DEVELOPMENTS IN REFRIGERATED TRANSPORT INSULATION SINCE THE PHASE OUT OF CFC AND HCFC REFRIGERANTS

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ABSTRACT

Under the Montreal Protocol in January 1996 many countries ceased production of CFC gases (chlorofluorocarbons). Then in January 2003 the use of interim HCFC gases (hydro chlorofluorocarbons) were banned for the production of polyurethane foam. These changes opened up the refrigeration industry for new developments in refrigerant gases, insulations and techniques. New developments in thermal insulation may benefit industry with alternative physical characteristics but foremost may offer energy savings and make new tax incentives available.

1. INTRODUCTION

Insulated and refrigerated vehicles and containers depend on thermal insulation in their structure to minimise heat transfer between the inside being temperature controlled and the external ambient[1]. Deterioration in insulation over time leads to oversized refrigeration equipment, increased refrigeration power requirements, excessive temperature ranges in cargoes and faster warming in the absence of refrigeration.

Traditional insulation materials have disadvantages and advantages but the most commonly used insulation material used in transport applications has been Polyurethane expanded with a suitable foam blowing reagent. The traditional choice was CFC-11, it was inert and with a boiling point around room temperature. Since the Montreal protocol CFC-11 was banned for use in 1996 and HFC-141b in 2003, though some countries are still able to use HFC-141b. In Europe several alternatives have been proposed, the most suitable probably cyclopentane.

The present paper presents information on measured thermal values of structures insulated with polyurethane foams, polyurethane foams incorporating vacuum insulation panels and a dry freight sea container insulated with an aerogel-impregnated blanket.

2. THERMAL TESTING

Thermal testing of containers is now universally carried out by the internal heating method. The container is placed in a controlled temperature chamber, heat is applied internally, and after a temperature stabilisation period the amount of heating power is measured over a time together with internal and external temperatures measured. Test details are defined by ISO[2] or by ATP[3], which is a test standard with precise tolerances. Results are usually expressed in Watts per square metre per

Kelvin, though for insulated marine containers may be expressed as an overall heat leakage figures in Watts per Kelvin as they are in standard unitised sizes, 20' or 40'.

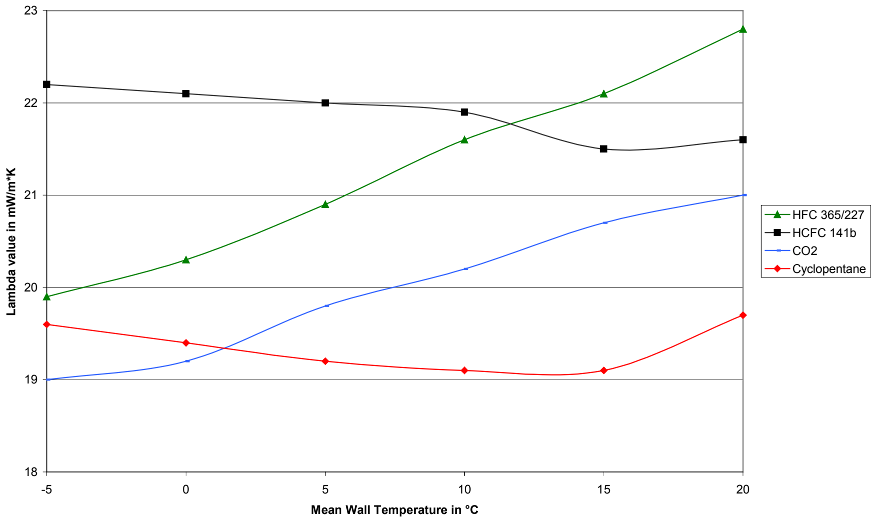
2. INSULATION MATERIALS

Traditional and recent insulation materials are mineral wools, various types of expanded foams, vacuum insulation panels in conjunction with expanded foams and recently developed Aerogel impregnated insulation blanket. In this paper results are presented for a combination of polyurethane foams and vacuum insulation panels and some preliminary measurements on Aerogel insulation blankets.

Polyurethane Insulation

Polyurethane foams in the past has been expanded with several blowing agents notably CFC-11 HCFC141b and carbon dioxide. CFC-11 and HFC-141b are both banned in Europe while carbon dioxide blown foam tends to age at an accelerated rate. Several alternative blowing agents have been investigated[4], their thermal properties are shown below, though it now appears the most likely substitute will be cyclopentane though this does add to production difficulties due to flammability.

Figure Chlorine Free Blowing Agents



Vacuum Insulation Panels

Vacuum insulation panels can offer excellent performance and long life (15+ years) and have been built since the mid 1950's. Unfortunately, the production process to make them has been both expensive and time-consuming and few companies have been able to develop more than small niche markets for the material. Due to their shape limitations they are usually going to be incorporated into an insulated structure[5]. Over the past few years' worldwide research on vacuum insulation technology has accelerated dramatically but now appears to have tailed off in favour of Aerogels.
Vacuum insulation panels virtually eliminate heat transfer by forms of conduction and convection by minimising the gas content of the product. It reduces radiation by the application of a reflective exterior surface coating.

Vacuum insulation panels (VIP's) are constructed from a metallised cellular structure to form a membrane barrier and prevent air penetrating each vacuumed cell. A vacuumed cell has an interstitial space to reduce the heat transfer and contains a core material to prevent the membrane walls from collapsing. There is also a small amount of chemical powder in each cell to scavenge any gases that manage to penetrate the membrane barrier or caused by out-gassing. A vacuum insulation panel cell is typically evacuated to about 0.05 Torr depending on the design.

Aerogel Insulation

Aerogel materials are derived from silicate materials. They represent a structural morphology (amorphous, open-celled nanofoams) rather than a particular chemical constituency. However, a great deal of study has been devoted to silica aerogels and their properties over the past 70 years since they were first discovered in 1931 by Kistler[6]. His process used polymerisation of silicic acid ($Si(OH)_4$), which in turn was generated by acidic neutralization of sodium silicate in water (Equation 1).

$$Na_2SiO_3 + H_2SO_4 + H_2O \Rightarrow Si(OH)_4 + Na_2SO_4 \quad \text{Eq.1}$$

The material under test at CRT was Aspen Aerogel's Opacified Silica Aerogel Blanket Spaceloft ™ 10251. This material is in a flexible 9mm thick blanket form and is composed of Silica gel, trimethylsilylated, and polyethylene terephthalate.

3. DETERIORATION MECHANISMS

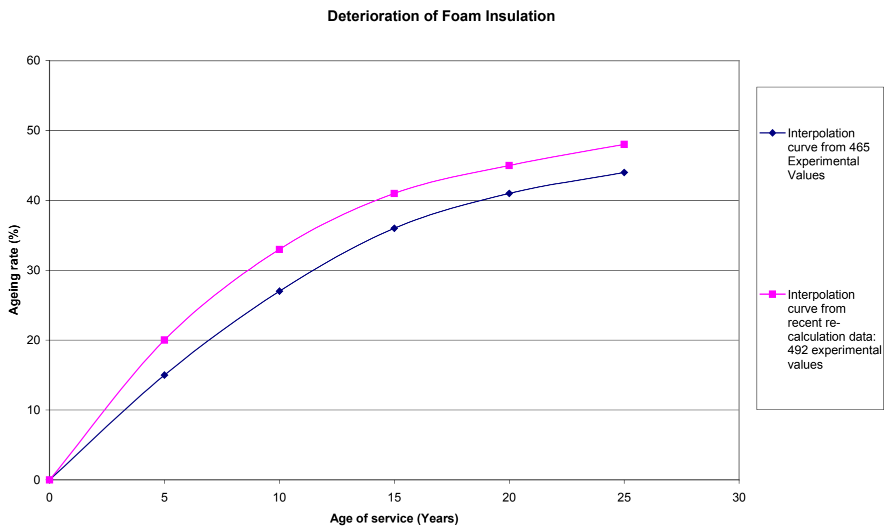
Mineral Wool

Deterioration of the thermal efficacy of mineral wools can occur not by any process of degradation but by increase of moisture either by capillary action or condensation due to damaged or ineffective vapour membranes.

Polyurethane Foam

Polyurethane foams depend on the retention of low conductivity blowing agents in their cells to maintain good thermal performance. Displacement of intercellular gas, infiltration of moisture, and mechanical damage all lead to deterioration. Studies indicate that deterioration can be between 2 – 15% each year depending on the encapsulation. CRT has found that fully welded metal encapsulated insulation ages more slowly than other types. Panozzo et al[7] reported the following ageing characteristics for a sample of 492 refrigerated vehicles.

Figure 1 Deterioration of Foam Insulation



Measurements on old samples up 30 years old the blowing agent can still be easily detected. Commonly after 15 years blowing agent retention remains above at least 50% of original.

Vacuum Insulation Panels

It is possible to make vacuum insulation panels (VIPs) that will maintain insulation values several times longer than of standard foam for well over 20 years. This is possible by using a silica core with high moisture and gas absorbing capacity, in any case silica-based panels are not sensitive to small elevations in internal pressure. Unfortunately, high cost remains a major barrier to wide scale adaptation of silica-based VIPs.

VIPs made recently with low-cost foam core materials give high insulation values and theoretically a reasonably long life and therefore the possibility of much cheaper vacuum insulation panels can be realised. However, panels made with this technology can have an unpredictable very short life, also as with all vacuum panels, any damage to them virtually destroys their insulating effect..

Aerogel Insulation

Aerogel insulation blanket is a new product and therefore there is very little historical data on its ageing properties.   According to the manufacturer, there is theoretically is no ageing effect on the insulation property in the traditional sense. However, other possible causes of ageing might be water absorption into the blanket, though this is unlikely due hydrophobic reagents. Based on these factors and the k value, which is better than PU foam, the material offers the potential to be a viable alternative to polyurethane foam.

4. TEST RESULTS

CRT to continue to test all manner of insulated structures; new data is presented concerning trends on insulation efficacy for PU panels, VIP panels and a general purpose sea container insulated with a prototype Aerogel insulation blanket.

Polyurethane Insulation

Structures insulated with polyurethane have seen two legislation changes that have affected the foam-blowing agent. CRT are not always informed as to the precise nature of the blowing agent but the mean and average minimum k values for new bodies that received ATP class C qualification surrounding significant phase out dates (Periods) are shown in table 1 below:

Table 1 Test Results Polyurethane Foam

Period	Mean Wall Temperature	Sample Number	Average Min K $W/m^2 °C$	Mean K value $W/m^2 °C$
1991 - 95	20	19	0.30	0.34
1996 - 00	20	54	0.32	0.36
2001 - 05	20	34	0.29	0.35

Vacuum Insulation Panels

Traditional 6m liquid bulk tanks constructed for ATP thermal tests have yielded relatively high k values depending on the designer's intention, as maximum volume entails thinner insulation.

Historically, these tanks were insulated by combining mineral wool and PU foam insulation with a general thickness between 100 to 150mm. Thermal bridging occurs wherever the insulation thickness is reduced or compromised because of the structural shape and strength design constraints. Constructions such as liquid bulk tanks are inherently rigid but due to the dimension constraints there are common potential thermal bridging points at the ends of the barrel and at 3, 6, 9 and 12 'o' clock longitudinally along the barrel.

ATP thermal tests have been conducted on tanks with and without vacuum insulation panels placed at the common thermal bridging points and as shown in Table 2, there is a considerable benefit.

Table 2 Test results PU Foam and VIP panels.

Types	Mean Wall Temperature °C	Sample no	Mean k value W/m^2C
PU + Mineral wool	20.0	4	0.5
PU + Vacuum panels	20.0	2	0.28

Aerogel Insulation

To provide comparative data to that derived for insulated reefer containers, a 20 foot standard general purpose container was lined with two 9mm layers of Aspen Aerogels' Spaceloft 10251 blanket material attached to the inside walls.

The insulation was held to the walls and ceiling of the container by using metal pins, which were held onto the wall using glue. Additional glue was also used to hold the two layers of insulation together. For the container floor, the insulation was rolled out and held in place at both ends.
The results are shown below:

Table 3 Test Results PU Foam and Aerogel Insulation.

Test No.	Mean Wall Temperature °C	Wall Thickness mm	Thermal k value W/m^2C
Aerogel	20.0°C	18	0.69
PU foam	20.0	80	0.35

In comparison with this result, thermal tests carried out earlier on reefer containers give a k value of between 0.30 – 0.40 W/m^2C. However a reefer container has a wall thickness of approximately 80mm thick and for this test the target wall insulation thickness was only 18mm thick, although there were areas of overlap necessitated by the fitting of the insulation.

Overall the results clearly show Aspen Aerogels' Spaceloft 10251 blanket to be an effective insulator which obtained an ATP thermal test figure of 0.69 W/m^2 °C in the test set up, with a target insulation thickness of 18mm and limited overlapping of layers. The overall heat leakage from the test set up was 46.8 W/°C.

This test was done purely for research purposes and the method used was on a very experimental basis. The figures given above could be improved upon if the insulation was integrated into the walls of the container. Thermal images have shown that the insulation around the container was not uniform and a number of thermal breaks were found. The pins used to secure the blanket (as anticipated) and areas around the doors proved to be areas of heat loss. If the blanket were to be made up into panels improved insulation figures would be anticipated. Calculations indicate that three layers of Aerogel blanket insulation would provide a k value of < 0.4 W/m^2 °C, which is the standard of insulation that classed as "Heavily Insulated Equipment" and required for the ATP certification.

5. TAX INCENTIVES

Encouraging the use of more energy efficient technologies by tax incentives is increasing. In the U.K. the Enhanced Capital Allowances (ECA) scheme enable a business to claim 100% first-year capital allowances on their spending on qualifying plant and machinery including refrigeration.
For example refrigerated cabinets, purchasers are entitled to tax rebates on the most efficient UNITS.
In the U.S, The Energy Policy Act of 2005 indicates that manufacturers of energy-efficient appliances are eligible for tax credits edits, including $75-$175 per refrigerator depending on efficiency.

6. CONCLUSIONS

Test results show that the k value has not changed significantly with changing blowing agents and insulated structure designers have managed to meet k value industry requirements. Aerogel insulation appears to offer several benefits over polyurethane foam and vacuum insulation panels. The principal benefits are superior insulation properties when compared to PU foams and a possibility of an absence of ageing that traditional materials exhibit. However, the use of such materials will prevent challenges as it does not have the structural strength that a foam has especially when incorporated into a sandwich panel that many structures now rely on. This absence of strength will present challenges for designers and engineers, though it is likely that it will be encouraged by tax incentives, therefore, in the future if the superior qualities of increased insulation effectiveness and lack of ageing are to be maximised.

7. REFERENCES

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