SLOVENSKI STANDARD
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

01-maj-2021

Vesoljska tehnika - Priročnik za toplotno zasnovo - 7. del: Izolacija

Space Engineering - Thermal design handbook - Part 7: Insulations

Raumfahrttechnik - Handbuch für thermisches Design - Teil 7: Isolationen

Ingénierie spatiale - Manuel de conception thermique - Partie 7: Isolations

iTeh STANDARD PREVIEW
(standards.iteh.ai)

Ta slovenski standard je istoveten z: **FprCEN/CLC/TR 17603-31-07**

---

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4f70199e-6b7a-4e5b-9a4d-d6a1f9a8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

ICS:

49.140	Vesoljski sistemi in operacije	Space systems and operations

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021	**en,fr,de**

2003-01.Slovenski inštitut za standardizacijo. Razmnoževanje celote ali delov tega standarda ni dovoljeno.

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

iTeh STANDARD PREVIEW
(standards.iteh.ai)

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4f70199e-6b7a-4e5b-9a4d-d6a1f9a8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

FINAL DRAFT FprCEN/CLC/TR 17603-31-07

February 2021

ICS 49.140

English version

Space Engineering - Thermal design handbook - Part 7: Insulations

Ingénierie spatiale - Manuel de conception thermique - Partie 7: Isolations

Raumfahrttechnik - Handbuch für thermisches Design - Teil 7: Isolationen

This draft Technical Report is submitted to CEN members for Vote. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

CEN and CENELEC members are the national standards bodies and national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

iTeh STANDARD PREVIEW
(standards.iteh.ai)

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4f70199e-6b7a-4e5b-9a4d-d6a1f9a8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

Warning : This document is not a Technical Report. It is distributed for review and comments. It is subject to change without notice and shall not be referred to as a Technical Report.

CEN-CENELEC Management Centre:
Rue de la Science 23, B-1040 Brussels

© 2021 CEN/CENELEC All rights of exploitation in any form and by any means reserved worldwide for CEN national Members and for CENELEC Members.

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Table of contents

European Foreword **14**

1 Scope **15**

2 References **16**

3 Terms, definitions and symbols **17**

3.1 Terms and definitions 17

3.2 Abbreviated terms 17

3.3 Symbols 17

4 Foams **22**

4.1 General 22

4.2 Inorganic foams 25

4.3 Organic foams 31

4.3.2 Thermal properties of organic foams 32

4.3.3 Mechanical properties of organic foams 35

4.3.4 Data on commercially available foams 53

5 Fibrous insulations **64**

5.1 General 64

5.2 Bulks 66

5.3 Blankets and felts 77

5.4 Papers 102

6 Multilayer insulations **108**

6.1 General 108

6.1.1 Fundamental concepts concerning MLI performance 109

6.1.2 Failure modes 111

6.1.3 Heat transfer through an MLI 111

6.1.4 Cost 118

6.2 Radiation shields 118

6.2.1 Aluminium foils and aluminium coated plastic films 118

6.2.2 Gold foils and gold coated plastic films 119

6.2.3 Silver coated plastic films 119

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4f70199e-6b7a-4e5b-9a4d-d0a19a8a7720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

6.2.4 Operating temperature ranges 119
6.2.5 Normally used plastic films 120
6.3 Emittance of metallic foils 120
6.4 Emittance of metallized films 135
6.5 Absorptance of metallic foils 148
6.6 Radiation shields. miscellaneous properties 165
6.7 Radiation shields. measurement of the coating thickness 180
6.8 Spacers 183
6.8.1 Multiple-resistance spacers 184
6.8.2 Point-contact spacers 184
6.8.3 Superfloc 184
6.8.4 Single-component MLI 185
6.8.5 Composite spacers 185
6.8.6 One-dimensional heat flow through an mli with absorbing and scattering spacers 187
6.9 Spacers. miscellaneous properties 189
6.10 Complete systems 208
6.11 Normal heat transfer 209
6.12 Lateral heat transfer 251
6.13 Effect of singularities 257
6.13.1 Joints 257
6.13.2 Stitches and patches 269
6.14 Effect of evacuating holes 272
6.15 Effect of mechanical damage 276
6.16 Effect of inner gas pressure 277
6.17 Evacuation 285
6.17.1 Interstitial pressure during rapid evacuation 285
6.17.2 Interstitial pressure in outgas controlled situations 292
6.17.3 Self-pumping multilayer insulations 301

Bibliography 319

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4f70199e-6b7a-4e5b-9a4d-d6a1f9a8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

Figures

Figure 4-1: Resin thermal conductivity 23
Figure 4-2 : Gas thermal conductivity 23
Figure 4-3: Radiation thermal conductivity 24
Figure 4-4: Thermal conductivity, *k*, of several ceramic foams as a function of arithmetic mean temperature, T_m 26

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Figure 4-5: Linear thermal expansion, $\Delta L/L$, of several ceramic foams as a function of temperature, T.....27

Figure 4-6: Temperature evolution of the hot and cold faces of several pieces of Zircon foam. Solid line: T_H, hot face. Dashed line: T_C, cold face.....28

Figure 4-7: Thermal conductivity k, of polyurethane foams vs. arithmetic mean temperature, T_m.....32

Figure 4-8: Thermal conductivity, k, of cryopumped polystyrene foams.....33

Figure 4-9: Thermal conductivity, k, vs. arithmetic mean temperature, T_m, of a polyurethane foam in the proximity of the condensation temperature of the filling gas.....34

Figure 4-10: Linear thermal expansion, $\Delta L/L$, of several organic foams as a function of temperature, T.....35

Figure 4-11: Ultimate tensile strength, of several foams as a function of temperature, T.....36

Figure 4-12: Ultimate shear strength, τ_{ult}, of several foams as a function of temperature, T.....37

Figure 4-13: Tensile stress, σ, vs. strain, δ, for several polyurethane foams at 76, 195 and 300 K.....46

Figure 4-14: Modulus of Elasticity-tensile-E, as a function of density, ρ, for several organic foams.....46

Figure 4-15: Ultimate tensile strength, σ_{ult}, as a function of density, ρ, for several organic foams.....47

Figure 4-16: Compressive stress, s, vs, strain, d, for several organic foams at 76, 195 and 300 K.....47

Figure 4-17: Modulus of Elasticity-tensile-E, as a function of density, ρ, for several organic foams.....48

Figure 4-18: Proportional limit-compressive-σ, as a function of density, ρ, for several organic foams.....49

Figure 4-19: Ultimate tensile strength, σ_{ult}, and Modulus of Elasticity-tensile-E, as functions of temperature, T.....50

Figure 4-20: Ultimate compressive strength, σ_{ult}, and Modulus of Elasticity-compressive-E, as functions of temperature, T.....51

Figure 4-21: Ultimate compressive strength, σ_{ult}, as a function of temperature, T.....52

Figure 4-22: Ultimate block shear strength, τ_{ult}, and Modulus of Elasticity-shear block-E, as functions of temperature, T.....53

Figure 4-23: Strain, δ, vs. compressive stress, σ, of Fiberfill Structural Foams.....62

Figure 4-24: Dielectric constant, ε_r, and dissipation factor, D, vs. frequency, f. Stycast 1090.....62

Figure 5-1: Thermal conductivity, k, vs. mean temperature, T_m, for several fibrous insulations. From Glasser et al. (1967) [23].....65

Figure 5-2: Thermal conductivity, k, of B & W Kaowool bulk vs. mean temperature, Tm.....74

Figure 5-3: Thermal conductivity, k, of Carborundum Fiberfrax bulk and washed fibers vs. mean temperature, Tm.....74

Figure 5-4: Temperature differential, $T_H - T_C$, vs. mean temperature of the hot face, T_H,.....75

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4f70198e-6b7e-4e5b-9eb1-d6a1f9a8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Figure 5-5: Temperature differential, T_H–T_C, vs. mean temperature of the hot face, T_H,.....75

Figure 5-6: Temperature differential, T_H–T_C, vs. mean temperature of the hot face, T_H,.....76

Figure 5-7: Temperature differential, T_H–T_C, vs. mean temperature of the hot face, T_H for different values of the insulation thickness, t. Fiberfrax washed fiber, ρ = 96 kg.m^{-3}.....76

Figure 5-8: Sound absorption coefficient, α, as a function of frequency, f, for B & W Kaowool blanket 2,54x10^{-2} m thick.....86

Figure 5-9: Sound absorption coefficient, α, as a function of frequency, f, for the following Fiberfrax products:.....86

Figure 5-10: Air permeability across B & W Kaowool blankets.....87

Figure 5-11: Air permeability across Carborundum Fiberfrax blankets.....88

Figure 5-12: Thermal conductivity, k, of B & Kaowool blankets vs. mean temperature, T_m.....88

Figure 5-13: Thermal conductivity, k, of Fiberfrax blankets vs. mean temperature, T_m.....89

Figure 5-14: Temperature differential, T_H–T_C, vs. temperature of the hot face T_H for different values of the blanket thickness, t. Fiberfrax Lo-Con Blanket & felt, ρ = 64 kg.m^{-3}.....89

Figure 5-15: Temperature differential, T_H–T_C, vs. temperature of the hot face, T_H, ...90

Figure 5-16: Sound absorption coefficient, α, as a function of frequency, f, for J-M Microlite Standard and Silicone Binder.....91

Figure 5-17: Calculated specific heat, c, as a function of temperature, T, for J.M Dyna-Quartz 91

Figure 5-18: Thermal conductivity, k, of J-M Micro-Quartz felt vs. mean temperature, T_m.....93

Figure 5-19: Thermal conductivity, k, of J-M Dyna-Quartz vs. mean temperature, T_m.....93

Figure 5-20: Thermal conductivity, k, of J-M Microlite "AA" and "B" vs. mean temperature, T_m.....94

Figure 5-21: Compressive stress, σ, vs. compressive strain, δ, for J-M Dyna-Quartz. 94

Figure 5-22: Linear Shrinkage, LS, and Total Weight Loss, TWL, of J-M Micro-Quartz Felt as a function of temperature, T.....95

Figure 5-23: Calculated specific heat, c, as a function of temperature, T, for several J-M insulations. 96

Figure 5-24: Thermal conductivity, k, of J-M Min-K 1301 vs. mean temperature, T_m. Numbers on curves indicate the density in kg.m^{-3}. 97

Figure 5-25: Influence of ambient pressure on the variation of thermal conductivity, k, of J-M Min-K 1301 vs. mean temperature, T_m, for several filling gases.....97

Figure 5-26: Thermal conductivity, k, of J-M Min-K 1301 vs. mean temperature, T_m, for different values of thickness, t. 98

Figure 5-27: Thermal conductivity, k, of J-M Min-K 2000 vs. mean temperature, T_m.....98

Figure 5-28: Influence of ambient pressure on the variation of thermal conductivity, k, of J-M Min-K 2000 vs. mean temperature, T_m, for several filling gases.....99

Figure 5-29: Thermal conductivity, k, of J-M Min-K 2000 vs. mean temperature, T_m, for different values of thickness, t. 99

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/d6a1f9a8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Figure 5-30: Thermal conductivity, k, of J-M unbounded B-Fiber batt vs. mean temperature, T_m. 100

Figure 5-31: Thermal conductivity, k, of J-M Micro-Fibers felt Type "E" vs. mean temperature, T_m. 100

Figure 5-32: Compressive stress, σ, vs. compressive strain, δ, for J-M Min-K 1301. Numbers on curves indicate the density in kg.m^{-3}. 101

Figure 5-33: Compressive stress, σ, vs. compressive strain, δ, for J-M Min-K 2000. 101

Figure 5-34: Thermal conductivity, k, of B & W Kaowool, Carborundum Fiberfrax 970 paper, and Fiberfrax Hi-Fi 660 paper vs. mean temperature, T_m. 106

Figure 5-35: Temperature differential, $T_H - T_C$, vs. temperature of the hot face, T_H, for different values of the paper thickness, t. Fiberfrax 970 paper, ρ = 160 kg.m^{-3} 106

Figure 5-36: Temperature differential, $T_H - T_C$, vs. temperature of the hot face, T_H, for different values of the paper thickness, t. Fiberfrax Hi-Fi 660 paper. 107

Figure 5-37: Thermal reflectance, ρ, of Fiberfrax 970-J paper vs. mean temperature, T_m. 107

Figure 6-1: Effective thermal conductivity, k_{eff}, of multilayer insulations as compared with other insulation materials. From Glaser et al. (1967) [23]. 109

Figure 6-2: Effective thermal conductivity, keff, of several multilayer insulation systems as a function of the characteristic temperature, T. Calculated by the compiler. 116

Figure 6-3: Summary of data concerning hemispherical total emittance, ε, of Aluminium foils and thin sheets as a function of temperature, T. 121

Figure 6-4: Summary of data concerning hemispherical total emittance, ε, of Copper as a function of temperature, T. 122

Figure 6-5: Hemispherical total emittance, ε, of Copper as a function of temperature, T. 123

Figure 6-6: Hemispherical total emittance, ε, of Copper as a function of temperature, T. 124

Figure 6-7: Hemispherical total emittance, ε, of Gold vs. temperature, T. 125

Figure 6-8: Hemispherical total emittance, ε, of Molybdenum vs. temperature, T. 126

Figure 6-9: Hemispherical total emittance, ε, of Nickel vs. temperature, T. 128

Figure 6-10: Hemispherical total emittance, ε, of oxidized Nickel as a function of temperature, T. 129

Figure 6-11: Normal total emittance, ε', of Nickel as a function of temperature, T. 130

Figure 6-12: Normal total emittance, ε', of Inconel as a function of temperature, T. 131

Figure 6-13: Normal total emittance, ε', of Inconel X as a function of temperature, T. 132

Figure 6-14: Hemispherical total emittance, ε, of Platinum as a function of temperature, T. 133

Figure 6-15: Hemispherical total emittance, ε, of Silver as a function of temperature, T. 134

Figure 6-16: Hemispherical total emittance, ε, of Aluminized Mylar as a function of coating thickness, t_c. 136

Figure 6-17: Hemispherical total emittance, ε, of Copper on Mylar as a function of coating thickness, t_c. 137

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/...-ksist-tp-fprcen-clc-tr-17603-31-07-2021

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Figure 6-18: Hemispherical total emittance, ε, of Goldized Mylar as a function of coating thickness, t_c.....138

Figure 6-19: Hemispherical total emittance, ε, of Gold on Double Aluminized Mylar as a function of Gold thickness, t_c. 139

Figure 6-20: Hemispherical total emittance, ε, of Silvered Mylar as a function of coating thickness, t_c. 140

Figure 6-21: Hemispherical total emittance, ε, of Silvered Mylar overcoated with Silicon Monoxide as a function of Silver thickness, t_c. 141

Figure 6-22: Hemispherical total emittance, ε, of Aluminized Kapton as a function of temperature, T.....143

Figure 6-23: Hemispherical total emittance, ε, of Aluminized Kapton as a function of coating thickness, t_c, for T = 300 K. 144

Figure 6-24: Hemispherical total emittance, ε, of Aluminized Kapton as a function of coating thickness, t_c, for T = 400 K. 145

Figure 6-25: Hemispherical total emittance, ε, of Silgle-Goldized Kapton as a function of temperature, T.....146

Figure 6-26: Hemispherical total emittance, ε, of Silgle-Silvered Kapton as a function of temperature, T.....147

Figure 6-27: Normal spectral absorptance, α'_λ, of Aluminium as a function of wavelength, λ.....148

Figure 6-28: Normal solar absorptance, α_s, of Aluminium as a function of temperature, T.....149

Figure 6-29: Normal spectral absorptance, α'_λ, of Copper as a function of wavelength λ....150

Figure 6-30: Normal solar absorptance, α_s, of Copper as a function of temperature T.....151

Figure 6-31: Normal spectral absorptance, α'_λ, of Gold as a function of wavelengthλ 152

Figure 6-32: Normal solar absorptance, α_s, of Gold as a function of temperature T.....153

Figure 6-33: Normal spectral absorptance, α'_λ, of Molybdenum as a function of wavelength λ. 154

Figure 6-34: Normal solar absorptance, α_s, of Molybdenum as a function of temperature T 155

Figure 6-35: Normal spectral absorptance, α'_λ, of Nickel as a function of wavelength λ.....156

Figure 6-36: Normal solar absorptance, α_s, of Nickel as a function of temperature, T.....158

Figure 6-37: Normal spectral absorptance, α'_λ, of Incoel as a function of wavelength λ.....159

Figure 6-38: Normal solar absorptance, α_s, of Incoel as a function of the temperature, T, to which samples had been previously heated. 160

Figure 6-39: Normal spectral absorptance, α'_λ, of Platinum as a function of wavelengthλ. 161

Figure 6-40: Normal solar absorptance, α_s, of Platinum as a function of temperature, T.....162

Figure 6-41: Normal spectral absorptance, α'_λ, of Silver as a function of wavelength, λ. 163

Figure 6-42: Normal solar absorptance, α_s, of Silver as a function of temperature, T. 164

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4f70199e-6b7a-4e5b-9a4d-d6a1Da8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Figure 6-43: Linear thermal expansion, $\Delta L/L$, of two nominally identical specimens of 6,35x10^{-6} m thick Mylar Double-Goldized as a function of temperature, T.....172

Figure 6-44: Linear thermal expansion, $\Delta L/L$ of 6,35x10^{-6} - 7,62x10^{-6} m thick Kapton Double-Goldized, with Dacron Flocking, as a function of temperature, T.....173

Figure 6-45: Coating thickness, t_c, given by several methods, compared with that gives by the electrical resistance method, $t_{c\Omega}$.....181

Figure 6-46: Thickness, $t_{c\Omega}$, of metallic coatings as a function of film electrical resistance, R. Calculated by the compiler.....183

Figure 6-47: Apparent emittance, ε_a, of a gray V-Groove as a function of surface emittance, ε, illustrating the effect of embossing or crinkling on the optical properties of the shield. Calculated by the compiler. 186

Figure 6-48: Effective thermal conductivity, k_{eff}, of several fibrous spacers as a function of mean temperature, T.....199

Figure 6-49: Effective thermal conductivity, k_{eff}, of Fiber-glass batting as a function of Nitrogen gas pressure, p.....200

Figure 6-50: Effective thermal conductivity, k_{eff}, of Dexiglas as a function of warm-boundary temperature, T_H. 201

Figure 6-51: Effective thermal conductivity, k_{eff}, of Tissuglas as a function of warm-boundary temperature, T_H. 202

Figure 6-52: Effective thermal conductivity, k_{eff}, of Refrasil as a function of warm-boundary temperature, T_H. 203

Figure 6-53: Effective thermal conductivity, k_{eff}, of several spacer materials as a function of bulk density, ρ. 204

Figure 6-54: Specific Heat, c, of several spacer materials as a function of temperature, T.....205

Figure 6-55: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, N/t.....211

Figure 6-56: Compressive mechanical load, P, on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t. 212

Figure 6-57: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, N/t.....215

Figure 6-58: Effective thermal conductivity, k_{eff}, as a function of the characteristic temperature, T.....216

Figure 6-59: Heat flux, Q/A, across a single-aluminized Mylar, crinkled, MLI on different substrate plates, as a function of the number of radiation shields, N. T = 195 K, p = 2 x 10^{-3} Pa. N/t = 1100 ± 200 m^{-1}.....217

Figure 6-60: Effective thermal conductivity, k_{eff}, of a single-aluminized Mylar, crinkled, MLI on two different substrate plates, as a function of the number of radiation shields, N.....218

Figure 6-61: Heat flux, Q/A, across a single-aluminized Mylar, crinkled, MLI on different substrate plates, as a function of the pressure, p. T = 195 K. Layer density, N/t = 1100 ± 200 m^{-1} in any case.....219

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/41961990-0b7a-4e58-9a4d-d6a1f9a8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Figure 6-62: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. 220

Figure 6-63: Effective thermal conductivity, k_{eff}, as a function of the characteristic temperature, *T*. 221

Figure 6-64: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. 222

Figure 6-65: Compressive mechanical load, *P*, on the multilayer insulation vs. the number of radiation shields per unit thickness, *N/t*. 223

Figure 6-66: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. number of radiation shields per unit thickness, *N/t*. 224

Figure 6-67: Compressive mechanical load, *P*, on the multilayer insulation vs. the number of radiation shields per unit thickness, *N/t*. 225

Figure 6-68: Effective thermal conductivity, k_{eff}, as a function of the characteristic temperature, *T*. 225

Figure 6-69: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. Arrows in curves indicate whether the system is being loaded or unloaded. 228

Figure 6-70: Compressive mechanical load, *P*, on the multilayer insulation vs. the number of radiation shields per unit thickness, *N/t*. 229

Figure 6-71: Effective thermal conductivity, k_{eff}, as a function of the characteristic temperature, *T*. 229

Figure 6-72: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. 231

Figure 6-73: Compressive mechanical load, *P*, on the multilayer insulation vs. the number of radiation shields per unit thickness, *N/t*. 232

Figure 6-74: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. 234

Figure 6-75: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. Complete loading-unloading history of system (△). 235

Figure 6-76: Compressive mechanical load, *P*, on the multilayer insulation vs. the number of radiation shields per unit thickness, *N/t*. 236

Figure 6-77: Compressive mechanical load, *P*, on the multilayer insulation vs. the number of radiation shields per unit thickness, *N/t*. Complete loading-unloading history of system (△). 236

Figure 6-78: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. 239

Figure 6-79: Effective thermal conductivity, k_{eff}, as a function of the characteristic temperature, *T*. 240

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4170199e-6b7a-4e5b-9a4d-

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Figure 6-80: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. 243

Figure 6-81: Effective thermal conductivity, k_{eff}, as a function of the characteristic temperature, *T*. 244

Figure 6-82: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. 245

Figure 6-83: Compressive mechanical load, *P*, on the multilayer insulation vs. the number of radiation shields per unit thickness, *N/t*. 246

Figure 6-84: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. 247

Figure 6-85: Compressive mechanical load, *P*, on the multilayer insulation vs. the number of radiation shields per unit thickness, *N/t*. 248

Figure 6-86: Effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}, vs. the number of radiation shields per unit thickness, *N/t*. 249

Figure 6-87: Compressive mechanical load, P, on the multilayer insulation vs. the number of radiation shields per unit thickness, *N/t*. 250

Figure 6-88: Effective thermal conductivity, k_{eff}, as a function of the characteristic temperature, *T*. 250

Figure 6-89: Lateral effective thermal conductivity, k_{eff}, as a function of characteristic temperature, *T*. 252

Figure 6-90: Lateral effective thermal conductivity, k_{eff}, as a function of characteristic temperature, *T*. 253

Figure 6-91: Lateral effective thermal conductivity, k_{eff}, as a function of characteristic temperature, *T*. 255

Figure 6-92: Lateral effective thermal conductivity, k_{eff}, as a function of characteristic temperature, *T*. 256

Figure 6-93: Effective emittance, $\Delta\varepsilon_{eff}$, vs. overlap, *l*. 267

Figure 6-94: Length, *L**, vs. overlap, *l*, of alternate layers. 267

Figure 6-95: Length, *L**, vs. underlap, *l*. 268

Figure 6-96: Length, *L**, vs. k_{eff}. Edge rejection. 268

Figure 6-97: Heat loss, ΔQ, due to stitching vs. the length of Stitch, *L*. 270

Figure 6-98: Heat loss, ΔQ, due to stitch patching vs. the number of patch layers, *N*. Undisturbed system and test method as in Figure 6-97. 271

Figure 6-99: Effect of perforations on the effective thermal conductivity of a multilayer insulation formed by 24 Radiation Shields 6,35x10^{-6} m thick Mylar Double-Aluminized, and 23 Spacers 7,11x10^{-4} m thick Polyurethane Foam. 272

Figure 6-100: Effect of perforations on the effective thermal conductivity of a multilayer insulation formed by 10 Radiation Shields 6,35x10^{-6} m thick by 0,279 m diameter Mylar Double-Aluminized, and 22 Spacers 2,54x10^{-5} m thick by 0,305 m diameter Glass Fabric. 273

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4f78109e-6b7e-4e1c-5b9d-0ea1f9a8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Figure 6-101: Effect of percentage of perforations, τ, on the heat flux through a multilayer insulation. 274

Figure 6-102: Effect of Meteoroid-Bumper debris damage on the effective thermal conductivity, k_{eff}, and product of apparent density and effective thermal conductivity, ρk_{eff}. 276

Figure 6-103: Effective thermal conductivity, k_{eff}, as a function of gas pressure, p. 278

Figure 6-104: Effective thermal conductivity, k_{eff}, as a function of gas pressure, p. 280

Figure 6-105: Effective thermal conductivity, k_{eff}, as a function of gas pressure, p. 281

Figure 6-106: Effective thermal conductivity, k_{eff}, as a function of gas pressure, p. 283

Figure 6-107: Effective thermal conductivity, k_{eff}, as a function of gas pressure, p. 284

Figure 6-108: Permeability, κ, of several multilayer insulation configurations as a function of the layer density, N/t. 287

Figure 6-109: Pressure differential, $p(0,t)-p_o(t)$. Vs. time, t. 290

Figure 6-110: Knudsen Diffusion Coefficient, D_K, as a function of gas molecular mass, M. From Coston (1967) [13], p. 4,3-31. 292

Figure 6-111: Outgassing rate, Q, as a function of pumping time, t, for Mylar Double-Aluminized. Effect of preconditioning. From Glassford (1970) [24]. 293

Figure 6-112: Outgassing rate, Q, as a function of pumping time, t, for Mylar Double-Aluminized. Effect of prepumping. From Glassford (1970) [24]. 294

Figure 6-113: Outgassing rate, Q, as a function of pumping time, t, for Mylar Double-Aluminized, as received. Effect of test temperature. 295

Figure 6-114: Outgassing rate, Q, as a function of pumping time, t, for several shielding materials, as received. 297

Figure 6-115: Outgassing rate, Q, as a function of pumping time, t, for several spacing materials. 298

Figure 6-116: Outgassing rate, Q, as a function of pumping time, t, for an MLI system and for its components. No preconditioning. From Glassford (1970) [24]. 299

Figure 6-117: Main characteristics of the different self-evacuated MLIs and experimental methods used to obtain the results summarized in Table 6-25. 303

Figure 6-118: Model for a guarded two-dimensional MLI. (a) Geometry. (b) Boundary conditions for the calculations. 317

Figure 6-119: Ratio of lateral to total heat transfer rate, $Q_x/(Q_x+Q_y)$, in an anisotropic two-dimensional continuous medium subject to the boundary conditions indicated in Figure 6-118: 318

Tables

Table 4-1: Relevant Properties of Ceramic Foams 25

Table 4-2: Properties of Ceramic Foams 29

Table 4-3: Characterization of Foams Whose Properties Will Be Given Later 38

Table 4-4: Average Tensile Data of Polyurethane and Polystyrene Foams 39

Table 4-5: Average Tensile Data of Polyurethane and Polystyrene Foams at T = 76 K T: Transverse; L: Longitudinal 40

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4170199e-6b7a-4e5b-9a4d-

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Table 4-6: Average Tensile Data of Polyurethane and Polystyrene Foams at T = 195 K T: Transverse; L: Longitudinal 41

Table 4-7: Average Tensile Data of Polyurethane and Polystyrene Foams at T = 300 KT: Transverse; L: Longitudinal 42

Table 4-8: Average Compressive Data of Polyurethane and Polystyrene Foams 42

Table 4-9: Average Compressive Data of Polyurethane and Polystyrene Foams at T = 76 K T: Transverse; L: Longitudinal 43

Table 4-10: Average Compressive Data of Polyurethane and Polystyrene Foams at T = 195 K T: Transverse; L: Longitudinal 44

Table 4-11: Average Compressive Data of Polyurethane and Polystyrene Foams at T = 300 K T: Transverse; L: Longitudinal 45

Table 4-12: Information Concerning Processing 60

Table 4-13: Information Concerning Processing of Fiberfil Products Recommendations for Molding 63

Table 5-1: Available Densities, ρ, and Thicknesses, t, of B & W Kaowool Blanket. X denotes available. 90

Table 5-2: Available Thicknesses, t, and Lengths, L, of Fiberfrax Lo-Con Blanket and Felt for densities of64 kg.m^{-3} and 96 kg.m^{-3} and roll widths 0,3 m, 0,61 m, and 1,22 m. 91

Table 5-3: Thermal Conductivity, k, [W.m^{-1}.K^{1}], of J-M Thermoflex Felt for different values of Density, ρ, [kg.m^{-3}], and Mean Temperature, T_m, [K]. 92

Table 5-4: Available Densities, ρ, [kg.m^{-3}], and Thicknesses, tx10^{3} [m], of J-M Thermoflex. 95

Table 5-5: Available Densities, ρ, and Thicknesses, t, of J-M Micro-Quartz 96

Table 5-6: Available Forms of J-M Min-K 1301 102

Table 5-7: Available Forms of J-M Min-K 2000 102

Table 5-8: Available Thicknesses of B&W Kaowool Paper 104

Table 5-9: Available Thicknesses of Fiberfrax 970 Paper 105

Table 5-10: Available Roll Sizes of Fiberfrax 970 Paper 105

Table 5-11: Available Thicknesses and Corresponding Mass/Area of Fiberfrax Paper H880; Hi-Fi 660, and 550. 105

Table 6-1: Properties of Metallic Foils 166

Table 6-2: Properties of Polymeric Films 168

Table 6-3: Properties of Several Marketed Polycarbonate Resins 169

Table 6-4: Tensile Strength of Mylar and Kapton H for Different. Values of the Temperature. 170

Table 6-5: Properties of Coated Plastic Films 170

Table 6-6: Flammability of Several Radiation Shields in Oxygen and in Air 174

Table 6-7: Outgassing Characteristics of Non-Metallized and Metallized Plastic Films 175

Table 6-8: Procurement Data 177

Table 6-9: ρ and $3\lambda\rho/8$ for Aluminium, Copper, Gold and Silver 182

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4f5b1f9a-d57e-4e0a-9a11-d6a1f9a8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021

kSIST-TP FprCEN/CLC/TR 17603-31-07:2021

Table 6-10: Absorption and Scattering Coefficients for Spacer Materials 188
Table 6-11: Properties of Staple Fibers Data is available for the following Staple Fibers 190
Table 6-12: Properties of Staple Fibers 191
Table 6-13: Properties of Staple Fibers 192
Table 6-14: Effect of Heat on Several Fibers 193
Table 6-15: Moisture Regain of Several Fibers 193
Table 6-16: Effect of Exposure Temperature, Pressure and Time on the Strength of Fabrics, *T* = 450 K 194
Table 6-17: Fiber Strength after 10 min Exposure to Temperature 195
Table 6-18: Effect of Cycling vs. Continuous Exposure to Temperature of Two Fibers in Woven Forms 196
Table 6-19: Thermal Properties of Fabrics Woven of Several Fibers 197
Table 6-20: Flammability per Vertical Flame Tests 206
Table 6-21: Flammability of Several Spacers in Oxygen and in Air 206
Table 6-22: Outgassing Characteristics of Several Spacers 207
Table 6-23: Thermal Effects of Joints 259
Table 6-24: Characteristics of Self-Pumping MLIs the performances of which are given in Table 6-25 302
Table 6-25: Characteristics of Several Self-Pumping Multilayer Insulations 304
Table 6-26: Summary of the Best and Worst Cases Reached by the Different Investigators 314

iTeh STANDARD PREVIEW
(standards.iteh.ai)
kSIST-TP FprCEN/CLC/TR 17603-31-07:2021
https://standards.iteh.ai/catalog/standards/sist/4f70199e-6b7a-4e5b-9a4d-d6a1f9a8a720/ksist-tp-fprcen-clc-tr-17603-31-07-2021