Thermal Insulation

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Abstract— Everyday life and other industrial use we often use some temperature for any process or thermal comfort but temperature not stay steady it is changing by time. Heat loss is done by the temperature go higher to lower side by the temperature gradient. We want to stop this so we use thermal insulation which is blocking the path of heat transfer thermal insulation material are different for different temperature range and different properties it has. In this report we see different type of thermal, mechanical and chemical properties which significant in insulation. Different material and way of blocking path of heat are discussed in this document.

Key words: Heat Transfer, Thermal Insulation, Conduction, Convection, Radiation

I. Introduction

All around we find constants transfer of heat and energy. But we in a pervasive attempt to obtain thermal comfort for our work, always try to stop environment to do what is usually done, is doing now and will continue so on.

Experts have traced the roots of the English term insulate back to the Latin term insula, which means "isle." Ancient references have suggested this to be attributed to the fact that an isle is "insulated" by water. In the same as that the water is an obstacle to nomadic warriors attacking an isle, insulation is an obstacle to the "invaders" of heat energy. [1]

A. The way of Heat Transfer

To know how thermal insulation is working, it helps to know the three mechanisms of heat transfer : conduction, convection, and radiation.

1) Conduction

Conduction is the mode of heat transfer in that heat can transfer between two body which are in physical contact. In conduction heat transfer kinetic energy transfer from molecule to molecule

2) Convection

In convection, heat transfer takes place by change in location of heated matter. In this matter can air or any fluid. For example, in a room air is heated and air reach at the floor by fan or the wind that is called force convection. When air can get heated by sun and that warm air molecule transferred is called free convection. Free convection also occur when shining of the sun comes in to building from window, and heats the air inside the building.

3) Radiations

In this mode of heat transfer does not required any medium. Means heat transfer through space. Even in vacuum also radiation can transfer. Basically, radiation is electromagnetic waves.

4) The Brief History of Thermal Insulation

The roots of the thermal insulation technology, although, are arduous to identify. Organic materials generally provide the natural replica for thermal insulators. Examples include fur covering the bear or skin of a bird, cotton, wool, and also hair. [2] In the same way ancient people wore clothes made from wool and leather of animals and crafted homes.of stone, wood and sand.

For centuries, building structures were crafted to best suit the climatic conditions of that place. The best example is to use the earth as an insulator. [3] Historians have believed old Greeks and Romans to discover asbestos and found its use in resistance for heat as well as fire. The Romans even utilized cork as insulation in shoes so that they can feel the feet warm. Pliny, in the first century, included in his study utilization of cork as an insulation material for roofs. Early inhabitants of Spain lined their stone houses with cork bark, and North African natives utilized cork with mixture of clay for the walls of their houses. [4]

As technology enhanced it led the inventions to increase the comfort for human beings. Norwegians on introducing the fireplace as well as chimney and "people of Iceland during the twelfth centuries provided controlled, artificial heat. [3]

B. Why thermal insulation ?

"Insulations are defined as those materials or combinations of materials which retard the flow of heat energy" by performing one or more of the following functions:

1) Conserve energy by reducing heat transfer."
2) Control surface temperatures for personnel prevention and thermal comfort."
3) Maintain temperature control of technique."
4) Protect water and vapour flow condensation on cold surfaces areas."
5) found in commercial and industrial installations."
6) Protect to equipment from exposure to fire or corrosive atmospheres."
7) Assist mechanical systems in meeting criteria in food and cosmetic plants and trees."
8) Reduce emissions of pollutants in to the environment

II. Types of Insulation

A. Types of insulation based on temperature

Temperature limit in which the word "thermal insulation" will apply, is from -75°C.to 815°C. Entire Applications below -75°C. temperature are called as "cryogenic", and which above 815°C temperature are called as "refractory".

range and its application divided into three general category as shown Thermal insulation based on temperature below.

1) Low temperature thermal insulation

Temperature range	Application
15ºC to 1ºC	Cold water
0ºC to -40ºC	Refrigeration, Glycol
-40ºC to -75ºC	Refrigeration, Brine
-76ºC to -273ºC	Cryogenic

Table 1: Low Temperature Thermal Insulation

2) Intermediate temperature thermal insulation

Temperature range	Application
16ºC to 100ºC	Hot water, Steam condensate.
101ºC to 315ºC	Steam, vapor, High temperature hot water.

Table 2: High Temperature Thermal Insulation

3). High temperature thermal insulation

Temperature range	Application
316ºC to 815ºC	Stacks, Breechings, Turbines, Boilers, Exhausts

Table 3: HIGH TEMPERATURE THERMAL INSULATION

B. Types of insulations based on mechanical properties

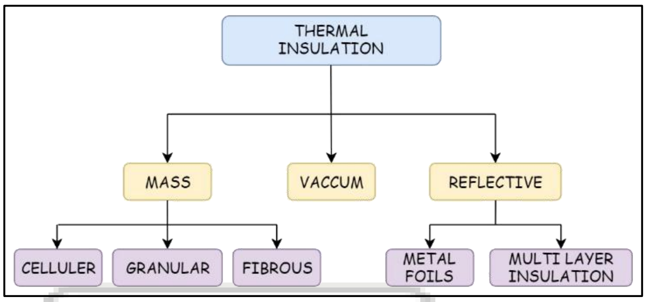

Fig. 1: TYPES OF INSULATION

C. Mass insulation

Mass insulation is blocking the path of heat transfer by conduction and convection using mass material like foam, powders, fibrous materials. This type of insulation dividing into further three parts basis of molecule's structure i.e. cellular, granular, fibrous. [5]

1) Cellular insulation

In cellular insulation material associated with cell. This cellular porous material might be fibre glass and foamed plastic like polystyrene.

2) Granular insulation

In this type of insulation material is associated with granular structure. Means material has small nodules which can contain hollow spaces. When gas in transfer between the individual spaces then we can say that material is true granular material. Calcium silicate, perlite, cellulose, expanded polystyrene are example of this insulation.

3) Fibrous insulation

Fibrous insulation is that kind of insulation that works by capturing air within the fibre, preventing heat transferred through convection. This insulation is flexible. Fiberglass, mineral wool, plastic fibre, natural fibre are some common type of fibrous insulation. this insulation such as fiberglass and mineral wool can be irritating eyes, skin. One should touch the insulation directly by hand.

D. Vacuum insulation

Vacuum is very good effective insulator ,air is itself a very good insulator. Example is stainless steel water bottle. If we remove physical matter between two surface it is called vacuum is created.

E. Reflective insulation

In this type of insulation due to some material we can reflect the radiation. So radiation heat transfer can blocked. Reflective insulation is divided in to two part metal foils and multilayer insulation. [6]

1) Metal foils insulation

This type of thermal insulation works like it reflect the temperature and sun rays back to again to environment. It works in both hot and cold environment by reflecting radiation. Aluminium foil is most suitable type of insulation of this insulation.

2) Multi-layer insulation

This insulation has two medium vacuum and reflective. In multi-layer insulation different layer put together and each layer has high reflecting shield which will take care of radiation and in between two layers low conductivity spacer are kept and vacuum is must. The high reflective shields are generally made of aluminium and copper. For optimum performance of this insulation vacuum level is in range of 7.5 x 10-5 torr.

III. PROPERTIES OF INSULATIONS

A. Thermal properties of insulations

Thermal properties are the first considering in to select insulations. [5]

1) Temperature range: high and low temperatures at intervals that the material should sustain entire characteristics.
2) Thermal conductance: the time rate of steady state heat transfer to unit area of a material construction caused by unit temperature difference between the body surface.
3) Emissivity: it is the comparative capability of its surface to emit energy by radiation. It is the quantitative relation of energy radiation obtained from a selected material to energy radiation obtained from a black body at the equal temperature.
4) Thermal resistance: Resistance offered by the material when heat transfer occurs.
5) Thermal transmission: the general conductivity for a heat transfer through a part.

B. Mechanical and chemical properties of insulation

Properties with thermal must be take into account when selecting materials for any applications. [5] Some of them are:

1) Alkalinity or acidity": Essential when moisture is there. Also insulation should not part to corrode the structure."
2) Appearance.: it is essential in exposed areas and for coding function.
3) Capillarity.: it should be significant when material can also be in touch with liquids.
4) Chemical reactivity.: when flammable chemicals are present it has risk to fire hazards. Corrosion resistance should also consider.
5) Chemical resistance.: it is important when the atmosphere is salty or chemical loaded and when pipe chemical leaks.
6) Coefficient of expansion and contraction": Enters in the plan and margin of expansion or contraction joints and use of multi-layer thermal insulation."

7) Compressive "strength":"it is essential if the insulation should endorse a load or withstand mechanical part without crushing. If filling in area is required as in expansion or contraction joints, fix material which has low compressive strength."
8) Density.: A material's density may have an impact on various characteristics of the material, like compressive strength. The weight of the insulated set up must be known because of design the correct loading.
9) Dimensional steadiness.: it is essential whenever the material is exposed to temperature ,expansion or contraction of the insulating material may occur and it cause stress cracking, slump, holes.
10) Resistance to UV rays.: it is significant when application is outside of building and high intensity indoors application.
11) Resistance"to fungal or bacterial growth": it is significant in all insulating material use in various application.
12) Coefficient of Sound absorption : it should be significant when sound attenuation is needed, as it is in radio stations, hospital areas, library, schools where decibel reduction is necessary.
13) Toxicity : it should be essential in the all insulating materials.

C. For Insulation system may need

In addition to the insulation material, a set up may require following [7]:

- Fastenings use for the attach insulation.
- Mechanical or environment protection of the insulation, for ex. metal coating.
- Supports for the safeguard.
- Fastenings use for the attach safeguard.
- Supports for the insulating material.
- A vapour seal if application is cold insulation.

IV. THERMAL INSULATION MATERIALS

A. Classification of materials

Insulation material classified in form of mass, vacuum and reflective.

- Expanded Foam – Mass
- Vacuum alone – Vacuum
- Evacuated Powders – Mass and Vacuum
- Gas Filled Powders & Fibrous Materials – Mass
- Opacified Powders – Mass, Vacuum and Reflective
- Multilayer Insulation – Vacuum and Reflective

B. Expanded foams

It is cellular structure and classified as mass insulation. And it is formed by evolving gases during the formation process. Generally, CO2 and Freon gases are used. Pipes of refrigerator and A.C this type of insulation are used. In this structure, there are small cells which are filled with gases. Here heat transfer due to conduction only and mainly solid Conduction. Convection and radiation are negligible. This is not a very reliable kind of insulation but very cheap insulation. Polystyrene foam, rubber, silica glass foam is an example of expanded foam type insulation.

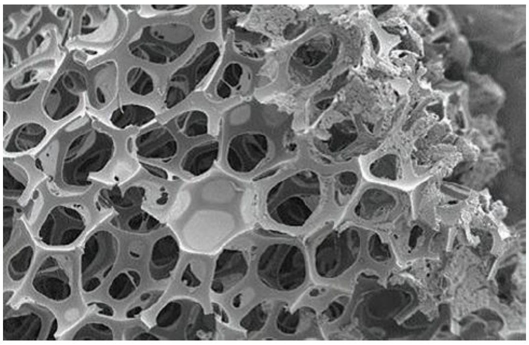

Fig. 2: Cellular Structure of Polyurethane Foam [9]

Working temperature is between 77 K to 300 K. "The kA of the foam is depends on the type of gas used and temperature of insulation. For the given gas we can improve the performance of by varying the mean cell diameter. If we reduce mean cell diameter then kA decrease. But a very small cell is not preferable because of this increase solid conduction path. Hence there should be minimum kA at an optimum bulk density and cell diameter

The major advantages of this insulation are it offers the ease of insulation. Also, many space insulation these foams are used because this is light in weight. And the cost of insulation is very low compared to other types of insulation. The disadvantage is that if we have used CO2, at very low temperature and pressure it can condense and so that thermal conductivity increase. [6]

C. Vacuum

If the physical matter between hot and cold surface is removed then we can call that vacuum is created. In vacuum conduction and convection are prevented. Heat transfer only due to radiation. Because even in a vacuum some residual gas is there which can't prevent. But some amount of gaseous conduction is present but heat transfer through gas conduction is very less compared to radiation heat transfer. As vacuum increase, this gas conduction decreases.

If we consider two surfaces having different temperature say T1 and T2. So the molecule can transfer the heat in two ways.

1) heat transfer due to a collision between two gas molecule and
2) heat transfer due to the collision of a molecule with the surface.

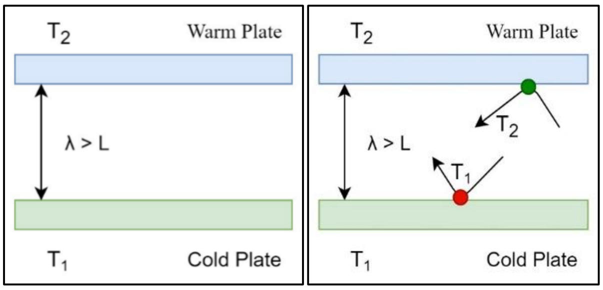

Fig. 3: MECHANISM OF HEAT TRANSFER IN VACUUM

If we talk about very high Vacuum. The mean free path (λ) of the molecules is more than the distance between the surfaces. So molecule rarely collides with each other. Because we have created a very high vacuum so the number of molecules is very less between two surfaces. Therefore in that case molecule to molecule conduction will be completely eliminated.

One molecule takes heat from one surface and it gives the heat to the second surface. This is also called residual gas conduction. It should be noted that it is only possible in perfect vacuum. For understanding the heat transfer mechanism consider two plates having different temperature T1 and T2 (T2 > T1). Consider a molecule colliding with(at T1) the cold plate and leaving to the upper side with T1' here (T1' > T1) this is because while colliding molecule doesn't have sufficient time for thermal equilibrium. Similarly, heat transfer going on. [6]

D. Multilayer Insulation

This insulation has two medium vacuum and reflective. In multilayer insulation different layers put together and each layer has high reflecting shields or foils which will take care of radiation and in between two layers have low conductivity spacers and also have very good vacuum. The high reflective shields are generally made up Al and Cu. Aluminium sheet of 6 micron thickness are generally used at low temperature. Low conductivity spacers are made of nylon net or coarse silk. Often glass fibre, silica fibre are also used as spacer material. One sheet of reflective foils and one sheet of spacer material is called one layer of multilayer insulation.

Reflective shields reduce the radiation heat transfer. Spacer reduce the solid conduction heat transfer. And multilayer insulation works only vacuum is there, vacuum minimize the residual gas conduction

Multilayer insulation are classified according to types of spacer used. [6]

1) Multiple resistance spacers: in this spacers are arranged in parallel manner to minimize contact area.
2) Single component MLI: instead of plane surface of shields this has crinkled surface. In this case we don't use any spacer material. Multilayer touches at those point where crinkles are present. Basically there are point contact at crinkle between two layers.

For optimum performance of MLI the vacuum level is in range of 7.5 x 10-5 torr or below it. MLI are placed perpendicular to direction of heat flow.

E. Evacuated Powder

An evacuated powder is Mass + Vacuum type insulation. In gas-filled powder, the gas conduction is the primary mode of heat transfer. One of the best modes of the reduce this heat transfer has evacuated the powder. Compared to gas-filled powder just remove the gas by a perfect vacuum. Usually, vacuum is maintained in a range of 103 to 10-5 torr.

If we plot the graph between apparent thermal conductivity and residual gas pressure. As per the graph if we talk about 760 to 15 torr. The kA is independent of the pressure. If we reduce the pressure 15 torr to 10-3 torr. The kA is directly proportional to the pressure. As we decrease pressure the apparent thermal conductivity also decrease. In this region, the mode of heat transfer is due to radiation, solid conduction and free molecular conduction (Dominant) which is depending on the kind of vacuum.

If we further decrease the pressure means below 10-3 torr, the variation of kA is almost negligible. Here vacuum is very good so molecular conduction is very low. The here mode of heat transfer is due to solid conduction and radiation. Due to powder solid conduction and due to residual gas radiation takes place. At same temperature evacuated powder is very good performance than vacuum alone. Because due to powder the radiation heat transfer can be minimized. And due to the very good vacuum, molecular conduction is very less. [6]

F. Gas filled powder and fibrous insulations

It reduces the gas convection . As the name suggests basically it is powder or very small size of powder material. These are the granular particle. There is a very small granular particle in which some gas molecules are there. This includes fiberglass, Perlite, Santocel, rock wool. The small size of voids within the material is responsible for the elimination of convection. Most of this found in liquid nitrogen plant.

The operating temperature is between 77 K to 300 K. The advantages of such insulation are low thermal conductivity and low particle distribution to minimize the vibration effects." This insulation can be evacuated and not evacuated. If we evacuate the insulation the further gas conduction can be minimized. And in this solid conduction path becomes disjointed and discontinuous. The value of kA is less than the expanded foam.

Drawbacks are that the fill gas should be nonreactive. And CO2 is widely used. Due to vibration powder tends to settle so that at some portion density of the powder is high and some part the density of the powder is low so heat transfer varies. Where vibration and shock are not exceeded at that place this insulation should be used. It should be noted that the operating temperature of the gas should not be less than the boiling point of the gas. Otherwise, the gas will get condense [6].

G. Opacified Powder

Opacified is (Mass + Vacuum +Reflective) type Insulation. As we have seen that even in evacuated powder some amount of radiation heat transfer takes place. as per research this radiation heat transfer can be eliminated by addition of Al or Cu flakes to the evacuated powder. This flakes act like radiant shield and it reflects the radiation.

In Fig.4.4 graph of apparent thermal conductivity(kA) vs %wt of opacifier is shown. It is clear that we should add specified amount of reflective flakes. If we have Al santocel ,opacifire is 40% of wt. than thermal conductivity is 0.4mW/mK. It reduce apparent thermal conductivity almost by 5 times. If you have copper santocel opacifier is 60% of weight. If we increase amount of opacifier more and more conduction. Because amount of reflective flakes have increased. Therefore more and more flakes so they might start touching each other so solid conduction path can increased.

Cu flakes are more preferred as compared to Al flakes. Because the Al flakes have large heat of combustion. This can react with O2 can lead to accidents. It should be noted that due to vibration these flakes can come near or can far away. Therefore you have certain zones where density of flakes are more and at certain zone density of the flakes are less. So where the flakes come together there solid conduction can increase and where density of flakes are less there radiation can directly transfer the heat. This the major disadvantages of this insulation . We should keep system away from the vibration [6].In this vacuum pressure is less than 10-3 torr for temperatures between 77 K to 300 K.

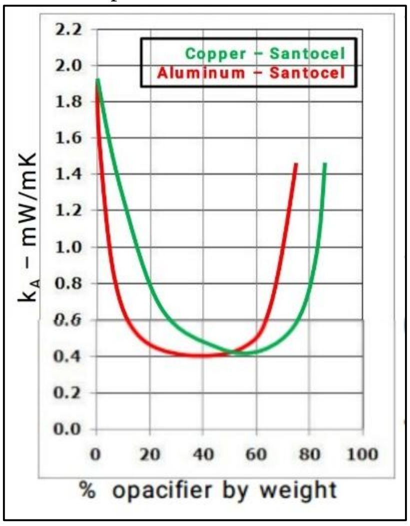

Fig. 4.4: graph of ka vs %wt of opacifier [6]

BIBLIOGRAPHY

[1] R. T. Bynum, Insulation Handbook, McGraw-Hill, 2000.
[2] D. Bozsaky, “The historical development of thermal insulation materials,” periodica polytechnica, pp. 1-2, 07 04 2011.
[3] A. F. Bemis, The Evolving House, Cambridge: Technology Press, 1933.
[4] P. D. Close, Thermal Insulation of Buildings, New York, 1947.
[5] TIAC MECHANICAL INSULATION BEST PRACTICES GUIDE, canada: Thermal Insulation Association of Canada, 2004.
[6] P. M. D. Atrey, “Cryogenic insulations,” NPTEL videos, IIT Bombay.
[7] thermal insulation handbook, Lyttelton: Thermal Insulation Association of Southern Africa, 2001.
[8] “wikimedia commons,” MediaWiki, [Online]. Available: https://commons.wikimedia.org/wiki/File:MultiLayerInsulationCloseup.jpg#file. [Accessed 22 04 2019].
[9] [Online]. Available: https://www.o-wm.com/files/owm/owm_february2015_soppi_f1.jpg.

