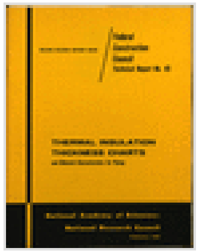

Thermal Insulation Thickness Charts and Material Characteristics for Piping (1963)

Pages
26

Size
8.5 x 10

ISBN
0309359066

Task Group T-29 on Thermal Insulation for Piping; Federal Construction Council

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*Advisory Committee to the Federal Construction Council

THERMAL INSULATION THICKNESS CHARTS
and Material Characteristics for Piping

Report Number 45 for the Federal Construction Council

by

Task Group T-29 (Reconvened)

Building Research Advisory Board

Division of Engineering and Industrial Research

NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

Washington, D. C.

1963

This report was prepared under Contract No. CST-690 between the National Academy of Sciences and the National Bureau of Standards, and published by the National Academy of Sciences with the concurrence of the Operating Committee of the Federal Construction Council. Requests for permission to reprint or quote extensively from this report should be directed to the National Academy of Sciences.

Price: $2.00

Available through the
Printing and Publishing Office
National Academy of Sciences—
National Research Council
Washington 25, D. C.

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Library of Congress Catalog Card Number: 63-60043

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ACKNOWLEDGMENT

This report represents the efforts of Task Group T-29 (Reconvened) on Thermal Insulation Thickness Charts and Material Characteristics, and does not necessarily reflect the opinions of the National Academy of Sciences—National Research Council. This Task Group was composed of highly qualified individuals who, at the request of the Operating Committee of the Federal Construction Council, gave freely of their time, knowledge, and effort.

The Building Research Advisory Board appreciates the contributions that have been made and takes this opportunity to acknowledge with gratitude the efforts of the Task Group. In addition, it would like to thank all who gave assistance to the Task Group through either correspondence or personal contact.

RICHARD H. TATLOW III, Chairman
Building Research Advisory Board

FOREWORD

Technical Report No. 41, THERMAL INSULATION FOR PIPING, prepared by the Federal Construction Council and published by the National Academy of Sciences—National Research Council in 1960, described a proposed method of calculating insulation thickness on the basis of economic considerations. While the method described was useful and accurate, it was recognized as unnecessarily time-consuming; consequently, a recommendation was made in Report No. 41 that the National Insulation Manufacturers Association (NIMA) prepare tables for determining the thickness of insulation. At least partly in response to this recommendation, NIMA prepared a manual entitled <u>How to Determine Economic Thickness of Insulation</u>. This manual is broad is scope, covers a large number and wide range of variables, and is applicable to a variety of pertinent situations. In view of the fact that most of the variables are constant for Government construction work, it was decided that concise tables could and should be devised to satisfy the limited needs of Government engineers. The first part of this report, then, is devoted to the development and explanation of such tables.

The second part of this report treats the fundamental properties of insulating materials, knowledge of which is essential to proper evaluation and selection. Report No. 41 called attention to the inadequacy of such information in existing specifications, and the incomplete understanding which exists as to those properties or characteristics which are important and/or measurable.

CONTENTS

TABLES

INTRODUCTION

1.0 Objectives

1.1 To determine whether the NIMA manual "How to Determine Economic Thickness of Insulation" meets the needs of FCC agencies.

1.2 To determine the numerical values required for computation of insulation thicknesses.

1.3 To prepare thickness tables, based on these computations, for elevated-temperature insulations (above 80° F).

1.4 To determine the important properties that an insulation for piping should possess.

2.0 Scope and Limitations

2.1 The study has been divided into two principal parts--the development of tables from which the proper thickness of piping insulation can be easily and rapidly determined, and the determination of the most important properties which should be possessed by piping insulation.

2.2 Thickness tables include piping insulations for 80° - 400° F service heating systems, other than underground heat-distribution systems. (Thickness tables for underground heat distribution systems are presented in FCC Technical Report No. 30R.)

3.0 Conduct of the Study

A group of Federal-agency engineers, specialists in the problems of insulation materials and costs, was appointed by the Operating Committee of the Federal Construction Council to conduct this study. The NIMA manual was reviewed in detail by this Task Group. The data necessary for use in the basic formulas for computation presented in the NIMA manual, such as fuel and insulation costs, labor, overhead, and plant investment, were obtained from both Government and industry sources.

CONCLUSIONS AND RECOMMENDATIONS

Part A. Required Thickness of Insulation

1.0 The method of calculation in the National Insulation Manufacturers Association manual How to Determine the Economic Thickness of Insulation[1] is fundamentally sound.

2.0 The thickness charts shown in this report (Tables I, II, III) should be used by FCC agencies when specifying the required thickness of heat insulation for piping.

Part B. Insulation Criteria, Physical Properties, and Test Methods

1.0 Known insulation specifications include data on too few physical properties, and, consequently, are inadequate for current use by FCC agencies.

2.0 Comprehensive insulation criteria should include reference to the following physical properties:

a. Thermal conductivity based on a specified mean temperature.

b. Chemical compatibility with adhesives, coverings, and piping.

c. Combustibility.

d. Compressive strength.

e. Density (in pounds per cubic foot).

f. Flexural strength.

g. Thermal shrinkage.

h. Temperature limits -- maximum and minimum for continuous and intermittent operation.

3.0 ASTM standard test methods (as cited in this report) should be used for determining the existence and quantitative measure of the above properties, wherever possible.

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[1] National Insulation Manufacturers Association, How to Determine Economic Thickness of Insulation, July, 1961.

4.0 Pending development of improved materials specifications by others, current Federal specifications should be used for insulating materials. However, Federal specifications should be strengthened--as expeditiously as possible--to include all the properties listed in 2.0 above.

In addition,

5.0 ASTM should be requested to revise its insulation specifications to include the twelve characteristics listed in 2.0 above.

SUPPLEMENTARY INFORMATION

Part A. Required Thickness of Insulation

1.0 NIMA Manual

The NIMA manual presents a basic graph-and-table method of determining economic thickness of insulation. In addition, it includes the development of the general equations for economic thickness of pipe and flat-surface insulation published by L. B. McMillan in 1926.

Prior to publication of the NIMA manual, the calculation of optimum thicknesses on an economic basis was a time-consuming effort even though a sound formula had been established. Because of the numerous variables to be considered--including costs of heat energy and insulation, capital investment, and insulation conductivities at various temperatures--separate calculations were necessary for each piece of equipment and each pipe run. The NIMA manual has incorporated a sufficiently-wide variety of design conditions and necessary tables and charts to cover essentially all needs of the designers and users of heating systems.

In this light, the manual, in the hands of an experienced engineer, is a valuable tool for determining insulation thicknesses. However, there remains difficulty in the assignment of numerical values to the variable factors included in the necessary mathematical computations for Federal-government work. Therefore, a major part of this study was directed toward the development of reliable data on capital investment, fuel costs, and installed insulation costs relevant to the Federal government for use in establishing valid parameters.

2.0 Thickness Charts

2.1 Basic Data Used for Computation of Thickness Charts

The thickness charts contained herein are based on the method and formulas in the NIMA manual. The values obtained for use in computations, and the method by which they are employed, are as follows:

a. Cost of steam. Taking the actual cost that one Federal agency charges for steam use, supplemented by additional analyses of steam costs of other agencies, a base value of $1.25 per 1000 pounds of steam was determined to be the current (1962) cost of steam provided by Government agencies.

b. Installed cost of insulation. To establish insulation costs, data were collected from manufacturers, contractors, and Government agencies. Five insulation materials with acceptable thermal conductivity were selected, and a table of comparison was prepared integrating installation costs with heat-loss costs over a period of ten years. The insulating material providing the most economical combination of initial and operating costs was used for determining that a range of $1.13 - $2.00 was representative of the cost per linear foot of installed insulation per inch thickness on a one-inch pipe.

c. Capital investment. Capital investment in plant facilities was obtained by analyzing the costs of a number of Government installations, of both military and civilian agencies, ranging in size from 10,000 to 75,000 pounds per hour capacity. The resulting average capital investment was $12.57 per pound of steam.

d. Depreciation. Since all funds are Congressionally-appropriated each year, the sinking-fund approach to depreciation is inapplicable to Government agencies. Consequently, the use of high-grade materials which offer extended service life is preferable, and a straight-line depreciation of ten years was utilized in the computations.

e. Operating and ambient temperatures. Operating temperatures were based on conditions of 220° F water, low-pressure steam, and high-pressure steam or high-temperature water. Ambient temperature was based on indoor condition of 60° F.

2.2 Procedure for Computation of Thickness Tables

After the basic data were established, the NIMA manual and the method contained therein were utilized to prepare the tables.

a. Using the insulation material found to provide the most economical combination of installed and heat-loss costs for a ten-year period, thicknesses of insulation costing $1.13, $1.18, $1.33, $1.53, and $2.00 per inch thickness on a one-inch pipe installed, were calculated for each of the three temperature conditions (220°, 300°, 400° F) for various pipe sizes and thermal conductivity.

b. These five thicknesses were then combined and made into one thickness on the following basis: If three or more were less than mid-way between the available thicknesses, the smaller thickness was used (Fig. 1); if three or more were more than half way to the next available thickness, the greater thickness was used (Fig. 2). Insulations are manufactured in increments of 1/2-inch thickness, and therefore exact calculated values cannot be used.

CALCULATED THICKNESS OF INSULATION

Thermal Conductivity (k)	Derived Thickness for Chosen Temperature Condition, based on installed cost (in.)					Thickness Used (in.)
0.25	2.0	2.0	2.2	2.5	2.2	2.0

Fig. 1

CALCULATED THICKNESS OF INSULATION

Thermal Conductivity (k)	Derived Thickness for Chosen Temperature Condition, based on installed cost (in.)					Thickness Used (in.)
0.25	2.0	2.0	2.4	2.5	2.4	2.5

Fig. 2

c. After a single table for each temperature range was prepared, the thicknesses were reviewed and made consistent and/or progressive. For example, if a 3-inch pipe required a 2-1/2-inch thickness of insulation while a 4-inch pipe required a 2-inch thickness, the thickness for the 4-inch pipe was arbitrarily increased to 2-1/2 inches.

d. A final chart was then prepared for the three temperature ranges.

e. As a final check, the charts were compared with those now in use by the Government and those recommended by the manufacturers. This final analysis revealed that values were equal to or higher than those of previous charts; in no case are the thicknesses less than those generally used.

TABLE I

OPTIMUM THICKNESS OF PIPE INSULATION

(operating at temperatures from 80° to 220° F)

Thermal Conductivity (k)	Pipe Size (in.)						
	2 or less	2-1/2 - 3	4	5 - 6	8	10	12
0.25	1.0	1.0	1.5	1.5	1.5	1.5	2.0
0.30	1.0	1.0	1.5	1.5	1.5	1.5	2.0
0.35	1.0	1.0	1.5	1.5	1.5	2.0	2.0
0.40	1.0	1.5	1.5	1.5	1.5	2.0	2.0
0.45	1.0	1.5	1.5	2.0	2.0	2.0	2.5
0.50	1.0	1.5	1.5	2.0	2.0	2.0	2.5
0.55	1.5	1.5	2.0	2.0	2.0	2.5	2.5
0.60	1.5	1.5	2.0	2.0	2.0	2.5	2.5

TABLE II

OPTIMUM THICKNESS OF PIPE INSULATION

(operating at temperatures from 221° to 300° F)

Thermal Conductivity (k)	Pipe Size (in.)						
	2 or less	2-1/2 - 3	4	6	8	10	12
0.25	1.5	1.5	1.5	2.0	2.0	2.0	2.0
0.30	1.5	1.5	1.5	2.0	2.0	2.0	2.0
0.35	1.5	1.5	2.0	2.0	2.5	2.5	2.5
0.40	1.5	1.5	2.0	2.0	2.5	2.5	2.5
0.45	1.5	2.0	2.0	2.5	2.5	2.5	2.5
0.50	1.5	2.0	2.0	2.5	2.5	2.5	2.5
0.55	2.0	2.0	2.0	2.5	2.5	2.5	3.0
0.60	2.0	2.0	2.0	2.5	2.5	2.5	3.0

TABLE III

OPTIMUM THICKNESS OF PIPE INSULATION

(operating at temperatures from 301° to 400° F)

Thermal Conduc-tivity (k)	Pipe Size (in.)						
	2 or less	2-1/2 - 3	4	6	8	10	12
0.25	1.5	1.5	2.0	2.5	2.5	2.5	2.5
0.30	1.5	1.5	2.0	2.5	2.5	2.5	2.5
0.35	2.0	2.0	2.0	2.5	3.0	3.0	3.0
0.40	2.0	2.0	2.0	2.5	3.0	3.0	3.0
0.45	2.0	2.0	2.5	3.0	3.0	3.0	3.5
0.50	2.0	2.0	2.5	3.0	3.0	3.0	3.5
0.55	2.5	2.5	2.5	3.0	3.5	3.5	3.5
0.60	2.5	2.5	2.5	3.0	3.5	3.5	3.5

3.0 Future Needs

The development by NIMA of a manual for calculating the thickness of heat insulations was of great value. The same effort is strongly urged for low-temperature insulations (below ambient).

It should be noted that the method of calculating thicknesses for low temperatures is well established. The major problem now encountered is that of establishing the ambient design conditions to be used in the formulas.

PART B. INSULATION CRITERIA

1.0 General

It is the considered opinion of the Task Group that all insulation criteria presently available are deficient in that they lack information on a sufficient number of properties or characteristics to permit adequate evaluation and effective use. It is hoped that this report will encourage the organizations involved to improve specifications as suggested herein.

2.0 Insulation Characteristics

Comprehensive criteria for an insulating material should include information on the following twelve characteristics: Thermal conductivity, absorptivity, chemical compatibility, combustibility, compressive strength, density, flexural strength, resistance to acids, resistance to caustics, resistance to abrasion, temperature limits, and shrinkage. Additional insulation characteristics are sometimes important for specific applications, and, in these cases, the list should be supplemented as required.

While all twelve characteristics are considered minimum for a complete specification, an analysis of available test methods, and of the significance of the numerical values obtainable from tests, revealed that only eight of the twelve could be designated with sufficient accuracy for use at the present time. The following list contains a brief description of these eight characteristics, and the applicable test procedure where such is presently available.

1. Thermal conductivity (k). The most important property of an insulation is its thermal conductivity, which is the measure of heat flow through an insulating material. Results are reported in terms of BTU per hour per degree Fahrenheit per inch thickness, for a dry insulation specimen at a specified mean temperature. ASTM Test Procedure C-177 is recognized as the absolute method. Test Procedure C-335 is applicable only to insulations that are produced in pipe form, and its results are not directly comparable with C-177 results.

2. Chemical compatibility with adhesives, coverings, and piping. Clarification of this property is made difficult by the variations with the material combinations involved; it needs to be established in each instance for the specific combination of insulating material with sealant or covering. As an example, an aluminum reflective insulating material should not be sealed with an adhesive containing corrosive salts, since the aluminum will corrode and deteriorate. If nothing else, the alkalinity (pH) should be specified.

3. Combustibility. Knowing the combustibility of a material is necessary if the degree of fire hazard which will exist is to be determined. However, determining combustibility is difficult, involving many considerations such as flash point, fire point, self-ignition point, rate of burning, flame spread, and melting point. In addition, there is no substantial agreement as to the meaning of some of the terms--such as flame. For this very important property, no satisfactory standard method of test has yet been established, and the manufacturer's test results should be used.

4. Compressive strength. A measure of mechanical strength, this characteristic covers the ability of a material to withstand a straight-line squeeze action uncrushed. Results are reported in psi at given percentages of deformation (usually 5 percent). ASTM Test C-165 is commonly used to determine compressive strength.

5. Density. This is the weight per unit volume of a given material, in pounds per cubic foot; its importance lies in the fact that many other properties of an insulation will vary with density. For a given material, a change in density may result in a change in the most important property, thermal conductivity. ASTM Tests C-302 and C-303 are considered suitable for density measurement.

6. Flexural strength. Representative of a combination of properties, the flexural strength of a material is an indication of its ability to bend without breaking or cracking. It is important in heat insulation because of the cyclic operation of the lines, with resultant expansion and contraction and piping sag due to pipe-support locations. Results are reported in psi at a specified deflection. ASTM Tests C-203 and C-446 can be used to measure flexural strength of various insulating materials, depending on composition.

7. Shrinkage. A measure of change in length and width of an insulating material after exposure to maximum heat, shrinkage is reported in terms of a percentage at the maximum service temperature. ASTM Test C-356 can be used to measure shrinkage for most insulating materials.

8. Temperature limits. When a material is developed, data are obtained that indicate at what extremes of temperature the material will no longer function effectively. These limits must be known to enable the designer to select the proper material for his service conditions. Temperatures are reported in terms of maximum and minimum values for continuous and intermittent service. (Since a particular insulation is likely to be a composite of several different materials, each with its own temperature limits and properties, no one test can be used to establish temperature limits for a specific insulation, and reliance on the manufacturer's recommendation is necessary.)

3.0 ASTM Test Procedures

Government engineers preparing specifications are confronted with a large number and variety of available test procedures, codes, and standards. ASTM is recognized for its standard test methods and procedures, most having been validated. Whenever possible, reference should be made to ASTM test procedures. Only when there are insulating characteristics of particular concern to an agency for which ASTM has not yet prepared a procedure should other acceptable test methods be utilized.

4.0 Existing Insulating Material Criteria

After reviewing insulating criteria published by various organizations, it was determined that Federal specifications contained information on the largest number of properties, and therefore better met the needs of the agencies of the Federal Construction Council. For this reason, the Task Group concludes that, pending development of improved specifications by other organizations, Federal specifications should be used for insulating materials. However, the Task Group also urges that Federal specifications be revised at the earliest possible date, to insure coverage of the twelve insulation properties cited herein as being significant.

5.0 Future Insulating Material Criteria

It has come to the attention of the Task Group that ASTM Committee C-16 (Thermal Insulation) has formed a subcommittee to investigate the philosophy of ASTM insulation specifications. It is hoped that this subcommittee will recommend the revision of existing ASTM insulation specifications to include the twelve properties listed in paragraph 2.0 above, and also recommend the development of standard tests for these properties where necessary.