ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 6, December 2012

State-Of-The-Art Insulation Materials: A Review

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Abstract— Energy conservation has become major task to satisfy the energy need of world. Different methods are tried for conservation of energy. Thermal insulators play a big role in preventing losses of heat. So for future work in thermal insulators, it has become essential to review insulating materials which has up till studied. Main Moto of this paper is to provide the database of insulting material for future work. Various types of insulating materials with Sources from agricultural products & its wastes, industrial wastes those have shown excellent insulating ability are presented in this paper. Some environment friendly and renewable insulating materials are also presented, whose performance as insulating material was excellent.

I. INTRODUCTION

The need of energy conservation has become a major thing, where a lot of work is required to do. In case of thermal losses, thermal insulating materials play an important role in preventing heat losses. Various Insulation materials are present in markets which have shown excellent insulating ability are discussed below. Researchers worked out on different alternative insulation materials like bagasse, coconut husks, corn by-products, cotton wool , sheep wool, which are presented in the paper. A point of interest is the development of the 'alternative' insulation materials, so it becomes essential to review literature on worked out insulation materials in the past. Keeping this view , various materials are studied & presented. For conservation of heat energy, thermal insulation plays a vital role in various applications by reducing heat losses from the system to environment. Different materials are tested in order to check their insulability like Glass wool, stone wool, Cotton wool, rock wool, dry cellulose, wet spray cellulose, perlite, blown fibre with binder, polyurethane. Renewable sources are always tried for obtaining insulating materials. Some examples are Corn cob, coconut husk, bagasse, sheep wool which are tried to find good insulators [2-4]. Good results found in these areas and found a good future scope to improve these materials as good insulators. In the mid of 1990's the materials tried to obtain better insulation materials are fiberglass, rock wool, dry cellulose, wet spray cellulose, perlite, blown fibre with binder , polyurethane, expanded polystyrene, rigid fiberglass. Bast fibers of flax and hemp for thermal insulations are also undergone through the experiments for checking its suitability for insulation. The waste and disposal produced by agricultural industry are also tried to obtain insulation materials. Coconut husk, bagasse, corn cob are the examples from agricultural wastes for obtaining insulating materials. Renewable raw material resources originating from agricultural sources like jute, flax and hemp have become good insulating materials [5].

II. CLASSIFICATION OF INSULATION MATERIALS

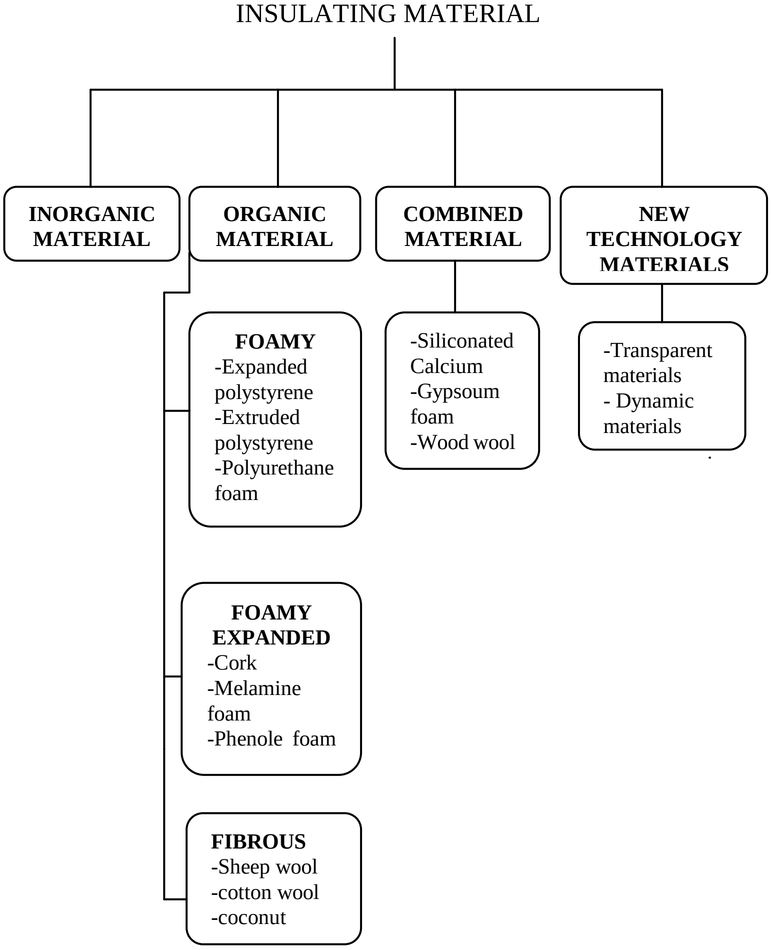

Fig.1.Classification Chart of Most Used Insulating Materials

A. Glass wool & Stone wool:

Glass and stone wool insulation are fibre-based products that deliver outstanding thermal performance. Both are made from plentiful, locally-sourced, renewable natural resources – sand and basalt rocks are the basic raw materials of mineral wool. Glass wool is made from natural sand to which recycled glass (cullet) and fluxing agents are added. Stone wool is made from slag and basalt. The material is melted to 1300°C to 1500°C in an electric furnace. The fibre is formed by centrifugation through drilled disks. Fiberising is integral. Binding products as well as elements specific to the usage are added and the wool mat is polymerized and rolled [6].

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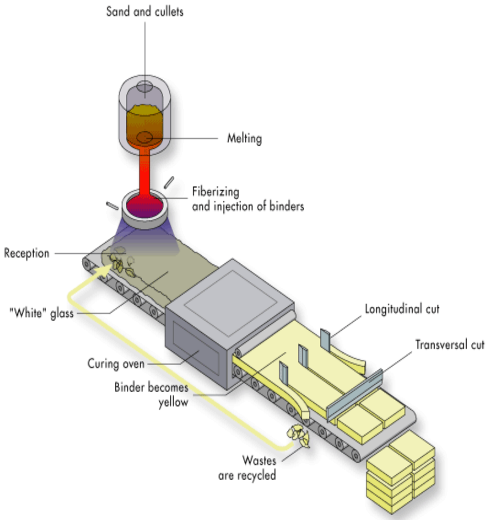

Fig.1 Production Process of Glass wool [12]

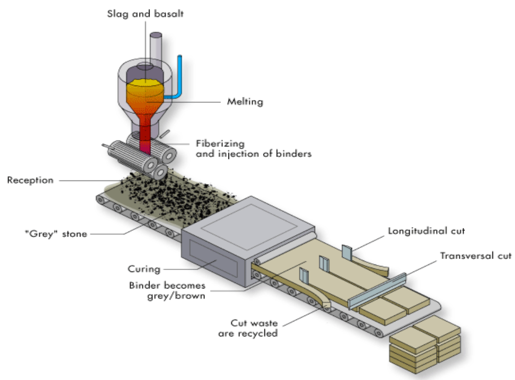

Fig.2 Production Process of Stone wool [12]

B. Polystyrene insulation (Thermocol):

Fig.3. Photo of Thermocol Balls

Polystyrene products are made of organic cellular plastic. It include families of expanded polystyrene (EPS) and extruded polystyrene (XPS).

Expanded Polystyrene (EPS):

EPS for short, is a lightweight, rigid, plastic foam insulation material produced from solid beads of polystyrene (with a diameter of 0,2 to 0.3 mm). Expansion is achieved by virtue of small amounts of pentane gas dissolved into the polystyrene base material during production. The gas expands under the action of heat, applied as steam, to form perfectly closed cells of EPS. These cells occupy up to 50 times the volume of the original polystyrene bead. The EPS beads are then moulded into appropriate forms suited to their application. Expanded polystyrene foam (EPS) is usually white. Some new innovative EPS products are grey due to the inclusion of graphite, which substantially increases the insulation performance. EPS is safe, non-toxic and inert. At any time of his life cycle does it contain any Chlorofluorocarbons (CFCs) or Hydro fluorocarbons (HCFCs) [6].

The most important properties of EPS are :

-excellent thermal performance (lambda between 0.038 and 0.030W/mK)
-high compressive strength
-outstanding impact absorption
-low weight
-imperviousness to moisture
-100% recyclable [6].

Extruded polystyrene (XPS) :

Extruded polystyrene is produced by a continuous extrusion process. Blowing-agent-free polystyrene granules are melted in an extruder and a blowing agent is injected into the extruder under high pressure where it dissolves into the polystyrene melt. This blowing-agent containing melt exits the extruder via a slot die. The blowing agent expands due to the drop in pressure which causes the polystyrene to foam into the form of a board with homogeneous and closed cell structure. The main used blowing agent is CO_2. [6].

C. Polyurethane foam:

For the manufacture of polyurethane polymers, two groups of at least bifunctional substances are needed as reactants. Compounds with isocyanate groups, and compounds with active hydrogen atoms are required. The physical and chemical character, structure, and molecular size of these compounds influence the polymerization reaction, as well as it influence the ease of the processing and final physical properties of the finished polyurethane. In addition, additive such as catalysts, surfactants, blowing agents, cross linkers, flame retardants, light stabilizers, and fillers are used to control and modify the reaction process and performance characteristics of the polymer [7]. This foam is mostly used in refrigerators.

D. Cellulose:

Cellulose fiber is produced from paper, which in turn is derived from wood. However the insulation is installed blown into the attic or damp-sprayed into wall cavities. It comes packed in bags that weigh from 25 to 35 pounds apiece. By weight, about 82% to 85% of the material is cellulose. Fiber most of which is reprocessed from old newspaper and the remainder consisting of chemical fire retardant. The fire retardants are added in the form of a dry powder. The borate chemicals is also used in combination with ammonium sulfate and also added with mold, insect, and rodent resistance.

Some new materials tried as insulating materials:

E. Corn cob:

Corn cobs with greater thickness can have the same insulating ability compared to traditional insulation. The corn cobs were used as wall insulator in ancient days. The corn cob

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ISO 9001:2008 Certified
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can be obtained from agricultural resources. Corn cobs were ground up into small granules measuring 0.5cm diameter. The ground corn cobs went through a cleaning process to wash away excess dust and then were dried thoroughly [2]. Then it was used as insulator.

F. Coconut husk and bagasse:

Fig.4. Photo of Coconut Husk

Coconut husk is waste material of dry coconut which is easily obtained in coastal areas of tropical countries. The coconut husk is available in large quantities as residue from coconut. The husk consists of 30% fibre and 70% pith. Both fibre and pith are extremely high in lignin and phenolic content and it has been found that the coconut husk lignin can be used as intrinsic resin in board production .Bagasse is a by-product of sugar production. Bagasse is rich in celluloses. It act as a binder when making board. Hence it's a binderless insulation board. Thermal conductivity of the binderless boards made from coconut husk and bagasse showed values close to those of conventional insulation materials. [3]. The properties of binderless bagasse insulation boards were superior than coconut husk boards. The binderless bagasse insulation boards at density of 350kg/m^3 satisy the requirement of the relevant standards (except the thickness swelling) can be used as building materials for thermal insulation applications. Since the binderless boards are made from waste materials and without any chemical binders, it is environmental friendly and can possibly compete with conventional insulation materials. Furthermore, the manufacturing process of binderless boards is very simple; no special equipment is needed so it can easily be applied to commercial production [3].

G. Sheep wool:

Fig. 5. Photo of Sheep Wool and Its Applications in Building Construction [4].

Wool is the textile fiber obtained from sheep. Sheep wool is renewable, recyclable and environmentally friendly. It consists of an average of 60% animal protein fibres , 15% moisture, 10% fat, 10% sheep sweat and 5% impurities [4]. wool has positive ecological and health properties. wool is a clean natural source. It's a highly hygroscopic, up to 35% .its safe to handle without any discomfort to human health [4]. Sheep wool is an excellent acoustic insulating material and highly energy efficient production. It has higher fire resistance property.

H. Narrow-leaved cattail (Typha angustifolia L.) :

It is found those cattails are marginal weeds which originated in Europe and America. It occurs in tropical area such as Thailand, Malaysia, Philippines, North America and Pacific coast. In Thailand they can even be found in ponds, marsh, paddy, watercourse and lake. Narrow-leaved cattail in marsh is growing through the year and flower from May to July. In early fall, the brown flower of cattail emerges its floppy seeds. These seeds are carried by wind or water to new places. Cattails rapidly spread via seeds and roots. In very short time cattails take over water areas. It is usual to see ponds that are completely surrounded by cattails. Narrow-leaved cattails have effected irrigation in Thailand. It spreads rapidly over the areas. Thus the other crops are affecting. So abundant amount of it forced to find its usefulness in insulation property. The insulation boards are prepared from narrow-leaved cattail fibers by using Methylene Diphenyl Diisocyanate (MDI) as a binder. Hot pressing method was employed to produce single layered plain thermal insulation boards with the size 350x350x10 mm. The physical, mechanical and thermal properties of the boards were found. As a result the insulation boards from narrow-leaved cattail fibers had good physical and mechanical properties according to the standard. Thermal conductivity of board measured with a density of 200-400 kg/m3 had the thermal conductivity values ranging from 0.0438-0.0606 W/mK. It was less than that of fibrous materials and cellular materials, low-density wheat straw Board, particle board from mixture of durian peel and coconut coir, kenaf binderless board, expanded perlite and vermiculite with the same density range. It was concluded that this insulation boards from narrow-leaved cattail fibers were an excellent insulating component for energy saving and environmentally friendly. Additionally, these insulation boards could be used to produce furniture with an advantage to help, and get rid of weeds [8].

I. Cotton stalks fibre:

This is obtained from natural and renewable raw materials. Binderless cotton stalk fibreboard (BCSF) was made from cotton stalk fibres and investigated for its insulating ability With no chemical additives. Boards was developed using high frequency hot pressing. The board with a density of 150-450kg/m^3 had the thermal conductivity values ranging from 0.0585 to 0.0815 w/mk. This value is close to that of the expanded perlite and vermiculite within the same density range [9].

J. Textile waste:

Clothes, woven fabrics and threads are among the most common types of textile waste. Two types of textile wastes are studied namely woven fabric waste (WFW) and Woven fabric sub waste (WFS). Both materials are 100% acrylic. Work was conducted using an external double wall with the air box filled with these two types of wastes. Two heat flow meters

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and four surface temperature sensors were placed on the wall surface to determine the thermal conductivity of the waste. Result show that by using WFW and WSF, thermal behavior was increased by 56% & 30% respectively. WFW shown the same thermal conductivity as expanded polystyrene (EPS), extruded polystyrene (XPS) and mineral wool (MW). WFS shown this value approximately equal to the value for granules of clay, vermiculite or expanded perlite. So textile waste became possible thermal insulation material and had environmental, sustainable and economical advantages [10].

(a) WFW - Woven fabric waste (b) WFS - Woven fabric sub waste
Fig.6. Textile Waste Types Studied [10].

III. PRINCIPLE EMPLOYED FOR OBTAINING THERMAL CONDUCTIVITY

The steady state heat flow and bisubstrate technique was used for obtaining the thermal conductivity of materials. The basic principle of operation was to create one dimensional axial heat flow through the surface in order to use the Fourier equation of heat conduction.

$$q = -kA\left(\frac{dT}{dX}\right)$$

Where,

q is the steady state flow
k is thermal conductivity
A is cross sectional area of the sample
-dT/dX is the temperature gradient.

The sample with a suitable cross section and thickness were sandwiched between two metallic substrates (a hot and a cold plate). Temperature sensors and heat flow meters were placed in two plates. The thermal conductivity was determined from the values of heat flux and temperature difference across the specimen thickness [9].

IV. METHOD EMPLOYED FOR OBTAINING PHYSICAL, MECHANICAL AND THERMAL PROPERTIES

A Physical property:

Moisture content are determined by conducting (MC) test on forty-five samples. The moisture content of samples was determined by the following equation.

$$MC\% = \frac{m_1 - m_2}{m_2} * 100$$

Where m1 is mass of sample before drying (g) and m2 is a mass of sample after drying (g) [8].

B. Mechanical property:

Mechanical properties are obtained by conducting Modulus of rupture (MOR) and Modulus of elasticity (MOE) test on Twenty seven samples. Forty five samples are made for tensile strength perpendicular to surface test. These properties were calculated from following equations:

$$MOR = \frac{3F_{max} l_1}{2bt^2}$$

Where,

F_{max} is the maximum load (N)
l_1 is the span (mm)
b is the width of the test sample (mm)
t is the thickness of the test sample (mm)

$$MOE = \frac{l_1^3 (F_2 - F_1)}{4bt^3 (a_2 - a_1)}$$

Where,

F_2-F_1 is the increasing load in the range of linear line of graph (N)
a_2-a_1 is the increasing bending distance in the range of linear line of graph (N)

$$\text{Tensile strength} = \frac{F_{max}}{W \times L}$$

Where,

W is the width of the test sample (mm).
L is the length of the test sample (mm) [8].

C. Thermal property:

The thermal conductivity (k) is measured on the basis of American Society for Testing Material (ASTM C518) [11] by using a heat flow meter (HC-074-200) . The thermal conductivity of a sample is determined by the following equation

$$K = \frac{Q_U + Q_L}{\frac{2 \times D}{\Delta T}}$$

Where,

Q_U is the output of the upper heat flux transducer,
Q_L is the output of the lower heat flux transducer,
D is the thickness of the sample,
and
ΔT is the temperature difference between the surfaces of the sample [8].

V. DENSITY AND THERMAL CONDUCTIVITY OF SOME MATERIALS

Material	Density Kg/m^3	Thermal conductivity factor λ (W/mK)	Reference

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Glass wool			
Minimum	13	0.030	
Maximum	100	0.045	[1]
Stone wool			
Minimum	30	0.033	
Maximum	180	0.045	[1]
Extruded Polystyrene			
Minimum	20	0.025	
Maximum	80	0.035	[1]
Expanded Polystyrene			
Minimum	18	0.029	
Maximum	50	0.041	[1]
Polyurethane foam			
Minimum	30	0.020	
Maximum	80	0.027	[1]
Binderless coconut Husk insulation			
Minimum	250	0.046	
Maximum	350	0.068	[3]
Binderless bagasse Insulation			
Minimum	250	0.049	
Maximum	350	0.055	[3]
Sheep wool			
Minimum	20	0.050	
Maximum	40	0.034	[4]
Flax			
Mimimum	20	0.035	
Maximum	100	0.045	[5]
Flax and Hemp	39	0.033	[5]
Cellulose			
Minimum	30	0.041	
Maximum	45	0.050	[5]
Cellulose (recycled paper)	30	0.041	
Cellulose (wood fibre)	30	0.050	[5]
Narrow-leaved Cattail fibre			
Minimum	200	0.0438	
Maximum	400	0.0606	[8]

VI. CONCLUSION

Verities of isulating materials are available in market. Various sources for thermal insulating material like Organic, Inorganic, agricultural industries, combined materials and new technology materials are discussed. These materials have excellent insulating ability. Methods of obtaining physical, mechanical and thermal properties for insulating material are seen. Its usefulness as thermal insulator is seen. Technique to check insulating ability is also seen.

VII. FUTURE SCOPE

Further there is a lot of scope to develop new insulating materials from available materials. By mixing different insulating materials with additives can give another insulating material. Different combinations can be tried for obtaining new insulating material. Adaptability, versatility, handling and cost are major factors which must be checked for every new insulation materials for its excellent usefulness.

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