CALCIUM SILICATE SYSTEM

. SCOPE This materials specification is for insulating pipe, tubing, fittings, duct ork, vessels and equipment. The specification includes insulation materials and barrier materials to form a complete insulation system. The system designation is xx. For complete designation, a barrier system must be selected. See Par. 4.

.1 Service Temperature 100 to 1200 F (35 to 650 C).

. MATERIALS

.1 Insulation The insulating material is asbestos-free premolded reacted hydrous calcium silicate. Shapes include pipe covering, flat blocks and fittings. Pipe overing is available with factory applied jackets.

.2 Acceptable Materials Select materials from those listed in the following tables. Substitution of materials not listed shall be authorized in writing by the Engineer.

PLAINTIFF'S EXHIBIT
MON-88

MATERIAL	VENDOR
Calsilite Insulation	Harbison-Walker
Thermo-12 Insulation	Manville Corporation
Kaylo 10 AF Insulation	Owens Corning Fiberglas Corp.
Caltemp Insulation	Pabco Insulation

.3 Insulating Cement Used to fill voids and insulate irregular surfaces.

MATERIAL	VENDOR
Supertemp 1900 Cement	Ramco Products
No. 375 Cement	Manville Corporation
MW-One Cement	Celotex Corporation

. AUXILIARY MATERIALS

.1 Description The following materials are used with the insulation and barrier aterials to form a complete insulation system in accordance with installation details.

C 003085

INSULATION MATERIAL PROPERTIES

Design Data

1. SCOPE This standard lists materials properties data for thermal insulation and barrier materials used in the Thermal Insulation System Specifications. Additional data for other common materials is provided.

2. MATERIALS PROPERTIES DATA

2.1 Insulation Materials Properties Table I provides physical and thermal properties for materials shown in the Insulation System Specifications and a few additional materials of frequent use.

TABLE I. MATERIALS PROPERTIES

Insulation Characteristics	Type of Insulation: Fibrous Glass K11.2 STD 5	ASTM Test Method	Calcium Silicate K11.2 STD 6	ASTM Test Method
Material Description	Glass Fiber With Organic Binder		Reacted Hydrous Calcium Silicate	
Form	Sheet and Pipe Covering		Block and Pipe Covering	
Temperature Range (F)	0 to 450		100 to 1200	
Thermal Conductivity BTU in. thk/hr ft² °F) ... Mean Temperature	K Temp .21 50 .24 100 .29 200 .35 300		K Temp .38 100 .40 200 .47 400 .56 600	
...r Shrinkage ...% at Temp Limit	None		1.5	
...sity lbs/Ft³	4 - 9		12	
...ile Strength PSI			20	
...pressive Strength PSI	3 at 10% Deformation		100 at 5% Deformation	
...ural Strength PSI				
...dulous of Elasticity PSI				
...rosion Resistance ...Loss by Tumbling			35 - 10 Min Run	
...Exposure			Non-Combustible	
... Spread Index	25			
...e Density Index	50			
... Absorption ... - 24 hr. Immersion	90		90	
...larity	None		Wicks	
...scopicity % Vol.	.2		10% by Weight	
... Vapor Transmission ... in.				
...alinity Ph	9		10.2	
...loride Content (PPM)	Less than 30		200	
...esivity				
...mal Diffusivity (Ft²/Hr.)	.02		.16	
...cific Heat (BTU/lb/° F)	.20		.20	
...arks			Good Strength. Absorbs Water.	

...ce T.F. STANLEY (4-6942)

NTA

CALCIUM SILICATE SYSTEM

Elevated Temperature

MANUALS	
K	
LOCATIONS	
STDS	A
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"A" INDICATES APPROVAL OR ACCEPTANCE AT LOCATION. "A" AT "DIV" INDICATES DIVISION-WIDE APPROVAL OR ACCEPTANCE.

1. INSULATING MATERIAL

1.1 Description Insulating material is premolded reacted hydrous calcium silicate and asbestos fiber. The following shapes and sizes normally are used in Monsanto practice:

ITEM	APPLICATION	SIZE	SPEC.
Flat blocks without bevel.	All flat surfaces; Vessels over 24'0" in diameter.	24" wide x 36" long, 1" to 3" thick.	ASTM C-344
Flat blocks bevelled to suit specified diameter.	Vessels 6'0" in diameter to 24'0" in diameter.	12" wide x 36" long, 1" to 3" thick.	
Sidewall segments curved and bevelled to suit specified diameter.	Vessels 3'0" in diameter to 6'0" in diameter.	12" wide x 18" long, 1" to 3" thick.	
Head segments shaped to suit type and specified diameter.	Vessel heads.	1" to 3" thick.	
Sectional covers.	Copper tubing 3/8" to 3" diameter.	ID to suit specified diameter. 1" to 3" thick.	
Sectional covers to 24" diameter, segmental covers 30" and 36" diameter.	Pipe and vessels to 36" diameter.	ID to suit specified diameter. 1" to 3" thick.	
Premolded sectional covers to 6" IPS, preformed sectional covers 8" to 36" nominal pipe size.	Copper tubing and pipe fittings, valves, and flanges.	ID to suit specified diameter. 1" to 3" thick.	

1.2 Thickness Thickness stated on Drawings or in the Thermal Insulation Schedule shall be used. Thicknesses given in Table I shall be used only when directed by the Engineer and when operating temperatures are given.

2. AUXILIARY MATERIALS

2.1 Description The following materials are used with the insulating material to form a complete system. Apply them as directed in the Construction Specifications.

ITEM	GENERIC TYPE	APPLICATION
WELDING STUDS	Carbon steel studs and clips.	Used to secure insulation to vessel and piping surfaces.
HIGH TEMPERATURE CEMENT	Expanded vermiculite cement with heat resistant binder. ASTM C-196 Spec.	Used to point up broken or rounded corners and irregular surfaces; fill voids and slots; build-up insulation on small pipe fittings.
FILLER MATERIAL	Calcined diatomaceous earth and long asbestos fiber, without binder.	Used to pack expansion spaces and to build-up insulation where preformed fitting covers are not available.
CAULKING AND FINISHING CEMENT	Nodular mineral fibers combined with bonding materials.	Used to smooth depressions and to fill minor voids and irregularities in the finished insulation surface.
BANDS AND SEALS	¾" x 0.015" flat Stainless Steel bands and sealing devices.	Used to secure insulation to vessels and piping.
TIE WIRE	16 gauge cold-drawn, bright-annealed Stainless Steel wire.	Used to secure insulation to vessels and piping.

C. 002908

REFERENCES

November 1, 1958 Revised January 31, 1964 Revised August 18, 1964	MONSANTO CHEMICAL COMPANY HYDROCARBONS DIVISION ENGINEERING CONSTRUCTION & MAINTENANCE SPECIFICATION	GS-11.4.603 SYSTEMS 603 PIPE COVERING FOR UNDERGROUND SERVICE

APPLICATION: Pipelines buried in earth, or on contact with earth or concrete at grade. Maximum service temperature 150°F. Mill applied coating and wrapping shall be equivalent to that below, and shall have an over-wrapping of Kraft paper.

STEP	MATERIAL OR PROCEDURE	METHOD (Note 1)	TOTAL DFT (Note 2)	REMARKS
	System 603 - Hot Enamel Coating and Wrapping for Underground Pipe Applied In The Field			
1	Clean outside of pipe with wire brush or traveling type motor driven cleaning machine. Remove grease and oil with suitable solvents. As an alternate, cleaning may be accomplished by sand-blasting to a commercial finish.			Remove all dirt, loose rust and millscale, and other foreign materials. Cutters, knives, brushes, etc., or machine shall be approved by Monsanto's engineer.
2	1 coat of pipeline primer	optional		Apply by spray, brush, mop or rotating carpet sling with revolving brushes. Finished coat shall be smooth and even. Allow to dry
3	1 coat of hot pipeline enamel		3/32"	Apply with a bucket and canvas sling, or with an approved coating machine. Heat enamel in accordance with manufacturer's recommendations.
4	1 spiral wrap of open mesh glass mat			Apply over enamel while it is soft and imbed in enamel.
5	1 coat of hot pipeline enamel		1/8"	Thoroughly saturate and cover glass mat.
6	1 spiral wrap 15 lb asphalt saturated asbestos felt			Lap preceeding spiral 1" minimum. Joints between succeeding strips shall lap at least 4", at the top of the pipe and be sealed with hot enamel or imbedded by heating the entire finish coat.
	Couplings, flanges, fittings and field welds in mill wrapped pipe shall be coated and wrapped in a manner equivalent to that above.			
	Repairs to defective or damaged coating shall be made by removing felt, daubing with hot enamel, and imbedding new felt, at the time the pipe is lowered into the ditch.			
				C 003909

NOTES:
1. Coatings may be brushed, rolled, or sprayed, when the method is optional.
2. Total dry film thickness (DFT) in mils (thousandths of an inch) accumulated at the step indicated.
3. Pipe shall be left on skids behind the wrapping machine for electrical inspection and repairs before lowering into ditch.
4. Coating shall be checked for holidays with an approved machine at 10,000 volts. On hot enamel coating, if the felt lap joints only are to be sealed, apply the spark test before wrapping. If the felt is to be imbedded in the hot finish coat, apply the test after wrapping.
5. Coated pipe shall be handled carefully, using belt slings of proper dimensions. Ropes, cables, or chains will not be permitted in contact.
6. No coating operations shall be carried out during weather which is unfavorable in the [illegible] engineer. Pipe shall be clean and dry before application of

NOTES:

1. Pipe shall be left on skids behind the wrapping machine for electrical inspection and repairs before lowering into ditch.

2. Coating shall be checked for holidays with an approved instrument at 10,000 volts. On hot enamel coating, if the felt lap joints only are to be sealed, apply the spark test before wrapping. If the felt is to be imbedded in the hot finish coat, apply the test after wrapping.

3. Coated pipe shall be handled carefully, using belt slings of proper dimensions. Ropes, cables, or chains will not be permitted in contact.

4. No coating operations shall be carried out during weather which is unfavorable in the opinion of Monsanto's engineer. Pipe shall be clean and dry before application of primer or enamel.

TABLE II. LENGTH OF CUT OR "STRETCH OUT" FOR STAINLESS STEEL JACKETING OVER PIPE COVERING

Pipe Size (In.)	Nominal Thickness of Pipe Covering Length of Cut for Stainless Steel, in Inches (Calculated to Nearest ¼")										
	1	1½	2	2½	3	3½	4	4½	5	5½	6
½	11	11	17¾	22¾	25¾	29	32	35½	38¾		
¾	11	14½	17¾	22¾	26	29	32½	35½	39		
1	13	16	19½	22¾	26	29	32½	35½	39		
1½	14½	17½	22½	26	29	32½	35½	38¾	41¾		
2	16	19½	22½	26	29	32½	35½	38¾	42		
3	19½	22¾	26	29	32½	35½	38¾	42	46	48¾	52
4	22¾	26	29	32½	35½	38¾	42	46	48¾	52	55¼
6	29	32½	35½	38¾	42	46	48¾	52	55¼	58¼	61½
8		29	42	46	48¾	52	55¼	58¼	61½	65	68
10		46	48¾	52	55¼	58¼	61½	65	68	71	74
12		52	55¼	58½	61½	65	68	71	74	77¼	80½
14		55¼	58½	61½	65	68	71	74	77¼	80½	83¾
16		61½	65	68	71	74	77¼	80½	83¾	86¾	90
18		68	71	74¼	77¼	80½	83¾	86¾	90	93	96¼
20		74¼	77¼	80½	83¾	86¾	90	93	96¼	99½	102½
24		86¾	90	93	96¼	99½	102½	105¾	108¾	112	115
30		105¾	108¾	112	115	118¼	121½	124½	127¾	130¾	134

STAINLESS STEEL JACKETING

Elevated and Low Temperatures

1. WEATHER BARRIER MATERIALS

1.1 Description Stainless Steel Jacketing is commercially available in forms of 36" × 96" sheets; rolls 36" wide at 300 sq ft per roll; and rolls 48" wide at 400 sq ft per roll. Material in both sheets and rolls in .010" thick, with $\frac{3}{16}$" corrugation. Moisture barrier backing on the inner surface is not required.

1.2 Fitting Covers Prefabricated sectional covers for insulated short and long radius elbows, tees, line flanges, and screwed and butt-welded ASA 150 lb and 300 lb valves shall be used when readily available.

1.3 Head Covers Prefabricated gore-type covers for insulated 2 to 1 elliptical heads shall be used through 13'–0" diameter when readily available.

1.4 Material Requirements and Coverage (for Insulation Piping) See Tables I and II.

2. AUXILIARY MATERIALS

2.1 Straps and Seals Straps and seals used to secure Stainless Steel jacketing in place shall be $\frac{3}{4}$" × .015" stainless steel or monel for vessel and equipment jacketing, $\frac{1}{2}$" × .015" stainless steel or monel for pipe jacketing.

2.2 Screws and Rivets Sheet metal screws used to secure Stainless Steel Jacketing in place (over insulation in elevated temperature service only) shall be Pan Head No. 7 × $\frac{1}{2}$" stainless steel. Pop rivets used in similar service shall be stainless steel.

TABLE I. STAINLESS STEEL WITH 2" LAP

Quantities (Square Feet) Required for 100 Linear Feet of Pipe Covering[1]

Pipe Size (In.)	Nominal Insulation Thickness (Inches): 1	1½	2	2½	3	3½	4	4½	5	5½	6
½	96	130	155	200	226	255	283	312	340		
¾	97	128	156	201	226	256	283	313	340		
1	114	142	172	201	229	256	284	313	341		
1½	127	155	198	227	255	283	312	340	367		
2	142	171	201	229	256	284	313	341	369		
3	171	201	229	256	284	313	341	369	405	416	450
4	201	229	256	284	313	341	369	423	429	450	480
6	256	284	313	341	369	403	430	457	486	506	533
8		341	369	405	429	457	488	515	543	562	590
10		403	431	458	486	514	541	569	597	603	642
12		458	486	516	541	569	598	626	654	675	692
14		488	516	543	571	598	626	654	681	707	727
16		543	571	599	626	654	681	709	737	754	781
18		598	629	654	682	709	737	764	792	808	834
20		654	682	709	737	764	792	820	847	875	889
24		764	729	820	847	875	903	930	958	972	1135
30		930	958	986	1013	1041	1069	1096	1124	1136	1163

[1] Quantities, in square feet, are those required to cover 100 linear feet of insulated straight piping. Longitudinal 2" laps are included; 2" butt laps, based on 48" long rolls of felt, also are included.

C 003912

MANUALS
LOCATIONS: STDS A | STAF A | SUDS A
AGRI. | CHEMSTR. | GERING | HYDRO | INORG | ES | ORG | ENG | PLASTIC | PLAX

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REFERENCES

TABLE II. LENGTH OF CUT OR "STRETCH OUT" FOR ALUMINUM JACKETING OVER PIPE COVERING

Pipe Size (In.)	Nominal Thickness of Pipe Covering — Length of Cut for Aluminum, in Inches (Calculated to Nearest ¼")										
	1	1½	2	2½	3	3½	4	4½	5	5½	6
½	11	11	17¾	22¾	25¾	29	32	35½	38½		
¾	11	14½	17¾	22¾	26	29	32½	35½	39		
1	13	16	19½	22¾	26	29	32½	35½	39		
1½	14½	17½	22½	26	29	32½	35½	38¾	41¾		
2	16	19½	22½	26	29	32½	35½	38¾	42		
3	19½	22¾	26	29	32½	35½	38¾	42	46	48¾	52
4	22¾	26	29	32½	35½	38¾	42	46	48¾	52	55¼
6	29	32½	35½	38¾	42	46	48¾	52	55¼	58¼	61½
8		29	42	46	48¾	52	55¼	58¼	61½	65	68
10		46	48¾	52	55¼	58¼	61½	65	68	71	74
12		52	55¼	58½	61½	65	68	71	74	77¼	80½
14		55¼	58½	61½	65	68	71	74	77¼	80½	83¾
16		61½	65	68	71	74	77¼	80½	83¾	86¾	90
18		68	71	74¼	77¼	80½	83¾	86¾	90	93	96¼
20		74¼	77¼	80½	83¾	86¼	90	93	96¼	99½	102½
24		86¾	90	93	96¼	99½	102½	105¾	108¾	112	115
30		105¾	108¾	112	115	118¼	121½	124½	127¾	130¾	134

2. AUXILIARY MATERIALS

2.1 Straps and Seals Straps and seals used to secure Aluminum Jacketing in place shall be ¾" × .016" aluminum for vessel and equipment jacketing, ½" × .016" aluminum for piping jacketing.

2.2 Screws and Rivets Sheet metal screws used to secure Aluminum Jacketing in place (over insulation in elevated temperature service only) shall be Pan Head No. 7 × ½", aluminum. Pop rivets used in similar service shall be aluminum.

ALUMINUM JACKETING

Elevated and Low Temperatures

1. WEATHER BARRIER MATERIALS

1.1 Description Aluminum jacketing is commercially available in standard forms of 36" × 96" sheets; rolls 36" wide at 300 square feet per roll; and rolls 48" wide at 400 square feet per roll. Material in both sheets and rolls is .016" thick, with 3/16" corrugation. A factory-attached moisture barrier covers the inner surface.

1.2 Fitting Covers Pre-fabricated sectional covers for insulated short and long-radius elbows, tees, line flanges, and screwed and butt-welded ASA 150 lb and 300 lb valves shall be used when readily available.

1.3 Head Covers Pre-fabricated gore-type covers for insulated 2 to 1 elliptical heads shall be used through 13'-0" diameter when readily available.

1.4 Material Requirements and Coverage (for insulated piping)

TABLE I. ALUMINUM WITH 2" LAP

Pipe Size (In.)	Quantities (Square Feet) Required for 100 Linear Feet of Pipe Covering[1]										
	Nominal Insulation Thickness (Inches)										
	1	1½	2	2½	3	3½	4	4½	5	5½	6
½	.96	130	155	200	226	255	283	312	340		
¾	97	128	156	201	226	256	283	313	340		
1	114	142	172	201	229	256	284	313	341		
1½	127	155	198	227	255	283	312	340	367		
2	142	171	201	229	256	284	313	341	369		
3	171	201	229	256	284	313	341	369	405	416	450
4	201	229	256	284	313	341	369	423	429	450	480
6	256	284	313	341	369	403	430	457	486	506	533
8		341	369	405	429	457	488	515	543	562	590
10		403	431	458	486	514	541	569	597	603	642
12		458	486	516	541	569	598	626	654	675	692
14		488	516	543	571	598	626	654	681	707	727
16		543	571	599	626	654	681	709	737	754	781
18		598	629	654	682	709	737	764	792	808	834
20		654	682	709	737	764	792	820	847	875	889
24		764	729	820	847	875	903	930	958	972	1135
30		930	958	986	1013	1041	1069	1096	1124	1136	1163

[1] Quantities, in square feet, are those required to cover 100 linear feet of insulated straight piping. Longitudinal 2" laps are included; 2" butt laps, based on 48" long rolls of felt, also are included.

C 003914

REFERENCES

CUTBACK ASPHALT VAPOR SEAL

Low Temperature

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LOCATIONS: STOS A; STAF A; SUBS A; AGRI. DIV A; CHEMSTR.; GERING; HYDRO DIV A; INORG DIV A; ORG DIV A; PLASTIC DIV A; PLAX

1. WEATHER BARRIER MATERIALS Weather barrier materials are vapor-sealing cutback asphalt mastic, fire-retardant spray grade for general weather barrier application, trowel grade for providing heavy fillets at inside corners in the insulation construction. Color of the cured film is black.

1.1 Description and Application Characteristics

Material Description	Film Thickness Wet	Film Thickness Dry	Coverage[1] Sq Ft/Gal	Limitations
Fire-retardant cutback asphalt, spray grade.	1/8"	1/32"	13	Materials may remain soft for 90 days or more, depending on climatic conditions. Materials are not recommended for areas subject to solvent or alkali splash and spillage.
Fire-retardant cutback asphalt, trowel grade.	Determined by requirements of construction.			Trowel must be kept wet with mineral spirits.

[1] Coverage values are 75% of theoretical; for estimating purposes only.

2. MIXING INSTRUCTIONS Mix spray grade materials thoroughly with mechanical agitation.

3. THINNING INSTRUCTIONS No thinning required.

3.1 Clean-Up Thinner Mineral Spirits.

4. APPLICATION INSTRUCTIONS Apply spray grade materials by brushing or with spray apparatus described in Paragraph 4.1. Apply trowel grade materials with steel trowel, in heavy fillets at inside corners as specified.

4.1 Spray Equipment Use DeVilbiss P-MBC gun with MB-4339-3/8 inch nozzle combination. Use 3/8 inch material hose.

4.2 Pot Life Indefinite

4.3 Recoat Time Two hours at 75 F.

5. AUXILIARY MATERIALS Auxiliary materials are glass fiber mesh, 10 × 10 mesh, asphalt impregnated, in sheets for vessels and equipment, and in rolls for piping.

C 003915

REFERENCES

TABLE I. MINIMUM COLD-SURFACE TEMPERATURE (DEGREES F)

IPS and Nominal Pipe Size	NOMINAL INSULATION THICKNESS[1]										
	Single Layer					Double Layer[2]					
	1"	1½"	2"	2½"	3"	3½"D	4"D	4½"D	5"D	5½"D	6"D
½"	25	15	-15	-40	-65						
¾"	35	15	-15	-35	-50						
1 "	45	20	-10	-25	-40						
1½"	45	30	-10	-25	-40						
2 "	55	30	-5	-15	-30						
3 "	55	30	5	-5	-20	-35	-50	-85	-90	-120	-125
4 "	55	40	15	0	-20	-25	-45	-80	-85	-90	-100
6 "	55	40	20	5	-20	-25	-45	-75	-80	-85	-95
8 "	55	45	20	10	-20	-25	-45	-70	-75	-80	-95
10 "	55	45	25	10	-20	-25	-45	-65	-70	-75	-95
12 "	55	45	25	10	-20	-25	-40	-60	-65	-70	-90
14 "	55	45	25	15	-15	-25	-40	-55	-60	-65	-85
16 "	55	45	25	15	-15	-25	-35	-50	-55	-60	-80
18 "	55	45	30	20	-15	-25	-35	-45	-50	-55	-75
20 "	55	45	30	20	-10	-25	-30	-40	-45	-50	-70
24 "	55	45	30	20	-10	-20	-30	-35	-40	-45	-65
30 "	60	45	30	20	-10	-20	-25	-30	-35	-40	-60
36 "	60	45	35	25	-5	-10	-20	-25	-30	-35	-55
Flat	65	50	40	30	15	0	-10	-15	-20	-25	-30

[1]Table I is based on design conditions to prevent condensation of moisture on the insulation surface. Design conditions to the left of and below the heavy black line are 90 F still air at 80% relative humidity; heat gains average 7-9 Btu/hr, sq ft, based on the exterior insulation surface. Design conditions to the right of and above the heavy black line are 40 F air at 80% relative humidity and moving air at 2 miles per hour velocity; heat gains average 2-4 Btu/hr sq ft, based on the exterior insulation surface; these design conditions apply only to installations in unprotected areas; consult manufacturers' literature for recommended thickness when installations are indoors or in sheltered areas. When cold-surface temperature falls between two thickness columns, use the greater thickness.

[2]Insulation in thicknesses 3½" through 6" shall be applied in double layers according to the following schedule:

- 3½" : 1½" inner layer, 2" outer layer.
- 4" : 2" inner layer, 2" outer layer.
- 4½" : 2" inner layer, 2½" outer layer.
- 5" : 2½" inner layer, 2½" outer layer.
- 5½" : 2½" inner layer, 3" outer layer.
- 6" : 3" inner layer, 3" outer layer.

C 003916

[illegible] AUXILIARY MATERIALS

[illegible].1 Description The following materials are used with the insulating material to form a complete system. Apply them as directed in the Construction Specifications.

ITEM	GENERIC TYPE	APPLICATION
ADHESIVE CEMENT	Low temperature hydraulic cement.	Used to secure insulation support clips to vessel or piping surfaces at temperatures −20 F and above.
SUPPORT CLIPS	Carbon Steel, galvanized.	Used to secure insulation to vessel and piping surfaces where additional support is required, at temperatures −20 F and above.
BORE COATING	Vinyl-base mastic.	Used to provide an anti-abrasive cushion between the cellular glass insulation and the surface to be insulated.
JOINT COMPOUND	Low temperature cutback asphalt with wax additive.	Used to butter joints of insulation and as a low temperature cement for filling slots, crevices, and voids in insulation blocks, segments, and sections.
CAULKING MASTIC	Fire-retardant cutback asphalt	Used to smooth depressions and to fill minor voids and irregularities in the finished insulation surface.
FILLER MATERIAL	Asphalt-impregnated flexible polyurethane.	Used to pack expansion and contraction spaces, and voids caused by construction methods.
SUPPORT AND ISOLATION CRADLES	Soft wood inner layer, hard wood outer layer.	Used to support and isolate pipe when piping is supported from below.
BANDS AND SEALS	¾" x 0.015" flat Stainless Steel bands and sealing devices.	Used to secure insulation to vessels and piping, and to secure metal jacketing in place.
FLASHING STRIPS	Flexible plastic sheet.	Used for flashing expansion joints.

C 003917

MANUALS K

LOCATIONS STOS A STAF A SUBS A AGRI. DIV A 41 42 69 CHEMSTR. GERING HYDRO DIV A 04 19 44 INORG DIV A 07 08 10 11 17 16 26 29 35 ES ORG DIV A 01 02 06 09 13 30 ENG PLASTIC DIV A 12 27 31 34 38 PLAX

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"A" INDICATES APPROVAL OR ACCEPTANCE AT LOCATION. "A" AT "DIV" INDICATES DIVISION-WIDE APPROVAL OR ACCEPTANCE.

1. INSULATING MATERIAL

1.1 Description Insulating material is foamed glass with hermetically sealed cells. The following shapes and sizes normally are used in Monsanto practice:

ITEM	APPLICATION	SIZE	SPEC.
Flat blocks without bevel.	All flat surfaces, vessels over 24'0" in diameter.	18" wide x 24" long, 1" to 3" thick.	ASTM C-343
Flat blocks bevelled to suit specified diameter.	Vessels 4'0" in diameter to 24'0" in diameter.	Cut to fit; 1" to 3" thick.	
Sidewall segments curved and bevelled to suit specified diameter.	Vessels 3'6" in diameter to 4'0" in diameter.	9" wide x 24" long, 1" to 3" thick.	
	Vessels 3'0" in diameter to 3'6".	6" wide x 18" long, 1" to 3" thick.	
Segments shaped to suit type and specified diameter.	Vessel heads.	1" to 3" thick.	
Sectional covers to 12" diameter, segmental covers 14" to 36" diameter.	Pipe and vessels to 36" diameter.	ID to suit specified diameters. 1" to 3" thick.	
Preformed covers.	Pipe fittings, line flanges, screwed or butt-welding valves to 12" IPS.	ID to suit specified diameters. 1" to 3" thick.	

1.2 Thickness Thicknesses stated on Drawings or the Insulation Schedule shall be used. Thicknesses given in Table I shall be used only when directed by the Engineer and when operating temperatures are given.

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REFERENCES

TABLE I. MAXIMUM HOT-SURFACE TEMPERATURE (DEGREES F)

IPS and Nominal Pipe Size	NOMINAL INSULATION THICKNESS[1]										
	Single Layer					Double Layer[2]					
	1"	1½"	2"	2½"	3"	3½"	4"	4½"	5"	5½"	6"
½"	500	600	800	1100	1200						
¾"	500	600	800	1000	1100	1200					
1 "	500	600	800	900	1100	1200					
1¼"	500	600	800	900	1100	1200					
1½"	400	600	800	900	1100	1200					
2 "	400	600	700	800	900	1100	1200				
3 "	400	500	600	800	900	1000	1100	1200			
4 "	300	500	600	800	900	1000	1000	1100	1200		
6 "	300	500	600	800	900	900	1000	1100	1200		
8 "	300	400	600	700	800	800	900	1000	1100	1200	
10 "	250	350	500	700	800	800	900	1000	1100	1200	
12 "	250	350	500	600	700	800	800	900	1000	1100	1200
14 "	250	300	400	500	600	700	800	900	1000	1100	1200
16 "	250	300	400	500	550	700	800	900	1000	1100	1200
18 "	250	300	400	500	550	700	800	900	1000	1100	1200
20 "	250	300	400	500	550	700	800	900	1000	1100	1200
24 "	250	300	400	500	550	700	800	900	1000	1100	1200
30 "	250	300	400	500	550	700	800	900	1000	1100	1200
36 "	250	300	400	500	550	700	800	900	1000	1100	1200
Flat	250	300	400	500	550	700	800	900	1000	1100	1200

[1]Table I is based on design conditions to hold the temperature of the insulation surface to 120 F, maximum, in 80 F still air. When hot-surface temperature falls between two thickness columns, use the greater thickness.

[2]*Insulation in thicknesses 3½" through 6" shall be applied in double layers according to the following schedule:*

- 3½" : 1½" inner layer, 2" outer layer.
- 4" : 2" inner layer, 2" outer layer.
- 4½" : 2" inner layer, 2½" outer layer.
- 5" : 2½" inner layer, 2½" outer layer.
- 5½" : 2½" inner layer, 3" outer layer.
- 6" : 3" inner layer, 3" outer layer.

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INSULATION MATERIAL PROPERTIES
Design Data

1. SCOPE This standard lists materials properties data for thermal insulation and barrier materials used in the Thermal Insulation System Specifications. Additional data for other common materials is provided.

2. MATERIALS PROPERTIES DATA

2.1 Insulation Materials Properties Table I provides physical and thermal properties for materials shown in the Insulation System Specifications and a few additional materials of frequent use.

TABLE I. MATERIALS PROPERTIES

Insulation Characteristics	Type of Insulation: Fibrous Glass K11.2 STD 5	ASTM Test Method	Calcium Silicate K11.2 STD 6	ASTM Test Method
Material Description	Glass Fiber With Organic Binder		Reacted Hydrous Calcium Silicate	
Form	Sheet and Pipe Covering		Block and Pipe Covering	
Temperature Range (F)	0 to 450		100 to 1200	
Thermal Conductivity (BTU in, thk/hr ft² °F) At Mean Temperature	K / Temp .21 / 50 .24 / 100 .29 / 200 .35 / 300		K / Temp .38 / 100 .40 / 200 .47 / 400 .56 / 600	
Linear Shrinkage Max % at Temp Limit	None		1.5	
Density lbs/Ft³	4 - 9		12	
Tensile Strength PSI			20	
Compressive Strength PSI	3 at 10% Deformation		100 at 5% Deformation	
Flexural Strength PSI				
Modulous of Elasticity PSI				
Abrasion Resistance % Wt. Loss by Tumbling			35 - 10 Min Run	
Fire Exposure			Non-Combustible	
Flame Spread Index	25			
Smoke Density Index	50			
Water Absorption % Vol. - 24 hr. Immersion	90		90	
Capillarity	None		Wicks	
Hygroscopicity % Vol.	.2		10% by Weight	
Water Vapor Transmission Perm In.				
Alkalinity Ph	9		10.2	
Chloride Content (PPM)	Less than 30		200	
Emissivity				
Thermal Diffusivity (Ft²/Hr.)	.02		.16	
Specific Heat (BTU/lb/° F)	.20		.20	
Remarks			Good Strength. Absorbs Water.	

SOURCE

TABLE I. MATERIALS PROPERTIES (Continued)

Insulation Characteristics	Type of Insulation: Cellular Plastic K11.2 STD 7	ASTM Test Method	Polyurethane K11.2 STD 8	ASTM Test Method
Material Description	Closed Cell Foamed Plastic		Expanded Polyurethane	
Form	Sheet and Pipe Covering		Block, Pipe Covering & Spray	
Temperature Range (F)	-50 to 220		-400 to 200	
Thermal Conductivity (BTU in. thk/hr ft² °F) At Mean Temperature	K / Temp .27 / 70 .28 / 90		K / Temp .16 / -100 .18 / -50 .18 / 0 .17 / 50 .18 / 100	
Expansion Coefficient			40×10^{-6}	
Linear Shrinkage Max % at Temp Limit	7			
Density lbs/Ft³	6	D-1667-64	2.0 - 2.5	D-1622
Tensile Strength PSI	80		40 - 70	D-1623
Compressive Strength PSI	40 at 10% Deformation		30 - 40	D-1621
Flexural Strength PSI			60 - 70	C-203
Modulous of Elasticity PSI				
Abrasion Resistance % Wt. Loss by Tumbling				
Fire Exposure	Self-Extinguishing	D-1692-59T	Self-Extinguishing	D-1692
Flame Spread Index	50		25 and Higher	
Smoke Density Index	500		Less Than 500	
Water Absorption % Vol. - 24 hr. Immersion	1	D-1056-62	1.5 to 3.0	
Capillarity	0			
Hygroscopicity % Vol.				
Water Vapor Transmission Perm In.	.28	C-355-64	1.5	C-355
Alkalinity Ph				
Chloride Content (PPM)				
Emissivity				
Thermal Diffusivity (Ft²/Hr.)			.012 to 025	
Specific Heat (BTU/lb/°F)	.19 to .27		.23	
Remarks	Coating Required for Exterior Exposure		Foam Should not be Exposed to Sun or Weathering Elements.	

TABLE I. MATERIALS PROPERTIES (Continued)

Insulation Characteristics	Type of Insulation: Mineral Fibers K11.2 STD 9	ASTM Test Method	Cellular Glass K11.2 STD 10	ASTM Test Method
Material Description	Mineral Fibers With Inorganic Binders		Hermetically Sealed Glass Cells	
Form	Block and Pipe Covering		Block and Pipe Covering	
Temperature Range (F)	100 to 1200		-450 to 800	
Thermal Conductivity (BTU in. thk/hr ft² °F) At Mean Temperature	K. / Temp .33 / 100 .36 / 200 .42 / 400 .51 / 600		K / Temp .32 / -50 .35 / 0 .41 / 100 .47 / 200 .55 / 300	
Expansion Coefficient			4.6×10^{-6}	
Linear Shrinkage Max % at Temp Limit	4			
Density lbs/Ft³	15		9	
Tensile Strength PSI			50	
Compressive Strength PSI	10 at 5% Deformation		100	
Flexural Strength PSI	40		75	
Modulous of Elasticity PSI			180,000	
Abrasion Resistance % Wt. Loss by Tumbling				
Fire Exposure	Non-Combustible		Non-Combustible	
Flame Spread Index				
Smoke Density Index				
Water Absorption %Vol. -24 Hr. Immersion	90		.2	
Capillarity	Wicks		0	
Hygroscopicity % Vol.	.2		0	
Water Vapor Transmission Perm In.			0	
Alkalinity Ph	8		7.5	
Chloride Content (PPM)	20		Less Than 5	
Emissivity				
Thermal Diffusivity (Ft²/Hr.)	.01		.018	
Specific Heat (BTU/lb/°F)	.22		.20	
Remarks			Good Compressive Strength.	

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TABLE I. MATERIALS PROPERTIES (Continued)

Insulation Characteristics	Type of Insulation			
	Expanded Silica K 1.2 STD 11	ASTM Test Method	Alumina Silica	ASTM Test Method
Material Description	Perlite With Glass Fiber Binder And Water Repellent		High Temperature Ceramic Fiber	
Form	Block and Pipe Covering		Blanket and Bulk	
Temperature Range (F)	100 to 1500		100 to 2300	
Theramal Conductivity (BTU in. thk/hr ft² °F) At Mean Temperature	K / Temp .33 100 .38 200 .47 400 .57 600		K [1] / Temp .40 600 .70 1000 1.10 1400 [1] 8 lb Density	
Linear Shrinkage Max % at Temp Limit	1.2			
Density lbs/Ft³	10		3 to 12	
Tensile Strength PSI				
Compressive Strength PSI	81 at 5% Deformation			
Flexural Strength PSI	85			
Modulous of Elasticity PSI				
Abrasion Resistance % Wt. Loss by Tumbling				
Fire Exposure	Non-Combustible		Non-Combustible	
Flame Spread Index				
Smoke Density Index				
Water Absorption % Vol. -24 Hr. Immersion	3.7			
Capillarity				
Hygroscopicity % Vol.				
Water Vapor Transmission Perm In.	18			
Alkalinity Ph	9			
Chloride Content (PPM)	50		Less Than 50	
Emissivity				
Thermal Diffusivity (Ft²/Hr.)	.014			
Specific Heat (BTU/lb/° F)	.22		.26 @ 1800 F	
Remarks			High Temperature And High Cost. May be Used in Combination With Low Cost Materials.	

GENERAL REVISION

MATERIAL SYSTEM SELECTION GUIDE

1. SCOPE This information standard outlines the selection and design procedures for thermal insulation, and discusses some of the considerations governing successful performance of insulation.

2. DESIGN PROCEDURE The essential steps in thermal insulation selection and design are:

(1) Determine whether insulation is required (Par. 3).

(2) Obtain application data (Par. 4).

(3) Select appropriate insulation material (Par. 5).

(4) Determine how much insulation is required (Par. 6).

(5) Verify material selection, select barrier materials for a complete system (Par. 7).

(6) Properly identify final selection on drawings, in schedules, and in summaries.

(7) Establish construction details (See K11.4 standards).

3. INSULATION FUNCTION Thermal insulation simply reduces heat flux out of hot surfaces or into cold surfaces. Because it is expensive to install and maintain, insulation must pay for itself in at least one of the following ways:

(1) Utility Conservation: Every heat flux represents a loss of energy. Most of these losses represent a cost increment in fuel, electrical power, cooling water, and other utilities.

(2) Equipment Economy: Unwanted heat losses may require oversizing heat exchangers, distillation columns, pipelines, etc., simply to make up for the loss - which may in some cases be a significant fraction of process heat flux. (The alternative to oversizing may be yield loss or product degradation from excessive heating and/or pressure drops in the equipment.)

(3) Process Protection: Heat flux requires temperature gradients in equipment walls and fluid contents. Undersirable effects of these gradients may include:

. . .crystallization or other deposits on the walls.

. . .viscosity changes or product degradation.

. . .vaporization losses (in cold service).

(4) Fire Protection: Insulation may serve the primary or secondary purpose of protecting equipment and structures from early loss of strength during a fire - at least long enough to permit fighting the fire to bring it under control.

(5) Personnel Protection: Where the foregoing considerations call for no insulation, or not enough, insulation must be added only in those areas where operating and maintenance personnel are likely to contact the hot surfaces. (See Par. 5.1.6).

(6) Insulation and Plant Protection: In cold service, insulation must be thick enough, regardless of the above considerations, to prevent deterioration and premature failure due to moisture attack. In "chilled" service insulation may be required to avert the housekeeping and maintenance expenses resulting from sweating and dripping. This requirement is most likely to apply in controlled environments.

3.1 Noise Control The use of insulation materials to absorb noise emitted from piping and equipment is a specialized subject not covered in this Selection Guide. Consult an expert in the noise control field.

4. APPLICATION DATA Prior to selection of insulation, the following kinds of data should be compiled to minimize the risk of picking an insulation system in the dark:

(1) Surface temperature range (Use temperature of contents unless a different temperature can be reliably specified. Note any rapid or extreme temperature fluctuations or cycling. For low temperature applications, determine whether the system will be heated under some circumstances, and list the maximum as well as minimum temperature.)

(2) Limits on permissible heat flux. (These are process-imposed requirements which should be in performance data. In most instances no specific limit will be imposed.)

(3) Critical temperature limits. (Same considerations as in Item (2) above.)

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(4) Critical environmental conditions. (These are normal temperature and relative humidity, indoors. Outdoors, the critical conditions for hot and cold services are discussed in Par. 5.1.1 thru 5.1.6 Consider possible wind damage.)

(5) Operating department data. (Consider fire hazard, possible leakage of flammable materials into insulation, washdown practices, possibility of hose stream impact during a fire, etc. Consider also possible abuse: foot, vehicle traffic, vibration, mechanical shock.)

(6) Economic data. (See normal values in T4.9 STD 2, List 8. These factors are required to choose economic insulation thickness. Actual economic values, if available, may be substituted for normal factors.)

5. INSULATION MATERIAL SELECTION Assuming a preliminary determination has been made that insulation is required, refer to Table I, entering at the appropriate surface temperature range. Observe remarks on Use and Limitations. If a Table II reference is given, review the general considerations in Par. 5.1 before selecting an insulation material. The preferred (bold-face) material will be the most economical selection unless one or more general considerations forces an alternative selection.

It is recommended that all insulation selections be reviewed at an early project stage with the Thermal Insulation Specialist. The process will be more efficient, and considerations can be evaluated on a broad basis of experience.

5.1 General Considerations In Table II, each material is characterized with respect to six considerations which may in some cases

TABLE I. PRELIMINARY INSULATION SELECTION

Surface Temperature °F	Surface Temperature °C	Remark on Use and Limitations	Refer to Table
Below -100	Below -73	No standard insulation system can be generally recommended. Consult insulation specialist.	---
Above -100 To -50	Above -73 To -46	Design and construction methods are critical. Consult insulation specialist.	II A
Above -50 To 0	Above -46 To -18	Close adherence to all material and installation details is essential to avoid rapid deterioration.	II B
Above 0 To 40	Above -18 To +4	Same as above. Outdoors, above 32 F (0 C) it may occasionally be possible to omit insulation.	II C
Above 40 To 140	Above 4 To 60	Insulate only if required by specific process or plant protection function.	II D
Above 140 To 450	Above 60 To 235	Optimum selection and application will result in greatest cost reduction.	II E
Above 450 To 1200	Above 235 To 650	Double layer insulation usually specified above 600 F (305 C); in any case, specify on drawings and summary.	II F
Above 1200	Above 650	No standard insulation system can be generally recommended. Internal insulation or refractory lining should be considered. Consult insulation specialist.	---

have a decisive effect on performance, safety, or economy. The preferred (bold-face) insulation material should be selected unless application data developed in Step 2 (Par. 4) indicates another choice.

5.1.1 Thermal Performance The key consideration is thermal conductivity (tabulated here for a single representative temperature). Stability of this value with respect to age, moisture content, etc., is noted. Maximum temperature limits are given, where significant. For infrequent cases where specific heat, diffusivity, or thermal shock limitations may apply, see K11.1 STD 3.

5.1.2 Chemical Interactions There are three types of interaction:

(1) insulation material affects insulated surface.

(2) process contents deteriorate insulation.

(3) flammable contents are degraded by insulation (Spontaneous combustion risk).

A number of insulating materials can release halides enough to cause stress corrosion cracking of austenitic stainless alloys. These are noted. Any alkaline insulation can attack aluminum, especially when moist.

Nearly all insulations are attacked by strong acids and alkalis. No special note is made, since most of surroundings are also attacked. Special note is made where solvents deteriorate the insulation.

Cases have been reported in which flammable liquid leakage has been absorbed by insulation. Later, when hot insulation was breached for repair work, flames were noted. Contributing factors have not all been identified, but it may be prudent to avoid some insulation materials on lines and equipment containing flammable liquids in areas classified as Division 1 with respect to electrical installations.

5.1.3 Mechanical Durability In some applications the completed insulation system must withstand unusual loadings or possible abuse. If a mechanically durable insulation cannot be used, shielding or guarding may be necessary.

Wind forces impose special support and attachment requirements in applications where uplift or suction can become significant. Loads on barrier membranes may be particularly hard to sustain.

Vibration and mechanical shock loadings also impose special support and attachment problems, particularly on rotary dryers or blenders, oscillating equipment such as sifters, and hoppers, chutes, or ducts fitted with vibrators to facilitate bulk material flow.

Materials of high compressive strength are first choice where vehicle damage or foot traffic must be reckoned with. Top heads of vessels with agitators usually require consideration. Insulation used to support flat bottomed vessels must be of high compressive strength.

5.1.4 Economics Systems offering the lowest installed cost for a given heat flux are listed in bold-face type. Others are selected only where process or performance considerations are over-riding.

5.1.5 Moisture Problems Most types of insulations, except those with closed-cell construction, have high water absorptivity. For elevated temperature service, the barrier system must be permeable enough to vent moisture vapor, yet resist passage of liquid water. For low-temperature service moisture in all forms must be excluded by an impermeable barrier, and the barrier must be mechanically durable. Low-temperature lines should always be located above-grade or in service tunnels if feasible. High-temperature lines may be routed above-grade or well-drained, ventilated trenches or tunnels. High-temperature lines insulated for direct burial represent a specialized problem not covered by standards.

5.1.6 Safety Considerations One safety hazard is mentioned in Par. 5.1.2. This is not a major risk. Others, more often encountered are:

(1) Fire damage protection

(2) Safe surface temperature

(3) Toxic contamination

The first problem is significant if it is determined that equipment or piping requires protection (time delay) from high temperature of a fire, and the thermal insulation is relied on for part or all of this protection. In such cases, ability of the insulation system to withstand heat effects and mechanical impact of water hose streams will be major considerations in selection. Aside from designing insulation for fire protection it will be desirable in some cases to avoid insulating materials which have a high flame spread index, or will add fuel to the fire.

The second consideration applies mainly where people can contact the insulation inadvertently (e.g., unprotected skin of back or upper arms). Informal experiments indicate that painted metal surfaces or painted metal insulation jackets should be limited to 140 F max. in areas of personnel exposure. Bare unpainted metal should be held to 130 F.

Non-metallic piping and insulation surfaces can be permitted up to 160 F. Metal surfaces in areas of low hazard and infrequent personnel contact (e.g., yard, piping near grade and storage tank farms) can be permitted to reach 160 F. Surfaces above these temperatures should be controlled by insulation only in areas where personnel contact is reasonably likely. (If portable ladders or scaffolds are needed for access, temporary safeguards may be provided at that time).

The final hazard - contamination of the insulation by toxic leaks and spills - must be dealt with on a case basis. Does the need to handle insulation aggravate an exposure problem? What disposal and decontamination problems are involved? Should insulation be omitted - or perhaps be provided with a barrier around the installation?

TABLE II A | TABLE II B

	Temperature Range -100 to -50 F (-73 to -46 C)	Temperature Range -50 to 0 F (-46 to -18 C)	
	Insulation Standard K11.2 STD 8 – POLYURETHANE	Insulation Standard K11.2 STD 8 – POLYURETHANE	Insulation Standard K11.2 STD 10 – CELLULAR GLASS
THERMAL * CONSIDERATION	k = 0.17 at -75 F Excellent thermal properties. 200 F limit when system is heated (e.g., for process clean out).	k = 0.18 at -25 F Excellent thermal properties. 200 F limit when system is heated (e.g., for process clean out).	k = 0.31 at -25 F Requires 2 to 3 times the insulation thickness compared with system 8.
CHEMICAL CONSIDERATION	No reaction between insulation and substrate.	No reaction between insulation and substrate.	No reaction between insulation and substrate.
MECHANICAL CONSIDERATION	Medium compressive strength; may require metal jacket application to improve resistance from external mechanical forces (foot traffic and bumps).	Medium compressive strength; may require metal jacket application to improve resistance from external mechanical forces (foot traffic and bumps). For equipment support consider K11.2 STD 10.	High compressive strength.
ECONOMIC CONSIDERATION	Use sectional shapes for pipe; block construction is applicable where *total* insulation equipment requirements are less than 500 square feet and sprayed foam for areas greater than 500 square feet.	Use sectional shapes for pipe; block construction is applicable where *total* insulation equipment requirements are less than 500 square feet and sprayed foam for areas greater than 500 square feet.	Installation cost of cellular glass systems are 50 to 100 percent greater than polyurethane.
MOISTURE CONSIDERATION	Where feasible provide a shelter from rain to extend life and retard heat flux.	Where feasible provide a shelter from rain to extend life and retard heat flux.	Where feasible provide a shelter from rain to extend life and retard heat flux.
SAFETY CONSIDERATION	Material is combustible; rated self-extinguishing. Interior spray application requires ventilation or respiratory equipment.	Material combustible; rated self-extinguishing. Interior spray application requires ventilation or respiratory equipment. For fire resistance consider K11.2 STD 10 or add non-combustible insulation over polyurethane.	Non-combustible.
REMARKS	Block construction for vessels requires insulation support hardware; reference D3.2 STD 83. Support hardware not required for spray application.	Block construction for vessels requires insulation support hardware; reference D3.2 STD 83. Support hardware not required for spray application.	Do not use on vibrating equipment.

* Thermal conductivity (k) units are Btu in. thk/hr ft²°F.

TABLE II C

	Temperature Range 0 to 40 F (-18 to +4 C)		
	Insulation Standard K11.2 STD 8 – POLYURETHANE	Insulation Standard K11.2 STD 7 – CELLULAR PLASTIC	Insulation Standard K11.2 STD 10 – CELLULAR GLASS
THERMAL * CONSIDERATION	k = 0.17 at 20 F Excellent thermal properties. 200 F limit when system is heated (e.g., for process clean out).	k = 0.24 at 20 F	k = 0.33 at 20 F Requires 2 to 3 times the insulation thickness as compared to polyurethane or cellular plastic insulation for comparable insulation value.
CHEMICAL CONSIDERATION	No reaction between insulation and substrate.	No reaction between insulation and substrate. Typical interior installations do not include a jacket covering and a solvent or plasticizer environment destroys the insulation.	No reaction between insulation and substrate.
MECHANICAL CONSIDERATION	Medium compressive strength; may require metal jacket application to improve resistance from external mechanical forces (foot traffic and bumps). For equipment support consider K11.2 STD 10.	Cellular sponge construction with low compressive strength.	High compressive strength.
ECONOMIC CONSIDERATION	Use sectional shapes for pipe; block construction is applicable where *total* insulation equipment requirements are less than 500 square feet and sprayed foam for areas greater than 500 square feet. For small diameter pipe consider K11.2 STD 7.	Low cost system for *interior* pipe and tubing to 2 inches nominal diameter; cost greater than polyurethane insulation for exterior application.	Installation cost of cellular glass systems are 50 to 100 percent greater than polyurethane or cellular plastic insulation.
MOISTURE CONSIDERATION	Where feasible provide a shelter from rain to extend life and retard heat flux.	Where feasible provide a shelter from rain to extend life and retard heat flux.	Where feasible provide a shelter from rain to extend life and retard heat flux.
SAFETY CONSIDERATION	Material is combustible; rated self-extinguishing. Interior spray application requires ventilation or respiratory equipment. For fire resistance consider K11.2 STD 10 or add non-combustible insulation over polyurethane.	Material is combustible; rated self-extinguishing.	Non-combustible.
REMARKS	Block construction for vessels requires insulation support hardware; reference D3.2 STD 83. Support hardware not required for spray application.	Sheet material is available for irregular shape equipment application (refrigeration compressors, instruments, etc.).	Do not use on vibrating equipment.

* Thermal conductivity (k) units are Btu in. thk/hr ft^2 °F.

TABLE II D

	Temperature Range 40 to 140 F (4 to 60 C)			
	Insulation Standard K11.2 STD 5 FIBROUS GLASS	Insulation Standard K11.2 STD 7 CELLULAR PLASTIC	Insulation Standard K11.2 STD 8 POLYURETHANE	Insulation Standard K11.2 STD 10 CELLULAR GLASS
THERMAL * CONSIDERATION	k = 0.23 at 70 F	k = 0.26 at 70 F	k = 0.17 at 70 F Excellent thermal properties.	k = 0.37 at 70 F
CHEMICAL CONSIDERATION		No reaction between insulation and substrate. Typical interior installations do not include a jacket covering and a solvent or plasticizer environment destroys the insulation.	No reaction between insulation and substrate.	No reaction between insulation and substrate.
MECHANICAL CONSIDERATION		Cellular sponge construction with low compressive strength.	Medium compressive strength; may require metal jacket application to improve resistance from external mechanical forces (foot traffic and bumps).	High compressive strength.
ECONOMIC CONSIDERATION	Low cost system.	Low cost system for *interior* pipe and tubing to 2 inches nominal diameter; cost greater than polyurethane or fibrous glass for exterior application.	Use sectional shapes for pipe; block construction is applicable where *total* insulation equipment requirements are less than 500 sq ft and sprayed foam for requirements greater than 500 sq ft. Polyurethane cost usually higher than fibrous glass or cellular plastic.	Installation cost of cellular glass is 50 to 100 percent greater than other insulation materials in this temperature range.
MOISTURE CONSIDERATION	For operating temperatures of 30 to 70 F and a relative humidity range of 70 to 100 percent use K11.2 STD 8, Polyurethane Insulation or K11.2 STD 7, Cellular Plastic Insulation.	Good performance in high humidity environments.	Good performance in high humidity environments.	
SAFETY CONSIDERATION	Glass fibers are non-combustible; contains small amount of resin binder which is combustible.	Material is combustible; rated self-extinguishing.	Material is combustible; rated self-extinguishing. Interior spray application requires ventilation or respiratory equipment.	Non-combustible.
REMARKS		Sheet material is available for irregular shape equipment application (refrigeration compressors, instruments, etc.).	Block construction for vessels requires insulation support hardware; reference D3.2 STD 83. Support hardware not required for spray application. Do not exceed 200 F for equipment or pipe clean-out operation.	Do not use on vibrating equipment.

* Thermal conductivity (k) units are Btu in. thk/hr ft^2 °F.

Monsanto
STANDARDS

TABLE II E

	Temperature Range 140 to 450 F (60 to 235 C)				
	Insulation Standard K11.2 STD 5 FIBROUS GLASS	Insulation Standard K11.2 STD 6 CALCIUM SILICATE	Insulation Standard K11.2 STD 9 MINERAL FIBER	Insulation Standard K11.2 STD 10 CELLULAR GLASS	Insulation Standard K11.2 STD 11 EXPANDED SILICA
THERMAL * CONSIDERATION	k = 0.31 at 250 F	k = 0.40 at 250 F Hygroscopic, k greatly increased by moisture.	k = 0.28 at 250 F	k = 0.50 at 250 F For thermal shock application consult insulation specialist.	k = 0.40 at 250 F
CHEMICAL CONSIDERATION		Insulation pH about 10. Wet insulation will corrode aluminum rapidly. Also, wet insulation will initiate stress corrosion of austenitic stainless steel. See K1.1 STD 2.			
MECHANICAL CONSIDERATION	Adequate compressive strength.	Good compressive strength.	Adequate compressive strength.	High compressive strength.	Good compressive strength.
ECONOMIC CONSIDERATION	Usually lowest cost system in this temperature range.	Calcium silicate installation cost usually higher than fibrous glass or mineral fiber; equal in cost as compared to expanded silica; cost less than cellular glass insulation.	Mineral fiber installation cost usually higher than fibrous glass; however, cost is less than other insulation listed within this temperature range.	Installation cost of cellular glass systems are 50 to 100 percent higher than other insulation systems listed in this temperature range.	Installation cost of expanded silica usually compares favorably with cost of calcium silicate systems.
MOISTURE CONSIDERATION	High water absorptivity.	High water absorptivity.	High water absorptivity.	Very low water absorptivity.	Low water absorptivity to 300 F. Insulation formulation contains a water repellent which degradates at temperatures above 300 F.
SAFETY CONSIDERATION	Glass fibers are non-combustible; contains small amount of resin binder which is combustible.	Non-combustible.	Non-combustible.	Non-combustible.	Non-combustible.
REMARKS				Water that enters the insulation system through the weather barrier tends to remain within the insulation system and will cause severe corrosion.	Water that enters the insulation system through the weather barrier tends to remain within the insulation system and will cause severe corrosion.

* Thermal conductivity (k) units are Btu in. thk/hr ft²°F.

TABLE II F

	Temperature Range 450 to 1200 F (235 to 650 C)		
	Insulation Standard K11.2 STD 9 – MINERAL FIBER	Insulation Standard K11.2 STD 6 – CALCIUM SILICATE	Insulation Standard K11.2 STD 11 – EXPANDED SILICA
THERMAL * CONSIDERATION	k = 0.40 at 500 F	k = 0.50 at 500 F Hygroscopic, k greatly increased by moisture.	k = 0.52 at 500 F
CHEMICAL CONSIDERATION			
MECHANICAL CONSIDERATION	Adequate compressive strength.	Good compressive strength.	Good compressive strength.
ECONOMIC CONSIDERATION	Usually lowest cost system in this temperature range.	Installation cost of calcium silicate is usually higher than mineral fiber systems.	Installation cost of expanded silica compares favorable with calcium silicate systems.
MOISTURE CONSIDERATION	High water absorptivity.	High water absorptivity.	Very low water absorptivity to 300 F. Water repellent degrades above 300 F.
SAFETY CONSIDERATION	Non-combustible.	Non-combustible.	Non-combustible.
REMARKS			

* Thermal conductivity (k) units are Btu in. thk/hr ft² °F.

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1. SCOPE This information standard lists exceptions to and modifications of Monsanto Standards, and other requirements for preferential use in the application of thermal insulation to projects at the Texas City Plant.

2. GENERAL REQUIREMENTS

2.1 Insulation for Personnel Protection Thermal insulation is applied to protect personnel from injuries due to burns or shock when temperature of the vessel, equipment, or piping is 140 F or greater.

OUT-DATED Current to check utilities for current cost

2.2 Insulation Economic Thickness Unit cost of steam at the Texas City Plant is approximately 51 cents per 1000 pounds produced, about 38 cents per M Btu. Calculation of economic insulation thickness that will hold to a minimum the combined costs of installed insulation and lost heat is warranted.

2.3 Insulation Materials As a general safety practice, all thermal insulation materials must be at least fire retardant, preferably non-combustible.

3. THERMAL INSULATION FOR ELEVATED TEMPERATURE SERVICE The following insulation materials are preferred for project application:

(1) Calcium Silicate Material and available shapes are described in K11.2 STD 100. Temperature range is suitable for all plant requirements. Preferred for general use in all plant areas.

3.1 Auxiliary Materials for Elevated Temperature Service

3.1.1 High Temperature Cement EAGLE - PICHER NO. 166 is the preferred material; other vendors are acceptable for projects.

3.1.2 Filler Material Use fibrous glass blanket material to fill expansion joints in insulation.

3.1.3 Bands and Seals Use 3/4" X .015" stainless steel bands and seals to secure insulation to equipment, vessels, and piping and to secure metal jacketing to insulation.

3.1.4 Tie Wire Use 16 gauge galvanized steel or 16 gauge stainless steel tie wire where required to secure field formed insulation covers, or in areas where banding is impractical.

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3.1.5 Welding Studs Use NELSON welding studs and caps of the same material as the metal to be insulated, and of size and length to suit the insulation thickness as supplementa secure-ments to bands and seals on large or irregular surfaces. DO NOT FIELD APPLY WELDING STUDS TO STRESS - RELIEVED SURFACES, OR TO ALLOY LESS THAN 1/4" THICK.

3.1.6 Aluminum Jacketing Use .016" thick aluminum jacketing epoxy coated on both sides, as weather protection on equipment, vessel sidewalls, and straight runs of piping. Use .016" thick preformed aluminum fitting covers for insulated piping tees and long or short radius elbows.

3.1.7 Weather Barrier Mastic Use LION M-10 Polyvinyl acetate mastic reinforced with glass fiber mesh as weather protection for insulation on pipe bends, flange covers, valve covers, special fittings, irregular shapes, and vessel heads where the cost of mitering, goring, and fitting metal jacketing in the field would be high.

4. THERMAL INSULATION MATERIALS FOR COLD AND CRYOGENIC SERVICES
The following insulation materials are preferred for project application.

(1) Rigid Polyurethane Material and available shapes are described in K11.2 STD 430. Temperature range is suitable for all plant requirements. Preferred for general use except for equipment, vessels, and piping in oxygen service. See Thickness Table in K11.1 NST 5201.

(2) Cellular Glass Material and available shapes are described in K11.2 STD 400. Temperature range is suitable for services to - 100 F. Preferred for equipment, vessels, and piping in oxygen service, and beneath concrete slabs or compacted sand bases that directly support vessels in other cold services. See Thickness Tables in K11.1 NST 5201.

No Alt. Cd. per RLB 5/3/73

4.1 Auxiliary Materials for Cold and Cryogenic Services

4.1.1 Intumescent Mastic Polyurethane insulation is destroyed in the early stages of accidental fire, provides no protection to the insulated surface from fire distortion. A recommended procedure is to apply intumescent fireproofing materials described in A4.10 STD 15 to critical vessels and piping prior to application of insulation.

4.1.2 Buttering Compound Use LION BUTTER ASPHALT for buttering joints in insulation blocks, segments, or sections where required.

4.1.3 Filler Material Use fibrous glass blanket material to fill expansion joints in insulation.

4.1.4 Bands and Seals Use 3/4" X .015" stainless steel bands and seals to secure insulation to equipment, vessels, and piping, and to secure metal jacketing to insulation where required.

4.1.5 Welding Studs DO NOT USE WELDING STUDS OR CLIPS TO SECURE LOW TEMPERATURE INSULATION.

4.1.6 Weather Barrier Mastic Use LION NOKORODE FIRE-RESISTANT SEA KOTE sealing type cutback asphalt mastic reinforced with glass fiber mesh, as weather protection for all insulation.

4.1.7 Aluminum Jacketing Use .016" thick aluminum jacketing epoxy-coated on the outside surface in addition to weather barrier mastic only on portions of insulation exposed to damage by plant operations or foot traffic. DO NOT USE SHEET METAL SCREWS OR POP RIVETS TO SECURE JACKETING.

5. THERMAL INSULATION FOR DUAL - TEMPERATURE SERVICE Use insulation materials for cold and cryogenic temperature service when process temperatures fluctuate between -100 F and 275 F. When upper temperature in the cycle is below -100 F or above 275 F, consult the plant for features of unique insulation design.

6. THERMAL INSULATION FOR ANTI-CONDENSATION SERVICE The following materials are preferred for project application to prevent condensation of moisture on cool or cold surfaces:

(1) Cellular Rubber Material and available shapes are described in K11.2 STD 910. Temperature range is 40 F to 150 F. Use on equipment items, small-diameter (5'-0") vessels, and piping thru 4" NPS.

(2) Cork-Filled Mastic Material and available grades are described in K11.2 STD 700. Temperature range is 40 F to 275 F. Use on airconditioning supply duct, large diameter vessels, and piping larger than 4" NPS. LION K-KOTE is preferred.

7. THERMAL INSULATION APPLICATION SPECIFICATIONS The following Monsanto Standards are acceptable for projects:

(1) K11.4 STD 2, "General Insulation Specification" for all applications.

(2) K11.4 STD 10, "Rigid Insulation Systems in Elevated Temperature Service."

7. THERMAL INSULATION APPLICATION SP[redacted]CATIONS (continued)

(3) K11.4 STD 20, "Rigid Insula[redacted] Systems in Low Temperatures Service."

(4) K11.4 STD 80, "Metal Jacketing Application" for all applications.

8. QUALIFIED CONTRACTORS The following contractors are familiar with plant safety procedures, have experience with Monsanto application specifications, and are well qualified to apply the types of thermal insulation preferred in plant practice:

ARMSTRONG CONTRACTING CO., Houston, Texas
B & B ENGINEERING CO., Houston, Texas
BALDWIN-EHRET-HILL CO., Houston, Texas
INDUSTRIAL INSULATORS CO., Houston, Texas
JOHNS-MANVILLE CO., Houston, Texas
PRECISION INSULATION CO., Houston, Texas

1. SCOPE This standard presents tables or recommended materials thickness to control temperature of the outside surface of thermal insulation.

2. THICKNESS OF MATERIALS FOR LOW TEMPERATURE SERVICES Tables I and II in this standard show minimum temperatures at which single and double layers of insulation materials preferred for the Texas City Plant can be used to prevent condensation of moisture on the insulation surface under 40 F, 85% R. H. ambient conditions.

Thicknesses in these tables do not necessarily coincide with those required when process requirements impose a minimum permissible rate of heat gain to the process fluid. Calculate thickness requirements when this design criterion prevails.

TABLE I

MINIMUM TEMPERATURES FOR POLYURETHANE USE. SEE NOTE 2.

NPS	NOMINAL INSULATION THICKNESS										
	Single Layer					Double Layer					
	1"	1½"	2"	2½"	3"	3½"	4"	4½"	5"	5½"	6"
½	0	-60	-120	-170	-260	-300					
3/4	0	-60	-110	-150	-250	-280	-320				
1	10	-40	-85	-110	-210	-260	-300				
1½	10	-30	-80	-110	-180	-250	-280	-310			
2	10	-30	-80	-110	-160	-250	-280	-310			
3	20	-15	-60	-90	-110	-220	-280	-310			
4	30	-10	-55	-80	-100	-180	-260	-300			
6	30	-10	-45	-75	-100	-120	-240	-300			
8	30	-10	-30	-60	-80	-110	-210	-300			
10	30	-10	-30	-60	-80	-110	-200	-280	-330		
12	30	-10	-30	-60	-80	-110	-200	-260	-320		
14	30	-10	-30	-60	-80	-100	-200	-240	-300		
16	30	-10	-30	-60	-80	-100	-180	-200	-280	-320	
18	30	-10	-30	-55	-80	-100	-160	-180	-260	-310	
20	30	-10	-30	-55	-75	-100	-150	-170	-240	-300	
24	30	-10	-30	-55	-75	-100	-140	-160	-220	-280	
30	30	-10	-25	-55	-75	-100	-130	-150	-200	-250	
36	30	-10	-25	-55	-75	-95	-125	-150	-180	-240	
FLAT	40	0	-20	-50	-75	-90	-120	-140	-160	-220	-270

NOTES: (1) Calculate thickness required to hold heat gain to process fluid within design limits.

(2) Ambient conditions are 40 F, 85% R. H.

TABLE II

MINIMUM TEMPERATURES FOR CELLULAR USE. SEE NOTE 2.

NPS	NOMINAL INSULATION THICKNESS										
	Single Layer					Double Layer					
	1"	1½"	2"	2½"	3"	3½"	4"	4½"	5"	5½"	6"
½	40	20	0	-20	-50	-105					
3/4	40	30	10	-10	-50	-95	-130				
1	40	30	10	-10	-50	-80	-110				
1½	50	45	20	0	-40	-60	-75	-110			
2	50	45	20	0	-30	-55	-65	-110			
3	55	45	20	10	-20	-40	-60	-95	-120		
4	55	45	30	20	-10	-30	-50	-85	-100		
6	60	45	30	20	0	-20	-40	-60	-85	-90	-130
8	60	45	30	20	0	-10	-30	-50	-70	-80	-110
10	60	45	30	20	0	-10	-30	-40	-65	-75	-100
12	60	45	40	30	10	0	-20	-35	-40	-70	-90
14	60	45	40	30	15	0	-10	-30	-35	-60	-80
16	60	50	40	30	15	0	-10	-25	-35	-60	-75
18	60	50	40	30	15	0	-10	-25	-35	-55	-75
20	60	50	40	30	15	5	-10	-20	-35	-45	-70
24	60	50	40	35	15	10	-10	-20	-35	-45	-70
30	60	55	40	35	20	10	-10	-15	-35	-45	-60
36	60	55	40	35	20	10	0	-10	-35	-45	-60
FLAT	60	55	45	35	20	10	0	-10	-20	-30	-50

NOTES: (1) Calculate thickness required to hold heat gain to process fluid within design temperature limits.

(2) Ambient conditions are 40 F, 85% R. H.

MATERIAL SYSTEM SELECTION GUIDE

1. SCOPE This information standard outlines the selection and design procedures for thermal insulation, and discusses some of the considerations governing successful performance of insulation.

2. DESIGN PROCEDURE The essential steps in thermal insulation selection and design are:

(1) Determine whether insulation is required (Par. 3).

(2) Obtain application data (Par. 4).

(3) Select appropriate insulation material (Par. 5).

(4) Determine how much insulation is required (Par. 6).

(5) Verify material selection, select barrier materials for a complete system (Par. 7).

(6) Properly identify final selection on drawings, in schedules, and in summaries.

(7) Establish construction details (See K11.4 standards).

3. INSULATION FUNCTION Thermal insulation simply reduced heat flux out of hot surfaces or into cold surfaces. Because it is expensive to install and maintain, insulation must pay for itself in at least one of the following ways:

(1) Utility Conservation Every heat flux represents a loss of energy. Most of these losses represent a cost increment in fuel, electrical power, cooling water, and other utilities.

(2) Equipment Economy Unwanted heat losses may require oversizing heat exchangers, distillation columns, pipelines, etc., simply to make up for the loss - which may, in some cases, be a significant fraction of process heat flux. (The alternative to oversizing may be yield loss or product degradation from excessive heating and/or pressure drops in the equipment.)

(3) Process Protection Heat flux requires temperature gradients in equipment walls and fluid contents. Undesirable effects of these gradients may include:

. . .crystallization or other deposits on the walls.
. . .viscosity changes or product degradation.
. . .vaporization losses (in cold service).

(4) Fire Protection Insulation may serve the primary or secondary purpose of protecting equipment and structures from early loss of strength during a fire - at least long enough to permit fighting the fire to bring it under control.

(5) Personnel Protection Where the foregoing considerations call for no insulation, or not enough, insulation must be added only in those areas where operating and maintenance personnel are likely to contact the hot surfaces. (See Par. 5.1.6).

(6) Insulation and Plant Protection In cold service, insulation must be thick enough, regardless of the above considerations, to prevent deterioration and premature failure due to moisture attack. In "chilled" service, insulation may be required to avert the housekeeping and maintenance expenses resulting from sweating and dripping. This requirement is most likely to apply in controlled environments.

3.1 Noise Control The use of insulation materials to absorb noise emitted from piping and equipment is a specialized subject not covered in this Selection Guide. Consult an expert in the noise control field.

4. APPLICATION DATA Prior to selection of insulation, the following kinds of data should be compiled to minimize the risk of picking an insulation system in the dark:

(1) Surface Temperature Range Use temperature of contents unless a different temperature can be reliably specified. Note any rapid or extreme temperature fluctuations or cycling. For low temperature applications, determine whether the system will be heated under some circumstances, and list the maximum as well as minimum temperature.

(2) Limits on Permissible Heat Flux These are process-imposed requirements which should be in performance data. In most instances, no specific limit will be imposed.

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(3) Critical Temperature Limits Same considerations as in Item (2) above.

(4) Critical Environmental Conditions These are normal temperature and relative humidity, indoors. Outdoors, the critical conditions for hot and cold services are discussed in Par. 5.1.1 through 5.1.6. Consider possible wind damage.

(5) Operating Department Data Consider fire hazard, possible leakage of flammable materials into insulation, washdown practices, possibility of hose stream impact during a fire, etc. Consider also possible abuse; foot, vehicle traffic, vibration, mechanical shock.

(6) Economic Data See normal values in Monsanto T1.10 STD 11, List 8. These factors are required to choose economic insulation thickness. Actual economic values, if available, may be substituted for normal factors.

5. INSULATION MATERIAL SELECTION Assuming a preliminary determination has been made that insulation is required (refer to Table I) entering at the appropriate surface temperature range. Observe remarks on Use and Limitations. If a Table II reference is given, review the general considerations in Par. 5.1 before selecting an insulation material. The preferred (bold-face) material will be the most economical selection unless one or more general considerations forces an alternative selection.

It is recommended that all insulation selections be reviewed at an early project stage with the Thermal Insulation Specialist. The process will be more efficient, and considerations can be evaluated on a broad basis of experience.

5.1 General Considerations In Table II, each material is characterized with respect to six considerations which may, in some cases, have a decisive effect on

TABLE I. PRELIMINARY INSULATION SELECTION

Surface Temperature		Remark on Use and Limitations	Refer to Table
°F	°C		
Below -100	Below -73	No standard insulation system can be generally recommended. Consult insulation specialist.	---
Above -100 To -50	Above -73 To -46	Design and construction methods are critical. Consult insulation specialist.	II A
Above -50 To 0	Above -46 To -18	Close adherence to all material and installation details is essential to avoid rapid deterioration.	II B
Above 0 To 40	Above -18 To +4	Same as above. Outdoors, above 32 F (0 C) it may occasionally be possible to omit insulation.	II C
Above 40 To 140	Above 4 To 60	Insulate only if required by specific process or plant protection function.	II D
Above 140 To 450	Above 60 To 235	Optimum selection and application will result in greatest cost reduction.	II E
Above 450 To 1200	Above 235 To 650	Double layer insulation usually specified above 600 F (305 C); in any case, specify on drawings and summary.	II F
Above 1200	Above 650	No standard insulation system can be generally recommended. Internal insulation or refractory lining should be considered. Consult insulation specialist.	---

performance, safety, or economy. The preferred (bold-face) insulation material should be selected unless application data developed in Step 2 (Par. 4) indicates another choice.

5.1.1 Thermal Performance The key consideration is thermal conductivity (tabulated here for a single representative temperature). Stability of this value with respect to age, moisture content, etc., is noted. Maximum temperature limits are given, where significant. For infrequent cases where specific heat, diffusivity, or thermal shock limitations may apply, see Monsanto K11.1 STD 3.

5.1.2 Chemical Interactions There are three types of interaction:

(1) Insulation material affects insulated surface.

(2) Process contents deteriorate insulation.

(3) Flammable contents are degraded by insulation (spontaneous combustion risk).

A number of insulating materials can release halides enough to cause stress corrosion cracking of austenitic stainless alloys. These are noted. Any alkaline insulation can attack aluminum, especially when moist.

Nearly all insulations are attacked by strong acids and alkalis. No special note is made, since most of surroundings are also attacked. Special note is made where solvents deteriorate the insulation.

Cases have been reported in which flammable liquid leakage has been absorbed by insulation. Later, when hot insulation was breached for repair work, flames were noted. Contributing factors have not all been identified, but it may be prudent to avoid some insulation materials on lines and equipment containing flammable liquids in areas classified as Division 1 with respect to electrical installations.

5.1.3 Mechanical Durability In some applications, the completed insulation system must withstand unusual loadings or possible abuse. If a mechanically durable insulation cannot be used, shielding or guarding may be neessary.

Wind forces impose special support and attachment requirements in applications where uplift or suction can become significant. Loads on barrier membranes may be particularly hard to sustain.

Vibration and mechanical shock loadings also impose special support and attachment problems, particularly on rotary dryers or blenders, oscillating equipment such as sifters, and hoppers, chutes, or ducts fitted with vibrators to facilitate bulk material flow.

Materials of high compressive strength are first choice where vehicle damage or foot traffic must be reckoned with. Top heads of vessels with agitators usually require consideration. Insulation used to support flat bottomed vessels must be of high compressive strength.

5.1.4 Economics Systems offering the lowest installed cost for a given heat flux are listed in bold-face type. Others are selected only where process or performance considerations are over-riding.

5.1.5 Moisture Problems Most types of insulations, except those with closed-cell construction, have high water absorptivity. For elevated temperature service, the barrier system must be permeable enough to vent moisture vapor, yet resist passage of liquid water. For low-temperature service moisture in all forms must be excluded by an impermeable barrier, and the barrier must be mechanically durable. Low-temperature lines should always be located above-grade or in service tunnels if feasible. High-temperature lines may be routed above-grade or well-drained, ventilated trenches or tunnels. High-temperature lines insulated for direct burial represent a specialized problem not covered by standards.

5.1.6 Safety Considerations One safety hazard is mentioned in Par. 5.1.2. This is not a major risk. Others more often encountered are:

(1) Fire damage protection

(2) Safe surface temperature

(3) Toxic contamination

The first problem is significant if it is determined that equipment or piping requires protection (time delay) from high temperature of a fire, and the thermal insulation is relied on for part or all of this protection. In such cases, ability of the insulation system to withstand heat effects and mechanical impact of water hose streams will be major considerations is selection. Aside from designing insulation for fire protection, it will be desirable in some cases to avoid insulating materials which have a high flame spread index, or will add fuel to the fire.

The second consideration applies mainly where people can contact the insulation inadvertently (e.g., unprotected skin of back or upper arms). Informal experiments indicate that painted metal surfaces or painted metal insulation jackets should be limited to 140 F max. in areas of personnel exposure. Bare unpainted metal should be held to 130 F. Non-metallic piping and insulation surfaces can be permitted up to 160 F. Metal surfaces in areas of low hazard and infrequent personnel contact (e.g., yard, piping near grade and storage tank farms) can be permitted to reach 160 F. Surfaces above these temperatures should be controlled by insulation only in areas where personnel contact is reasonably likely. (If portable ladders or scaffolds are needed for access, temporary safeguards may be provided at that time.)

The final hazard - contamination of the insulation by toxic leaks and spills - must be dealt with on a case basis. Does the need to handle insulation aggravate an exposure problem? What disposal and decontamination problems are involved? Should insulation be omitted - or perhaps be provided with a barrier around the installation?

6. HURRICANE DESIGN In 1983, the chemical and oil refinery plants in the Houston area sustained severe insulation damages from Hurricane Alicia. Insulation damage increased as vessel diameter increased (25 ft. and larger) and as height above ground increased (25 ft. and higher). A survey of storm damages and recommended design improvements concluded the following:

(1) Minimum thickness of aluminum insulation jacket (1 1/4" corrugated) should be .024".

(2) Band spacing should be 12" with 4" expansion spring at 25 foot intervals.

(3) Use weld construction (.063" aluminum) for fabricated components.

(4) Use 3/16" diameter structural "cherry T rivet" at 6" spacing for joint closure.

The above design criteria should be considered for coastal locations such as Alvin, Texas City, Luling and Pensacola.

TABLE II A · TABLE II B

	Temperature Range −100 to −50 F (−73 to −46 C)	Temperature Range −50 to 0 F (−46 to −18 C)	
	Insulation Standard K11.2 STD 8 – POLYURETHANE	Insulation Standard K11.2 STD 8 – POLYURETHANE	Insulation Standard K11.2 STD 10 – CELLULAR GLASS
THERMAL * CONSIDERATION	k = 0.17 at −75 F Excellent thermal properties. 200 F limit when system is heated (e.g., for process clean out).	k = 0.18 at −25 F Excellent thermal properties. 200 F limit when system is heated (e.g., for process clean out).	k = 0.31 at −25 F Requires 2 to 3 times the insulation thickness compared with system 8.
CHEMICAL CONSIDERATION	No reaction between insulation and substrate.	No reaction between insulation and substrate.	No reaction between insulation and substrate.
MECHANICAL CONSIDERATION	Medium compressive strength: may require metal jacket application to improve resistance from external mechanical forces (foot traffic and bumps).	Medium compressive strength: may require metal jacket application to improve resistance from external mechanical forces (foot traffic and bumps). For equipment support consider K11.2 STD 10.	High compressive strength.
ECONOMIC CONSIDERATION	Use sectional shapes for pipe; block construction is applicable where *total* insulation equipment requirements are less than 500 square feet and sprayed foam for areas greater than 500 square feet.	Use sectional shapes for pipe; block construction is applicable where *total* insulation equipment requirements are less than 500 square feet and sprayed foam for areas greater than 500 square feet.	Installation cost of cellular glass systems are 50 to 100 percent greater than polyurethane.
MOISTURE CONSIDERATION	Where feasible provide a shelter from rain to extend life and retard heat flux.	Where feasible provide a shelter from rain to extend life and retard heat flux.	Where feasible provide a shelter from rain to extend life and retard heat flux.
SAFETY CONSIDERATION	Material is combustible; rated self-extinguishing. Interior spray application requires ventilation or respiratory equipment.	Material combustible; rated self-extinguishing. Interior spray application requires ventilation or respiratory equipment. For fire resistance consider addition of non-combustible insulation over polyurethane.	Non-combustible.
REMARKS	Block construction for vessels requires insulation support hardware; reference DO3-2004. Support hardware not required for spray application.	Block construction for vessels requires insulation support hardware; reference DO3-2004. Support hardware not required for spray application.	Do not use on vibrating equipment.

* Thermal conductivity (k) units are Btu in. thk/hr ft^2 °F.

Monsanto
STANDARDS

TABLE II C

	Temperature Range 0 to 40F (−18 to +4C)		
	Insulation Standard K11.2 STD 8 — POLYURETHANE	Insulation Standard K11.2 STD 7 — CELLULAR PLASTIC	Insulation Standard K11.2 STD 10 — CELLULAR GLASS
THERMAL * CONSIDERATION	k = 0.17 at 20F Excellent thermal properties. 200F limit when system is heated (e.g., for process clean out).	k = 0.24 at 20F	k = 0.33 at 20F Requires 2 to 3 times the insulation thickness as compared to polyurethane or cellular plastic insulation for comparable insulation value.
CHEMICAL CONSIDERATION	No reaction between insulation and substrate.	No reaction between insulation and substrate. Typical interior installations do not include a jacket covering and a solvent or plasticizer environment destroys the insulation.	No reaction between insulation and substrate.
MECHANICAL CONSIDERATION	Medium compressive strength; may require metal jacket application to improve resistance from external mechanical forces (foot traffic and bumps). For equipment support consider K11.2 STD 10.	Cellular sponge construction with low compressive strength.	High compressive strength.
ECONOMIC CONSIDERATION	Use sectional shapes for pipe; block construction is applicable where *total* insulation equipment requirements are less than 500 square feet and sprayed foam for areas greater than 500 square feet. For small diameter pipe consider K11.2 STD 7.	Low cost system for *interior* pipe and tubing to 2 inches nominal diameter; cost greater than polyurethane insulation for exterior application.	Installation cost of cellular glass systems are 50 to 100 percent greater than polyurethane or cellular plastic insulation.
MOISTURE CONSIDERATION	Where feasible provide a shelter from rain to extend life and retard heat flux.	Where feasible provide a shelter from rain to extend life and retard heat flux.	Where feasible provide a shelter from rain to extend life and retard heat flux.
SAFETY CONSIDERATION	Material is combustible; rated self-extinguishing. Interior spray application requires ventilation or respiratory equipment. For fire resistance consider addition of non-combustible insulation over polyurethane.	Material is combustible; rated self-extinguishing. Avoid application in concealed ceiling space.	Non-combustible.
REMARKS	Block construction for vessels requires insulation support hardware; reference DO3-2004. Support hardware not required for spray application.	Sheet material is available for irregular shape equipment application (refrigeration compressors, instruments, etc.).	Do not use on vibrating equipment.

* Thermal conductivity (k) units are Btu in. thk/hr ft^2 °F.

TABLE II D

	Temperature Range 40 to 140 F (4 to 60 C)			
	Insulation Standard K11.2 STD 5 FIBROUS GLASS	Insulation Standard K11.2 STD 7 CELLULAR PLASTIC	Insulation Standard K11.2 STD 8 POLYURETHANE	Insulation Standard K11.2 STD 10 CELLULAR GLASS
THERMAL * CONSIDERATION	k = 0.23 at 70 F	k = 0.26 at 70 F	k = 0.17 at 70 F Excellent thermal properties.	k = 0.37 at 70 F
CHEMICAL CONSIDERATION		No reaction between insulation and substrate. Typical interior installations do not include a jacket covering and a solvent or plasticizer environment destroys the insulation.	No reaction between insulation and substrate.	No reaction between insulation and substrate.
MECHANICAL CONSIDERATION		Cellular sponge construction with low compressive strength.	Medium compressive strength; may require metal jacket application to improve resistance from external mechanical forces (foot traffic and bumps).	High compressive strength.
ECONOMIC CONSIDERATION	Low cost system.	Low cost system for *interior* pipe and tubing to 2 inches nominal diameter; cost greater than polyurethane or fibrous glass for exterior application.	Use sectional shapes for pipe; block construction is applicable where *total* insulation equipment requirements are less than 500 sq ft and sprayed foam for requirements greater than 500 sq ft. Polyurethane cost usually higher than fibrous glass or cellular plastic.	Installation cost of cellular glass is 50 to 100 percent greater than other insulation materials in this temperature range.
MOISTURE CONSIDERATION	For operating temperatures of 30 to 70 F and a relative humidity range of 70 to 100 percent use K11.2 STD 8, Polyurethane Insulation or K11.2 STD 7, Cellular Plastic Insulation.	Good performance in high humidity environments.	Good performance in high humidity environments.	
SAFETY CONSIDERATION	Glass fibers are non-combustible; contains small amount of resin binder which is combustible.	Material is combustible; rated self-extinguishing. Avoid application in concealed ceiling space.	Material is combustible; rated self-extinguishing. Interior spray application requires ventilation or respiratory equipment.	Non-combustible.
REMARKS	Integrity of vapor barrier must be maintained or the system will fail.	Sheet material is available for irregular shape equipment application (refrigeration compressors, instruments, etc.).	Block construction for vessels requires insulation support hardware; reference DO3-2004. Support hardware not required for spray application. Do not exceed 200 F for equipment or pipe clean-out operation.	Do not use on vibrating equipment.

* Thermal conductivity (k) units are Btu in. thk/hr ft^2 °F.

TABLE II E

	Temperature Range 140 to 450 F (60 to 235 C)				
	Insulation Standard K11.2 STD 5 FIBROUS GLASS	Insulation Standard K11.2 STD 6 CALCIUM SILICATE	Insulation Standard K11.2 STD 9 MINERAL FIBER	Insulation Standard K11.2 STD 10 CELLULAR GLASS	Insulation Standard K11.2 STD 11 EXPANDED SILICA
THERMAL * CONSIDERATION	k = 0.31 at 250 F	k = 0.40 at 250 F Hygroscopic, k greatly increased by moisture.	k = 0.28 at 250 F	k = 0.50 at 250 F For thermal shock application consult insulation specialist.	k = 0.40 at 250 F
CHEMICAL CONSIDERATION		Insulation pH about 10. Wet insulation will corrode aluminum rapidly. Also, wet insulation will initiate stress corrosion of austenitic stainless steel. See K1.1 STD 2.			
MECHANICAL CONSIDERATION	Adequate compressive strength.	Good compressive strength.	Adequate compressive strength.	High compressive strength.	Good compressive strength.
ECONOMIC CONSIDERATION	Usually lowest cost system in this temperature range.	Calcium silicate installation cost usually higher than fibrous glass or mineral fiber; equal in cost as compared to expanded silica; cost less than cellular glass insulation.	Mineral fiber installation cost usually higher than fibrous glass; however, cost is less than other insulation listed within this temperature range.	Installation cost of cellular glass systems are 50 to 100 percent higher than other insulation systems listed in this temperature range.	Installation cost of expanded silica usually compares favorably with cost of calcium silicate systems.
MOISTURE CONSIDERATION	High water absorptivity.	High water absorptivity.	High water absorptivity.	Very low water absorptivity.	Low water absorptivity to 375 F. Insulation formulation contains a water repellent which degradates at temperatures above 375 F.
SAFETY CONSIDERATION	Glass fibers are non-combustible; contains small amount of resin binder which is combustible.	Non-combustible.	Non-combustible.	Non-combustible.	Non-combustible.
REMARKS				Water that enters the insulation system through the weather barrier tends to remain within the insulation system and will cause severe corrosion.	Water that enters the insulation system through the weather barrier tends to remain within the insulation system and will cause severe corrosion.

* Thermal conductivity (k) units are Btu in. thk/hr ft^2°F.

TABLE II F

	Temperature Range 450 to 1200 F (235 to 650 C)		
	Insulation Standard K11.2 STD 9 – MINERAL FIBER	**Insulation Standard K11.2 STD 6 – CALCIUM SILICATE**	**Insulation Standard K11.2 STD 11 – EXPANDED SILICA**
THERMAL * CONSIDERATION	k = 0.40 at 500 F	k = 0.50 at 500 F Hygroscopic, k greatly increased by moisture.	k = 0.52 at 500 F
CHEMICAL CONSIDERATION			
MECHANICAL CONSIDERATION	Adequate compressive strength.	Good compressive strength.	Good compressive strength.
ECONOMIC CONSIDERATION	Usually lowest cost system in this temperature range.	Installation cost of calcium silicate is usually higher than mineral fiber systems.	Installation cost of expanded silica compares favorable with calcium silicate systems.
MOISTURE CONSIDERATION	High water absorptivity.	High water absorptivity.	Very low water absorptivity to 375 F. Water repellent degrades above 375 F.
SAFETY CONSIDERATION	Non-combustible.	Non-combustible.	Non-combustible.
REMARKS			

* Thermal conductivity (k) units are Btu in. thk/hr ft^2°F.

7. INSULATION THICKNESS Insulation thickness for the Thermal Insulation System Specification standards are shown in Table III as a convenience to the user who may need approximate data. Each tabulation shows the design conditions. The design conditions for elevated temperature service are based on a maximum outer surface temperature limit of 140 F with an ambient temperature of 70 F and a wind velocity of 3 mph. Design conditions for low temperature service are noted in the thickness tables.

TABLE III A. INSULATION THICKNESS (IN.)
Rigid Fibrous Glass System – K11.2 STD 5

Nominal Pipe Size (in.)	Temperature of Pipe, $^{\circ}F$							
	30 to 100	100 to 149	150 to 199	200 to 249	250 to 299	300 to 349	350 to 399	400 to 450
1/2								
3/4								
1								
1½								
2								
3								
4								
6	1" insulation thickness for all pipe sizes and temperature ranges indicated.							
8								
10								
12								
14								
16								
18								
20								
22								
24								

Note:
(1) Insulation thickness is based on design conditions to hold the temperature of the insulation surface to 140 F maximum, at ambient conditions of 70 F and a 3 mph wind, for a temperature range of 150 F to 450 F.

TABLE III B. INSULATION THICKNESS (IN.)
Calcium Silicate System – K11.2 STD 6

Nominal Pipe Size (in.)	Temperature of Pipe, °F										
	100 to 199	200 to 299	300 to 399	400 to 499	500 to 599	600 to 699	700 to 799	800 to 899	900 to 999	1000 to 1099	1100 to 1200
1/2	1	1	1	1	1½	2	2	2	2½	2½	2½
3/4	1	1	1	1½	1½	2	2	2½	2½	2½	3
1	1	1	1	1½	1½	2	2	2½	2½	[illegible]	[illegible]
1½	1	1	1	1½	1½	2	2	2½	2½	3	[illegible]
2	1	1	1	1½	1½	2	2½	2½	[illegible]	3	[illegible]
3	1	1	1	1½	2	2	2½	3	3	3½	3½
4	1	1	1	1½	2	2½	2½	[illegible]	3	3½	[illegible]
6	1	1	1	1½	2	2½	[illegible]	3	3½	4	[illegible]
8	1½	1½	1½	1½	2	2½	3	3½	4	[illegible]	4½
10	1½	1½	1½	1½	2	2½	[illegible]	3½	4	4½	[illegible]
12	1½	1½	1½	1½	2	2½	3	3½	4	4½	5
14	1½	1½	1½	1½	2	2½	[illegible]	3½	[illegible]	[illegible]	[illegible]
16	1½	1½	1½	1½	2	2½	[illegible]	3½	[illegible]	[illegible]	[illegible]
18	1½	1½	1½	1½	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	1½	1½	1½	1½	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	1½	1½	1½	1½	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Notes:
(1) Insulation thickness is based on design conditions to hold the temperature of the insulation surface to 140 F maximum, at ambient conditions of 70 F and a 3 mph wind.
(2) Insulation thickness shown in shaded area is double-layer, staggered joint construction.

TABLE III C. INSULATION THICKNESS (IN.)
Cellular Plastic System – K11.2 STD 7

Nominal Pipe Size (in.)	Temperature of Pipe (F)						
	0 to 14	15 to 29	30 to 44	45 to 59	60 to 74	75 to 89	90 to 105
1/2	3/4	3/4	1/2	3/8			
3/4	3/4	3/4	1/2	3/8			
1	3/4	3/4	1/2	3/8			
1½	3/4	3/4	1/2	3/8			
2	3/4	3/4	1/2	3/8			
3	3/4	3/4	1/2	3/8			
4	3/4	3/4	1/2	1/2			
6	3/4	3/4	1/2	1/2			
Flat Surface	1	1	3/4	1/2			

Insulation thickness is based on condensation prevention of indoor piping, at a maximum ambient severity of 85 F and 70% relative humidity.

Nominal Pipe Size (in.)	Temperature of Pipe (F)						
	0 to 14	15 to 29	30 to 44	45 to 59	60 to 74	75 to 89	90 to 105
1/2	1/2	3/8	3/8	3/8			
3/4	1/2	3/8	3/8	3/8			
1	1/2	3/8	3/8	3/8			
1½	1/2	3/8	3/8	3/8			
2	1/2	3/8	3/8	3/8			
3	1/2	1/2	1/2	1/2			
4	1/2	1/2	1/2	1/2			
6	1/2	1/2	1/2	1/2			
Flat Surface	1/2	3/8	3/8	3/8			

Insulation thickness is based on condensation prevention of indoor piping, at a maximum ambient severity of 80 F and 50% relative humidity.

Nominal Pipe Size (in.)	Temperature of Pipe (F)						
	0 to 14	15 to 29	30 to 44	45 to 59	60 to 74	75 to 89	90 to 105
1/2	-	-	3/4	3/4			
3/4	-	-	3/4	3/4			
1	-	-	3/4	3/4			
1½	-	-	3/4	3/4			
2	-	-	3/4	3/4			
3	-	-	3/4	3/4			
4	-	-	3/4	3/4			
6	-	-	3/4	3/4			
Flat Surface	-	-	1	3/4			

Insulation thickness is based on condensation prevention of indoor piping, at a maximum ambient severity of 90 F and 80% relative humidity.

TABLE III D. INSULATION THICKNESS (IN.)
Polyurethane System – K11.2 STD 8

Nominal Pipe Size (in.)	Temperature of Pipe, °F							
	-100 to -76	-75 to -51	-50 to -26	-25 to -1	0 to 24	25 to 49	50 to 74	75 to 100
1/2	1½	1½	1	1	1	1	1	1
3/4	1½	1½	1½	1	1	1	1	1
1	1½	1½	1½	1	1	1	1	1
1½	1½	1½	1½	1	1	1	1	1
2	1½	1½	1½	1	1	1	1	1
3	2	1½	1½	1½	1	1	1	1
4	2	2	1½	1½	1	1	1	1
6	2	2	1½	1½	1	1	1	1
8	2½	2	2	1½	1½	1	1	1
10	2½	2	2½	1½	1½	1	1	1
12	2½	2	2½	1½	1½	1	1	1
14	2½	2	2½	1½	1½	1	1	1
16	2½	2½	2½	2	1½	1	1	1
Flat Surface	2½	2½	2½	2	1½	1	1	1

Notes:
(1) Insulation thickness is based on condensation prevention at a maximum ambient severity of 90 F and 80% relative humidity.
(2) Insulation thickness shown in shaded area is double-layer, staggered joint construction.

TABLE III E. INSULATION THICKNESS (IN.)
Rigid Mineral Fiber System – K11.2 STD 9

Nominal Pipe Size (in.)	Temperature of Pipe, °F										
	100 to 199	200 to 299	300 to 399	400 to 499	500 to 599	600 to 699	700 to 799	800 to 899	900 to 999	1000 to 1099	1100 to 1200
2	1	1	1	1½	1½	2	2½	2½	3	3	3½
3	1	1	1	1½	2	2	2½	3	3	3½	3½
4	1	1	1	1½	2	2½	2½	3	3	3½	4
6	1	1	1	1½	2	2½	3	3	3½	4	4½
8	1½	1½	1½	1½	2	2½	3	3½	4	4	4½
10	1½	1½	1½	1½	2	2½	3	3½	4	4½	5
12	1½	1½	1½	1½	2	2½	3	3½	4	4½	5
14	1½	1½	1½	1½	2	2½	3	3½	4	4½	5
16	1½	1½	1½	1½	2	2½	3	3½	4	5	5
18	1½	1½	1½	1½	2	2½	3	3½	4½	5	5
Flat Surface	1½	1½	1½	1½	2	2½	3	3½	4½	5	5

Note:
(1) Insulation thickness is based on design conditions to hold the temperature of the insulation surface to 140 F maximum, at ambient conditions of 70 F and a 3 mph wind.

TABLE III F. INSULATION THICKNESS (IN.)
Cellular Glass System – K11.2 STD 10

Nominal Pipe Size (in.)	Temperature of Pipe, °F											
	-50 to -24	-25 to -1	0 to 24	25 to 49	50 to 74	75 to 99	100 to 124	125 to 149	150 to 174	175 to 199	200 to 224	225 to 250
1/2	2½	2	1½	1	1	1	1	1	1	1	1	1
3/4	3	2½	2	1½	1	1	1	1	1	1	1	1
1	3	2½	2	1½	1	1	1	1	1	1	1	1
1½	3	3	2½	2	1½	1	1	1	1	1	1	1
2	3	3	2½	2	1½	1	1	1	1	1	1	1
3	3½	3	2½	2	1½	1½	1	1	1	1	1	1
4	3½	3	2½	2	1½	1½	1½	1	1	1	1	1
6	3½	3	2½	2	1½	1½	1½	1½	1½	1½	1½	1½
8	4	3½	3	2	1½	1½	1½	1½	1½	1½	1½	1½
10	4	3½	3	2½	1½	1½	1½	1½	1½	1½	1½	1½
12	4	3½	3	2½	1½	1½	1½	1½	1½	1½	1½	1½
14	4½	4	3	2½	1½	1½	1½	1½	1½	1½	1½	1½
Flat Surface	4½	4	3	2½	1½	1½	1½	1½	1½	1½	1½	1½

Notes:
(1) Insulation thickness is based on condensation prevention at a maximum ambient severity of 90 F and 80% relative humidity for low temperature application. Insulation thickness for elevated temperature service is based on design conditions to hold the temperature of the insulation surface to 140 F maximum, at ambient conditions of 70 F and a 3 mph wind.
(2) Insulation thickness shown in shaded area is double-layer staggered joint construction.

TABLE III G. INSULATION THICKNESS (IN.)
Expanded Silica System – K11.2 STD 11

Nominal Pipe Size (in.)	Temperature of Pipe, °F										
	100 to 199	200 to 299	300 to 399	400 to 499	500 to 599	600 to 699	700 to 799	800 to 899	900 to 999	1000 to 1099	1100 to 1200
1/2	1	1	1	1	1½	2	2	2	2½	2½	2½
3/4	1	1	1	1½	1½	2	2	2½	2½	2½	3
1	1	1	1	1½	1½	2	2	2½	2½	[illegible]	[illegible]
1½	1	1	1	1½	1½	2	2	2½	2½	[illegible]	[illegible]
2	1	1	1	1½	1½	2	2½	2½	[illegible]	[illegible]	[illegible]
3	1	1	1	1½	2	2	2½	[illegible]	[illegible]	[illegible]	[illegible]
4	1	1	1	1½	2	2½	2½	3	[illegible]	[illegible]	[illegible]
6	1	1	1	1½	2	2½	3	3	[illegible]	[illegible]	[illegible]
8	1½	1½	1½	1½	2	2½	3	3½	[illegible]	[illegible]	[illegible]
10	1½	1½	1½	1½	2	2½	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	1½	1½	1½	1½	2	2½	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	1½	1½	1½	1½	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	1½	1½	1½	1½	2	2½	[illegible]	3½	[illegible]	[illegible]	[illegible]
18	1½	1½	1½	1½	2	2½	3	3½	[illegible]	[illegible]	[illegible]
Flat Surface	1½	1½	1½	1½	2	[illegible]	[illegible]	3½	[illegible]	[illegible]	[illegible]

Notes:
(1) Insulation thickness is based on design conditions to hold the temperature of the insulation surface to 140 F maximum, at ambient conditions of 70 F and a 3 mph wind.
(2) Insulation thickness shown in shaded area is double-layer, staggered joint construction.

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8. BARRIER SELECTION The Thermal Insulation System Specifications contain barrier materials identified by symbols. The symbol identifies the major material of construction for the pipe or vessel and, in addition, identifies minor materials of construction for fittings, valves, pumps, etc. The symbols and corresponding barrier materials are listed in Table IV. The use and application of the barrier symbols for drawings and schedules are described in K11.1 STD 2.

Table V. Barrier Materials shows selective barriers for the Thermal Insulation System Specifications. The tables are developed based on available manufacturer's standards and typical usage for pipe, equipment, and duct work. A numerical cost index is shown which compares cost of the various barrier systems for each Thermal Insulation System Specification. The lowest cost barrier is identified by number "1", and as barrier cost increases, numerals increase. The cost index is a relative guide only and should not be used for direct cost comparison. Select the lowest cost barrier for which an "X" appears in the columns representing the particular design conditions.

TABLE IV. BARRIER MATERIALS AND SYMBOLS

CANVAS & FABRIC BARRIERS	
Symbol	Material
CF	8 oz canvas
CG	Pre-sized glass cloth, 7.8 oz per sq yd
CJ	Pre-sized glass cloth, 7.9 oz per sq. yd. bonded to a vapor barrier.

METALLIC BARRIERS	
Symbol	Material
MB	.010" thk 3/16" corrugated aluminum
MC	.016" thk 3/16" corrugated aluminum
MD	.016" thk 3/16" corrugated aluminum - COATED
ME	Vapor barrier jacket and .016" thk aluminum sheet
MH	.016" thk 1 1/4" corrugated aluminum
MS	.016" thk 3/16" corrugated 316 SS
MW	.016" thk galvanized steel, surfaced with vinyl resin; 4 mils exterior film and 2 mils interior film.

FOIL & PAPER BARRIERS	
Symbol	Material
FB	125 mil thk asphalt, glass cloth and aluminum foil.
FL	.001" thk aluminum foil, glass scrim and Kraft paper.
FM	White Kraft paper, glass scrim and .001" thk aluminum foil.

PLASTIC & RESIN BARRIERS	
Symbol	Material
PV	.028" PVC sheet
RA	Asphalt cut-back, vapor barrier type
RC	Asphalt cut-back, breathing type
RE	Asphalt cut-back, aluminum
RP	Latex; PVA or acrylic
RS	Chlorinated rubber

TABLE V. BARRIER MATERIALS

(Select lowest cost alternative which conforms to application – "X" mark. Then review selection for serviceability in expected environmental conditions.)

FIBROUS GLASS
K11.2 STD 5

COST INDEX	INTERIOR	EXTERIOR	PIPE – ELEV TEMP	PIPE – LOW TEMP	CYL VESSELS & EQUIP. (1)	IRREGULAR SHAPES (1)	DUCT WORK	BARRIER
1	X						X	FL
1	X		X	X				FM
2	X		X					CG
3	X			X				CJ
4	X	X	X					MB
5	X	X	X		X			MC
5	X	X			X			MH
6	X	X	X		X			MD
7	X	X		X				ME
8	X	X	X		X			MW
8	X	X	X	X			X	PV
9	X	X	X		X			MS
10	X	X				X		RC
10	X	X				X		RP

(1) ELEVATED TEMPERATURE ONLY.

CALCIUM SILICATE
K11.2 STD 6

COST INDEX	INTERIOR	EXTERIOR	PIPE – ELEV TEMP	PIPE – LOW TEMP	CYL VESSELS & EQUIP.	IRREGULAR SHAPES	DUCT WORK	BARRIER
1	X		X					CF
2	X	X	X					MB
3	X	X	X		X			MC
4	X	X	X		X			MD
5	X	X	X		X			MW
6	X	X	X		X			MS
7	X	X				X		RC
7	X	X				X		RP

CELLULAR PLASTIC
K11.2 STD 7

COST INDEX	INTERIOR	EXTERIOR	PIPE – ELEV TEMP	PIPE – LOW TEMP	CYL VESSELS & EQUIP.	IRREGULAR SHAPES	DUCT WORK	BARRIER
1	X			X	X	X	X	NB (1)
2	X	X		X	X	X	X	RS

(1) NB = NO BARRIER.
WEATHER BARRIER NORMALLY NOT REQUIRED FOR INTERIOR INSTALLATION. EXTERIOR EXPOSURE REQUIRES WEATHER BARRIER.

POLYURETHANE
K11.2 STD 8

COST INDEX	INTERIOR	EXTERIOR	PIPE – ELEV TEMP	PIPE – LOW TEMP	CYL VESSELS & EQUIP.	IRREGULAR SHAPES	DUCT WORK	BARRIER
1	X			X				FM
2	X	X		X	X			MC
3	X	X		X	X			MD
4	X	X		X				PV
5	X	X		X	X			MW
6	X	X		X	X			MS
7	X	X			X	X		RA
7	X	X			X	X		RE
7	X	X			X	X		RP

TABLE V. BARRIER MATERIALS (Continued)

MINERAL FIBER
K11.2 STD 9

COST INDEX	INTERIOR	EXTERIOR	PIPE – ELEV TEMP	PIPE – LOW TEMP	CYL VESSELS & EQUIP.	IRREGULAR SHAPES	DUCT WORK	BARRIER
1	X	X	X		X			MC
2	X	X	X		X			MW
3	X	X	X		X			MS
4	X	X				X		RC
4	X	X				X		RP

CELLULAR GLASS
K11.2 STD 10

	COST INDEX	INTERIOR	EXTERIOR	PIPE – ELEV TEMP	PIPE – LOW TEMP	CYL VESSELS & EQUIP.	IRREGULAR SHAPES	DUCT WORK	BARRIER
	1	X		X					FM
	2	X	X	X		X			MC
	3	X	X	X	X	X			ME
	4	X	X	X	X	X			MD
	5	X	X	X	X	X			MW
	6	X	X	X	X				FB
	7	X	X	X	X	X			MS
(NOTE 1)	4	X	X				X		RA
(NOTE 2)	4	X	X				X		RC
(NOTE 3)	4	X	X				X		RP

NOTES:
1. Low temperature barrier only.
2. Elevated temperature barrier only.
3. Low, elevated and dual temperature barrier.

EXPANDED SILICA
K11.2 STD 11

COST INDEX	INTERIOR	EXTERIOR	PIPE – ELEV TEMP	PIPE – LOW TEMP	CYL VESSELS & EQUIP.	IRREGULAR SHAPES	DUCT WORK	BARRIER
1	X		X					CF
2	X	X	X					MB
3	X	X	X		X			MC
4	X	X	X		X			MD
5	X	X	X		X			MW
6	X	X				X		RC
6	X	X				X		RP

9. REFERENCES The following publications and standards, in addition to insulation suppliers' catalogs, have been consulted in the preparation of the thermal insulation standards:

(1) "Thermal Insulation" by John F. Malloy, Van Nostrand Reinhold Co. (1969)

(2) "Industrial Thermal Insulation" by Allen C. Wilson, McGraw-Hill Book Co. (1959)

(3) Handbook, American Society of Heating, Refrigeration and Air Conditioning Engineers

(4) "Climatic Atlas" U.S. Printing Office

(5) "Thermal Insulation Design" Standard T1.10 STD 11

IDENTIFICATION AND SYMBOLS

1. SCOPE This Design Standard covers identification of thermal insulation systems on Drawings.

2. IDENTIFICATION OF THERMAL INSULATION SYSTEMS Thermal insulation systems are denoted on the Drawings by an identification symbol as illustrated in Figure 1. They are denoted in the Pipeline Summary and the Insulation Summary - Equipment by the same symbol.

2.1 Insulation System Identification

2.1.1 First Part The first part of the identification symbol indicates the thickness of the insulation and the type of insulation material, e.g., 1 1/2"-5. The following rules apply:

(1) Do not use decimal inches to indicate insulation thickness. (Millimeters are used in metric practice.)

(2) The insulation thickness does not include the thickness of weather barrier.

(3) Identification of insulation applied to piping or duct terminates at a numbered equipment item or where indicated by an insulation termination symbol as illustrated in Figure 1.

(4) The letter "D" following the insulation thickness designation (as 5"D-6, for example) denotes a double-layer of insulation.

(5) Where required by design, two or more different types of insulation may be indicated. (Example, 1/2"-5, 1 1/2"-10 designates 1/2" thickness of fibrous glass and 1 1/2" of cellular glass. Materials are applied in the order listed.)

2.1.2 Second Part The second part of the identification indicates the barrier material to be applied over the insulation. The second part of the identity directly follows the first part, e.g., 1 1/2"-6MC. (1 1/2" of calcium silicate insulation covered with an aluminum jacket barrier.) The barrier materials applicable to the system are listed in the Thermal Insulation System Specification. The barrier materials are denoted by two capital letters. The letters "NB" (as 1/2"-7NB) denotes no barrier material application over the insulation material. For composite insulate (see Par. 2.1.1(5)) the barrier symbol follows the last insulation designation: 1/2"-5, 1 1/2"-10MC.

2.2 Identification Symbols Symbols illustrated in Figure 1 are used to indicate thermal insulation on engineering flow diagrams and piping drawings.

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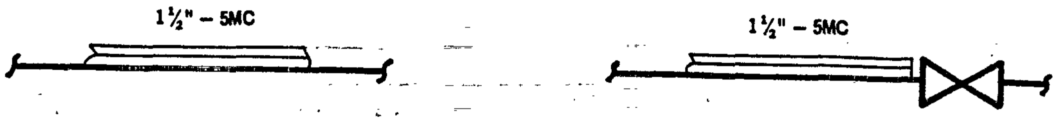
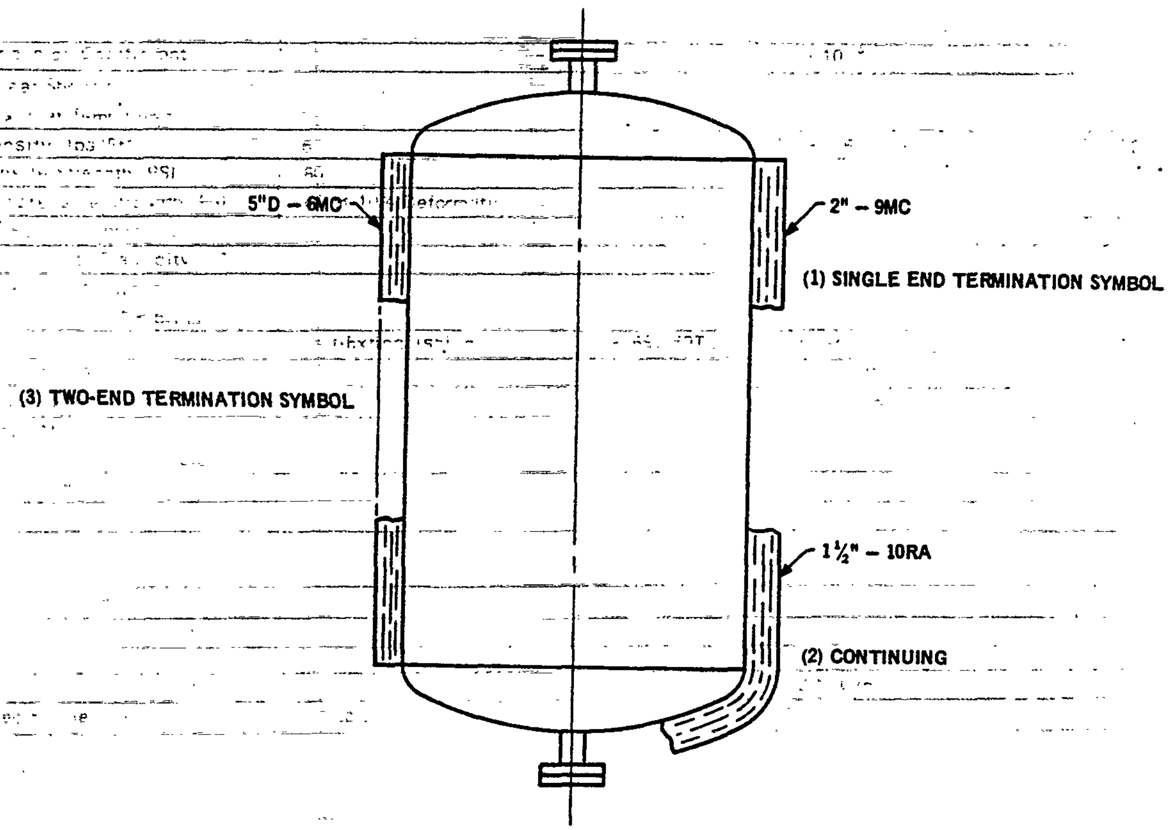


CONTINUING INSULATION

TERMINATION OF INSULATION

PIPING



EQUIPMENT

FIGURE 1. TYPICAL IDENTIFICATION SYMBOLS

INSULATION MATERIAL PROPERTIES

Design Data

1. SCOPE This standard lists materials properties data for thermal insulation and barrier materials used in the Thermal Insulation System Specifications. Additional data for other common materials is provided.

2. MATERIALS PROPERTIES DATA

2.1 Insulation Materials Properties Table I provides physical and thermal properties for materials shown in the Insulation System Specifications and a few additional materials of frequent use.

TABLE I. MATERIALS PROPERTIES

Insulation Characteristics	Type of Insulation: Fibrous Glass K11.2 STD 5	ASTM Test Method	Calcium Silicate K11.2 STD 6	ASTM Test Method
Material Description	Glass Fiber With Organic Binder		Reacted Hydrous Calcium Silicate	
Form	Sheet and Pipe Covering		Block and Pipe Covering	
Temperature Range (F)	0 to 450		100 to 1200	
Thermal Conductivity (BTU in. thk/hr ft² °F) At Mean Temperature	K / Temp .21 / 50 .24 / 100 .29 / 200 .35 / 300		K / Temp .38 / 100 .40 / 200 .47 / 400 .56 / 600	
Linear Shrinkage Max % at Temp Limit	None		1.5	
Density lbs/Ft³	4 - 9		12	
Tensile Strength PSI			20	
Compressive Strength PSI	3 at 10% Deformation		100 at 5% Deformation	
Flexural Strength PSI				
Modulous of Elasticity PSI				
Abrasion Resistance % Wt. Loss by Tumbling			35 - 10 Min Run	
Fire Exposure			Non-Combustible	
Flame Spread Index	25			
Smoke Density Index	50			
Water Absorption % Vol. - 24 hr. Immersion	90		90	
Capillarity	None		Wicks	
Hygroscopicity % Vol.	.2		10% by Weight	
Water Vapor Transmission Perm In.				
Alkalinity Ph	9		10.2	
Chloride Content (PPM)	Less than 30		200	
Emissivity				
Thermal Diffusivity (Ft²/Hr.)	.02		.16	
Specific Heat (BTU/lb/° F)	.20		.20	
Remarks			Good Strength. Absorbs Water.	

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TABLE I. MATERIALS PROPERTIES (Continued)

Insulation Characteristics	Type of Insulation: Cellular Plastic K11.2 STD 7	ASTM Test Method	Polyurethane K11.2 STD 8	ASTM Test Method
Material Description	Closed Cell Foamed Plastic		Expanded Polyurethane	
Form	Sheet and Pipe Covering		Block, Pipe Covering & Spray	
Temperature Range (F)	-50 to 220		-400 to 200	
Thermal Conductivity (BTU in. thk/hr ft^2 °F) At Mean Temperature	K / Temp .27 / 70 .28 / 90		K / Temp .16 / -100 .18 / -50 .18 / 0 .17 / 50 .18 / 100	
Expansion Coefficient			40×10^{-6}	
Linear Shrinkage Max % at Temp Limit	7			
Density lbs/Ft^3	6	D-1667-64	2.0 - 2.5	D-1622
Tensile Strength PSI	80		40 - 70	D-1623
Compressive Strength PSI	40 at 10% Deformation		30 - 40	D-1621
Flexural Strength PSI			60 - 70	C-203
Modulous of Elasticity PSI				
Abrasion Resistance % Wt. Loss by Tumbling				
Fire Exposure	Self-Extinguishing	D-1692-59T	Self-Extinguishing	D-1692
Flame Spread Index	50		25 and Higher	
Smoke Density Index	500		Less Than 500	
Water Absorption % Vol. - 24 hr. Immersion	1	D-1056-62	1.5 to 3.0	
Capillarity	0			
Hygroscopicity % Vol.				
Water Vapor Transmission Perm In.	.28	C-355-64	1.5	C-355
Alkalinity Ph				
Chloride Content (PPM)				
Emissivity				
Thermal Diffusivity (Ft^2/Hr.)			.012 to 025	
Specific Heat (BTU/lb/°F)	.19 to .27		.23	
Remarks	Coating Required for Exterior Exposure. Not Recommended in Confined Air Space without Fire Protection.		Foam Should not be Exposed to Sun or Weathering Elements.	

TABLE I. MATERIALS PROPERTIES (Continued)

Insulation Characteristics	Type of Insulation			
	Mineral Fibers K11.2 STD 9	ASTM Test Method	Cellular Glass K11.2 STD 10	ASTM Test Method
Material Description	Mineral Fibers With Inorganic Binders		Hermetically Sealed Glass Cells	
Form	Block and Pipe Covering		Block and Pipe Covering	
Temperature Range (F)	100 to 1200		-450 to 800	
Thermal Conductivity (BTU in. thk/hr ft² °F) At Mean Temperature	K / Temp .33 / 100 .36 / 200 .42 / 400 .51 / 600		K / Temp .32 / -50 .35 / 0 .41 / 100 .47 / 200 .55 / 300	
Expansion Coefficient			4.6×10^{-6}	
Linear Shrinkage Max % at Temp Limit	4			
Density lbs/Ft³	15		9	
Tensile Strength PSI			50	
Compressive Strength PSI	10 at 5% Deformation		100	
Flexural Strength PSI	40		75	
Modulous of Elasticity PSI			180,000	
Abrasion Resistance % Wt. Loss by Tumbling				
Fire Exposure	Non-Combustible		Non-Combustible	
Flame Spread Index				
Smoke Density Index				
Water Absorption %Vol. -24 Hr. Immersion	90		.2	
Capillarity	Wicks		0	
Hygroscopicity % Vol.	.2		0	
Water Vapor Transmission Perm In.			0	
Alkalinity Ph	8		7.5	
Chloride Content (PPM)	20		Less Than 5	
Emissivity				
Thermal Diffusivity (Ft²/Hr.)	.01		.018	
Specific Heat (BTU/lb/° F)	.22		.20	
Remarks			Good Compressive Strength.	

TABLE I. MATERIALS PROPERTIES (Continued)

Insulation Characteristics	Type of Insulation: Expanded Silica K 1.2 STD 11	ASTM Test Method	Alumina Silica	ASTM Test Method
Material Description	Perlite With Glass Fiber Binder And Water Repellent		High Temperature Ceramic Fiber	
Form	Block and Pipe Covering		Blanket and Bulk	
Temperature Range (F)	100 to 1500		100 to 2300	
Theramal Conductivity (BTU in. thk/hr ft^2 °F) At Mean Temperature	K / Temp .33 / 100 .38 / 200 .47 / 400 .57 / 600		K [1] / Temp .40 / 600 .70 / 1000 1.10 / 1400 [1] 8 lb Density	
Linear Shrinkage Max % at Temp Limit	1.2			
Density lbs/Ft^3	10		3 to 12	
Tensile Strength PSI				
Compressive Strength PSI	81 at 5% Deformation			
Flexural Strength PSI	85			
Modulous of Elasticity PSI				
Abrasion Resistance % Wt. Loss by Tumbling				
Fire Exposure	Non-Combustible		Non-Combustible	
Flame Spread Index				
Smoke Density Index				
Water Absorption % Vol. -24 Hr. Immersion	3.7			
Capillarity				
Hygroscopicity % Vol.				
Water Vapor Transmission Perm In.	18			
Alkalinity Ph	9			
Chloride Content (PPM)	50		Less Than 50	
Emissivity				
Thermal Diffusivity (Ft^2/Hr.)	.014			
Specific Heat (BTU/lb/° F)	.22		.26 @ 1800 F	
Remarks			High Temperature And High Cost. May be Used in Combination With Low Cost Materials.	

TABLE I. MATERIALS PROPERTIES (Continued)

Insulation Characteristics	Type of Insulation			
	Cork-Filled Bituminous Resin	ASTM Test Method	Cork-Filled Sythetic Resin	ASTM Test Method
Material Description	Asphalt Mastic, Cork Filler		Polyvinyl Acetate Mastic, Cork Filler	
Form	Trowel or Spray Mastic		Trowel or Spray Mastic	
Temperature Range (F)	40 to 220		40 to 170	
Thermal Conductivity (BTU in. thk/hr ft² ° F) At Mean Temperature	K .90, Temp 100		K .70, Temp 100	
Linear Shrinkage Max % at Temp Limit				
Density lbs/Ft³	31			
Tensile Strength PSI				
Compressive Sttength PSI				
Flexural Strength PSI				
Modulous of Elasticity PSI				
Abrasion Resistance % Wt. Loss by Tumbling				
Fire Exposure	Self-Extinguishing		Self-Extinguishing	
Flame Spread Index				
Smoke Density Index				
Water Absorption % Vol. -24 Hr. Immersion				
Capillarity				
Hygroscopicity % Vol.				
Water Vapor Transmission Perm In.	.007			
Alkalinity Ph			7.5	
Chloride Content (PPM)				
Emissivity				
Thermal Diffusivity (Ft²/Hr.)				
Specific Heat (BTU/lb/° F)				
Remarks	Film Thickness ¼" or Greater, or Films on Smooth Surfaces Such as Stainless Steel Requires a Reinforcement Membrane.		Film Thickness ⅛" to ¼" Used For Control of Condensation on Irregular Shaped Equipment (Pumps, Compressor, Etc.).	

TABLE I. MATERIALS PROPERTIES (Continued)

Insulation Characteristics	Type of Insulation: Polystyrene	ASTM Test Method	Isocyanurate	ASTM Test Method
Material Description	Expanded Polystyrene		Cellular Plastic	
Form	Block and Pipe Covering		Block, Pipe Covering & Spray	
Temperature Range (F)	0 to 175		-100 to 300	
Thermal Conductivity (BTU in. thk/hr ft² °F) At Mean Temperature	K / Temp .22 / 0 .25 / 50 .27 / 100		K / Temp .16 / -100 .18 / -50 .18 / 0 .17 / 50 .18 / 100	
Expansion Coefficient	25×10^{-6}		5×10^{-6}	
Linear Shrinkage Max % at Temp Limit				
Density lbs/Ft³	1		2	
Tensile Strength, PSI	70		30 to 40	
Compressive Strength, PSI	10 at 5% Deformation		18 to 28	
Flexural Strength, PSI			35	
Modulous of Elasticity, PSI			$.20 \times 10^{-6}$	
Abrasion Resistance % Wt. Loss by Tumbling				
Fire-Exposure	Self-Extinguishing			
Flame Spread Index			25	
Smoke Density Index			70 @1" THK.	
Water Absorption % Vol -24 Hr. Immersion	1		1.5 to 3	
Capillarity	None			
Hygroscopicity % Vol				
Water Vapor Transmission Perm In.	2.5		2 to 3	
Alkalinity Ph				
Chloride Content (PPM)				
Emissivity				
Thermal Diffusivity (Ft²/Hr)	.017			
Specific Heat (BTU/lb/°F)	.27		.23	
Remarks	Easy Fabrication And Light Weight. Material Temperature Limit May Not Be Adequate For Equipment Clean-Out Operation.			

2.2 Insulation Barrier Properties Table II provides physical data for barrier materials shown in the Insulation System Specifications. The barrier material type is identified generically and with the barrier symbols (e.g., CF, CG, CJ, etc.).

TABLE II. BARRIER PROPERTIES

Barrier Characteristics	Type of Barrier			
	8 oz Canvas (CF)	Glass Cloth (CG)	Glass Cloth Vapor Barrier (CJ)	Asphalt-Foil Paper (FB)
Material Description	Cotton Canvas Cloth, 7 oz per sq yd	Pre-sized Glass Cloth, 7.8 oz per sq yd	Pre-sized Glass Cloth Bonded to a Plastic Film, 7.9 oz per sq yd	Laminate of Asphalt, Glass Cloth and Aluminum Foil, 1/8" Thick, 67 lbs per sq
Form	Pliable Fabric	Pliable Fabric	Pliable Fabric	Sheet
Color	White	White	White	Black
Temp Limit (F)				200
Fire Exposure	Combustible	Non-Combustible	Non-Combustible	Combustible
Flame Spread Index				
Smoke Density Index				
Smoke Toxicity				
Water Vapor Transmission Perm In.	Not a Vapor Barrier	Not a Vapor Barrier	.03	
Beach Puncture, oz in per in Tear		215	215	
Emissivity @ 100 F		0.60	0.60	0.94
Remarks	Canvas is attached to insulation. Surface is usually painted.	May be painted.	May be painted.	Heavy Duty Barrier, Heat Sealed Joints.

Barrier Characteristics	Type of Barrier			
	Foil - Glass Scrim - Kraft Paper (FL)	Foil - Glass Scrim - Kraft Paper (FM)	Aluminum Sheet - .010" (MB)	Aluminum Sheet - .016" (MC)
Material Description	Laminate of Aluminum Foil, Glass Scrim and Kraft Paper	Laminate of Aluminum Foil, Glass Scrim and Kraft Paper	1/16" Corrugated Aluminum Sheet with Kraft-Polyethlene Film Backing	1/16" Corrugated Aluminum Sheet with Kraft-Polyethlene Film Backing
Form	Sheet	Sheet	Sheet	Sheet
Color	Aluminum	White	Aluminum	Aluminum
Temp Limit (F)			1100	1100
Fire Exposure			Non-Combustible	Non-Combustible
Flame Spread Index				
Smoke Density Index				
Smoke Toxicity				
Water Vapor Transmission Perm In.	.02	.02	Not a Vapor Barrier	Not a Vapor Barrier
Beach Puncture, oz in per in Tear		215	215	
Emissivity @ 100 F	Bright 0.05 Dull Gray 0.07 Oxidized 0.11	0.60	Bright 0.05 Dull Gray 0.07 Oxidized 0.11	Bright 0.05 Dull Gray 0.07 Oxidized 0.11
Remarks	Light Duty Barrier. Usually Applied to Sheet Insulation at the Factory for Heating and Air Conditioning Duct Work.	Light Duty Barrier. Usually Applied to Sheet Insulation at the Factory.		

TABLE II. BARRIER PROPERTIES (Continued)

Barrier Characteristics	Type of Barrier			
	Aluminum Sheet .016" - Coated (MD)	Aluminum Sheet .016" with ASJ Inner Jacket (ME)	Aluminum Sheet .016" (MH)	Stainless Steel Sheet .010" (MS)
Material Description	1/16" Corrugated Aluminum Sheet with Kraft-Polyethlene Film Backing: Surface Acrylic Coated	Same as System (MC) with Inner Jacket (FM)	1 1/4" Corrugated Aluminum Sheet with Kraft-Polyethlene Film Backing	3/16" Corrugated Sheet - Type 316 SS
Form	Sheet	Sheet	Sheet	Sheet
Color	Aluminum	Aluminum	Aluminum	Gray
Temp Limit (F)	1100	1100	1100	1450
Fire Exposure	Non-Combustible	Non-Combustible	Non-Combustible	Non-Combustible
Flame Density Index				
Smoke Density Index				
Smoke Toxicity				
Water Vapor Transmission Perm In.	Not a Vapor Barrier	(FM) used as a Vapor Barrier	Not a Vapor Barrier	Not a Vapor Barrier
Beach Puncture, oz in per in Tear				
Emissivity @ 100 F	Bright 0.05 Dull Gray 0.07 Oxidized 0.11	Bright 0.05 Dull Gray 0.07 Oxidized 0.11	Bright 0.05 Dull Gray 0.07 Oxidized 0.11	Bright 0.24 Dull Gray 0.37 Oxidized 0.82
Remarks	Coated Aluminum Used Primarily for Corrosion Protection in Coatal Areas.	Used for Cold Service Requiring a Bapor Barrier.	Corrugations Collect Liquids in a Horizontal Position.	

Barrier Characteristics	Type of Barrier			
	Galvanized Steel .016" - Vinyl Coated (MW)	Polyvinyl Chloride Sheet .028" (PV)	Asphalt Vapor Barrier (RA)	Asphalt Breathing Barrier (RC)
Material Description	Smooth Surface Coated with Vinyl Resin: 4 mils Exterior and 2 mils on Back Surface	Smooth Surface PVC Sheet - Solvent or Tape Sealed.	Solvent Cutback Asphalt	Solvent Cutback Asphalt
Form	Sheet	Sheet	Mastic	Mastic
Color	White	8 colors	Black	Black
Temp Limit (F)	220	180	250	250
Fire Exposure	Non-Combustible	Combustible	Combustible	Combustible
Flame Density Index		5		
Smoke Density Index				
Smoke Toxicity				
Water Vapor Transmission Perm In.	Not a Vapor Barrier	.000015	.003	.03
Beach Puncture, oz in per in Tear				
Emissivity @ 100 F	0.60		0.94	0.94
Remarks	Higher Cost Barrier for Corrosives Environments.	May Deform Slightly in Sun Light.	Corrugations Collect	

TABLE II. BARRIER PROPERTIES (Continued)

Barrier Characteristics	Type of Barrier		
	Asphalt Aluminum (RE)	Latex Mastic (RP)	Chlorinated Rubber Paint (RS)
Material Description	Solvent Cutback Asphalt	PVA Resin	Chlorinated Rubber Resin
Form	Mastic	Mastic	Paint
Color	Aluminum	Various	Various
Temp Limit (F)	250	180	180
Fire Exposure	Combustible		
Flame Spread Index		25	
Smoke Density Index			
Smoke Toxicity			
Water Vapor Trans-mission Perm In.	.002	.5	Not a Vapor Barrier
Beach Puncture, oz in per in Tear			
Emissivity @ 100 F			
Remarks			Used to Prevent Deterioration of Cellular Rubber Insulation in Weathering Exposures.

HEAT TRANSFER CALCULATIONS

1. SCOPE This Design Standard provides equations and Tables for calculating heat loss and heat gain through thermal insulation on both flat and cylindrical surfaces. Definitions of terms used in the equations and Tables, and convection coefficients for flat and cylindrical surfaces in elevated and low temperature services also are given.

2. USE OF THIS STANDARD Figure 1 is a Flow Chart that shows how the equations and Tables in this Design Standard are used in solving thermal insulation problems.

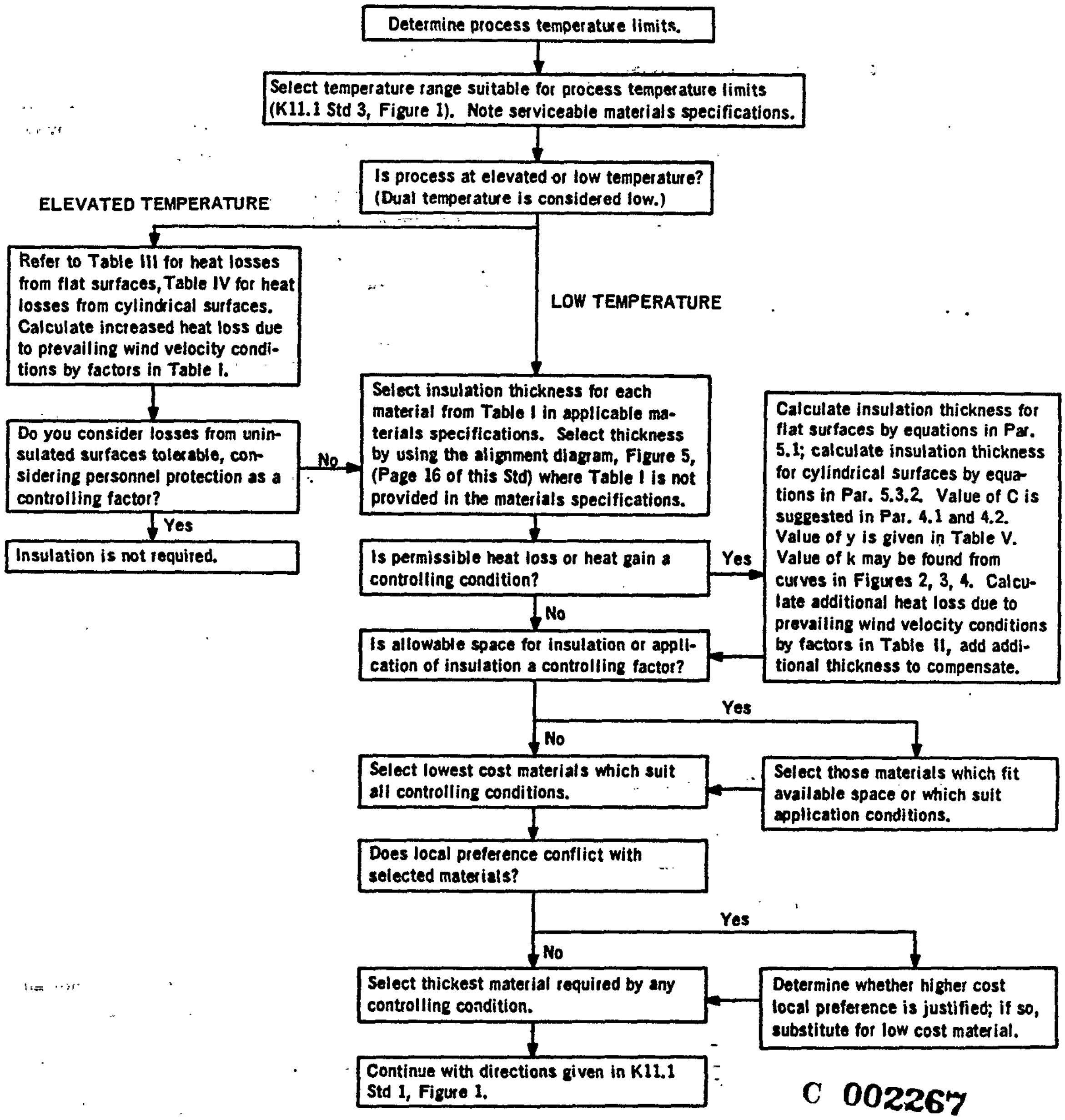

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FIGURE 1. HOW TO USE THE EQUATIONS, TABLES, AND FIGURES

3. DEFINITIONS OF TERMS Terms used in this standard have the following definitions:

V = Heat flux, Btu/hr, sq ft, from bare steel surfaces.

Q = Heat flux, Btu/hr, sq. ft, at equipment or pipe surface beneath the insulation.

q = Heat flux, Btu/hr, sq ft, at outer surface of insulation.

t_1 = Temperature, F, of the hot or cold surface to be insulated.

t_a = Temperature, F, of air surrounding the insulation (ambient).

t_s = Temperature, F, of the outer surface of insulation.

$\Delta t_1 = t_1 - t_a$ for elevated temperature service, $= t_a - t_1$ for low temperature service.

$\Delta t_2 = t_s - t_a$ for elevated temperature service, $= t_a - t_s$ for low temperature service.

RH = Relative humidity of ambient air.

R = The sum of resistances, hr, sq ft, °F/Btu, through the insulation and the air film surrounding the insulation, e.g., $\frac{x}{k} + \frac{1}{C}$ for flat surfaces.

C = Convection coefficient, Btu/hr, sq ft, °F, used to estimate resistance through the air film surrounding the insulation.

$\frac{x}{k}$ = Internal resistance of a single thickness of insulation over a flat surface; x = thickness of insulation, in inches; k = conductivity of the insulation, Btu/hr, sq ft, in., at the mean temperature $\frac{t_1 + t_a}{2}$.

$\frac{y}{k}$ = Internal resistance of a single thickness of insulation over a cylindrical surface; y = effective thickness of insulation; k is defined above.

NOTE: Where the sum of internal resistances of insulation in double layer or compound systems is expressed as $\frac{x_1}{k_1} + \frac{x_2}{k_2}$ for flat surfaces, and $\frac{y_1}{k_1} + \frac{y_2}{k_2}$ for cylindrical surfaces, x_1 and y_1 always represent the inner layer of insulation, x_2 and y_2 always represent the outer layer; k_1 and k_2 are selected to suit the materials and mean temperatures indicated by x_1, y_1, x_2 and y_2.

D_o = Outside diameter of the outer layer of insulation, inches.

D = Outside diameter of the inner layer of insulation, inches.

D_p = Outside diameter of pipe or equipment, inches.

d = Inside diameter of either the inner layer or outer layer of insulation, inches.

4. CONVECTION COEFFICIENTS An adequate treatment of convection coefficients is not within the scope of this standard. The following coefficients (expressed as C and defined above), are suggested for use in heat transfer equations:

4.1 Flat Surfaces The value of C for flat surfaces in still air at elevated temperatures may be considered 1.39 for vertical plates, 1.79 for horizontal plates facing upward, and 0.89 for horizontal plates facing downward.

The value of C for flat surfaces in still air at low temperatures may be considered 1.39 for vertical plates, 0.89 for horizontal plates facing upward, and 1.79 for horizontal plates facing downward.

4.2 Cylindrical Surfaces The value of C for cylindrical surfaces in still air, at both elevated and low temperatures, may be considered 1.6.

The value of C for cylindrical surfaces in air moving at 2 miles per hour nominal velocity, at both elevated and low temperatures, may be considered 1.77. The effect of air moving at higher velocities is indicated in Table II, but exact coefficients are not given.

5. HEAT TRANSFER CALCULATIONS Heat transfer calculations presented in this Standard do not cover personnel protection at elevated temperatures or prevention of surface moisture condensation at low temperatures. Thicknesses of insulation adequate to meet these design conditions have been calculated from equations based on the insulation surface, and are presented in tabular form in each of the Materials Specifications for insulation. There is no point in repeating these equations here.

Equations in this standard are based on the hot or cold equipment surface beneath the insulation, and are provided for use when control of process temperature and heat flow is the governing design factor.

5.1 Flat Surfaces The equation for calculating heat flow through a single layer of insulation over a flat surface is:

$$q = \frac{\Delta t_1}{\frac{x}{k} + \frac{1}{C}} \; ; \; q = Q \qquad (1)$$

The value of k is determined from Figures 2, 3, and 4; the value of C is suggested in Par. 4.1. For increased heat loss due to wind velocity conditions, multiply q by conversion factors in Table II.

Where more than one layer of insulation is applied over a flat surface, the equation becomes:

$$q = \frac{\Delta t_1}{\frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{1}{C}} ; q = Q \quad (2)$$

5.2 Cylindrical Surfaces Cylindrical insulation or pipe covering offers a path of varying area for the flow of heat, and equations are more complicated than for flat surfaces. The classical mathematical treatment utilizes a log mean area for the transfer of heat.

By suitable rearrangement of terms, it is possible to calculate heat flux both on the basis of the external surface of the insulation, and on the basis of the pipe or equipment surface diameter. In practice, there are uses for both methods of calculation; however, only the pipe or equipment surface basis is covered in this standard.

Note that while heat fluxes q and Q are equal for flat surfaces, this is never true for cylindrical surfaces.

5.3 Calculations for Cylindrical Surfaces Equations are based on the pipe or equipment diameter which does not vary with insulation thickness. Calculations are intended to provide the rate of heat loss or gain from or into the process fluid at the pipe or equipment wall.

Equations (1) and (2) still are applicable as long as the heat flow area or the effective thickness of insulation are adjusted to suit a cylindrical object. The common method used for this adjustment is the calculation of an *effective insulation thickness*, y, which takes into account the variable area in the heat flux path.

5.3.1 *Calculation of y* The following equation defines y:

$$y = 1.1513\ Dp \log \left(\frac{D}{d}\right) ; \quad (3)$$

D_o may be used in place of D.

Values of y for single layer insulation in thicknesses 1", 1½", 2", 2½", and 3" over piping ½" through 40" pipe size; and values of y for each layer of double insulation in thicknesses 1", 1½", 2", 2½", and 3" over thicknesses 1", 1½", 2", 2½", and 3" over piping 3" through 40" have been calculated by Equation (3) and are given in Table V.

5.3.2 *Heat Flow Equations* The equation for calculating heat flux from the surface of a cylindrical object through a single layer of insulation is:

$$Q = \frac{\Delta t_1}{\frac{y}{k} + \frac{1}{C}\left(\frac{D_p}{D_o}\right)} \quad (4)$$

The value of y is given in Table V. The value of k is determined from Figures 2, 3, and 4. The value of C is suggested in Par. 4.2. For increased heat loss due to wind velocity conditions, multiply Q by conversion factors in Table II.

Where more than one layer of insulation is required, or the variation of k with temperature is large and it is desirable to treat the insulation as consisting of layers of varying heat resistance, the equation becomes:

$$Q = \frac{\Delta t_1}{\frac{y_1}{k_1} + \frac{y_2}{k_2} + \frac{1}{C}\left(\frac{D_p}{D_o}\right)} \quad (5)$$

5.4 Temperature of the Insulation Surface Temperature of the insulation surface, t_s, may be found by dividing the heat flux for the external surface of the pipe, or equipment by C to obtain the temperature difference:

$$Q\left(\frac{D_p}{D_o}\right) = q = \frac{\Delta t_2}{\frac{1}{C}} ; \Delta t_2 = \frac{q}{C} = \frac{Q}{C}\left(\frac{D_p}{D_o}\right) \quad (6)$$

From Paragraph 3, "Definitions":

$\Delta t_2 = t_s - t_a$ for elevated temperature service;

$= t_a - t_s$ for low temperature service.

Substituting in Equation (6):

$t_s = t_a + \frac{q}{C}$ for elevated temperature service;

$t_s = t_a - \frac{q}{C}$ for low temperature service.

5.5 Square Feet to Linear Feet Where it is necessary to determine the rate of heat transfer per linear foot of pipe or cylindrical surface, multiply Q in Equation (4) and (5) by the appropriate conversion factors in Table VI.

6. HEAT LOSSES FROM BARE SURFACES Many insulation manufacturers rate their product in terms of efficiency percentage according to results of the following equation:

$$\text{Efficiency} = \left(\frac{V - q}{V}\right)100 \quad (7)$$

Efficiency ratings so derived can be misleading because of other variables that are not considered. The concept of insulation "efficiency" is not recommended.

Tables III and IV show heat losses from uninsulated flat and cylindrical surfaces at various temperature gradients. To determine the effect of wind velocity on heat loss from bare surfaces, multiply the factors in Tables III and IV by the conversion factors in Table I. *Do not use the conversion factors in Table IV to determine increase in heat loss from insulated surfaces, however.*

7. INSULATION THICKNESS TO PREVENT MOISTURE CONDENSATION AT MODERATE TEMPERATURES The alignment diagram, Figure 5, provides a rapid means for calculating adequate thickness of insulation to prevent moisture condensation on surfaces cooler than the ambient temperature, and under a variety of relative humidity conditions. Solve problems as indicated by the dotted line on the diagram, entering the chart at the lower left scale. This chart provides adequate thickness under still air conditions at moderate temperatures; since still air conditions are the most serious condition in moisture-condensation problems at these temperatures, no conversion factors for wind velocity conditions is required.

This alignment diagram has been reprinted directly from the current edition of the *ASHRAE GUIDE*, and there is no record of results from actual field use. However, recommended thicknesses are within the range of those actually calculated and appearing in the Materials Specifications, and the approach seems adequate for the practical solution of problems.

TABLE I. MULTIPLYING FACTORS FOR USE WITH TABLES III AND IV

Increased Heat Loss due to Wind Velocity Conditions, Bare Surfaces.[1]

Temp, F, of Uninsulated Hot Surface	Wind Velocity, Miles Per Hour				
	2½	5	7½	10	15
200	1.43	1.72	1.92	2.10	2.42
300	1.40	1.66	1.86	2.03	2.33
400	1.36	1.60	1.77	1.93	2.21
500	1.32	1.54	1.70	1.85	2.10
600	1.30	1.48	1.63	1.75	1.97
700	1.26	1.43	1.56	1.66	1.85
800	1.23	1.37	1.49	1.59	1.77
900	1.19	1.33	1.44	1.53	1.67
1000	1.17	1.29	1.38	1.40	1.52
1100	1.15	1.26	1.33	1.40	1.52
1200	1.13	1.23	1.29	1.33	1.44

[1]Factors shown in this Table are averaged for flat surfaces and for various pipe sizes, and are recommended as close enough for practical use.

TABLE II. MULTIPLYING FACTORS FOR USE WITH EQUATIONS (1), (2), (4), AND (5)

Increased Heat Loss due to Wind Velocity Conditions, Insulated Surfaces.[1]

Insulation Thickness (Inches)	Wind Velocity, Miles Per Hour					
	5	10	15	20	25	30
1	1.07	1.09	1.11	1.12	1.13	1.14
1½	1.05	1.07	1.08	1.09	1.10	1.11
2	1.04	1.06	1.07	1.075	1.08	1.085
2½	1.03	1.04	1.05	1.055	1.06	1.07
3	1.025	1.035	1.04	1.045	1.05	1.06
3½	1.02	1.03	1.035	1.04	1.045	1.05
4	1.015	1.025	1.03	1.035	1.04	1.045
4½	1.013	1.023	1.028	1.033	1.038	1.043
5	1.011	1.021	1.026	1.031	1.036	1.041
5½	1.009	1.019	1.024	1.029	1.034	1.039
6	1.007	1.017	1.022	1.027	1.032	1.037

[1]Factors shown in this Table are averaged for flat surfaces and for various pipe sizes, and are recommended as close enough for practical use.

TABLE III

Heat Loss from Bare Flat Surfaces under Still Air Conditions at 70 F Ambient Temperature.

Temperature of Uninsulated Hot Surface, F	Btu/Square Feet, Hour		
	Vertical Surface C = 1.394	Horizontal Surface Facing Upward C = 1.79	Horizontal Surface Facing Downward C = 0.89
100	50	67	42
200	300	395	252
300	650	880	600
400	1150	1550	965
500	1800	2420	1510
600	2650	3570	2125
700	3750	5070	3150
800	5100	6890	4280
900	6800	8200	5700
1000	8900	12100	7500
1100	11400	15400	9800
1200	14400	19400	12100
1300	17900	24100	15000
1400	21750	29350	18250
1500	26000	35000	21800
1600	30500	41200	25600
1700	35500	48000	29800
1800	40800	55000	34300
1900	46500	62800	39000

TABLE IV

Heat Loss from Bare Cylindrical Surfaces under Still Air Conditions at 70 F Ambient Temperature. C = 1.6 for all Cylindrical Surfaces.

Temp F of Hot Surface	Pipe Size (IPS or Nominal), Inches								
	½	¾	1	1½	2	3	4	6	8
100	13	16	20	27	34	48	61	87	112
200	76	93	114	159	196	280	354	503	644
300	166	205	250	326	432	620	784	1122	1436
400	287	353	434	613	753	1083	1370	1976	2530
500	445	547	674	955	1176	1695	2149	3105	3988
600	649	801	989	1403	1732	2505	3179	4604	5927
700	901	1113	1379	1960	2423	3511	4467	6479	8356
800	1218	1508	1865	2661	3295	4784	6094	8858	11433
900	1602	1984	2462	3514	4355	6337	8079	11769	15211
1000	2075	2576	3194	4568	5665	8259	10545	15366	19895
1100	2644	3282	4080	5841	7251	10582	13513	19740	25568
1200	3317	4122	5123	7345	9133	13344	17049	24909	32293

Temp F of Hot Surface	Pipe Size (IPS or Nominal), Inches							
	10	12	14	16	18	20	24	30
100	136	159	174	197	221	244	289	351
200	791	930	1009	1142	1282	1416	1683	2042
300	1769	2076	2258	2560	2875	3168	3772	4642
400	3114	3664	3989	4529	5074	5618	6679	8242
500	4918	5809	6316	7160	8032	8897	10595	13103
600	7312	8627	9404	10697	12010	13270	15825	19606
700	10325	12194	13301	15124	16992	18777	22375	27758
800	14147	16721	18236	20769	23346	25810	30836	38299
900	18812	22248	24279	27663	31109	34432	41112	51107
1000	24621	29133	31844	36257	40788	45157	53958	67126
1100	31679	37501	40965	46689	52539	58159	69536	86588
1200	40051	47429	51856	59089	66456	73691	88221	109872

NOTE: Heat loss is given in Btu's per *Linear Foot* of cylindrical surface per hour; to convert to square feet, use the appropriate factor in Table VI.

TABLE V. VALUES OF y (EFFECTIVE THICKNESS) FOR SINGLE-LAYER AND DOUBLE-LAYER INSULATION[1]

Pipe Size (Inches)		Factors (Note 1)	Single Layer or Inner Layer Insulation		Outer Layer over Single Layer Insulation Thickness, Inches				
Nominal	OD (D_p)		Thk		1	1½	2	2½	3
½	0.84	D	1	2.88					
		y							
		D	1½	4.00					
		y		0.66					
		D	2	5.00					
		y		0.75					
		D	2½	6.63					
		y							
		D	3	7.63					
		y							
¾	1.05	D	1	3.50					
		y		0.63					
		D	1½	4.50					
		y		0.76					
		D	2	5.56					
		y		0.88					
		D	2½	6.63					
		y		0.97					
		D	3	7.63					
		y		1.04					
1	1.32	D	1	3.50					
		y		0.64					
		D	1½	4.50					
		y		0.81					
		D	2	5.56					
		y		0.95					
		D	2½	6.63					
		y		1.07					
		D	3	7.63					
		y		1.16					

[1] $D = D_1$, $y = y_1$ for single or inner layer; $D = D_0$, $y = y_2$ for outer layer.

TABLE V. VALUES OF y (EFFECTIVE THICKNESS) FOR SINGLE-LAYER AND DOUBLE-LAYER INSULATION[1]
(Continued)

Pipe Size (Inches)		Factors (Note 1)	Single Layer or Inner Layer Insulation		Outer Layer over Single Layer Insulation Thickness, Inches				
Nominal	OD (D_p)		Thk		1	1½	2	2½	3
1½	1.90	D	1	4.00					
		y		0.71					
		D	1½	5.00					
		y		0.92					
		D	2	6.63					
		y							
		D	2½	7.63					
		y							
		D	3	8.63					
		y							
2	2.38	D	1	4.50					
		y		0.76					
		D	1½	5.56					
		y		1.01					
		D	2	6.63					
		y		1.22					
		D	2½	7.63					
		y		1.39					
		D	3	8.63					
		y		1.53					
3	3.50	D	1	5.56	7.63	8.63			
		y		0.81	0.55	0.77			
		D	1½	6.63		9.63	10.75		
		y		1.12		0.65	0.85		
		D	2	7.63			11.75	12.75	14.00
		y		1.36			0.76	0.90	1.06
		D	2½	8.63				14.00	15.00
		y		1.58				0.85	0.97
		D	3	9.63					16.00
		y		1.77					0.89

[1] $D = D_1$, $y = y_1$ for single or inner layer; $D = D_0$, $y = y_2$ for outer layer.

TABLE V. VALUES OF *y* (EFFECTIVE THICKNESS) FOR SINGLE-LAYER AND DOUBLE-LAYER INSULATION[1]
(Continued)

Pipe Size (Inches)		Factors (Note 1)	Single Layer or Inner Layer Insulation		Outer Layer over Single Layer Insulation Thickness, Inches				
Nominal	OD (D_p)		Thk		1	1½	2	2½	3
4	4.50	*D*	1	6.63	8.63	9.63			
		y		0.87	0.59	0.84			
		D	1½	7.63		10.75	11.75		
		y		1.19		0.77	0.97		
		D	2	8.63			12.75	14.00	15.00
		y		1.47			0.88	1.09	1.24
		D	2½	9.63				15.00	16.00
		y		1.71				1.00	1.14
		D	3	10.75					17.00
		y		1.96					1.03
6	6.63	*D*	1	8.63	10.75	11.75			
		y		0.87	0.73	1.02			
		D	1½	9.63		12.75	14.00		
		y		1.24		0.93	1.24		
		D	2	10.75			15.00	16.00	17.00
		y		1.60			1.10	1.32	1.52
		D	2½	11.75				17.00	18.00
		y		1.90				1.22	1.41
		D	3	12.75					19.00
		y		2.17					1.32
8	8.63	*D*	1	10.75	12.75	14.00			
		y		0.95	0.74	1.14			
		D	1½	11.75		15.00	16.00		
		y		1.33		1.05	1.33		
		D	2	12.75			17.00	18.00	19.00
		y		1.68			1.24	1.49	1.72
		D	2½	14.00				19.00	20.00
		y		2.09				1.32	1.54
		D	3	15.00					21.00
		y		2.39					1.45

[1]D = D_1, y = y_1 for single or inner layer; D = D_0, y = y_2 for outer layer.

TABLE V. VALUES OF y (EFFECTIVE THICKNESS) FOR SINGLE-LAYER AND DOUBLE-LAYER INSULATION[1]
(Continued)

Pipe Size (Inches)		Factors (Note 1)	Single Layer or Inner Layer Insulation		Outer Layer over Single Layer Insulation Thickness, Inches				
Nominal	OD (D_p)		Thk		1	1½	2	2½	3
10	10.75	D	1	12.75	15.00	16.00			
		y		0.92	0.87	1.22			
		D	1½	14.00		17.00	18.00		
		y		1.42		1.04	1.35		
		D	2	15.00			19.00	20.00	21.00
		y		1.79			1.27	1.55	1.81
		D	2½	16.00				21.00	22.00
		y		2.14				1.46	1.71
		D	3	17.00					23.00
		y		2.46					1.62
12	12.75	D	1	15.00	17.00	18.00			
		y		1.04	0.80	1.16			
		D	1½	16.00		19.00	20.00		
		y		1.45		1.10	1.42		
		D	2	17.00			21.00	22.00	23.00
		y		1.83			1.35	1.64	1.93
		D	2½	18.00				23.00	24.00
		y		2.20				1.56	1.83
		D	3	19.00					25.00
		y		2.54					1.75
14	14.00	D	1	16.00	18.00	19.00			
		y		0.93	0.82	1.20			
		D	1½	17.00		20.00	21.00		
		y		1.36		1.14	1.48		
		D	2	18.00			22.00	23.00	24.00
		y		1.76			1.40	1.72	2.01
		D	2½	19.00				24.00	25.00
		y		2.14				1.64	1.92
		D	3	20.00					26.00
		y		2.50					1.84

[1] $D = D_1$, $y = y_1$ for single or inner layer; $D = D_0$, $y = y_2$ for outer layer.

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TABLE V. VALUES OF y (EFFECTIVE THICKNESS) FOR SINGLE-LAYER AND DOUBLE-LAYER INSULATION[1]
(Continued)

Pipe Size (Inches) Nominal	Pipe Size (Inches) OD (D_p)	Factors (Note 1)	Single Layer or Inner Layer Insulation Thk		Outer Layer over Single Layer Insulation Thickness, Inches: 1	1½	2	2½	3
16	16.00	D	1	18.00	20.00	21.00			
		y		0.94	0.84	1.23			
		D	1½	19.00		22.00	23.00		
		y		1.37		1.17	1.53		
		D	2	20.00			24.00	25.00	26.00
		y		1.79			1.46	1.79	2.10
		D	2½	21.00				26.00	27.00
		y		2.18				1.71	2.01
		D	3	22.00					28.00
		y		2.55					1.93
18	18.00	D	1	20.00	22.00	23.00			
		y		0.95	0.86	1.26			
		D	1½	21.00		24.00	25.00		
		y		1.39		1.20	1.57		
		D	2	22.00			26.00	27.00	28.00
		y		1.81			1.50	1.84	2.17
		D	2½	23.00				28.00	29.00
		y		2.21				1.77	2.09
		D	3	24.00					30.00
		y		2.59					2.01
20	20.00	D	1	22.00	24.00	25.00			
		y		0.95	0.87	1.28			
		D	1½	23.00		26.00	27.00		
		y		1.40		1.23	1.60		
		D	2	24.00			28.00	29.00	30.00
		y		1.82			1.54	1.89	2.23
		D	2½	25.00				30.00	31.00
		y		2.23				1.82	2.15
		D	3	26.00					32.00
		y		2.62					2.08

[1] $D = D_1$, $y = y_1$ for single or inner layer; $D = D_0$, $y = y_2$ for outer layer.

TABLE V. VALUES OF y (EFFECTIVE THICKNESS) FOR SINGLE-LAYER AND DOUBLE-LAYER INSULATION[1]

(Continued)

Pipe Size (Inches)		Factors (Note 1)	Single Layer or Inner Layer Insulation		Outer Layer over Single Layer Insulation Thickness, Inches				
Nominal	OD (D_p)		Thk		1	1½	2	2½	3
24	24.00	D	1	26.00	28.00	29.00			
		y		0.96	0.89	1.31			
		D	1½	27.00		30.00	31.00		
		y		1.41		1.26	1.66		
		D	2	28.00			32.00	33.00	34.00
		y		1.85			1.60	1.97	2.33
		D	2½	29.00				34.00	35.00
		y		2.27				1.91	2.26
		D	3	30.00					36.00
		y		2.68					2.19
30	30.00	D	1	32.00	34.00	35.00			
		y		0.97	0.91	1.34			
		D	1½	33.00		36.00	37.00		
		y		1.43		1.31	1.72		
		D	2	34.00			37.00	39.00	40.00
		y		1.87			1.67	2.06	2.44
		D	2½	35.00				40.00	41.00
		y		2.31				2.00	2.37
		D	3	36.00					42.00
		y		2.73					2.31
36	36.00	D	1	38.00	40.00	41.00			
		y		0.97	0.92	1.37			
		D	1½	39.00		42.00	43.00		
		y		1.44		1.33	1.76		
		D	2	40.00			44.00	45.00	46.00
		y		1.90			1.72	2.12	2.52
		D	2½	41.00				46.00	47.00
		y		2.34				2.07	2.46
		D	3	42.00					48.00
		y		2.77					2.40

[1] $D = D_1$, $y = y_1$ for single or inner layer; $D = D_0$, $y = y_2$ for outer layer.

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TABLE V. VALUES OF y (EFFECTIVE THICKNESS) FOR SINGLE-LAYER AND DOUBLE-LAYER INSULATION[1]
(Continued)

Pipe Size (Inches)		Factors (Note 1)	Single Layer or Inner Layer Insulation		Outer Layer over Single Layer Insulation Thickness, Inches				
Nominal	OD (D_p)		Thk		1	1½	2	2½	3
40	40.00	D	1	42.00	44.00	45.00			
		y		0.98	0.93	1.38			
		D	1½	43.00		46.00	47.00		
		y		1.45		1.35	1.78		
		D	2	44.00			48.00	49.00	50.00
		y		1.91			1.74	2.16	2.60
		D	2½	45.00				50.00	51.00
		y		2.36				2.12	2.52
		D	3	46.00					52.00
		y		2.80					2.46

[1] $D = D_1$, $y = y_1$ for single or inner layer; $D = D_0$, $y = y_2$ for outer layer.

TABLE VI. SQUARE FEET PER LINEAR FOOT OF PIPE, BARE

Pipe Size, IPS or Nominal (Inches)	Bare	Pipe Size, IPS or Nominal (Inches)	Bare
½	.220	10	2.82
¾	.272	12	3.37
1	.346	14	3.66
1½	.500	16	4.18
2	.625	18	4.71
3	.917	20	5.25
4	1.18	24	6.30
6	1.74	30	7.85
8	2.26	36	9.44

°F = Mean Temperature, $\frac{(t_1 + t_a)}{2}$. t_a = 80 F.

k = Btu/inch thickness/hr/sq ft/°F.

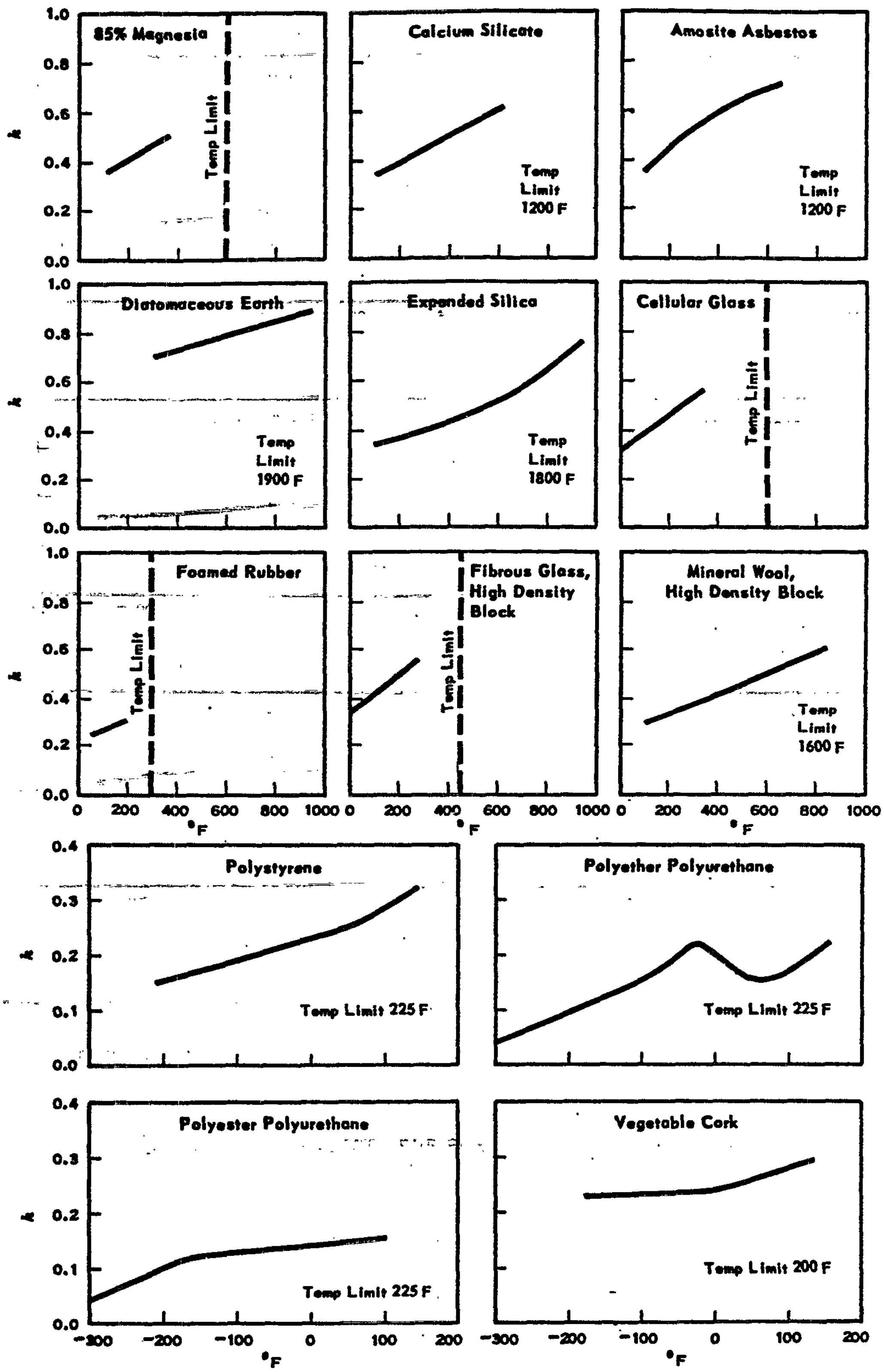
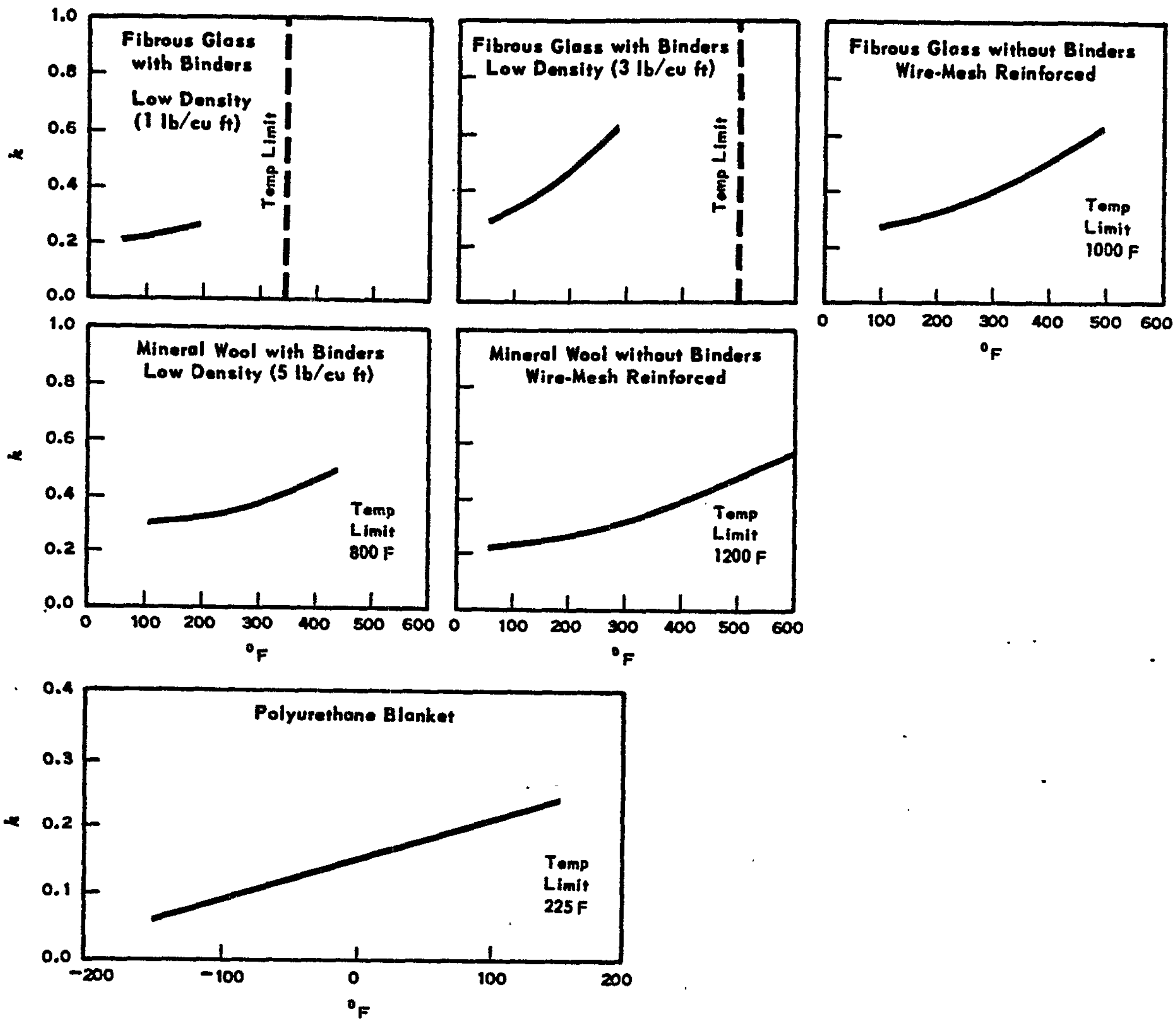


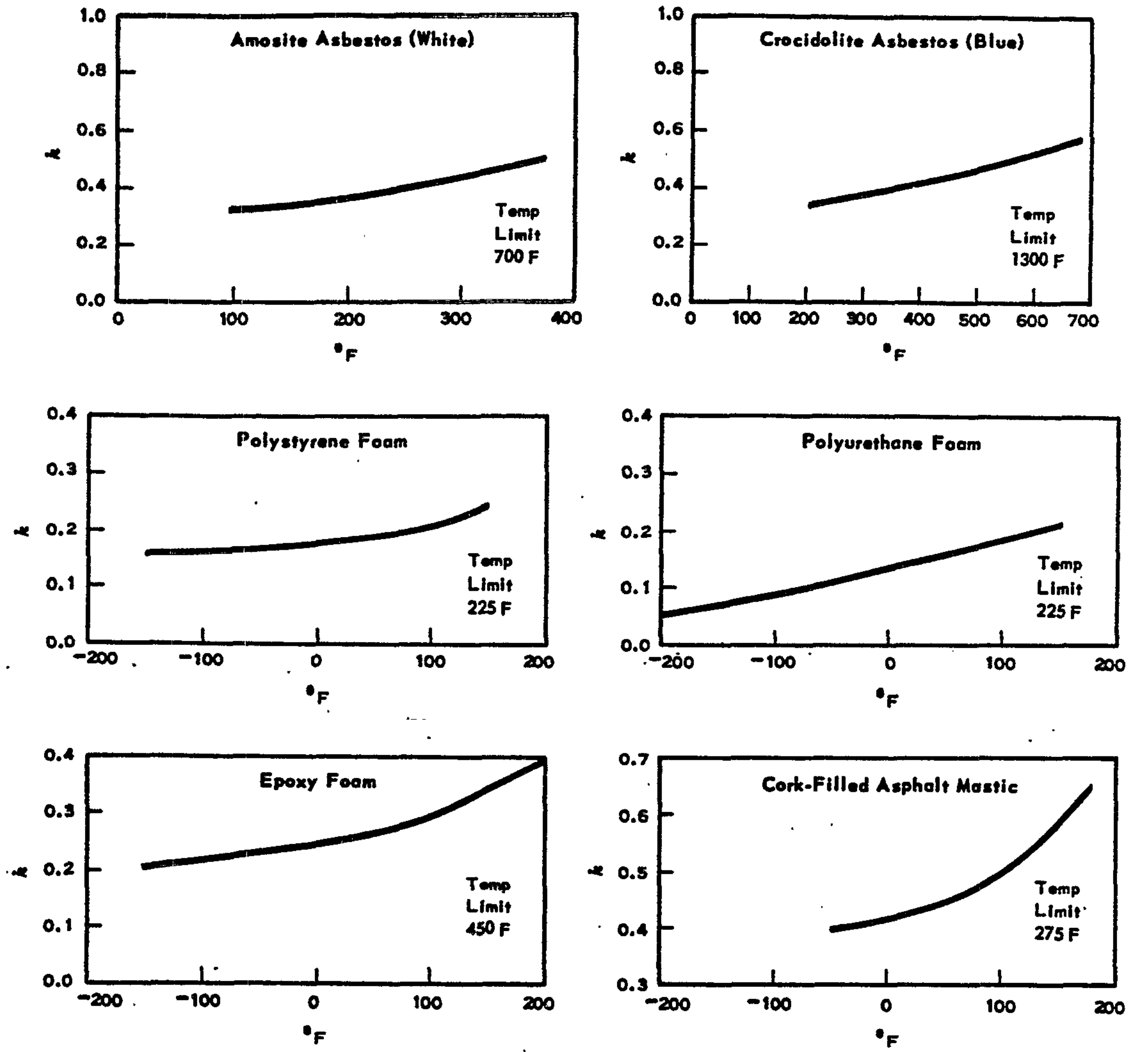
FIGURE 2. MEAN CONDUCTIVITY FACTORS FOR RIGID INSULATION MATERIALS



°F = Mean Temperature, $\frac{(t_1 + t_a)}{2}$. t_a = 80 F.

k = Btu/inch thickness/hr/sq ft/°F.

FIGURE 3. MEAN CONDUCTIVITY FACTORS FOR BLANKET OR BATT INSULATION MATERIALS



°F = Mean Temperature, $\frac{(t_1 + t_a)}{2}$. t_a = 80 F.

k = Btu/inch thickness/hr/sq ft/°F.

FIGURE 4. MEAN CONDUCTIVITY FACTORS FOR FOAMED AND SPRAYED INSULATION MATERIALS

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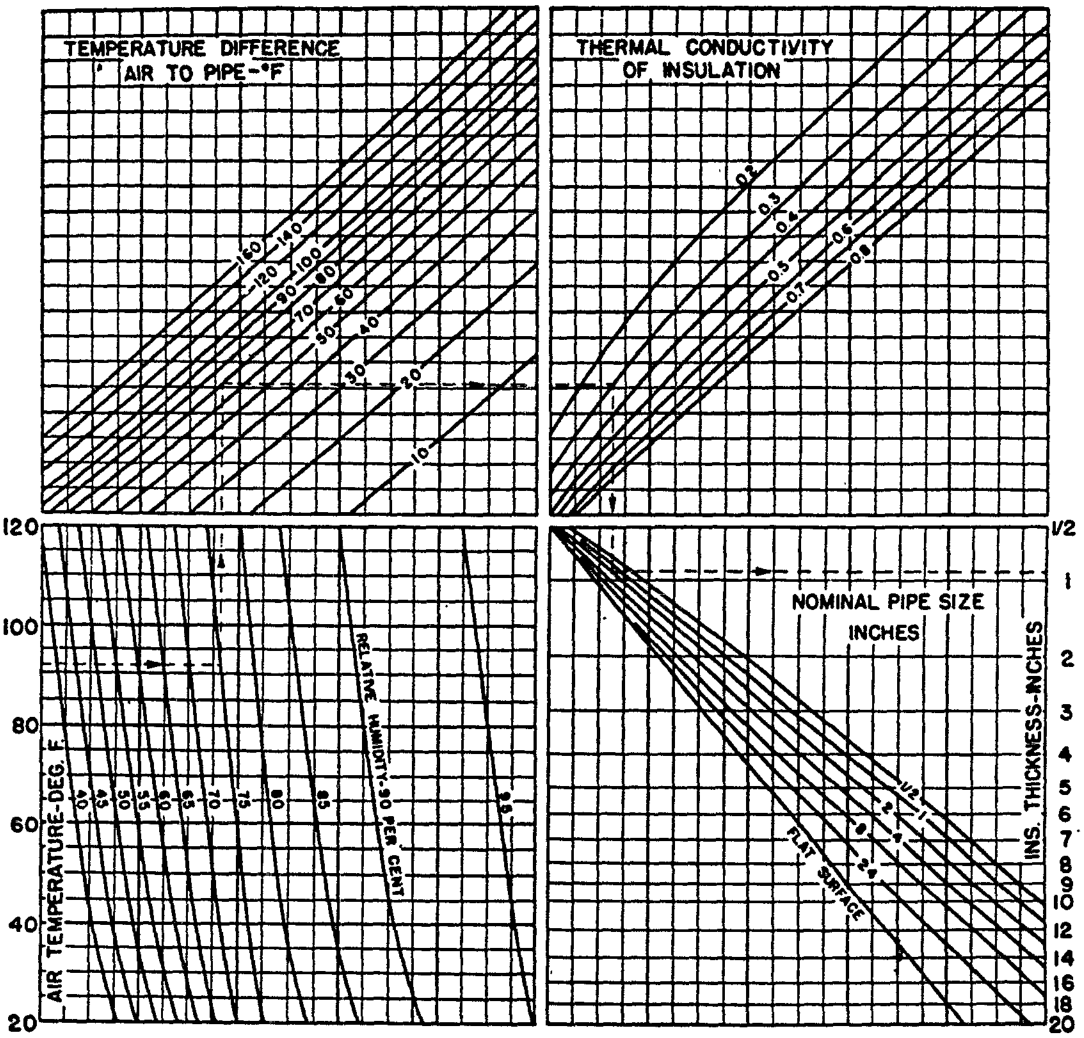

FIGURE 5. THICKNESS OF PIPE INSULATION TO PREVENT CONDENSATION ON OUTER SURFACE