The Impact of Barrier Laminates on Thermal Property and Service Life of Vacuum Insulation Panels

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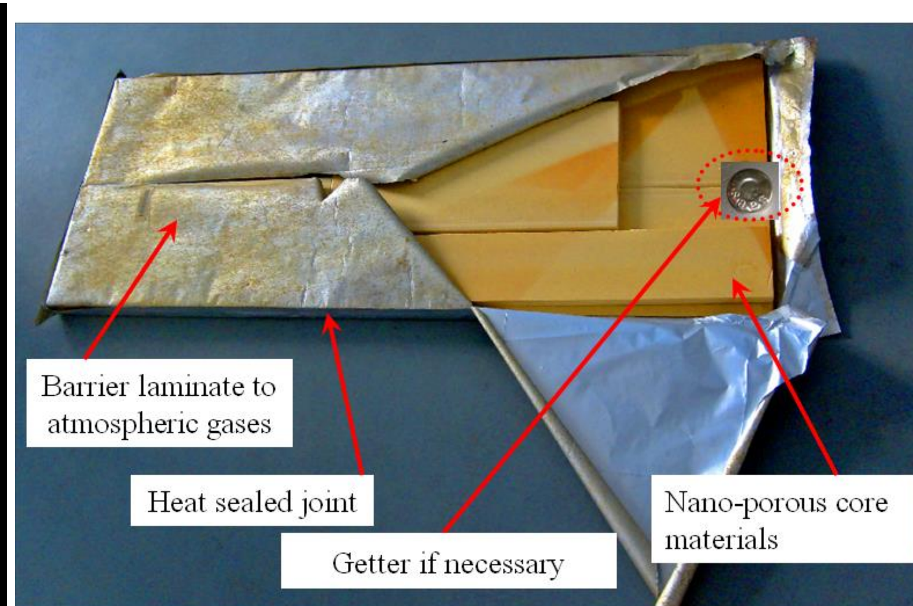
Thermal mechanism of VIPs

Thermal conduction(TC) in Porous material

- TC by solid frame 31%

TC in porous material

Components of VIPs



British ICI (Imperial Chemical Industries) research report 2005

The content

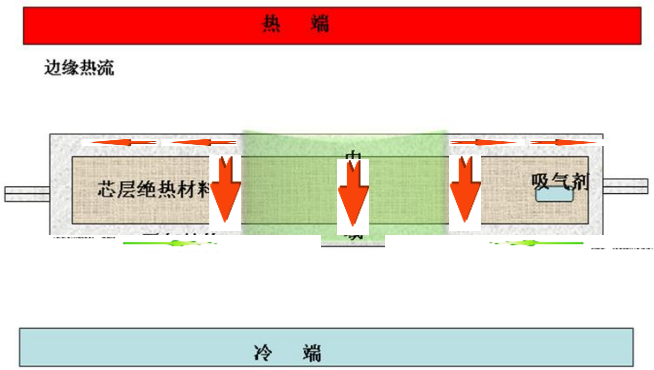
Introduction

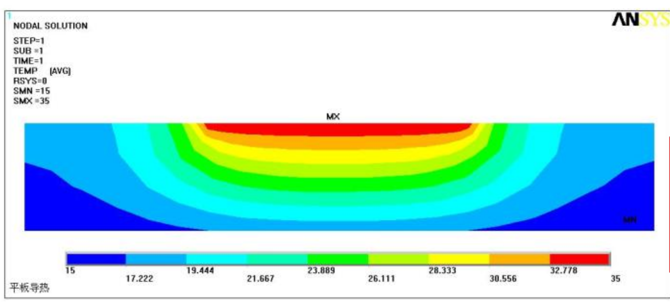
When we take use of VIPs, We mainly focus on:

- Low thermal conductivity
- **Light、thin and tolerance**
- **Economical and environment protectiveness**
- **Long service life**

Introduction

The impact of the barrier





Barrier laminates

Thermal insulation

Vacuum keeping

Thermal bridge

Gas & vapor permeating

Inner air pressure

Effective thermal conductivity

Service life

2. The effective thermal conductivity of VIPs

$$\lambda_e(\tau) = \lambda_{ini} + \lambda_g(\tau) + \lambda_{wv}(\tau)$$

thermal conductivity of VIPs versus time going (W/(m·K)

initial thermal conductibility of VIPs (W/(m·K)

the additional increase value of thermal conductivity caused by **permeation of gases** with the time going (W/(m·K)

the additional increase value of thermal conductivity caused by **permeation of vapor** with the time going (W/(m·K)

2. The effective thermal conductivity of VIPs

2.1 Additional increase value of thermal conductivity caused by permeation of gases

Gas transmission rate (***GTR***) Oxygen Transmission Rate (***OTR***)

$$\lambda_{e,g} = \frac{\lambda_{g,0}}{1 + \frac{\sqrt{2}\beta k_B T_m}{\pi d_g^2 \delta p_g}}$$

$$GTR_{tot} = GTR_A A_{VIP} + GTR_C C_{VIP} = (OTR_A + OTR_A/5)A_{VIP} + (OTR_C + OTR_C/5)C_{VIP}$$

$$Q_g = \frac{GTR_{tot}}{\Delta p}$$

$$\frac{dp_g}{d\tau} = \frac{p_0 Q_g (p_0 - p_g)}{T_0}\frac{T_m}{V_e} = \frac{GTR_{tot,air}}{V_e}\frac{T_m}{T_0}(p_0 - p_g)$$

$$p_g(\tau) = p_0 - (p_0 - p_{ini})e^{-\frac{T_m GTR_{tot,air}(p_0 - p_{ini})}{T_0 V_e}\tau}$$

$$\lambda_g(\tau) = \frac{\lambda_{g,0}}{1 + \frac{\sqrt{2}\beta k_B T_m}{\pi d_g^2 \delta [p_0 - (p_0 - p_{ini})e^{-\frac{T_m GTR_{tot,air}(p_0 - p_{ini})}{T_0 V_e}\tau}]}}$$

2. The effective thermal conductivity of VIPs

2.2 Additional increase value of thermal conductivity caused by permeation of vapor

Moisture Vapor Transmission Rate ***(MVTR)***

$$\frac{dm_{mv}}{d\tau} = MVTR_A \times A_{VIP} + MVTR_C \cdot C_{VIP} = \Delta p_{mv} \times Q_{wv,tot}$$

$$\Delta p_{mv} = p_{mv,out} - p_{mv,in} = (\varphi_{out} - \varphi_{in}) p_{mv,satu,T_m}$$

$$x_{mv}(\tau) = K\varphi_{out}(1 - e^{-\frac{(MVTR_A \cdot A_{VIP} + MVTR_C \cdot C_{VIP})\, p_{mv,stau,T_m}}{Km_{VIP,dry}}\tau})$$

$$\lambda_{wv}(\tau) = bx_{mv}(\tau) = Kb\varphi_{out}(1 - e^{-\frac{(MVTR_A \cdot A_{VIP} + MVTR_C \cdot C_{VIP})\, p_{mv,stau,T_m}}{Km_{VIP,dry}}\tau})$$

2. The effective thermal conductivity of VIPs

2.3 Effective thermal conductivity prediction model of VIPs

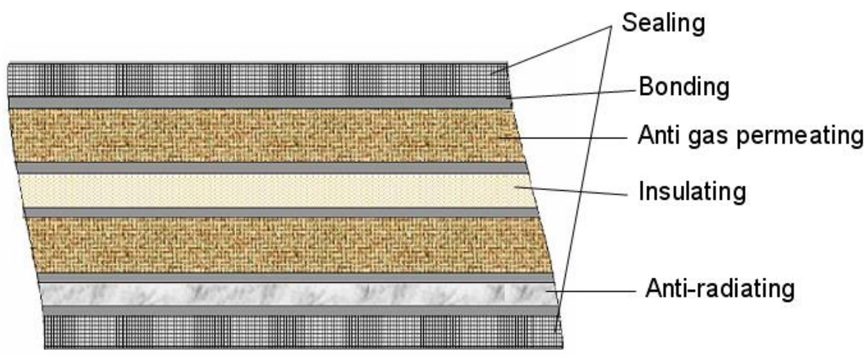
$$\lambda_e(\tau) = \lambda_{ini} + \frac{\lambda_{g,0}}{1 + \dfrac{\sqrt{2}\beta k_B T_m}{\pi d_g^2 \delta [p_0 - (p_0 - p_{ini}) e^{-\frac{T_m GTR_{tot,air}(p_0 - p_{ini})}{T_0 V_e}\tau}]}} + Kb\varphi_{out}(1 - e^{-\frac{(MVTR_A \cdot A_{VIP} + MVTR_C \cdot C_{VIP})\, p_{mv,stau,T_m}}{K m_{VIP,dry}}\tau})$$

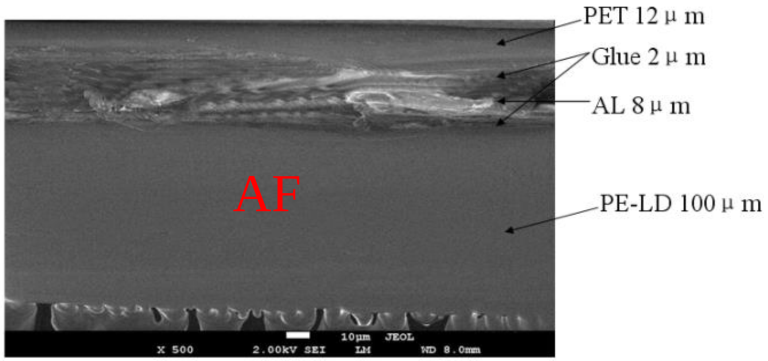
About the service life

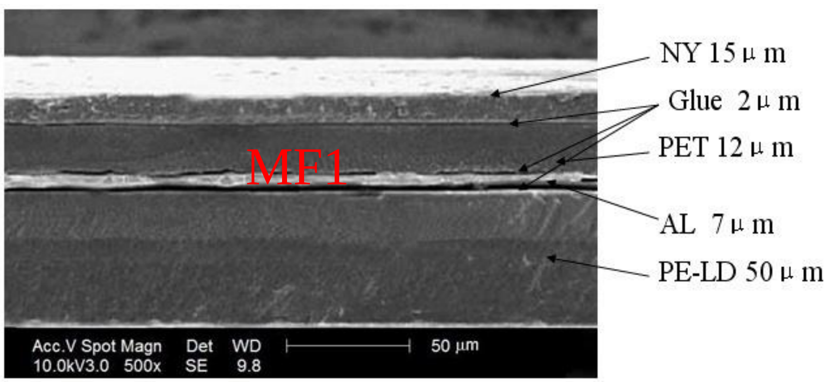
With the time going under a certain boundary condition, while the $\boxed{\lambda(\tau) \geq 0.011495}$ W/(m K), the VIPs can be defined failure and the corresponding time $\boxed{\tau}$ is so called service life of VIPs.

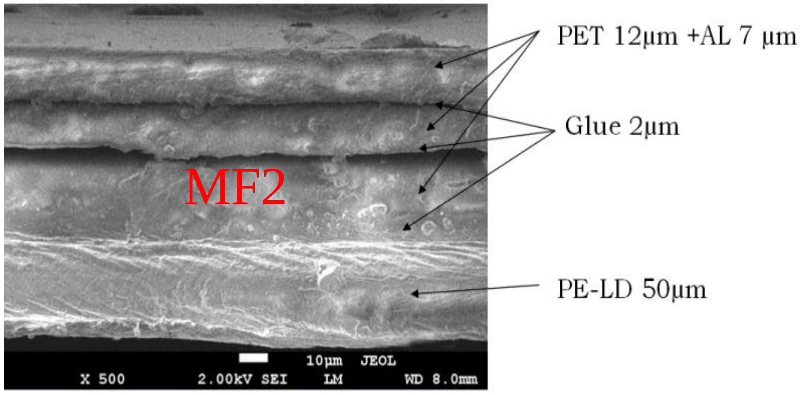
3. Composition and property parameters of barrier laminates

3.1 The composition of barrier laminates









3. Composition and property parameters of barrier laminates

3.2. The physical parameters of the barrier laminates

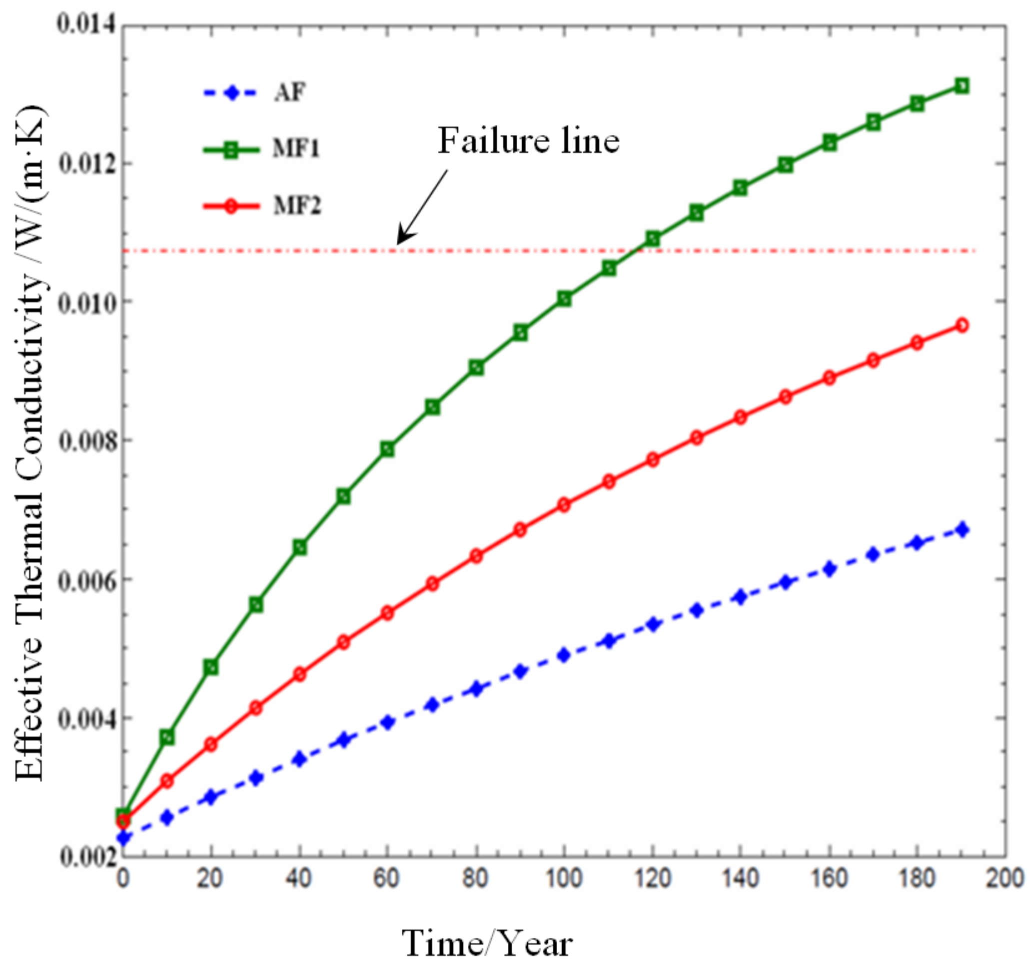
Table.1. The parameters of barrier laminates

Properties	Barrier laminate materials			Source or Test Methods
	AF	MF1	MF2	
Thickness (μm)	124	90	113	
OTR_A $(cm^3/(m^2 \cdot d))$	0.0013	0.0009	0.0004	ASTM D3985 (23℃,50%PH)
OTR_C $(cm^3/(m \cdot d))$	0.0015	0.0067	0.0033	ASTM D3985 (23℃,50%PH)
$MVTR_A$ $(g/(m^2 \cdot d))$	0.0005	0.0192	0.0048	ASTM F1249-90 (38℃,100%PH)
$MVTR_C$ $(g/(m \cdot d))$	0.0012	0.0008	0.0006	ASTM F1249-90 (38℃,100%PH)
Thermal diffusion coefficient (mm^2/s)	0.132	0.119	0.116	NETZSCH LFA (25℃)
Thermal conductivity $(W/(m \cdot K))$	0.230	0.221	0.256	NETZSCH LFA (25℃)

4.The results and discussion

4.1. The simulation results and discussion

Assumed that the VIP service environment is standard atmospheric pressure, the mean temperature, 24℃, the relative humidity,50%, The theoretical prediction of the three VIPs with the different barriers is shown in Fig..



4.The results and discussion

4.2 The testing results and discussion

Aging test in high temperature

The setting temperature was 70℃ and the relative humidity, 80%. And the setting condition was keeping for 30 days.

Table.2. Aging test results in constant temperature & humidity box and the comparison with theoretical results

Specimens	Barrier envelopes	Initial thermal conduction W/(m·K)	Aging condition		Final thermal conductivity W/(m·K)	Theoretical thermal conductivity W/(m·K)
			T ℃	RH %		
1	AF	0.00225	70	80	0.00253	0.00241
2	MF1	0.00256	70	80	0.00277	0.00267
3	MF2	0.00249	70	80	0.00274	0.00262

4.The results and discussion

4.2 The testing results and discussion

Aging test in high air pressure

The initial temperature in box was 25 ℃ ， and relative humidity 50%.Then the box was pressured to 800kPa, and the condition was kept for 30 days.

Table 3. Comparison with the testing data and theoretical calculation values in high air pressure aging test

Specimen	Barrier envelopes	d_i/mm	λ_i/ mW/(m·K)	d_f/ mm	λ_f/ mW/(m·K)	λ_t/ mW/(m·K)
1	AF	19.5	3.14	16.8	4.53	4.52
2	MF1	19.3	3.32	16.6	4.92	4.57
3	MF2	19.0	3.33	16.3	4.43	4.25

5. The optimization methods to prolong the service life of VIPs

5.1 Raw materials

Core materials

The core materials with the high porosity and no gas releasing are the ideal raw core for VIPs.

Barrier envlopes

The thermal performance, anti gas & moisture permeability, gas releasing property, mechanical intensity , sealing performance, environmental protection and fire prevention are all factors shoud be taken into consideration .

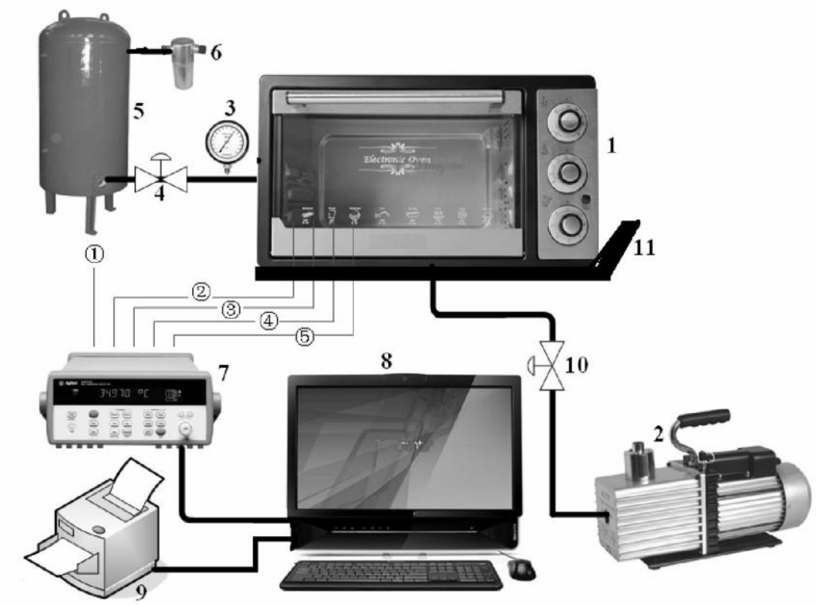
Getter and desiccant

The categories, quantity of getter and desiccant should be based on the core materials, barriers, gas permeability and gas releasing.

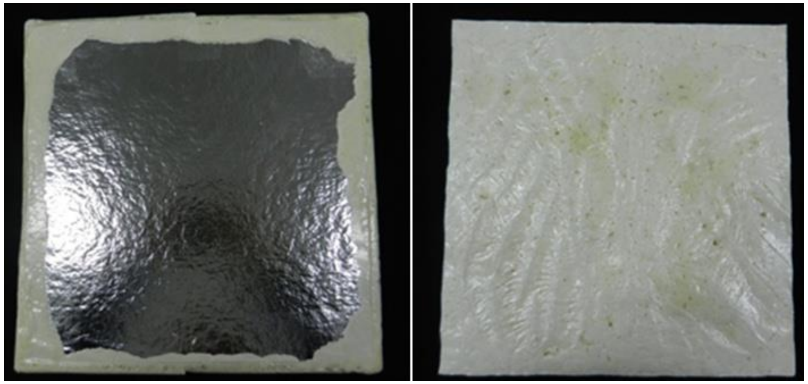
5. The optimization methods to prolong the service life of VIPs

5.2 pre-handling process and transportation & installation crafts

The authors take the process of **vacuum alternating heating method** to pre-handle the core materials.

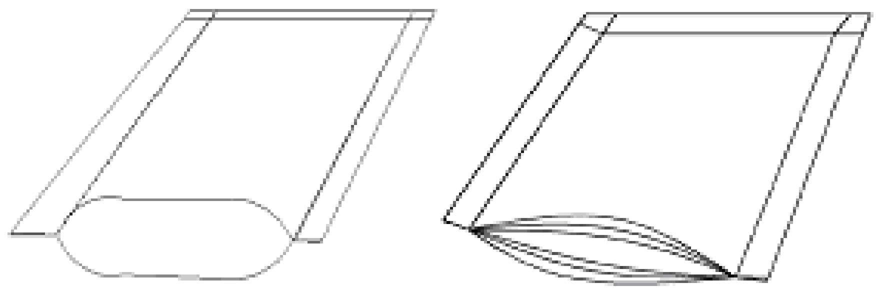


The protection from mechanical damage should be taken in the transporting and installation operation.



5. The optimization methods to prolong the service life of VIPs

5.3. Nesting barriers to enhance anti gas permeability



Core material layers are separated into several independent chambers. the gas permeating from the outmost chamber to the second chamber is slim or negligible. the out chambers can protect the inter one from mechanical damage.

The normal barrier envelopes always contain two pieces. Nesting barriers design was developed by authors and effectively envelopes are innovated to prolong the service life.

6. CONCLUSIONS

壹 There should be one aluminum layer existing in barrier laminates.

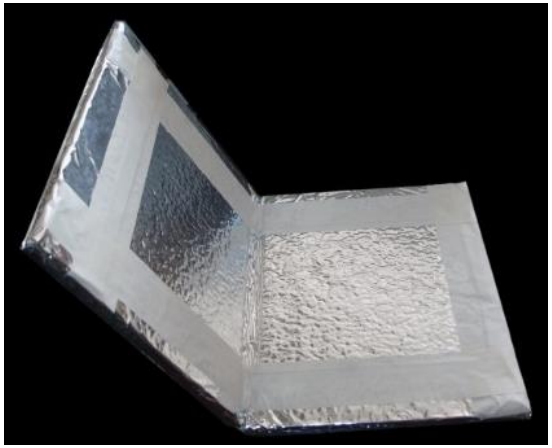
贰 The barrier laminates, can also cause thermal bridge effect. The thickness of the aluminum layer(s) should be decided by the application conditions, the system, and the service life of the unit.

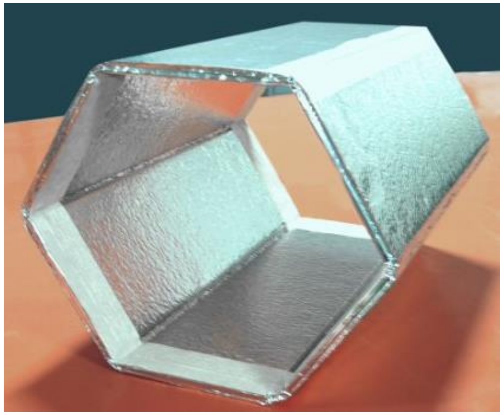
叁 The real temperature, air pressure, relative humidity, imported into the mathematics model, can be used to predict the real service life.

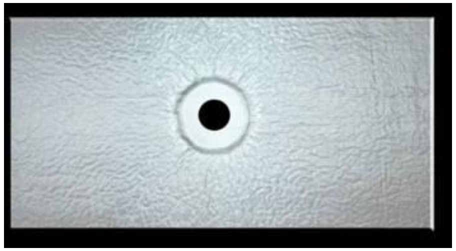
肆 The service life can be prolonged by the raw materials selection, the improvement of manufacturing, transportation and installation craft, nesting design of barrier envelopes, outside protective layer(s), and so on.

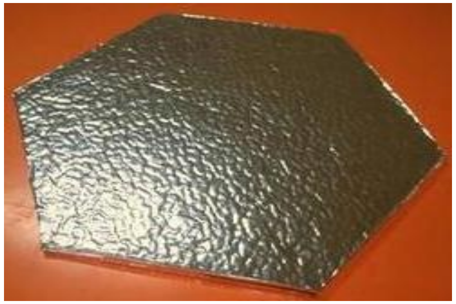
FURTHER BUT NOT THE EDN

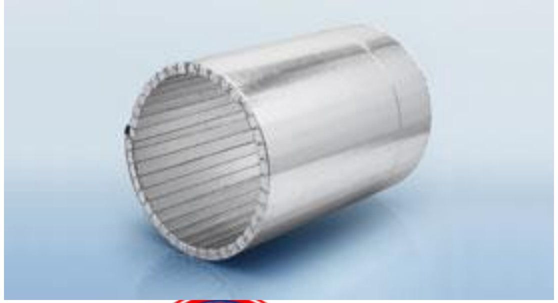
What we can do

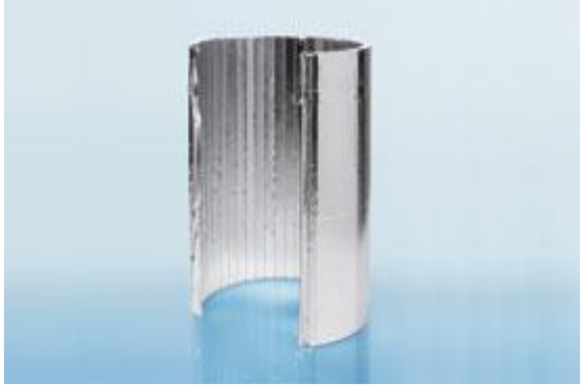


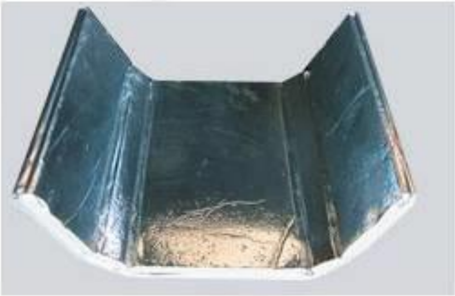












FURTHER BUT NOT THE EDN

We have applied VIPs into

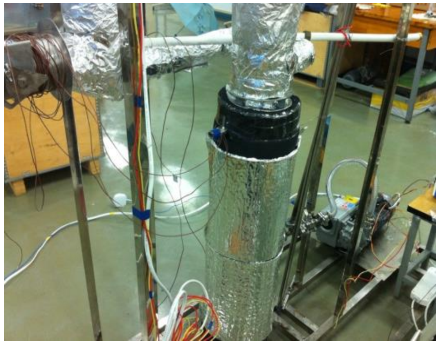
特种冷藏集装箱

箱式活动房

华银大厦

热水器

家用电器



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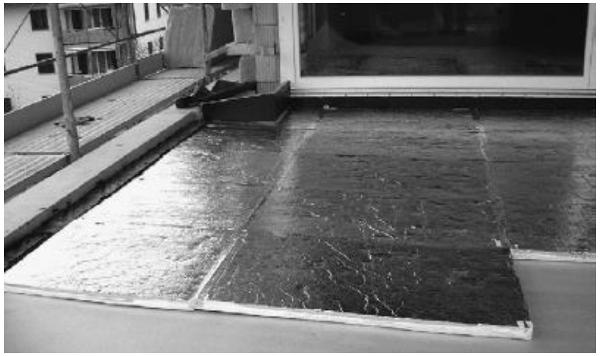

地暖工程

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We got 5 patents


证书号第1013147号

发明专利证书

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发明人：阚安康；韩厚德；周家明

专利号：ZL 2010 1 0517997.X

专利申请日：2010年10月25日

专利权人：上海海事大学

授权公告日：2012年07月25日

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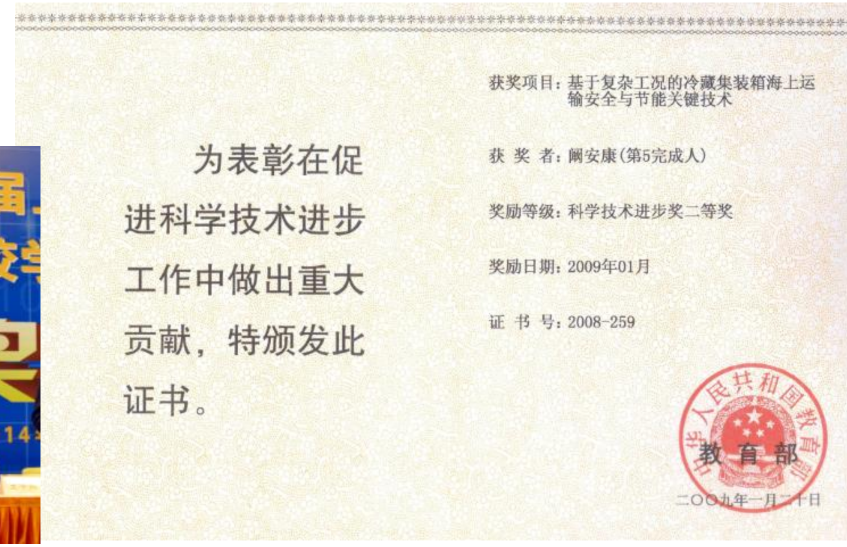
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