rainy season or in coastal areas, the inside RH usually increases to 85-90%. Hence, to avoid condensation during the rainy season in non-ventilated spaces, the insulation thickness should be selected at 32°C and 85% RH or higher.

Table 1: Effect of RH on minimum insulation thickness to prevent condensation

Constant Parameters		
Fluid temperature		6°C
Ambient temperature		32°C
Wind speed		low
K value		0.034 w/mK
RH %	**50 mm pipe**	**100 mm pipe**
50	6	6
60	9	9
70	13	13
80	25	25
90	40	45

Good Installation Practices

Even if insulation thickness is correctly selected, it may still lead to condensation due to poor installation (see *Figure 7*). Since the two pipes are running close together, there is virtually no air movement; hence condensation can occur. One should normally keep insulated pipelines 3" apart for small sizes (less than 3"NB), and 4" apart for large sizes (more than 4") (see *Figure 8*). This will enable free movement of air and prevent dew formation. Also all butt/longitudinal joints need to be properly sealed with rubber based adhesive and finished with elastomeric foam tape.

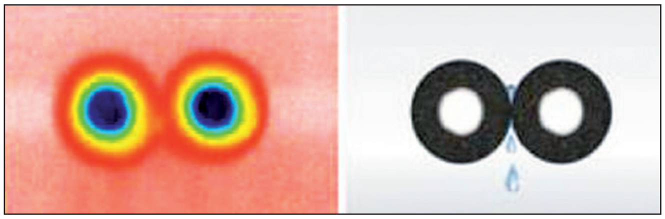

Figure 7: Infrared photo shows thermal energy around the pipes especially at the bottom contact of insulated pipe, where there is no or less air movement and accumulation of moisture that causes severe condensation

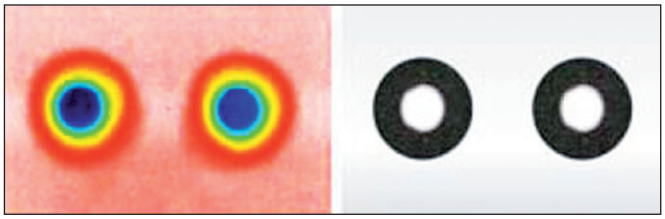

Figure 8: Infrared photo shows thermal energy around insulated pipes located 4" apart, allowing free air movement without accumulation of moisture and no condensation problem

Location of Pipes/Ducts

It is important to properly understand the location of insulated ducts and pipes in an area that is ventilated by untreated fresh air. In such areas, no amount of insulation can prevent condensation, as almost 100% saturated air will pass across the cold surface. Also, in certain conditioned areas, at certain places like a shower area or a sauna area, the humidity is likely to reach 100%, which may again lead to condensation. Hence, insulated cold ducts and pipelines should not be located in such areas.

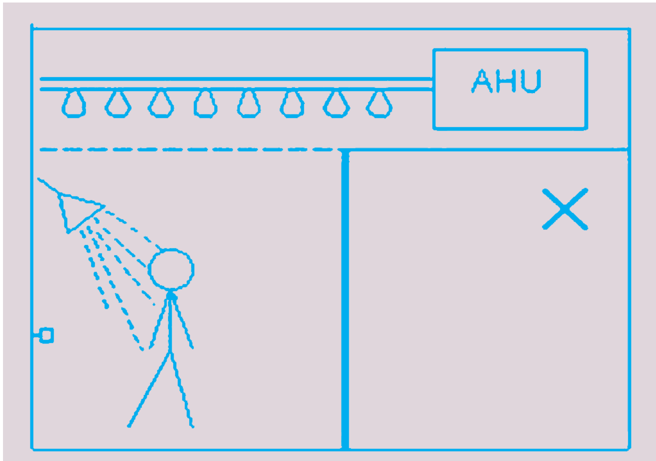

Figure 9: Avoid locating cold ducts in high humidity areas

Saving Energy

Closed cell elastomeric insulation is designed for cooling and heating lines, to save energy and to prevent condensation, which means saving of natural and financial resources. Saving of energy implies saving of GHG (green house gases) and less global warming (see *Table 2*).

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Table 2: Insulation thickness vs. energy saving, CO_2 emission and condensation

Insulation Thickness	mm	No Insulation	13	25	38	50	63	75
Surface Temperature	°C	5	24.1	26.8	27.9	28.5	28.9	29.1
RH to Prevent Condensation	%	21	71	83	89	92	94	95
Energy Consumption	kw.hr/m/yr	142.8	46.4	30.6	23.6	20.1	17.5	15.8
Energy Cost	INR/m/yr	1285.2	417.6	275.4	212.4	180.9	157.5	142.2
CO_2 Emission	kg/yr	71.4	23.2	15.3	11.8	10.05	8.75	7.9

Note: Calculation based on 2-1/2" IPS pipe (73mm OD), operating temperature of 5°C, room temperature of 30°C, K value of 0.0375 W/mK and energy cost of INR 9/kw.hr in 24 hrs x 365 days

For selecting an insulation material, certain physical and chemical properties are desirable:

- Low and stable thermal conductivity
- High resistance to water vapor transmission, or high vapor diffusion resistance
- Ease of installation and flexibility
- Good fire and smoke performance
- Health and safety of applicators
- Environmental impact

Low and Stable Thermal Conductivity

Thermal conductivity is a measure of the ability of a material to allow heat to pass through it. The common unit is W/(m•K). It is desirable to select insulation with a low thermal conductivity so as to minimize the loss or gain of energy. The insulation should not only have a low K value, but it should remain stable across its service life. Under high humidity conditions of tropical regions, insulators with low vapor diffusion resistance will gradually absorb moisture leading to increase in K value. As can be seen from *Figure 10*, open cell insulators will have the maximum increase in K value followed by interconnecting cell, then semi-closed cell and the least by closed cell insulators over their service life.

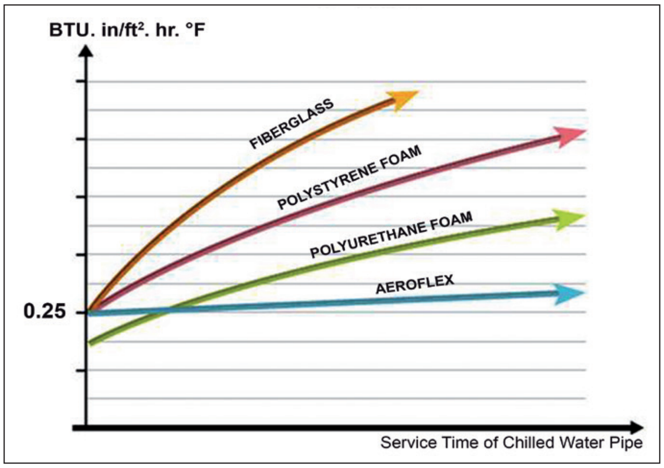

Figure 10: Change in thermal conductivity over time

Resistance to Water Vapor Transmission

The resistance to water vapor transmission (μ value) is the ratio of the water vapour diffusion coefficient of air to that of the material in question. The μ value is a measure for the vapour tightness of a material. It indicates how many times greater the resistance to transmission of a layer of material is, compared to a static layer of air of the same thickness.

A high water vapor transmission resistance ensures a stable K Value and a durable product. As such, open cell materials have the least μ value and hence are not suitable for cold applications. On the other hand, closed cell insulators with μ value above 7000 are most suitable for cold applications, preventing the loss or gain of energy and condensation.

Table 3: Properties of insulation materials

Material	Maximum medium temperature (°C)	Density (Kg/m³)	Thermal conductivity (W/m.K) at 10°C	Water vapor diffusion resistance (μ)
Closed Cell				
EPDM rubber foam (HT)	125 (150)	40 – 60	0.034 – 0.035	7000 – 12000
NBR rubber foam	115	40 – 60	0.034 – 0.035	7000 – 12000
Semi-closed Cell				
Polyethylene (PE)	85 – 105	20 – 60	0.035 – 0.038	1000 – 5000
Interconnecting Cell				
Extruded foam (XPS)	80	30 – 40	0.030 – 0.032	80 – 300
Expanded foam (EPS)	80	20 – 30	0.035 – 0.037	20 – 100
Open Cell				
Mineral wool (MW)	200 – 750	24 – 180	0.032 – 0.040	10 – 100
Cellular glass (CG)	430	90 – 200	0.040 – 0.045	

Flexibility/Ease of Installation

It is good to have a flexible insulation material as it enables quick and easy installation on any straight duct or pipe piece, bend, tee, elbow, fitting, valve, etc. In addition, flexible insulation ensures that none of the butt and seam joints are left exposed, as the ends stick together in an airtight manner. On the other hand, inflexible or rigid insulations such as PU, EPS and XPS will always have gaps in the joints, which may lead to moisture transfer and hence condensation and under-insulation corrosion (UIC). All closed cell elastomers have this property.

Fire and Smoke Safety Performance

With the National Building Code of India (NBC) laying down strict guidelines for fire safety, it is imperative to install a fire and smoke safe insulation for HVAC systems. Each country has defined its own standards for fire, flame and smoke. In India we follow BIS and ASTM standards. The important considerations for fire and smoke safety are:

- Surface flame spread
- Heat generation during fire
- Smoke density
- Smoke toxicity
- Self extinguishing, non drip

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Table 4: Parameters covered under test standards

Test Standard	Fire Spread	Smoke Density	Flaming Drips	Toxic Gas	Self Extinguishing
ASTM E84	Yes	Yes	Observe	–	–
UL 94V	Yes	–	Yes	–	–
BS 476	Yes	–	–	–	–
ASTM D635	–	–	–	–	Yes
IMO MSC61(67)	Yes	Yes	–	Yes	–

BS 476 Part 7 governs surface flame spread. The test measures the distance and time a flame will spread across a surface (or speed of flame). The results range from Class 1 to Class 4. The worst is Class 4, i.e. the longest distance and fastest flame spread. The best is Class 1, i.e. the least distance and slowest of flame spread. A good Class 1 result would mean the flame not spreading further than 165mm from the point of ignition over the total test time of 10 minutes.

Class 0 is not a fire test, but in fact a classification from The Building Regulations 1991 – Fire Safety, Approved Document B. In order for a system to achieve a Class 0 rating, it must meet the following requirements:

1. Achieve a Class 1 fire rating from BS 476 Part 7 – Surface Spread of Flame,
2. Achieve an index of I = less than 12 and i1 = less than 6 from BS 476 Part 6 – Fire Propagation.

The fire propagation test measures the amount of heat the surface is giving off during the fire. Measurements are taken frequently throughout the 20-minute test, and calculations are made using a special formula to achieve an 'index rating'.

Class 0 rating is a mandatory requirement for large projects such as government buildings, schools, hospitals, multiplexes, IT buildings, hotels, offices, etc., while small commercial buildings and residential villas generally call for Class 1 rating.

Now, with more research in building fire safety, it is important to look into the effects of smoke toxicity and density. International Maritime Organization (IMO) MSC 61 (67) is the test standard to determine smoke toxicity. Though most insulators comply with either Class 1 or the more stringent Class 0 rating, only EPDM elastomeric rubber insulation complies with IMO smoke toxicity test. On burning, it will not melt nor generate flaming drops with low smoke density. The gases released while burning are hydrocarbon and carbon dioxide, which are not hazardous to health, unlike hydrogen cyanide gases that are highly toxic. It is self-extinguishing within a short time when the flame is removed.

On the other hand, semi-closed cell PE foam, containing butane or similar gases, is highly combustible and can cause rapid flame transfer. It will melt and generate flaming balls (fire balls), causing flame transfer to other materials in buildings such as ceilings, carpets, and furniture.

Polyurethane foam insulation is composed of polyols and polyisocyanates mixed with pentane, HCFCs or similar gases. Although there may be some self-extinguishing grades, it will still produce large quantities of smoke while burning, releasing hydrogen cyanide gas (HCN). It is one of the most noxious gases, and is fatal within a short time. HCN at 300 ppm is fatally noxious within 2-3 minutes.

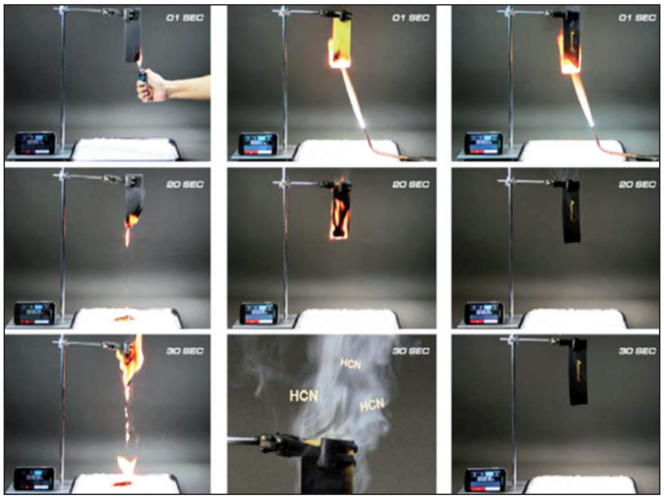

Figure 11: Flammability test

Health and Safety

It is important that insulation used in the HVAC system does not pose any health hazard to the applicator. Open cell materials like fiberglass and mineral wool, if in contact with humans, will cause eye irritation, skin rashes and sore nose and throat, and sometimes stomach ache if swallowed. An applicator using open cell material needs to wear a face mask, safety goggles, full body covered dress and hand gloves. Any loose particles in the air system can clog filters, affect belt drives and motors and deteriorate the air quality in the conditioned space. In addition, open and semi-closed cell insulation is prone to growth of mold and mildew under humid conditions, resulting in deterioration of the material and indoor air quality. On the other hand, closed cell elastomeric insulation is free from any loose fibers and hence can be applied without any safety gear and does not pose any health hazard. Antimicrobial agents can be added to elastomers to prevent growth of bacteria or fungi. NBR and EPDM rubber foam, when tested as per ASTM G21 and ASTM G2180, show zero growth of microbes.

Figure 12: Safety gear is required for application of open cell insulation

Environmental Impact

Last but not the least, the insulation should not have any negative impact on the environment. Elastomers have superior resistance against some chemicals such as acids and alkalis, and they are manufactured without the use of CFCs, HFCs, HCFCs, butane, pentane or other ozone depleting or flammable gases, unlike semi-cosed and interconnected cell insulators.

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Features of EPDM Rubber Foam Insulation

EPDM is considered the next generation insulation because of its following features:

Temperature Range

EPDM standard insulation saves energy and prevents condensation when used in operating temperatures down to -200˚C, and insulates against heat loss up 125˚C. However, for higher temperature up to 150˚C (300˚F), EPDM-HT is recommended, which is suitable for low pressure steam applications. Within these recommended operating temperatures, the thermal efficiency of EPDM will not be affected.

UV and Weather Resistance

EPDM based insulation has excellent ultraviolet and weather resistance. EPDM is widely used in outdoor applications (solar, VRF tubing, etc.), automobile industry, window strips and rubber hoses in engine rooms. Due to this feature, EPDM has a service life of more than 25 years for indoor applications at the recommended thickness.

Water Absorption and Moisture Permeability

The EPDM closed cell structure protects against moisture and results in very low water absorption, which can eliminate the need for a water vapor barrier in the most humid conditions. However, under severe condition of high humidity (90% RH and above) and direct exposure to sunlight, additional water vapor barrier will be required.

Non-Polar Material

EPDM is made from EPDM synthetic rubber, classified as a non-polar material, which is highly water resistant while NBR and PVC are classified as polar materials, which slowly dissolve in water, resulting in surface deterioration. Water is also a polar material, so continuous contact with condensate water damages NBR and PVC insulation much faster than EPDM based insulation.

Thermal Efficiency

EPDM insulation, made from EPDM based synthetic rubber foam with low density and closed cell structure, mainly contains inert dry nitrogen gas. It thus has a stable low K value of 0.033 W/mK at 25°C, which can save energy on heating and cooling lines throughout its service life.

Figure 13: EPDM based insulation has a neat finish

Flame- and Smoke-Proof

EPDM rubber insulation is formulated to international fire standards such as ASTM E84, UL 94, JIS K6911, EMPA and IMO A653, and can be customised for other specific fire standards.

Anti-Vibration and Resonance

The high elasticity of EPDM insulation minimizes the vibrations and resonance of chilled water and hot water pipelines during operation.

Neat Appearance

The flexibility and smooth surface of EPDM offers a neat and finished appearance even at joints, elbows and crosses. No decorative or protective coating is required.

Wide Size Range

EPDM comes in a wide range of thicknesses and inner diameters (IDs) for all pipes sizes, together with accessories.

References

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