



# Long-term Functionality of Vacuum Insulation Panels (VIP) Subjected to Simulated Random Vibrations

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# Introduction

Energy consumption related to temperature control plays an important role in the cold chain industry, and the novel design of new thermal insulation materials for refrigerated units has attracted more attention. Vacuum insulation panels (VIP) are products recognized for their high thermal insulation properties in buildings. The performance response of VIP under variable moisture and temperature conditions been well investigated by previous has researchers, but the application of insulated shipping containers differs from the working of buildings. In particular, the constant vibration during transportation is an inevitable factor.







# **Working Principle of VIP**



- Reduce the inner pressure
- Use the high-porosity core material (fibreglass or fumed silica)





# **Truck Vibration** Acceleration RMS = $\sqrt{\int_{f_1}^{f_2} a(f) * df}$



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Truck	Truck	Level	Direction	Frequency	Acceleration	Duration	Number of
Vibration	Suspension			[Hz]	RMS [m^2/s]		Breakpoints
ASD	Туре						
ASTM	NA	High	Vertical	1-200	6.87	Until	12
D4169/4728		Medium			5.29	damage	
		low			3.92	detected	
ISTA 3H	Steel spring	NA	Vertical	1-200	5.29	4 hours	12
						Max	
	Air ride			0.6-100	2.75		9
ISO13355	NA	NA	Vertical	2-200	5.93	30min	5
						Min.	
MIL-STD 810-	NA	Na	Vertical	10-500	10.2	Not	3
G			Transverse		1.96	defined	7
			Longitudinal		7.26		8



# **Truck Vibration**





### Trip from Carlisle to Hawkesbury, On, Canada [1]







[1]:Singh, J., Singh, S. P., & Joneson, E. (2006). Measurement and analysis of US truck vibration for leaf spring and air ride suspensions, and development of tests to simulate these conditions. Packaging Technology & Science, 19(6), 309–323. <u>https://doi.org/10.1002/pts.732</u>



# **Objectives**





 Evaluate the long-term thermal insulating performance of VIPs at the application of insulated shipping containers, the simulated random vibration tests were conducted at variable condition.



# Methodology



- 2 type of specimens: Glassfiber & fumed silica
- 2 conditions of specimens: Brand-new & aged

Aged specimens were experienced air aging or water aging before vibration test

## Air Aging

- 70° C & 0-5% Relative humidity
- 2 type of specimens, 6 panels in total
- Weight / thermal conductivity were measured every 5 or 10 days
- Total duration 120 days



# Water Vapor Aging

- 70° C & 95-100% Relative humidity
- 2 type of specimens, 6 panels in total
- Weight / thermal conductivity were measured every 5 or 10 days
- Total duration 120 days







# Methodology



### **Vertical Orientation**



# Horizontal Orientation





 Modified PSD distribution: 1-200 Hz, Acceleration RMS 0.7 m/s<sup>2</sup>





# **Findings**



- In the air and water vapor aging test, fiberglass specimens aged faster than fumed silica specimens.
- Fumed silica VIP maintained stable thermal conductivity at the vertical orientation during the simulated random vibration test, but was found to fail when tested in the horizontal direction.
- Glassfiber VIP shows the thermal conductivity increased by more than 6% after the simulated random vibration test, and the fiber rearrangement could occur under the vibration.
- In a high humidity environment, vibration will accelerate the degradation of VIP.



### Long-term Functionality of Vacuum Insulation Panels (VIP) Subjected to Simulated Random Vibrations

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### INTRODUCTION

Energy consumption related to temperature control plays an important role in cold chain industry, and the novel design of new thermal insulation materials for refrigerated unit has attracted more attention. Vacuum insulation panels (VIP) are products recognized for their high thermal insulation properties in building. The performance response of VIP under variable moisture and temperature conditions has been well investigated by previous researchers, but the application of insulated shipping container differs from the working of buildings. In particular; the constant vibration during transportation is an inevitable factor:

#### Working Principle of VIP

VIP works on the principle at the sufficient low pressure, the distance between gas molecular collision exceeds the size of material pores, and then the general conductivity drops. Hence, VIPs are typically made from a high-porosity core material and airtight barriers to maintain the lowest possible internal pressure after vacuum operation.



#### **Truck Vibration**

Truck vibration is affected by various factors, including vehicle's damping system, load, road conditions. However, many researches report the most significant intensities occurring at a frequency range from 1 Hz to 200 Hz, while the general vibration level varies widely (RMS acceleration 0.5 -2.5 m/sA2 on NA highway).

### **OBJECTIVE**

Most study of the functionality of VIP integrated insulated shipping container is currently focus on the modeling stage of energy efficiency, their thermal response to vibration has not been well-investigated. To evaluate the long-term thermal insulating performance of VIPs at the application of insulated shipping containers, the simulated random vibration tests were conducted at variable condition.

### **METHODOLOGY**

There are some standards for vibration test for shipping container, while the proposed vibration intensity is higher than that of in-service level during truck transportation due to the application of time compressed method. In our experimental, a modified power spectra density (PSD) distribution was used throughout the random vibration test, and the original PSD profile is from ASTM D4169. This experiment tested brand-new specimens and some aged specimens that had been air aged as well as water vapor aged





The specimens were vibrated for hundreds of hours, and after each specific time interval (24 or 48 hours) their weight and thermal conductivity were measured by using a balance and a heat flow meter.

### **Experimental setup**

- a) Test Specimens
- <u>Glassfiber</u> VIPs
- Fumed silica VIPs

#### b) Experimental Apparatus

APS long-stroke shaking system Vibration control software Oven Customized environmental chamber Heat flow meter

c) Vibration Set-up

Specimens were vibrated in vertical orientations and loaded horizontal orientations, to simulate the two different assembles of VIP in the insulated shipping containers.

Vertical orientationui Horizontal oMentation with 14Kpa at th



#### d)Air aging

70° C&0-5% Relative humidity 2 type of specimens, 6 panels in total Weight/ thermal conductivity were

measured every 5 or 10 days Total duration 120 days

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