offered as a guide to current practice in heating and air conditioning. It is based on practice in a number of consulting engineers' offices and information extracted from Reference 7. It should be borne in mind that selection of material to be used will also be influenced by the familiarity of local artisans with methods of using different materials.

REFERENCES

[1] American Standard Code for Pressure Piping, *ASA* B-31.1—1942, *American Standards Association.*

[2] See *API Specification* 5L *for Line Pipe, American Petroleum Institute.*

[3] *Standard Manual on Pipe Welding (Heating, Piping and Air Conditioning Contractors National Association,* Second Edition, 1951). *Welding Handbook (American Welding Society,* 1942).

[4] *ASME* Power Boiler Code, *American Society of Mechanical Engineers.*

[5] Marine Engineering Regulations of the Coast Guard, *American Bureau of Shipping.*

General Specifications for Inspection of Material, Appendix VII, Welding, *U. S. Navy.* Specifications for Welding, Appendix 5, Part 1—General—for Vessels of the *U. S. Navy, Bureau of Ships,* April, 1940.

[6] See (1) *Piping Handbook,* by Sabin Crocker (McGraw-Hill Co.); (2) *A Manual for The Design of Piping for Flexibility by the Use of Graphs,* by E. A. Wert, S. Smith, E. T. Cope (The Detroit Edison Company).

[7] Control Valves and Positioners, by C. S. Beard (*Industry and Power,* Vol. 64 March, 1953, p. 67–101).

CHAPTER 27

PIPE AND INDUSTRIAL INSULATION

Industrial Insulation: Uses, Properties, Temperature Range of Use, Temperature Limitations, Forms; Bare Surface Heat Loss; Conductivities; Heat Flow Calculations; Thickness for Application; Economical Thickness; Low Temperature Insulation; Insulation to Prevent Freezing; Application; Underground Insulations

THE PAST 50 years have seen an enormous increase in the use of thermal insulation by industry. Where once it was not uncommon to see hot water and steam lines, and even boiler surfaces, uninsulated, it is now rare indeed to see any surface operating more than a little above or below ambient temperature without insulation. Higher costs of fuel, increased efficiency of industrial operations, and the necessity for close control of the temperature of industrial processes are among the factors which have caused this greatly increased usage of thermal insulation.

USES OF INDUSTRIAL INSULATION

Thermal insulation serves five principal purposes: (1) to conserve heat or some other form of energy, for example, electrical energy to operate a refrigeration compressor; (2) to increase the comfort of living spaces; (3) to facilitate control of the temperature of a process; (4) to reduce the temperature of the shell of a pressure vessel; and (5) to control the external temperature of the insulated space in order to avoid danger to personnel, to protect surrounding structural members from damage by high temperature, to reduce the temperature of working spaces, and, in case of equipment operating below ambient temperatures, to prevent sweating or icing at the warmer surface. Depending on the application, one or another purpose may govern the choice of insulation; usually two or more are concurrently of importance.

PROPERTIES OF INSULATIONS

Low thermal conductivity is the property that distinguishes a thermal insulation. Thermal conductivity is defined as *the rate of heat flow through unit area of a homogeneous substance under the influence of unit temperature gradient in the direction perpendicular to the area.* Many units have been used to express thermal conductivity but the most common engineering unit is Btu per (hour) (square foot) (Fahrenheit degree per inch of thickness). The usual symbol for thermal conductivity is k.

Reflective insulations, such as aluminum, and steel coated with a reflecting coating, depend not upon low thermal conductivity for their resistance to heat flow, but upon the low thermal emissivity of their surfaces and subdivision of the air space. To be effective in retarding heat flow by radiation, the reflective surface must face an air space.

Thermal conductivity values of the most commonly used industrial and pipe insulations are shown in Table 1. These values have been selected as typical and useful for engineering calculations, and may or may not apply to a particular material or application. For accurate values for a particular