The future of insulation: Vacuum insulation panels

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ABSTRACT

Vacuum insulation panels have higher efficient materials than the insulation materials which have known their heat insulation properties. Heat insulation could be provided by vacuum insulation panels ten times according to conventional insulation materials. The most important difficulty of growing up for vacuum insulation panels is high production costs at present. When this situation was analyzed, it is known that core materials are most important elements which affect to cost. Production of core material at more economical conditions will reduce vacuum insulation panels' production costs significantly, and then VIP's usage will be growing up increasingly. Expansion of applications brings about energy efficiency and economy and will create significant added value to Turkey's economy, in addition this it will be more positive contribution to the environment. VIP is not widely used as insulating material in our country. The main reasons for this situation, VIP‟s are unknown, its core can't produce domestically, and its imports are not economical for using in industrial. In addition, scientific researches and studies have been limited about VIP. Using of the VIP will become widespread in our country with the production of economic core. Wide spreading of the application will provide energy efficiency and conservation. In addition the country's economy will create significant added value, energy conservation will also be a very positive contribution to the environment. In this paper, scientific research findings about VIP's physical, structural, performance characteristics and production methods of VIP have been presented in summary so far in order to contribute to the scientific and industrial research. VIP's performance and costs have been compared with conventional thermal insulation materials.

1. INTRODUCTION

Heat is a kind of energy which is transferred from high temperature to the low temperature environment. Heat flow is the maximum at low resistance way which the flow provided easily. A heat gradient occurred from high temperature to low temperature region. Thermal insulation protects heat gradient by reduced heat flow from inner heat gradient. Briefly, preventing of heat transfer between two different ambient is called "thermal insulation". Generally insulation prevents heat loss to the environment. It is rarely provides protection against the heat from the environment. Most equipments, vehicles and constructions (e.g. furnaces, coolers, freezers, water heaters, buildings) which requiring heating and cooling has thermal insulation. Thermal insulation is applied to roofs, façades, walls of non- used parts of garages and depots, floors which contacts to soil and non-living places of buildings, installation pipes and ventilating channels. Additionally, by using special covered insulation glass units and insulated woodworking heat loss reduced from windows at winters, and sun heat entry to the buildings is limited at summers. In this way, an energy saving is provided for used to heating and cooling. Thermal insulation, made with application of special insulation materials that reduced heat transfer to outer and non-used part of buildings from ground to roof.

Nowadays, energy needs increases exponentially and energy unit prices rise rapidly although energy resources run out gradually (especially fossils). This situation causes new searches for using energy effective in many countries which have limited energy resources. In European Union, almost all the members make their laws harder about thermal insulation and intensive research activities were initiated for Low Energy Buildings. This also brings search of new generation insulation materials which are most effective than the conventional insulation materials. In 2011, there are some changes made about energy consumption declaration classes in European countries and Turkey, accordingly, some necessities are emerged about reducing energy consumption especially for household refrigerators. For example, in 2010 it has been declared that the lowest energy level is A++ for a refrigerator, the new defined level is A+++ and for this level 26% improvement must have been made at energy consumption.

In Turkey, there is no industrial production of vacuum insulation panels, but it is considered after start-up new regulations for white goods sector. Most important obstacles for increasing the amount of use are lack of information, and high costs of materials and production. The inner core is most important thing affects the cost. The expansion of the application creates a serious value-added economics for the Turkey and brings energy productivity and savings. And also it affects a very positive contribution to environment.

2. THERMAL INSULATION AND THERMAL INSULATION MATERIALS

Nowadays, there is a big effort to improve high performance thermal insulation materials for buildings and industrial applications. Developed countries like USA, Canada, Japan and Germany intensify their researches effective using of energy and thermal insulation. Developments will be provided about this subject depends on the good understanding of heat transfer mechanisms along the air gaps. Heat flows along the air gaps based on the convection and radiation[18].

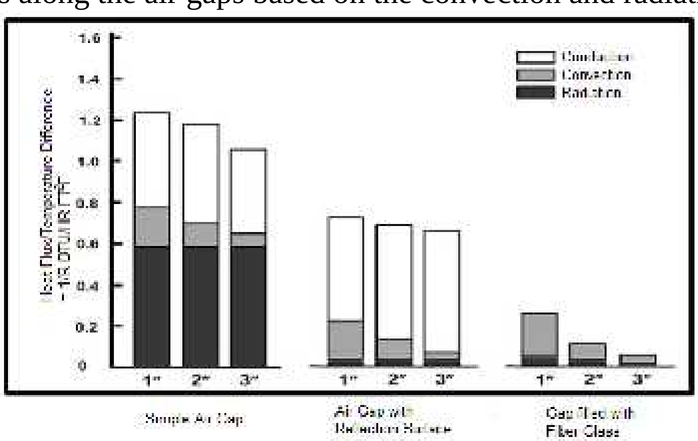

Figure 1. Effect of radiation, conduction and convection to heat transfer in air gaps.

However, a reflective surface in air gap, could be reduced inlet radiation component a minimum level. Also, adding some fibrous materials (glass fiber etc.) could be limited air flow and almost removed heat flow.

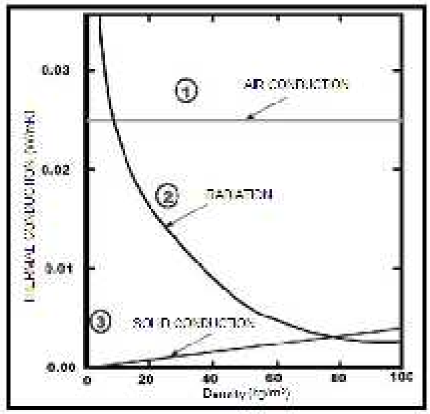

Figure 2. Heat transfer mechanisms in conventional insulation (fiber and foam)[14].

Heat transfer occurs in a conventional insulation materials with three components: air conduction, radiation and solid conduction. (Figure 2). Solid conduction and radiation related with density of insulation material. Heat transfer (i.e. air conduction) is reduced by replacing air with a gas that has lower conductivity value from air. This situation, known by researchers for a long time although is a new research area [21]. It is known phenomenon that the insulation increases with the reduced air pressure and it is a function of thermal insulation materials' pore size [14]. With the reduced effect of pore size, heat conductivity of air reduces.

Although thermal conductivity coefficients of used inner filling materials is equivalent or higher than conventional insulation materials, at vacuum is lower than conventional insulation materials. Related studies show that the thermal insulation potential increases with decreasing gas pressure in a porous material.

2.1. Conventional Thermal Insulation Materials:

In recent years, with the improved technology, thermal insulation materials became more plentiful. The main purpose of insulation products is increasing the resistance of building elements. Thermal conductivities define insulation property of these products. Lower conductivity means high thermal insulation. Thermal insulation materials which have high thermal resistance used for reduce heat loss and gains.

Materials which have thermal conductivities under 0.06-0.10 W/mK values defined as "insulation materials" according to European Standards. The products used for the thermal insulation purpose could be classified open porous and closed porous. Examples for the open textured or fibred materials are glass wool, rock wool (minerals), wood wool, ceramic wool, slag wool and examples for the closed textured materials are EPS (expanded polystyrene), XPS (extruded polystyrene), elastomeric rubber, polyethylene foam and glass foam.

Sound absorption values, performances for fire, freeze-thaw strengths, and pressure strengths under load of insulation materials play a big role at their selection. They are also preferred because of being user friendliness and economical.

2.2. High Performance Thermal Insulation

In Europe, there was a revision and an update study for standards of applications related thermal insulation and thermal energy amount was decreased.

Thermal insulation basically used at construction of buildings by creating an air gap between two layers in the building. With the best understanding of heat transfer, it is understood that importance of R-Value at thermal insulation.

Subjects of improvement of insulation properties and application areas of insulation materials have been of an area that so many researches intensify their studies. Especially through studies about vacuum insulation panels, the thermal insulation technology was improved in a great amount. In recent years, studies were intensified about heat treated micro-porous structure silica and silica aero gel products.

So, approaching of low energy buildings is more popular increasingly, and this situation is directed researchers and manufacturers to search and produce insulation materials have low conductivities. It is impossible or so expensive to provide desired insulation properties by common insulation materials because of the limited area of applications.

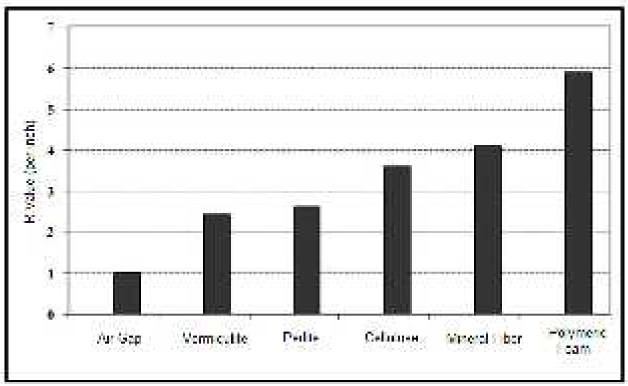

Figure 3. R values of insulation materials still used [16].

But, production of new technologies is relatively slow. Each thermal insulation value shown in Figure 3 are accepted the highest thermal insulation until next insulation material has higher R-value [16].

Conductivities of these materials vary in the range of 10-22 w/mK and they are lower than the conventional insulation materials. It is possible to reach to low values like 4 mw/mK by vacuuming both micro-porous structure and conventional insulation materials. Applications prove that the new products have good performances and also show that the new products open for development according to industrial applications.

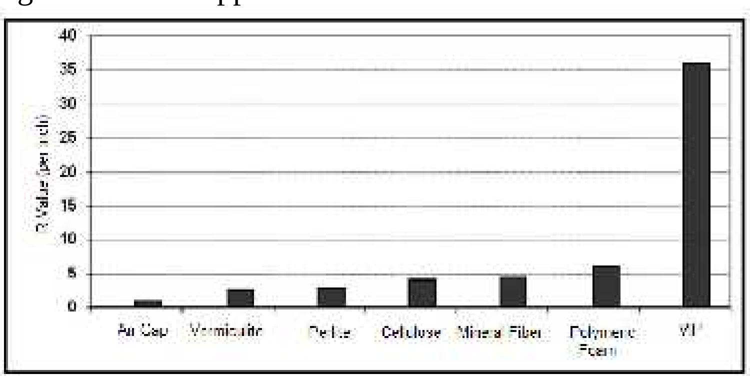

Figure 4. Comparison of VIP thermal resistance with still used insulation materials [16] .

2.3. Vacuum Insulation Panels (VIP)
2.3.1. Defining of VIP's

Vacuum insulation panels have higher performance materials then to known insulation materials in terms of thermal insulation properties. It is provided ten times better a thermal insulation with VIPs (λ_{max} = 0.004 W/mK) then to conventional insulation materials (λ_{max}=0.04 W/mK). VIPs are produced according to character of a porous structure inner filling material (core) by using getters or only by putting in a outer envelope with provided leak proofing (Figure 5) [5].

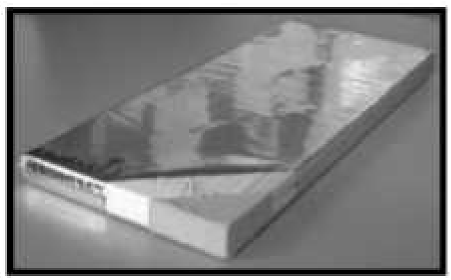

Figure 5. View of a core, inner and outer envelopes of a VIP.

2.3.2. VIP's Usage Areas

VIPs are high performance insulation products developing recently. Thermal insulation takes place in industrial equipments and tools like furnaces, coolers, freezers, water heaters and etc. Especially their usage takes widespread in coolers. However, for the buildings around us it is required to develop high performance insulation materials and systems. Insulation performance of materials which are used at large volume buildings such as hospitals, schools, state-buildings, depots, sports halls, shopping centers, business centers, terminals, factories, cold storages assume great importance. Energy savings at buildings depends on the insulation materials' performance used for covering buildings. Developed vacuum insulation panels present high thermal insulation properties and reduce energy consumption significantly. However, VIP systems are little known and used rarely at buildings insulation. It is required to produce low cost core materials for growing up at construction sector. Vacuum insulation panels are more useful especially for places which have high energy demand and high energy cost.

Some applications of VIP are used for insulation materials could be see below:

- Ceilings, floors and walls
- Façades,
- Roof and attics,
- Window insulations,
- Precast concrete panel applications [2,3] .
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2.3.3. VIP Performance:

Decisive factors on VIPs are thermal bridge effect and the process of aging which are the most critical properties [19].

Nowadays, different VIPs' service life varies 5-10 years. Life of VIPs' first depends on the gas barrier (outer envelope) and core material. Additionally, it varies depends on settlement in structure detail. VIPs perform their duties when they're in a vacuum. Increment at vacuum levels of VIPs' caused from gas and water stream permeability performed trough outer envelope and welding points and also caused form gas emissions from inner core material and envelope material. To prevent vacuum level increment, getters are putted in VIPs. Getters are chemical elements and they hold waste gases and water vapor in the panels. After defining of VIPs' life, by considering the values of gas and water vapor permeability and gas emissions, when the getters life is ended putting in the panel, the panel's life is also ended [5].

2.3.4. Importance of Materials Used at VIP Production

Thermal insulation performance of VIPs' are directly related with vacuum capability and core material properties for the support function against the atmosphere pressure. Core is a thermal insulation material generally open cell and reduced conduction in low level. Except for this property, another major task is providing flexibility and durability to structure. It is known that aerogel, recycling urethane, open cell extruded polystyrene, fiberglass and powder materials used for inner filling material of VIPs at recent studies. Almost all studies about VIPs' are made with inner filling materials occurred from silica powder, polymer based, hydro-gels and aero-gels (SiO_2) and their composition with different envelope materials, and conductivities of these compositions were researched (Figure 6).

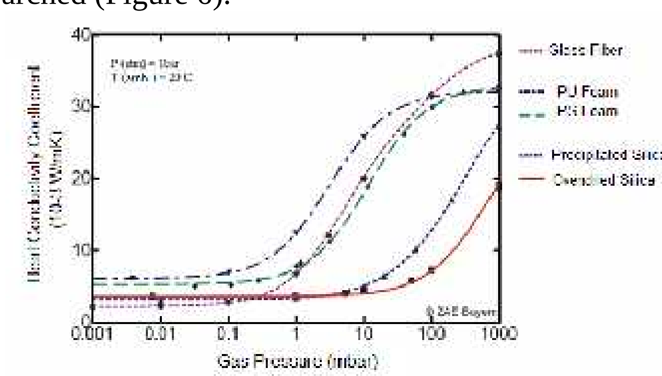

Figure 6. Heat Conductivities of VIPs' have different core materials[2,3].

Core is closed with a high barrier layer occurred from a few layer consist of polyethylene terephthalate (PET) or aluminum revised polyethylene (PE) and vacuumed under the 1 mbar pressure level. Barrier layers are made available for a long service life that required for building applications and against humidity with very low level leakages of air. While the gas barrier is helped for insulation against air and humidity, core material is increased thermal insulation capacity. Vacuumed core has almost 0.004 W/mK conductivity value at room temperature. For 2 cm thickness, U value is 0.2 w/m^2K. This thickness is provided a great advantage at façade's insulation structure in a large scale.

Lower conductivity coefficient of open cell filler material in core material is related with materials pore structure. Smaller porous core materials can have lower heat conductivity coefficients at higher pore pressures [20]. An ideal core material could have open cell structure and very small pore diameter; it must be resist against atmosphere pressure and radiation [17].

2.3.5. VIP Advantages and Disadvantages:

Thermal insulation capacity of VIPs' is higher than (10 times) the conventional insulation materials. This situation is providing a big advantage for easy using, usage area is widespread at the same time. Panels are especially useful at high energy demand and cost.
Increased insulation values of VIPs' are provided to decrease thickness of building covering materials. Insulation section could be reduced at the situation of the elements of the building have to carry insulation material then the structural strength. In this way, it could be saved from used materials, usable building area could be increased, and waste materials could be decreased which were appeared when the building's life completed [5]. The most important obstacle is high manufacturing costs for the expansion of existed VIPs. Vacuuming and packaging is not an expensive method and it is used in widespread so many industrial areas. It is known that the most important element that affects the cost is the core materials at VIPs. However, VIPs' prices cannot compete with the other insulation materials' because of the less number of VIP Manufacturer Company and not enough studies about VIPs. The more economical production of core material will be decrease of VIPs significantly and so their usage will be gradually increase.

2.3.6. VIP Core Raw Materials:

VIPs are a few main parts according to the fill material. These parts are porous structure "core", permeable "inner envelope" which is used powder material as filling material for core, leak proof "outer envelope (barrier)" which is provided gas impermeability by closing the core material to atmosphere after vacuuming and "getters/dryers" which could absorb gases-humidity in the core.

The cores which are obtained used powder material could be vacuumed after putting in the inner envelope material prepared by using fiber fabric or paper. The vacuum ability, unit weight and porous size of the fabric used as inner envelope are important things. The fabric of the cores which the powder material used in, could be hold the powder material when vacuum occurs, could not to prevent vacuuming and its unit weight could be selected comparatively low (thin). There is no need to using inner envelope with non-powder materials like open cell polyurethane or polystyrene, fiberglass.

Barrier film is a material which forms the outer surface of the VIPs'. The most important function of this material is providing to continuous vacuum against atmospheric gases and humidity by forming an impermeable layer. In addition this, the surfaces of the films consist of aluminum folio or metalized layer are bright. The reflection ability of barriers is significantly important in terms of decreasing heat transfer of VIPs' by radiation. Some films are formed by very thin metal films (especially aluminum) reinforced with each surfaces layered plastic film (polyethylene-PE or polyethylene terephthalate-PET). Some special sheets that have low melting temperature were added to film layer to provide leak proof by making thermal bonding instead of welding. While these films have perfect impermeability but at the edges there is also heat transfer (thermal bridge). For decreasing this thermal effect (edge effect), some films were improved that used spray coating for making metal films even finer (thin film deposition technique). Metalized films were occurred by collecting metal on the film. Here, superfine aluminum layer which is intensified on the film was gained impermeability to the film against light, water vapor, oxygen and other gases. The layer number of these films could be reached nine that each one has a good barrier property and occurred from plastic/polymer/metal layers. A seven layered metalized film's property shown at Figure 7 and Table 1 as an example.

Figure 7. An example outer barrier (metalized film) layers used in VIP production.

Table 1. Some technical specifications of an example barrier used in VIPS.

Barrier Technical Specifications	**Value**	**Related Standard**
Thickness (μm)	97	-
Unit weight (m^2/kg)	9.25	-
Tensile Strength (MPa)	82	ASTM D-882
Thermal bonding strength (N/mm)	> 4.4	165°C, 4 kg/cm^2, 4 s
Yield (%)	53	ASTM D-882
Strength of stratification	> 0.39	ASTM D-882
Puncture Resistance (N)	86	FTMS 101C 2065
O_2 permeability (cc/m^2day)	< 32.10^{-6}	ASTM D 3985, 23°C, RH %50
Humidity permeability (g/m^2day)	0.01	ASTM F1249-90, 38°C, RH %100

Films occurred from plastic-metalized layers in VIP production used as barriers effectively. For all that, it is impossible to say they provide 100% impermeability according to layer number of these films, material kinds used in layers and production technology. In time, the following factors cause gas inlet to the VIP:

- Air bubbles and holes stayed in layer that was forming layers during the production of films (production defects),
- Cracks caused by wrinkles during the production of VIPs and thermal bonding errors.

Gas-humidity inlet is increased internal pressure in time. This increment is caused the increment of convectional heat transfer. Today, films that allow the internal pressure increment at the maximum level of 2 mbar/year after vacuuming were accepted as suitable barriers for VIP production, it was reported that this kinds of VIPs' service life could be reached 50 years [15].

In the case of using mineral origin powder materials as fillers, gas and humidity that penetrated into the barrier in time were absorbed. However, the pore size of the core which was obtained by compressed this powder materials generally vary from 10 micron to 50 nm. This micro-porous structure was reduced the conductivity of gases that penetrates into VIP. There is a getter/dryer effect of powder materials used as filler at the same time. Because of these, in the VIPs which mineral origin materials used as filler, using of getter/dryer is not required.

VIPs' production is basically explained with air proof packaging of open porous structured core material by vacuuming. Thermal insulation performance of VIPs' are directly related with vacuum capability and core material properties for the support function versus the atmosphere pressure. Almost 15 psi (~1.055kg/cm2) atmospheric pressure affects on a vacuumed panel. This means, almost 10 tons of force affects to a vacuumed panel which has 1 m^2 surface area. There is an appropriate inner support material is required for compensate a pressure like this. This material (core);

- could be enough strong to compensate this pressure without collapsed,
-could consist of micro porous that can be vacuumed,
-has a structure that could not to transfer heat.

The core was produced from materials like aero gel, fumed silica, precipitated silica or open porous polyurethane (or polystyrene) generally.

Studies made until today were shown that the highest insulation performance was provided with the cores produced by using aero gel.

But the aero gel is produced by high technology today's conditions and is a quite expensive material. Therefore, the core is most important element which affects VIP costs.

Fibers were used both for the improving the mechanical properties of core used powder materials and for the reducing of convectional heat transfer. The fibers' (which were mixed with powder materials in defined ratios) physical properties like slenderness ratio (or denier), tensile strength, specific gravity, conductivity are affected the composite's (core's) psycho-mechanical properties. But here, the most important element is the homogeneity of mineral powder-fiber mixture. 3 different fiber as organic fiber, glass fiber and cellulosic fiber could be used in core production.

With decreasing gas pressure in a porous material, thermal insulation potential was increasing. According to this, a VIP could be made from open porous (connected) core materials. Filling material was bringing mechanical strength and high thermal insulation capacity to the VIPs by preventing free flow of gas/air molecules. So, the heat transfer ability by convection of gas molecules was decreasing in VIP. An ideal core material must have:

-High porosity,
-An open cell structure,
-Very small pore diameter,
-Enough compression strength.

Having open cell porous structure of filling material is of great importance according to vacuum ability of the core. Gas/water vapor could not be vacuumed consisted by closed pores. Because of this conductivity of VIP was increased. Mean pore diameter of core material is another important parameter according to VIP's conductivity coefficient. When the pore diameter was decreasing, densities of residual gas/water vapor molecules after vacuum, so the pore pressure was decreasing. This situation was also decreasing convectional heat transfer. Relation between heat conductivity coefficients of VIPs' and pore diameter is shown in Figure 8 [19].

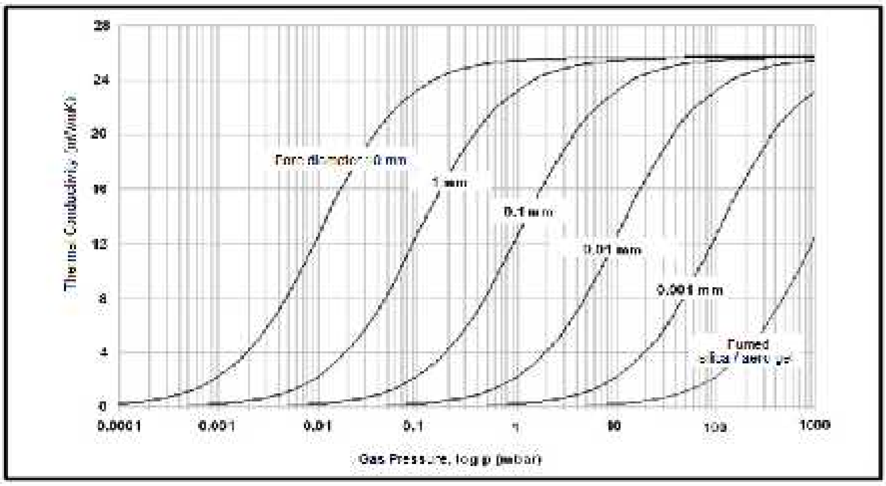

Figure 8. Variation of value conductivity of air as a function of pore diameter and gas pressure.

Clearly seen in Figure 8, when gas pressure increases, heat conductivity value also increases exponentially at the same pore diameter. Similarly, when pore diameter increases, heat conductivity coefficient increases exponentially at the stable gas pressure value. But except in this case, there are different gas pressure threshold limit values for different pore diameters. For example when threshold limit value is almost 0.1 mbar for 10 micron pore diameter, it is 1 mbar for 1 micron. If the Figure 8 commented, the vacuum level (gas pressure threshold limit value) which will provide minimum heat conduction coefficient (<1 mW/mK) at VIPs according to mean pore size of core material could be calculated with the below correlation:

$$P_e = 1/Ø_g \quad (1)$$

Here;

P_e : Vacuum level which provide <1 mW/mK value at core material, mbar

$Ø_g$: Mean pore diameter of filling material, micron.

Open-micro porous core materials have the ability of protect low heat conduction properties at relatively high pore pressure level. For this reason, materials like open cell polyurethane –polystyrene foams (in contrast to glass and mineral fibers), micro and nano – porous nano gel, aero gel and fumed silica protects their very low heat conduction properties about 10 mbar pressure level (Figure 9 and 10).

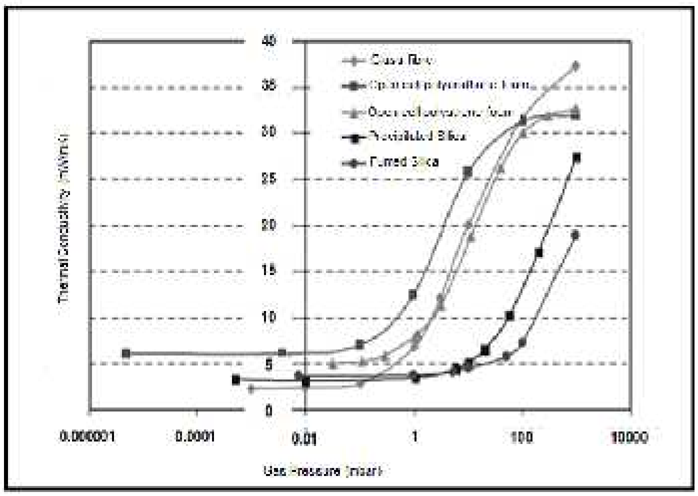

Figure 9. Variation of pore pressure-heat conductivity of core material [13].

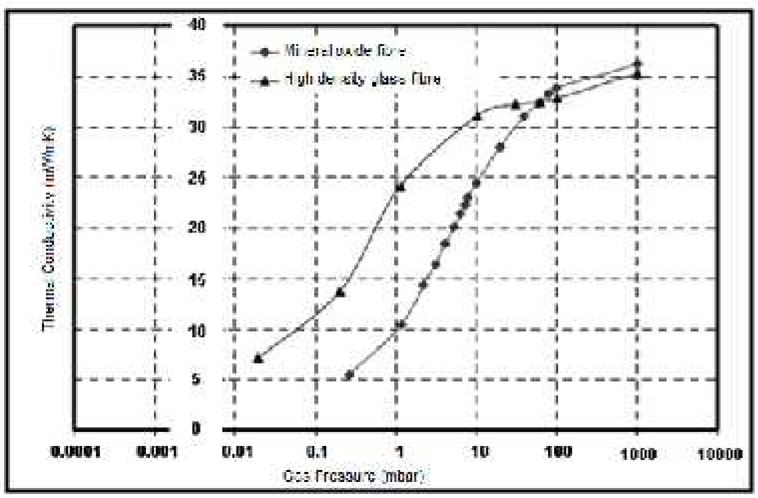

Figure 10. Heat conduction coefficients of fiber filing VIP’s according to gas pressure. [1,13]

Minimizing of radiation heat transfer is of great importance according to total heat transfer of core material. For this purpose at the cores which were produced with powder material as filling material; opacifiers like carbon black, silicon carbide, titanium dioxide were added to mixture. So, ultraviolet rays reached to the core were absorbed by opacifiers or heat transfer with radiation was reduced the lowest value by reflection.

2.3.7. Desired Mechanical and Physical Properties at VIPs

Mechanical properties like deformation, tensile stress, compressive strength and physical properties like mass per unit volume, thermal conductivity, and dimensional stability of VIP cores are so important. These properties were related with core panel highly. The Published German National standards related with physical and mechanical properties are required to provide by VIPs, were accepted by German Buildings Technology Institute (Deutsches Institut für Bautechnik) and European Union Technical Committee to be valid from June 2010 (Table 2).

Table 2. Desired Mechanical and Physical Properties at VIPs [6,..,12].

Evaluation Criteria	Limit Value and Standard	Explanation
Unit Volume Mass (kg/m^3)	≤ 210 (DIN EN 1602)	-
Dimensional Stability	% 1 (DIN EN 16041)	70°C and %90 humidity
Thermal Conductivity (λ_{10}) (W/mK)	≤ 0.0053(DIN EN 12667)	At room tempereature, %10 humidity
Compressive Strength ($\sigma_{\%10}$) (kPa)	≥ 150 (DIN EN 826)	%10 compression
Deformation (Thickness)	%2(DIN EN 1605)	40 kPa and 70°C
Tensile Strength (kPa)	40(DIN EN 1607)	Toward to direction of panel's length

2.3.8. General Production Method of VIP Cores

Production of VIP cores by using binders and non binding materials. Basic filling material is powder materials at the cores produced with non binding materials. Particle diameters of researched powder group materials vary between 12 nm ~ 100 µm. While mean particle diameters of powder materials like micronized pumice, diatomite, amorphous silica, and filtered perlite vary 7-26 µm, diameter of micro silica varies 1-10 µm, diameter of precipitated silica varies 250-500 nm, and the fumed silica's is about 7-12 nm.

The process of VIP core production with powder group materials is defined below with outlines:

I. Weighing of filling materials: Powder, fiber and opacifiers are weighed defined amounts according to prepared prescription.

II. Mixing of filling materials: Weighed materials are mixed at stable revolution and time in a closed and leak proof in a container.

III. Making panels from material mixture: Mixture poured to the mold are compressed to a defined pressure (forming a rigid panel) and waited in a fixed period time under pressure.

IV. Enveloping: Removed panel from the mold is covered a suitable envelope material.

V. Drying of Core: Composite panel content is dried to until the situation of constant weight (100 % dry situation) and it is cooled to ambient temperature in the desiccators. Production method was given in Figure 11 schematically.

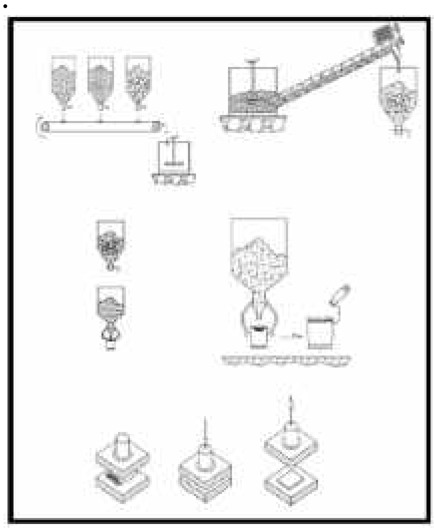

Figure 11. VIP core production method (schematically).

2.3.9. Production of VIP:

Practical size of core (commonly 300x300x25 mm) is putted in an outer envelope (alu-pet) which is closed from three sides as leak proof and placed in vacuum machine. VIPs have core material produced with silica powder are vacuumed to reach until 1 mbar pressure level and VIPs with open cell polystyrene vacuumed to lower inner pressure (~0.1 mbar), and mouth of the outer barrier is sealed automatically. At the VIPs produced with mineral powders, considering with used core materials and outer barrier properties, the success of the vacuum is increased when vacuuming after heating to between 60-90 °C temperatures.

2.3.10. Comparison of VIP Thermal Performance and Unit Cost with Traditional Insulation Materials

Thermal insulation performances of traditional insulation materials and VIPs' could be evaluated by comparing heat conductivities (λ) or equivalent resistances (R_{eq}).However, R_{eq} value is to allow for healthier comparison to make performance-cost evaluations of insulation materials together.

At Table 3, by comparing R_{eq} values and unit prices of VIPs produced with two different cores made from XPS, rock wool and insulation perlite, per square meter costs were calculated. When Table 4 examined, for R_{eq} (5 m^2K/W) value XPS (15.40 €/m^2) is outstanding as the most economical thermal insulation material. But for the value of R_{eq} (5 m^2K/W), application thickness of XPS is 175 mm. Similarly, application thickness of rock wool panel is 200 mm, and the perlite's is 225 mm. In other words, at the applications of cooling equipments which have section limitations and desired the energy efficiency for the value of R_{eq} =5 m^2K/W, these insulation materials are not suitable.

Especially, for many applications like heating-cooling equipments which have section limitations and desired the energy efficiency, between the investigated products at Table 3, VIP_{FS} and VIP_{AJ} remained. VIP_{AJ} is the most expensive one of these products. When VIP_{FS} comparing with VIP_{AJ}, it is corresponding to 25 mm cross-section, 56 % cheaper. In the investigated insulation materials, VIP_{FS} which shows the close cost to 200 mm cross section thickness rock wool's unit cost is the only and still economic comparatively and applicable product for the thermal insulation applications which have section limitations.

Table 3.Costs of thermal insulation materials according to cross section thickness (d) provided equivalent thermal permeability value (R_{eq}) [4].

Insulation Material	a (mW/m.K)	d (mm)	R_{eq} (m^2K/mW)	Unit Price[1] (€ /m^2)	Cost [2] (€ /m^2)
VIP_{FS}	5	25.00	5.000	50	60.00
VIP_{AJ}	4.5	22.50	5.000	150	135.00
XPS	35	175.00	5.000	2.2	15.40
Rock wool	40	200.00	5.000	6.7	53.60
Perlite	67	225.00	5.000	1.6	21.44
[1]	25 mm thickness panel cost				
[2]	Panel Cost (d thickness) provided equivalent R value				
VIP_{FS}	Fumed silica cored VIP provided DIN EN 12667 standards				
VIP_{AJ}	VIP produced with aero gel				
XPS	30-32 kg/m^3 density closed porous polystyrene foam panel				
Rock wool	150 kg/m^3 density compressed jacketing panel				
Perlite	130 kg/m^3 density perlite aggregate between 2-1 mm				
R_{eq}	Equivalent thermal permeability resistance (R = d/λ)				

3. RESULTS

Thermal insulation performance of VIPs' are directly related with vacuum capability and core material properties for the support function against the atmosphere pressure. The core could be enough strong to compensate this pressure without collapsed and could consist of micro porous that can be vacuumed and in addition to this, has a structure that could not to transfer heat.

Mechanical properties like deformation, tensile stress, compressive strength and physical properties like mass per unit volume, thermal conductivity, and dimensional stability of VIP cores are so important. The fibers' (which were mixed with powder materials in defined ratios) physical properties like slenderness ratio (or denier), tensile strength, specific gravity, conductivity are affected the composite's (core's) psycho-mechanical properties. But here, the most important element is the homogeneity of mineral powder-fiber mixture. An ideal core material must have high porosity, an open cell structure, very small pore diameter, enough compression strength. Minimizing of radiation heat transfer is of great importance according to total heat transfer of core material. The reflection ability of barriers (outer envelope) and opacifier kind and ratio used in inner filler is affected of heat transfer of VIPs' by radiation.

When the commonly used thermal insulation materials at the present time examined, fumed silica cored VIP is comparatively economic and applicable and unique product for the thermal insulation applications for the thermal insulation applications.

While 25 mm cross section thickness VIP has equivalent insulation performance with 200 mm cross section thickness rock wool, it shows a close cost at the same time.

Number of scientific researches about VIP is quite restricted. R&D studies about VIPs are almost non-existent. But first heating-cooling equipments which have section limitations and with an emphasis on energy efficiency in so many industrial areas, using of VIP is becoming of a necessity. Today, industrial organizations and universities have to act fast at the subjects about production of economical VIPs and improving of their insulation performances. After all information and findings about VIP production processes and their thermal performances evaluated, researches could be intensify about different types mineral powders as filling material, opacifiers, fiber types and mixture ratios, compress pressure at core production processes and their effects on conductivities and physico-mechanical properties of material, required application vacuum level according to different core types, and alternative methods at core production. For this, attention should be paid about cooperation of industry and universities.

4. ACKNOWLEDGEMENTS

This study was supported by the Scientific and Technological Research Council of Turkey (TUBITAK-Project No: 111M072).

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