Experimental Evaluation of Apparent Mean Thermal Conductivity of Exfoliated Vermiculite Powder Insulation

Chirag Parekh [1], Prof. Nisha. V. Bora [2]
[1]*M.E. Cryogenic Engineering Student, L.D. College of Engineering, Ahmedabad, India*
[2]*Associate Prof., L.D. College of Engineering, Ahmedabad, India*

Abstract

Expanded vermiculite is the commonest (very low temperature) cryogenic insulation. [1] In evacuated condition, it gives better thermal performance. Still a large portion of heat is transferred through evacuated vermiculite powder with one surface at a room temperature and other at a cryogenic temperature due to radiant energy [5]. In this paper, the apparent mean thermal conductivity is measured by using radial flow type boil off calorimeter connected with vacuum system. Prof. C.R. Maiti [2] has also conducted the experiments for vermiculite only. In this paper, a comparison has been presented with two different experiments.

1. Introduction

The expanded vermiculite is mostly used powder insulation material at low temperature. Expanded vermiculite is hygroscopic, which adapts it for use under vacuum conditions. In evacuated condition it gives better thermal performance. Apparent thermal conductivity of this mixture is found by using boil off calorimeter method, to get optimum mixture composition.

In metal vermiculite powder insulation mainly heat transfer occurs in following ways [4],

1. Heat conduction through a single particle.
2. Heat transfer among the contact particles.
3. Convective heat transfer of gas in the space among particles.
4. Radiative heat transfer among the particles.

So apparent thermal conductivity is equal to,

$$K_a = K_t + K_c + K_r$$

Where,

K_a = apparent thermal conductivity of insulation.
K_t = thermal conductivity of solid and gases.
K_c = thermal conductivity between particles.
K_r = thermal conductivity of radiation

2. Construction and Working of a Test Apparatus

Figure 1, shows the schematic diagram of test apparatus [3]. The test chamber consist of two concentric cylinders the inner cylinder contains measuring vessel and two guard vessels. Insulation is to be tested is filled in annular space between two cylinders. The outer cylinder is a vacuum vessel that forms warm boundary of the sample which is at atmospheric temperature. Pressure in the insulation is then reduced by diffusion pump to the desired pressure. Measuring vessel and the guard vessels are filled with the liquid nitrogen, which is at a cryogenic temperature 77.4 K. Heat flux passing through the insulation causes the liquid nitrogen to vaporize and the volume of gas leaving the measuring vessel is measured with positive displacement type wet test gas flow meter. By knowing the volume of gas which evaporates from the measuring vessel, it is possible to determine total amount of heat flux flowing through the insulation. This, in turn, leads to the determination of the thermal conductivity. Heat flowing from the top of the calorimeter is intercepted by the guard vessel. The temperature of the fluid in the guard vessel is raised slightly above the boiling point of the fluid in the measuring vessel by bubbling the exhaust gas through a column of water. This is done to inhibit recondensation of the measuring vessel vent gas as it passes through the guard vessel. Nitrogen vapour coming out from the measuring vessel is saturated in a water saturator before going to the rotameter.

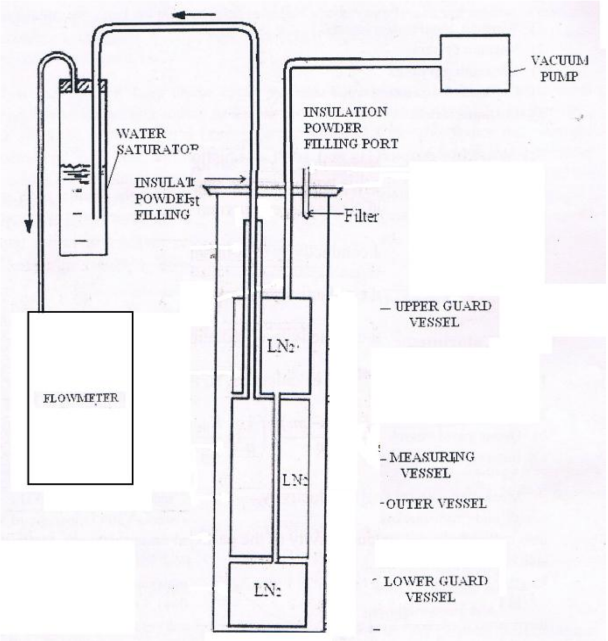

Figure 1. Schematic diagram of Experimental Set-Up

Figure 2. Photograph of Experimental Set-Up

A	Vacuum Collar	F	Pirani Gauge
B	High vacuum valve	G	Penning Gauge
C	LN_2 trap	H	Direct drive Rotary pump
D	Baffle	I	Roughing Valve
E	Diffusion Pump		

3. Measurement Procedure

The apparent mean thermal conductivity of insulation sample can be found by using the Fourier's equation:
i.e.

$$Q = \frac{K_a \times A_m \times (T_h - T_c)}{\Delta x}$$

……….. (1)

Therefore, from equation …. (1)

$$K_a = \frac{Q \times \Delta x}{A_m \times (T_h - T_c)} \quad \text{……….. (2)}$$

Q = Radial heat flow calculated from boil-off rate measurement.

$$Q = \frac{dm}{dt} \times L_v$$

Where,

$\frac{dm}{dt}$ = Boil-off rate in m3/sec. x ρ in kg/m3

L_v = Latent heat of vaporization at 77.3 K

Am = Mean heat transfer area

$$= \frac{A_2 - A_1}{\ln \frac{A_2}{A_1}} \quad \text{……….. (3)}$$

A_1 = Surface area of enclosed surface

i.e. Inner surface of measuring vessel

= π x D1 x L

A_2 = Surface area of outer cylinder

= π x D2 x L

Δx = Thickness of insulation

4. Results

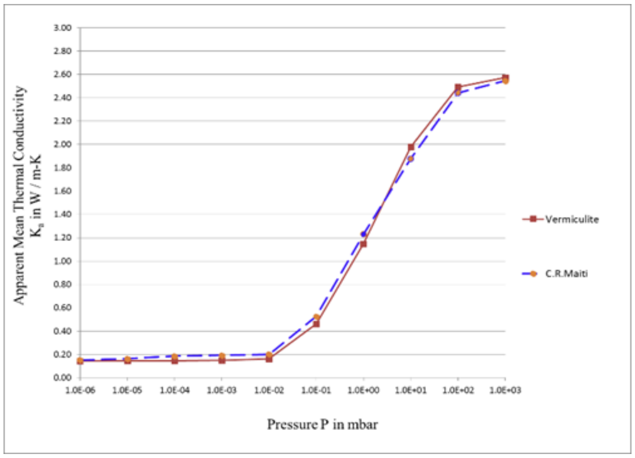

Figure 3. Apparent mean thermal conductivity vs. interstitial gas pressure

Figure-3 shows the graphical comparison of apparent mean thermal conductivity of pure vermiculite powder at different vacuum levels. The lowest value of Ka is obtained when the interstitial gas pressure is below $5x10^{-6}$ mbar.

5. Conclusion

From this experiment result, it can be concluded that the apparent thermal conductivity experimented by Prof. C. R. Maiti is little bit higher side from pressure $1x10^{-06}$ mbar to $1x10^{1}$ mbar. It matches at approx. 1x101 mbar then the values are little bit less. The graph shows the fairly good results compared with Prof. C.R. Maiti's results. Hence the experiment performed is quite comparable.

6. References

[1] Randall.F.Barron, "cryogenic system", 2nd edition, oxford university, New York, 1985.

[2] Some aspects of the thermal performance indigenous powder insulators, C.R. Maiti, Cryogenics, October – 1982.

[3] M.M. Fulk, R.J. Devereux, J.E. Schrodt, "Heat transport through powder", Advances in cryogenic engg Vol-2, pp 165-165, 1960.

[4] "Vermiculite for cryogenic insulation", R.H.Kropschot and R.W.Burgess, advances in cryogenic engg. Vol-8, pp 425-435.

[5] R. Ya. Akhtyamov, V. A. Shchetinkin, O. N. Popov, et al., "Expanded vermiculite as a heat insulator for the arch of glass-melting furnaces," Steklo Keram., No. 2, 29 – 39 (1986).

[6] N. N. kal'yanov and A. N. Merzlyak, Vermiculite and Pearlite —Porous Fillers for Heat Insulation Objects and Concretes [in Russian], Gosstroizdat, Moscow 91967).

[7] HIND HIVAC Vacuum system manual.

[8] Sanjay M. Solanki, "Experimental Evaluation of Powder Insulation". 1998.