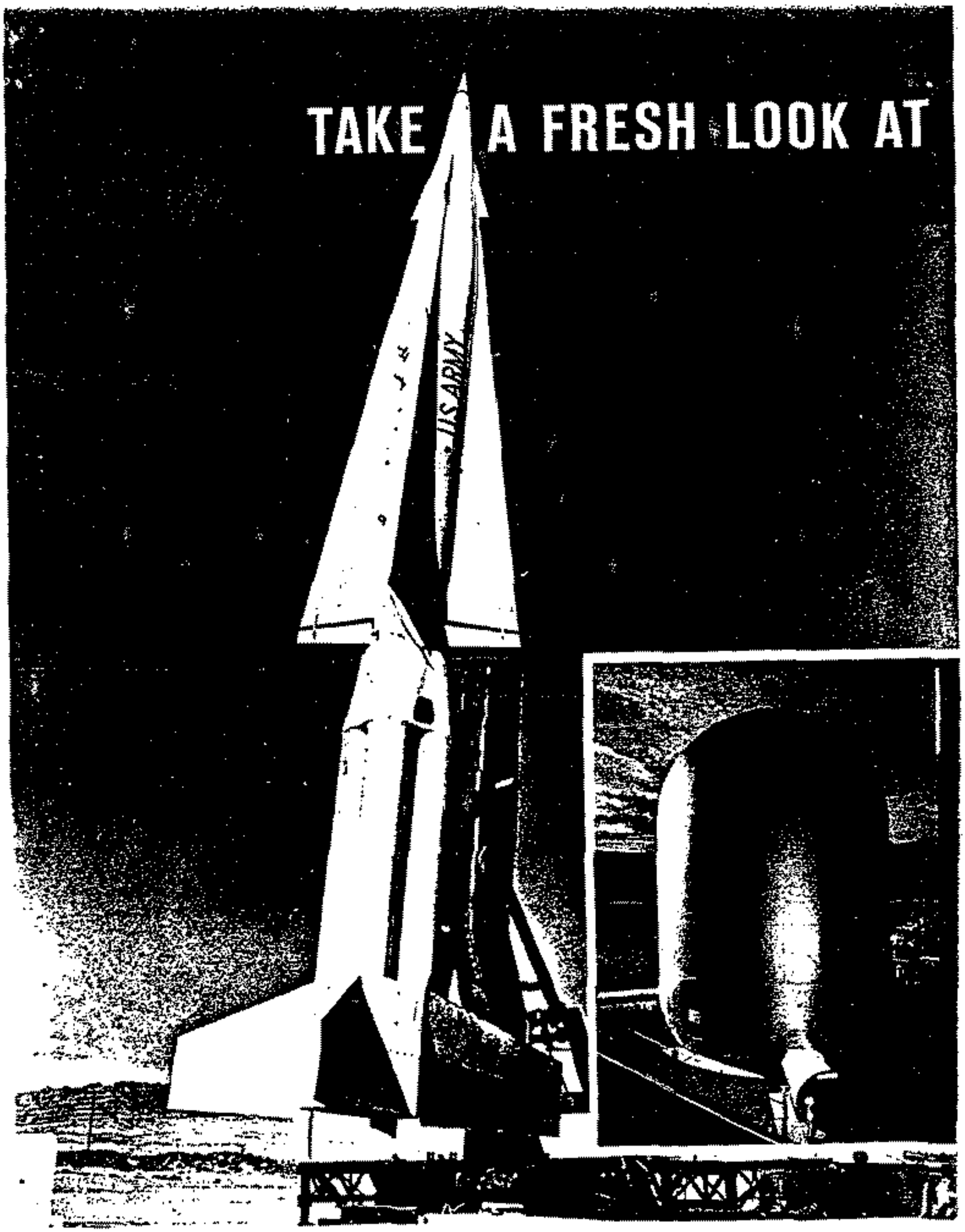
RE-THINKING THERMAL INSULATION

000914

Your guide to the best use of thermal insulations under the changing conditions of modern industry . . . how insulation saves, controls, and protects

NATIONAL INSULATION MANUFACTURERS ASSOCIATION


TAKE A FRESH LOOK AT
US ARMY

INSULATION

As even the most faithful servant works better if not taken for granted, thermal insulation will serve more efficiently and more economically if scrutinized anew each time it is specified. New methods, materials, and total costs make these questions imperative: Could your insulation do its job better? Could you *save more money?*

The mind-stirring achievements in space-probes, astronautics, missiles, and atomics dramatize what is an old story to the insulation engineer: certain processes just won't work without the right kind and the right amount of thermal insulation. With delicate instruments operating in an environment of extremes of temperature—from liquid oxygen at take-off to the undimmed radiation of the sun in clear space, and the friction of re-entry into our atmosphere—insulation makes it all possible. Dogs, monkeys—and yes, men—would not survive more than minutes in space without insulation.

Here on earth these two functions of insulation—process control and personnel protection—are joined by a third, saving money. A few hundred dollars more invested in adequate insulation for a new plant could save many thousands in a few years!

Heat energy is becoming more valuable every day, with rising fuel and labor costs. Although the cost of insulation is normally written off in a relatively short period, it continues to afford savings for the life of the installation. For maximum savings, you need close figuring. Routine repetition of old specifications will get the job done, but a lot of money will be wasted.

General or "rule-of-thumb" specifications and tables in catalogs and handbooks should be consulted only as approximate guides to the requirements of the new job. Each job should be figured separately by the "economic thickness" method recommended by the National Insulation Manufacturers Association and demonstrated in these pages. You may actually need less insulation and thus save on material cost; or the job may prove to need as little as an extra half-inch that will cost slightly more but will save many times its cost in a few years, a few months—or even immediately, if in addition to fuel savings it permits a reduction of capital expenditures for heating or cooling equipment.

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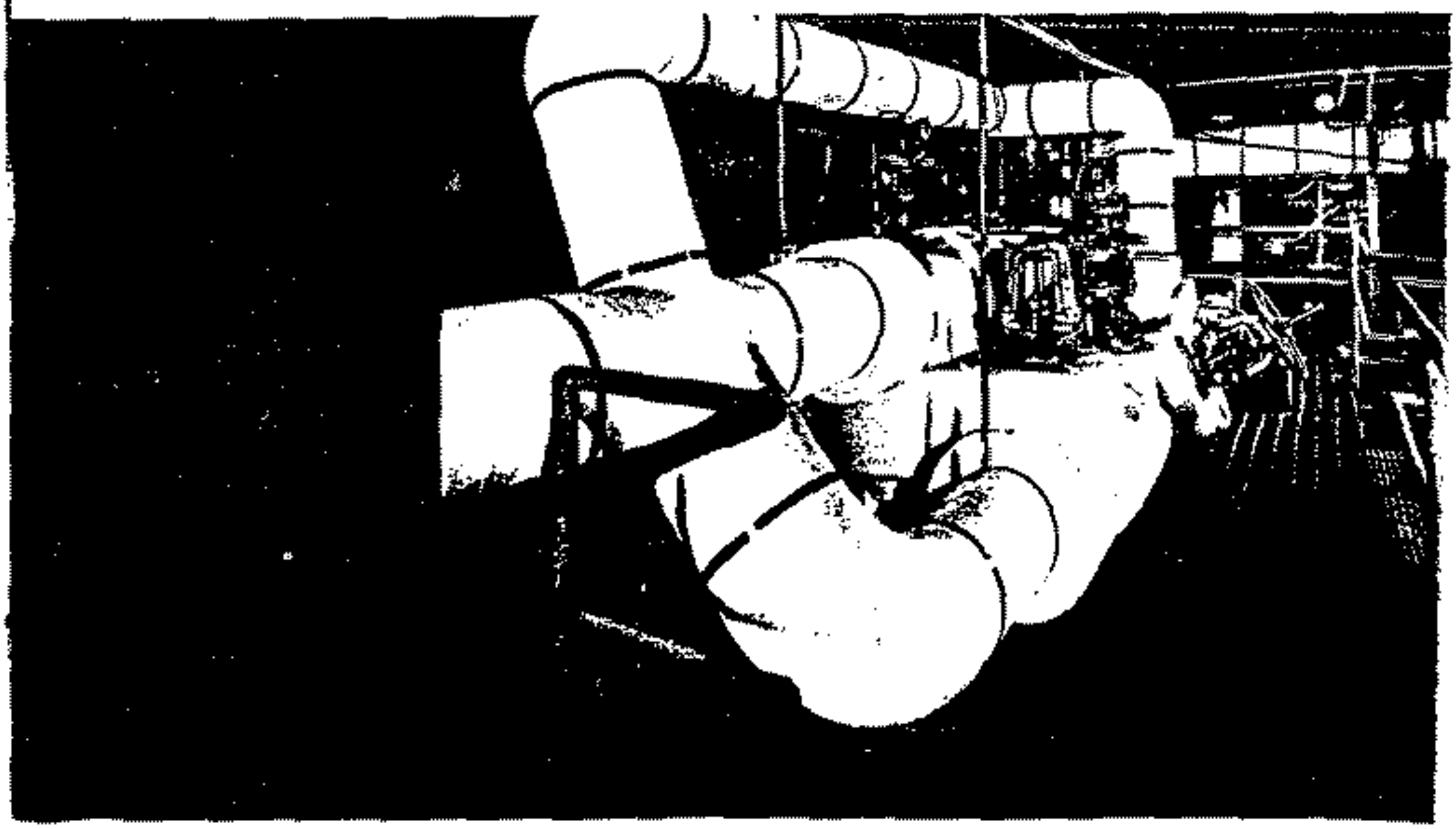
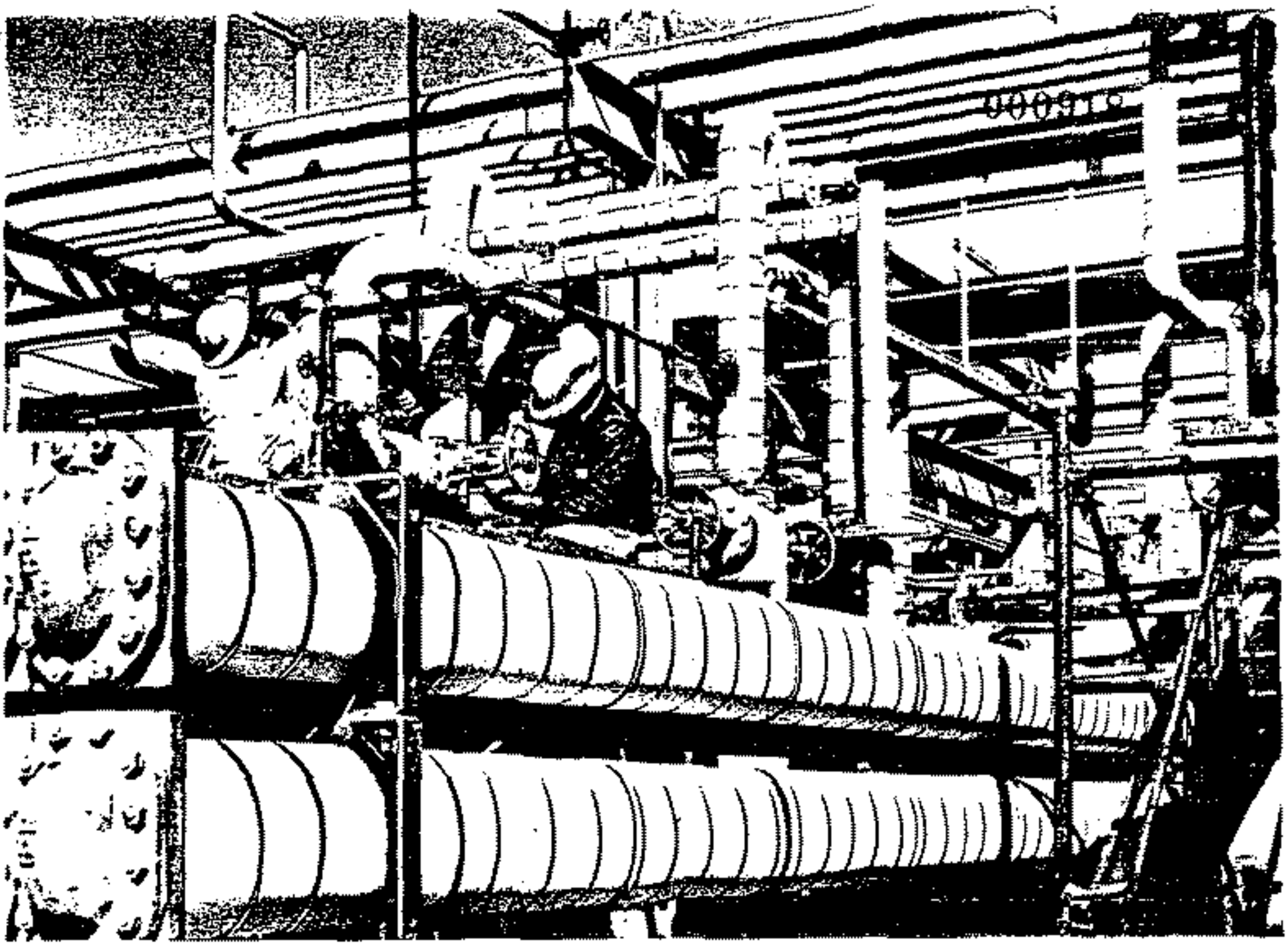
4 TO INSULATE

1 SAVE MONEY In insulating to keep heat energy where we want it, not going to waste all along a system, the basic criterion is "Economic Thickness." *This is the thickness at which the cost of* insulation gives best return on your money, considering both operating and capital costs. Whether we're dealing with power generation, a chemical processing plant, refrigeration, or heating and air conditioning, the economic thickness is that increment beyond which the extra *cost of the applied insulation would outweigh* the cost of the energy or the equipment it saves.

A thought for the future: If your calculations point to another increment only a little way up the curve, specify it now. Fuel and energy costs will continue to rise.





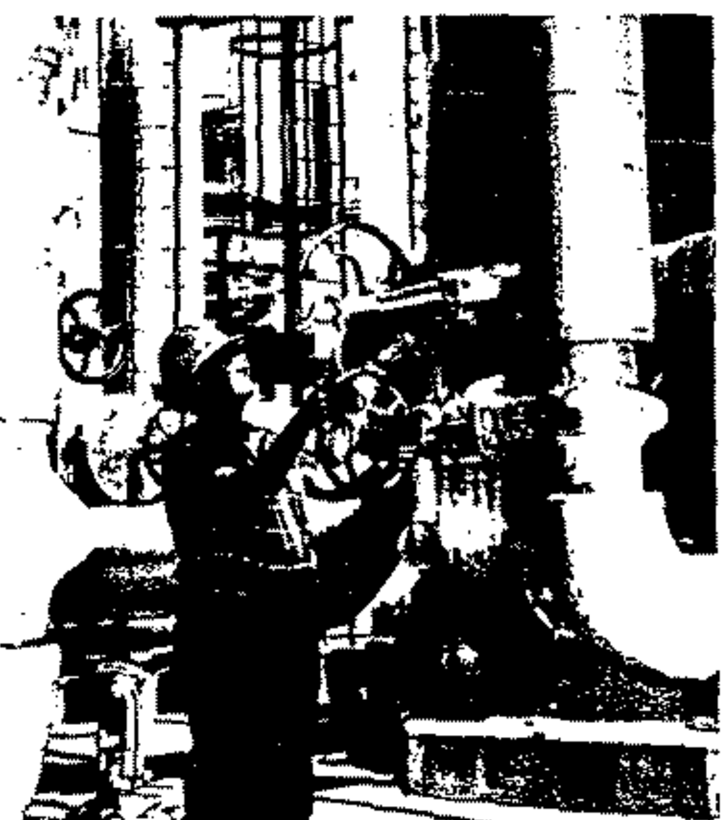
CONTROL PROCESSES In many manufacturing processes, especially of chemicals, the line temperatures, hot or cold, must be controlled within close limits. Without thermal insulation some processes simply would not work: specifications must start with the minimum thickness necessary for temperature control. Next enters the factor of economy. How many increments of insulation is it advisable to add to achieve optimum economy? (Of course you may need more insulation for control than for strictly economic reasons.)

A recent survey made for NIMA indicated that process control and "return on investment" are closely associated in the minds of both production engineers and management *and are prominent in their thinking* when specifying insulation thickness. To keep the two criteria clearly resolved, a sound approach to economic thickness is required.

3 PREVENT CONDENSATION

In cold processes and cold storage rooms, in air conditioned buildings, and in intermittent hot and cold processes, condensation of atmospheric moisture on cold surfaces (sweating) is a constant hazard. Condensation can reduce efficiency of the processes and the insulation, and it can corrode metals and rot organic materials.

Condensation is prevented by insulation thick enough to prevent the temperature of the surface of the pipes, ducts, equipment, etc. from getting below the dew point of the atmosphere. A vapor barrier is installed over the insulation to prevent entry of water vapor into the insulation where by diffusion it may travel to some point in the insulation which may be below the dew point. The vapor barrier may be of metal in foil or laminated form, plastic films such as polyethylene, an asphaltic material or a waterproof mastic, usually applied with a reinforcing membrane. The integrity and continuity of the vapor barrier are crucial.



For particular applications, considerations other than thickness alone may be important. Temperature limits, coefficient of thermal expansion, heat capacity, mechanical strength, moisture absorption, health, safety, and flame resistance may require consideration by a qualified engineer in the choice of an insulation for specific installations.

4 PROTECT PERSONNEL AND EQUIPMENT

Provision for safety is necessary if men are to work close to hot equipment and piping; comfort is necessary if their work is to be efficient over an extended period. A safe surface temperature is the primary requirement when insulating for protection of personnel, and, just as where the primary requirement is process control, more insulation may be used than simple economy would justify.

Desired temperatures for spaces surrounding hot piping and equipment vary with the industry, the equipment, and the design of the building, but surfaces that might be a hazard to personnel preferably are kept under 130 F and usually under 150 F.

In outdoor plants, insulation keeps sensitive instruments and major equipment safe from freezing weather. It is used strategically in plants as a fire stop.

The protective function of insulation increases as plants become more compact, with hot lines and equipment closely spaced. By the same token, more careful consideration of insulation requirements and application will return greater dividends.

THERE'S NO SUBSTITUTE FOR BRAINS

Management and engineers, like lawyers, are glad to find precedents to guide current decisions. But the leader in his field is also alert to peculiar conditions that distinguish his case from any other, old or new. Each insulation job is unique. Even two identically designed plants in different sections of the country would most likely have differences in labor and fuel costs, equipment efficiency, length of amortization, insulation cost, period of operation, environmental conditions, and the cost of money.

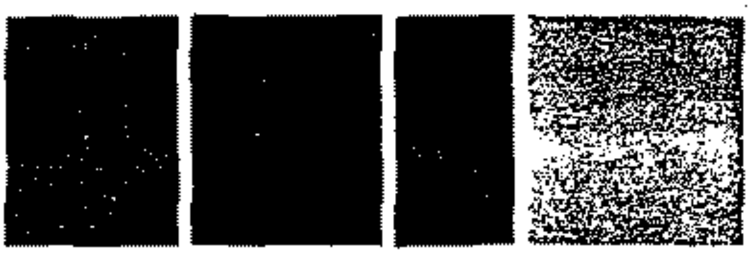
Failure to consider such variables may be wasteful in two ways: (a) there may be more insulation than is necessary for some parts of the system, and (b) less than is economically justified for others.

The variable that must be analyzed anew for each job, whether hot or cold, is the relationship between the cost of applied insulation and the cost of energy; and for complete analysis we must consider the cost of capital *equipment and the cost of the money to buy the capital equipment.* This relationship is the basis of the economic thickness approach, which is defined as *the thickness of a given insulation that will save the greatest cost of energy while paying for itself within an assigned period of time.* The amortized cost of insulation obviously increases in proportion to thickness, *but the total cost of heat loss for a stated thickness decreases.* Therefore the thickness at which the sum of these two costs is a minimum (all expenditures considered) is the most economical.

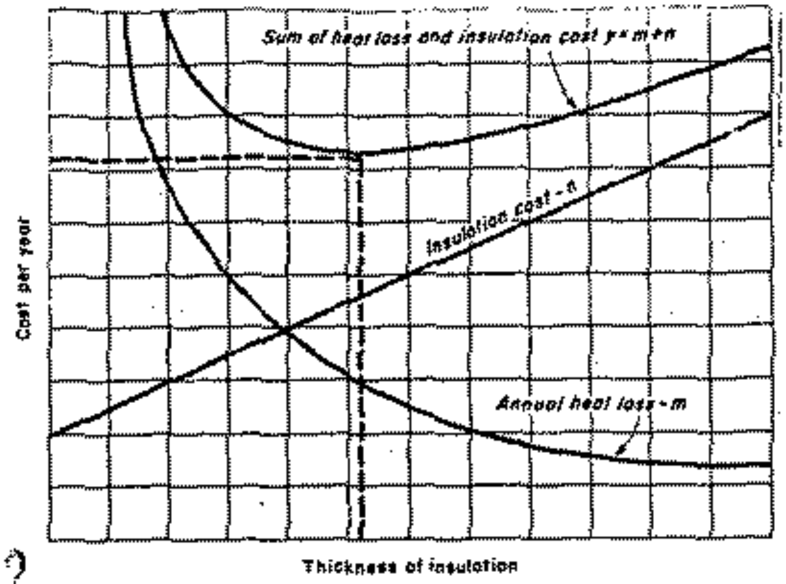
Although this system requires close attention to the actual details of the job, a long series of calculation is usually not necessary. The basic economic thickness equations are available in standard reference works, along with charts, tables, and nomographs, from which close economic thicknesses can be read for a wide range of applications. (For a simplified method of calculating economic thickness, see pp. 13-15.)

Where inexpensive fuel reduces the total cost of producing heat at, say, the main steam line leaving a boiler, less insulation will be needed for maximum economy than if the plant were located far from coal, oil or gas resources. A petrochemical plant in Oklahoma will usually specify less insulation than one in New Jersey—unless, of course, the need for close process control calls for greater thickness than would be required on an economic thickness basis alone. Note also that not all parts of the same plant would be evaluated w[illegible] cost factors: e.g., waste heat has a different value than prime heat.

Occasionally you may find a sound specification which calls for comparatively little insulation on economic grounds, but which may be inadequate for personnel safety at certain points of the system. Obviously, additional insulation must be specified to bring the surface temperatures at these points down for safety and comfort.



[illegible] SURFACE TEMPERATURE DETERMINE THICKNESS?



Only if safety and comfort are involved is the temperature at the surface of the insulation a significant matter. But reliance on this one factor as the sole guide to thickness is a common violation of sound engineering doctrine. As far back as 1926 L. B. McMillan declared, in discussing the use of surface temperature, "probably no other conception in connection with heat transfer is so generally misused."

It has long been a practice in the industry to publish sample recommended thicknesses of pipe and block insulation at different operating temperatures. But these suggestions apply only to an "average" set of conditions that practically never match an actual case. NIMA is recommending to its members that all tables showing heat losses and surface temperatures be accompanied by a qualifying statement to this effect:

> Insulation surface temperatures are given only to indicate an approximate value for purposes of personnel safety or fire hazard for hot surfaces, or for determining whether condensation occurs on cold surfaces. They are theoretical values usually based on one set of conditions such as in ambient still air at F. Actual surface temperatures vary widely depending on the nature of the insulation surface finish, the temperature and velocity of air over the surface, radiation to and from nearby objects, etc. Surface temperatures alone are absolutely no reliable indication of heat loss and therefore should not be specified or used as an exclusive means of selecting the proper thickness of insulation. Since the major purpose for using heat insulation is to save valuable heat, the proper thickness to achieve this objective should be based on economics. . . .

Here are some of the shortcomings of the surface temperature approach:

1. *Ambient air temperature.* If one wall of a boiler with a surface temperature of 135 F is exposed to air at 105 F, it will lose much less heat than another wall of the same boiler at 135 F exposed to air at 75 F.

2. *Air velocity.* Different rates of air movement over a surface can cause heat losses to vary over a range of several hundred per cent. Air circulating at 400 feet per minute (about 4½ mph) will cause a greater heat loss from a surface at 100 F than still air will cause for a surface at 150 F.

Carrying this point further, we might find that the higher the heat loss due to air movement, which reduces surface temperature, the less insulation would be specified according to surface temperature requirements alone. With air movement, the surfaces become progressively cooler, but they lose an increasing amount of heat!

3. *Proximity of hot or cold surfaces.* Heat transfer by radiation varies according to the differences in the fourth powers of the absolute temperatures of the radiating surface and of its surroundings. A slight decrease in the temperature of an environmental surface produces a relatively great increase in radiation loss. If a hot vessel has one side facing a cold wall and another side facing a nearby warm surface, the side facing the cold wall will have a cooler surface, and according to surface temperature tables would need less insulation—and would lose much more heat.

4. *Emissivity.* The bright polished surface on some types of jacket applied over insulation has a higher surface temperature than a dull one, but might be losing heat at only half the rate. Some metals, *e.g.*, aluminum, have relatively low radiation loss when new, but the loss increases as the surface becomes dull from oxidation. Deposits of oil and dust also increase emissivity.

INDEX TO ASTM AND GOVERNMENT SPECIFICATIONS FOR INDUSTRIAL INSULATIONS

PRODUCT FORM	REFERENCE NAME AND GENERAL DESCRIPTION	ACCEPTED MAX. TEMP.(a) DEGREES F	ASTM SPECIFICATIONS(b)	MILITARY (MIL) and MARITIME (MA) SPECIFICATIONS(b)	FEDERAL SPECIFICATIONS(b)
PIPE INSULATION	ASBESTOS (Molded Amosite and Binder)	1200		MIL-I-2781 Grade II, Class c Grade III, Class f	HH-I-561, Type IV
	CALCIUM SILICATE (Calcium Silicate and Asbestos)	1200	C-345	MIL-I-2781 Grade I, Class b Grade II, Class d Grade III, Class e, Type I	HH-I-523, Class 2
	CELLULAR GLASS (Foamed, Fabricated from Block)	800	C-385		HH-I-551
	CELLULAR SILICA (Foamed, Fabricated from Block)	1600 (cyclic) 2200 (cont.)			
	DIATOMACEOUS SILICA (Diatomaceous Silica and Asbestos)	1600 1900	C-334 C-334	MIL-I-2781 Grade III, Class e, Type II	
	85% MAGNESIA *(Basic Magnesium Carbonate and Asbestos)*	600	C-320	MIL-I-2781 Grade I, Class b	HH-I-554, Type II
	MINERAL FIBER (Rock, Slag or Glass) Low Temp (Organic Binder)	250	C-300		HH-I-562, Type II HH-I-552, Type I
	Low and Medium Temp (Fine Fiber, Organic Binder)	370	C-281 C-300	MIL-I-22344	HH-I-562, Type II HH-I-552, Type I
	High Temp (Blanket-Type Metal Reinforced)	1200	C-280		HH-I-552, Type II
BLOCKS and BOARDS	CALCIUM SILICATE (Calcium Silicate and Asbestos)	1200	C-344	MIL-I-2819, Classes a & b MIL-I-002819, Classes 1 & 2	HH-I-523, Class 1
	CELLULAR GLASS (Foamed)	800	C-343		HH-I-551
	CELLULAR SILICA (Foamed)	1600 (cyclic) 2200 (cont.)			
	DIATOMACEOUS SILICA (Diatomaceous Silica and Asbestos)	1600 1900	C-333 C-333	MIL-I-2819, Classes b & c MIL-I-002819, Class 3 MIL-I-002819, Class 4	
	85% MAGNESIA (Basic Magnesium Carbonate and Asbestos)	600	C-319	MIL-I-2819, Class a MIL-I-002819, Class 1	HH-I-554, Type I
	MINERAL FIBER (Rock, Slag or Glass) Low Temp (Organic Binder)	250	C-378	32-MC-2(c) MIL-I-742(d)	HH-I-564, Class A HH-I-526, (for Roofs) HH-I-562, Type I
	Low Temp (Fine Fiber, Organic Binder)	400	C-378, C-392, Class 1		HH-I-562, Type I
	High Temp (Inorganic Binder)	1800	C-392, Class 2		HH-I-564, Class B, C, D
CEMENTS	CALCIUM SILICATE (Calcium Silicate, Asbestos and Binders)	1200			HH-I-523, Class 3
	DIATOMACEOUS SILICA (Diatomaceous Silica and Asbestos)	1900	C-197	MIL-C-2861, Type A	HH-I-00500, Type V
	MAGNESIA (Basic Magnesium Carbonate, Asbestos and Binder)	600	C-193	MIL-P-2886	HH-I-00500, Type I
	MINERAL FIBER (Rock, Slag or Glass) Insulating (Colloidal Clay and Binder)	1800	C-195	MIL-C-2861, Type B	*HH-I-00500, Type III* HH-C-168
	Finishing (Hydraulic-setting Cement and Binder)	1200	C-449	MIL-C-2908, Type II	
BLANKETS and FELTS	MINERAL FIBER (Rock, Slag or Glass) Metal-Reinforced Blanket	1200	C-263	MIL-I-2818	HH-I-563, Type I
	Flexible (Organic Bonded)	400	C-264 C-382	MIL-I-942 MIL-B-5924 }(e) MIL-I-7171 } MIL-I-15475 MIL-I-22023(f) MIL-I-16688 32-MA-3(c)	HH-I-542, Type I
	Industrial Batt (No Binder)	1200	C-262	MIL-W-15427	
	Felt (Semi Rigid, Organic Bonded)	400	C-264 C-382	MIL-I-16688 }(g) MIL-I-15475 } MIL-I-942 32-MC-1(c)	HH-I-521, Type I HH-I-542, Type II HH-I-563, Type II
LOOSE and GRANULATED	MINERAL FIBER (Rock, Slag or Glass)	1200			HH-I-521, Type I—Loose Type II—Gran

(a) These temperatures are generally accepted as maximum. For specific applications consult the manufacturer. (b) See latest revisions of these specification numbers. In columns where no specification number appears, no specifications have yet been adopted. (c) Specifications 32-MC-1 and -2 and 32-MA-2 apply to Maritime Administration use only. (d) Specification MIL-I-742 applies to special mineral fiber board used by the Navy for hull and duct insulation. (e) Specifications MIL-B-5924 and MIL-I-7171 apply to glass fiber batting and blanket for thermal and acoustical insulation of aircraft compartments. (f) Supersedes MIL-I-15365 and MIL-I-16022. (g) Specifications MIL-I-15475 and MIL-I-16688 apply to Naval cold storage and refrigeration spaces, etc.

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TYPES OF INSULATION

Thermal insulations are supplied in various forms. They are molded or cut into cylinders, half cylinders or curved segments for application to piping, and into flat or curved blocks for vessels and large equipment. Insulating cements come in dry form to be mixed with water, for application by trowel on irregular surfaces, or as a final finish on other types. Fibrous materials, in addition to the above forms, also come in flexible blankets, semi-rigid felts, and loose and granulated forms.

Pipe insulations are made in "simplified thicknesses," in which the outside insulation diameter is approximately the same as the diameter of standard iron pipe, so that building up the thickness of insulation in layers is possible. Actual thicknesses are related to but vary above and below *nominal* thicknesses. All pipe insulations are furnished in 1, 1½, 2, 2½ inch, etc., *nominal* thicknesses, and in specifying and ordering, pipe insulation is referred to by pipe size and nominal thickness only.

ASBESTOS

is molded from asbestos fiber, principally of the amosite variety, combined with diatomaceous silica and bonded with heat-resisting binders. It comes in pipe sections and is used for temperatures up to 1200 F. Density ranges from 15 to 18 pounds per cubic foot (pcf). Typical conductivities—expressed as "K" factors, or Btu per (hour) (sq. ft.) (Fahrenheit degree per inch of thickness)—are 0.37 at 200 F, 0.47 at 400 F, 0.57 at 600 F mean temperatures.

CALCIUM SILICATE

is made from silica and lime, molded with a small amount of asbestos fiber, and chemically converted by steam pressure autoclaving into hydrous calcium silicate. It is furnished in pipe sections and in flat and curved blocks, to apply on heated surfaces up to approximately 1200 F. Density of calcium silicate insulations ranges from 11 to 13 pcf. Typical average conductivities are 0.37 Btu at 200 F, 0.47 at 400 F, 0.57 at 600 F mean temperatures. A second type of calcium silicate of slightly higher density is suitable for temperatures up to 1800 F. Typical conductivities of this higher temperature type are 0.46 at 200 F, 0.58 at 400 F, and 0.70 at 600 F mean.

DIATOMACEOUS SILICA

or diatomaceous earth is made from the siliceous remains of microscopic diatoms, with clay and asbestos for bonding and reinforcing. It is molded into pipe sections and segments, and into flat and curved blocks for large surfaces. One type is suitable for temperatures to approximately 1600 F, and a second type to 1900 F. It is often used as the inner layer of two-layer insulation construction so as to permit use of a lower temperature product as the outer layer. The 1600 F type has a density of 21-22 pcf, with typical thermal conductivities of 0.66 at 500 F, 0.70 at 700 F, and 0.74 at 900 F mean. The 1900 F type weighs 23-25 pcf, with typical average conductivities of 0.71 at 500 F, 0.75 at 700 F, and 0.80 at 900 F mean. Diatomaceous silica also is available in aggregate form for fill and as an ingredient in cements.

TYPES OF INSULATION

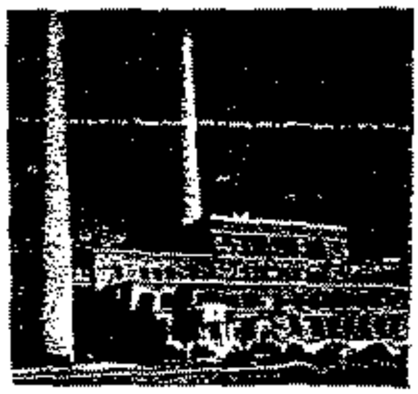
GLASS (CELLULAR)

is made from a modified boro-silicate type of glass, melted and formed by a heating and chemical process. The resulting rigid glassy material contains sealed cells and weighs approximately 8 to 10 pcf. It is used for insulating piping and equipment operating at temperatures up to 800 F. The material is furnished in pipe sections and in flat and curved blocks. Typical thermal conductivities are 0.41 at 100 F, 0.48 at 200 F and 0.55 at 300 F mean.

GLASS (FIBROUS)

insulations are manufactured from specific proportions of silica and other glass-forming compounds. These are fused and drawn, flame-blasted or spun into boro-silicate glass fibers of consistent chemical composition. The fibers are combined with binders and molded into self-contained boards and cylindrical pipe insulation; with or without binders they are formed into flexible blankets and semi-rigid felts; they also come in loose forms.

Fine-fiber type flexible and semi-rigid blankets, with organic binders, are used up to 400 F, in densities of 0.65 to 3 pcf. Conductivities of the 0.65 pcf material are 0.25 at 40 F, 0.31 at 100 F, and 0.58 at 300 F mean temperatures; of the 3 pcf material: 0.21 at 40 F, 0.23 at 100 F, and 0.35 at 300 F mean. Typical conductivities of 3 to 8 pcf semi-rigid felt would be 0.24 at 40 F, 0.27 at 100 F, and 0.44 at 300 F mean. Several types of high-strength, long-textile-type glass fiber blankets are available in densities from nominal 0.50 pcf to 3 pcf and are used up to 400 F with binders, or 1000 F without binders.

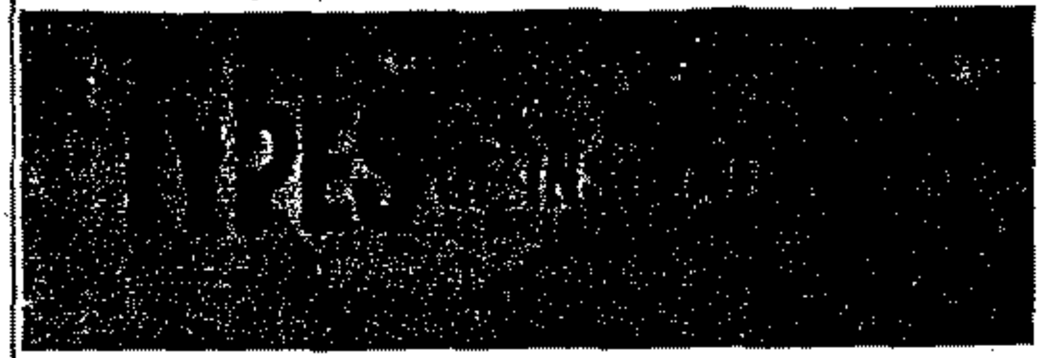


Molded pipe insulation, fine-fiber organic bonded, is used up to 370 F. At 3 pcf density, conductivities are 0.21 at 40 F, 0.23 at 100 F, and 0.29 at 200 F mean temperatures.

Blocks and boards with organic binders are used up to 400 F. Typical conductivities for densities of 6-10 pcf are 0.28 at 100 F, 0.35 at 200 F, 0.43 at 300 F mean.

85% MAGNESIA

is a molded material composed principally of basic magnesium carbonate reinforced with asbestos fiber. It is used on heated surfaces at temperatures up to 600 F, and comes in semi-cylindrical sections and segments for pipes, and in flat and curved blocks for other surfaces. It also comes in dry cement form to be mixed with water and applied in a plastic state to pipe fittings and other irregular surfaces. Where temperatures exceed 600 F it is often used as the outer layer over a diatomaceous silica inner layer. Density is 11 to 12 pcf. Typical conductivities are 0.35 at 100 F, 0.38 at 200 F, 0.42 at 300 F mean.



MINERAL FIBERS

ROCK AND SLAG FIBERS

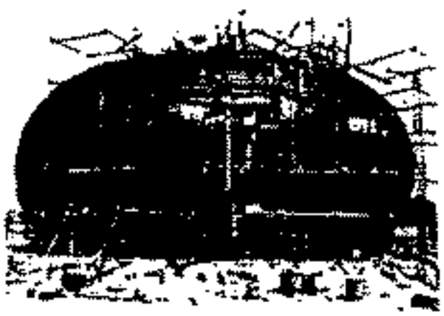
[For Glass Fibers . . . see Glass (Fibrous) page 11]

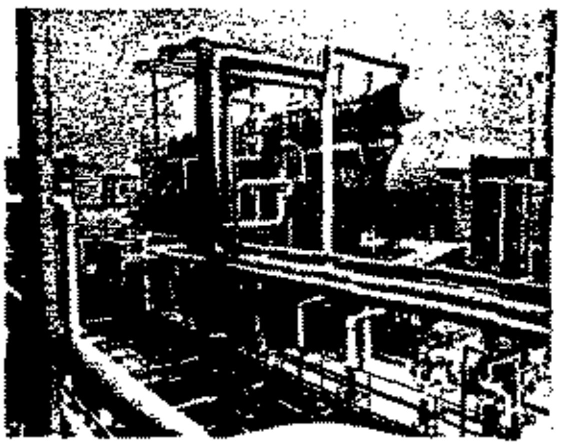
Rock and slag fibers are made by melting siliceous rocks and slags and steam-blowing or spinning the molten mass into fibers. These are combined with binders and formed into boards, blocks, and cylindrical pipe sections; blankets or felts are sometimes encased in wire mesh. Fibers in loose or granulated form are used for packing into spaces. Combined with high-temperature bonding clay or other binders to form cements, *they are applied* by troweling to form a monolithic insulation.

Blocks and boards with inorganic binder, such as bonding clay, asbestos fiber, etc., are used up to 1800 F, in densities from 16 to 24 pcf. Typical conductivities are 0.39 at 200 F, 0.49 at 400 F, and 0.59 at 600 F mean. Other blocks, made with organic binder at densities of 6 to 18 pcf, are used up to 400 F; typical conductivities are 0.28 at 40 F, 0.29 at 70 F, and 0.30 at 100 F mean.

One type of blanket, with felted fibers held between wire mesh and with or without binders, is used on flat and cylindrical surfaces at temperatures up to 1200 F. Density ranges from 6 to 15 pcf. Typical conductivities are 0.35 at 200 F, 0.49 at 400 F, 0.63 at 600 F mean. A second type, *with organic binder, consists of felts (semi-rigid) up to 6 or* 8 pcf. Typical conductivities are 0.26 at 75 F, 0.27 at 100 F, 0.35 at 200 F mean.

One type of cement, applied in several heavy coats to build the required thickness, has a density of 24 to 30 pcf and is used at temperatures up to 1800 F. A second type, a *hydraulic-setting*, finishing cement, is quick hardening, has a density of 30 to 35 pcf, and is used up to 1200 F.





ECONOMIC THICKNESS

HOW TO FIGURE IT

Given the principle, "Make the most out of your investment," how do you calculate at what point you are getting the most value out of your insulation? Every job must be calculated on its own terms, but no special skill in engineering or mathematics is required to use the formulas prescribed here. The following simplified example does not consider the cost of capital equipment or the cost of the money to buy the equipment.

Calculating the economic thickness of insulation to be specified for any plant requires easily obtainable data on ten basic factors. These ten factors are listed in the left column below, while the figures of a realistic example are presented, point for point, in the column at the right. The example is for hot pipe insulation, but the same method can be used for flat surfaces, and with obvious modifications, for cold insulation.

SIGNIFICANT FACTORS:	*EXAMPLE:*
1. Value of fuel (fuel cost, plus cost of labor, maintenance, water, etc.)	1. Oil at $.08/gal. ($.07/gal. fuel cost, plus $.01 for maintenance, labor, etc.)
2. Hours of operation per year	2. 8760 hr./yr.
3. Btu content of fuel	3. 145,000 Btu/gal.
4. Efficiency of combustion	4. 80% efficiency
5. Average exposure (ambient still-air temperature)	5. 80 F ambient still-air
6. Operating temperature of pipe (cause of heat loss)	6. 600 F operating temperature
7. Pipe diameter (source of heat loss)	7. 3" pipe size
8. *Estimated cost of installed insulation* (obtain from insulation manufacturer or contractor)	8. Estimated cost:

Insulation Thickness	Cost/100 lin. ft. of pipe
1"	$200
1½"	$230
2"	$260
2½"	$295
3"	$340
3½"	$395

9. Amortization period	9. 6 yr. amortization period
10. Heat loss per lin. ft. (or sq. ft. if flat, or heat gain in cold systems)	10. Heat loss in Btu/hr./lin. ft. at 600 F operating temp. and 80 F ambient (obtain from insulation manufacturer's tables)

Insulation Thickness	Heat Loss Btu/hr./lin. ft.
0"	2437
1"	230
1½"	175
2"	150
2½"	133
3"	120
3½"	111

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Using these data, economic thickness is determined by following the three steps below, A, B and C. The objective is to find the half-inch increment of insulation at which the total cost of heat loss and insulation is least. This is shown on the graph presented as a summary of the calculations. (Note that according to a realistic economic calculation, 3½" will cost less in the long run than 2".)

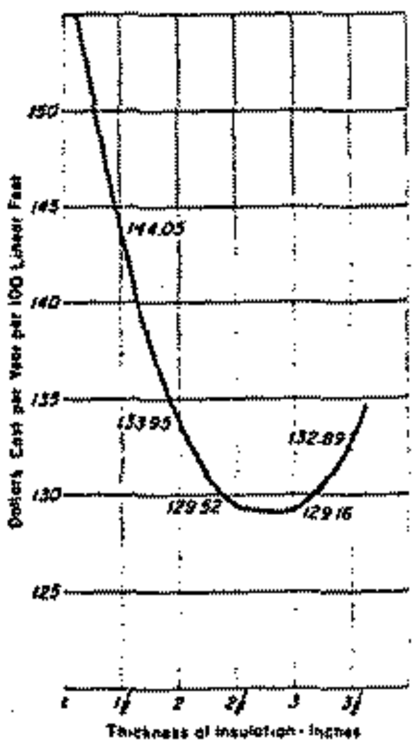
Compute cost of heat loss per yr. per 100 lin. ft. by using this equation:

$$\frac{\text{Btu/hr./lin. ft.} \times \text{hr.-yr.} \times \$/\text{gal.} \times 100}{\text{Btu/gal.} \times \text{efficiency}} = \$/100 \text{ lin. ft./yr.}$$

Insulation Thickness		Cost of Heat Loss $/100 lin. ft./yr.
0"	$\frac{2437 \times 8760 \times \$.08 \times 100}{145{,}000 \times .80}$	= $1472.28
1"	$\frac{230 \times 8760 \times \$.08 \times 100}{145{,}000 \times .80}$	= $ 138.95
1½"	$\frac{175 \times 8760 \times \$.08 \times 100}{145{,}000 \times .80}$	= $ 105.72
2"	$\frac{150 \times 8760 \times \$.08 \times 100}{145{,}000 \times .80}$	= $ 90.62
2½"	$\frac{133 \times 8760 \times \$.08 \times 100}{145{,}000 \times .80}$	= $ 80.35
3"	$\frac{120 \times 8760 \times \$.08 \times 100}{145{,}000 \times .80}$	= $ 72.50
3½"	$\frac{111 \times 8760 \times \$.08 \times 100}{145{,}000 \times .80}$	= $ 67.06

Installed insulation cost per year equals cost of 100 linear feet of insulation divided by the amortization period (in this example 6 years).

Insulation Thickness	Installed cost/yr.
1"	$\frac{\$200}{6} = \$33.33$
1½"	$\frac{\$230}{6} = \$38.33$
2"	$\frac{\$260}{6} = \$43.33$
2½"	$\frac{\$295}{6} = \$49.17$
3"	$\frac{\$340}{6} = \$56.66$
3½"	$\frac{\$395}{6} = \$65.83$



Total cost per hundred linear feet per year = Step A + Step B

Insulation Thickness	Step A (Heat loss cost)	Step B (Insul. Cost)	Total Cost
0"	$1472.28	$ 0.	$1472.28
1"	138.95	33.33	172.28
1½"	105.72	38.33	144.05
2"	90.62	43.33	133.95
2½"	80.35	49.17	129.52
3"	[illegible]	[illegible]	[illegible]
3½"	67.06	65.83	132.89

In this example, 3" is the economic thickness, because either a lesser or greater thickness results in a higher total yearly cost.

FOR FLAT SURFACES

The table below deals with insulation of flat surfaces, at 300 F and 80 F ambient air, using insulation with an average "K" of .40 at 200 F mean temperature. In the first year alone, the first inch of insulation saves $2.41 per sq. ft., more than its installed cost. The real problem, how much more insulation to add, in half-inch increments, and still save more than its cost, is shown in the table. Assumed is an amortization period of ten years, and a cost of $.15 for each additional half inch, divided by ten for the yearly charge per sq. ft.

Each increment saves fewer Btu than the last, until finally the extra half inch to make 3½" costs more than it saves, So 3" is the optimum thickness.

Dollar value of heat saved by insulation for flat surface at 300 F and 80 F ambient air

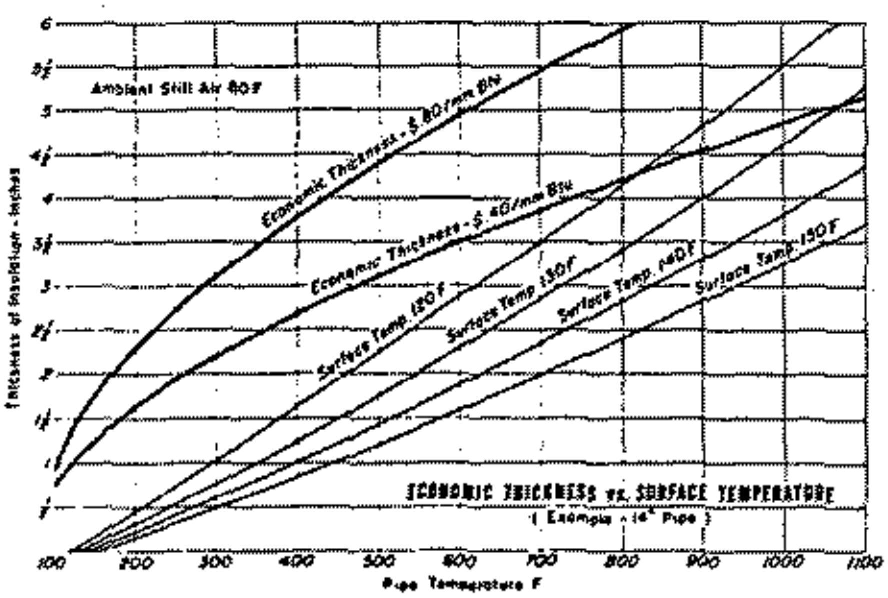
Insulation thickness	Heat lost	Heat saved	Incremental saving	Heat lost	Heat saved	Incremental saving	Total savings	Incremental saving
	Btu per sq ft per hr			Million Btu per sq ft per year (8760 hr)			Dollars per sq ft at 50¢ per million Btu	
Bare surface	620	0	0	5.43	0	0	0	0
1"	70	550	550	0.613	4.817	4.817	2.41	2.41
1½"	50	570	20	0.438	4.992	0.175	2.499	0.088
2"	38	582	12	0.333	5.097	0.105	2.551	0.053
2½"	31	589	7	0.272	5.158	0.061	2.582	0.031
3	26	594	5	0.228	5.202	0.044	2.604	0.022
3½"	23	597	3	0.202	5.229	0.027	2.617	0.013

ECONOMIC THICKNESS VS. SURFACE TEMPERATURE

This graph demonstrates the savings in valuable heat when economic thickness rather than surface temperature is used as the basis of selection. Economic thicknesses are given for 14" pipe at two heat costs, $0.40 and $0.80 per million Btu's, under conditions of ambient still-air at 80 F and 8,760 hours of operation per year.

By comparison: at $0.40/million Btu, thicknesses chosen to meet a surface temperature of 140 F would fall a full inch or more short of economic amounts, at operating temperatures of 1000 F and below, and this inadequate insulation would waste heat for the life of the equipment. At a heat cost of $0.80/million Btu, the result would be even greater waste of fuel dollars as a result of specifying insulation merely to meet a 140 F surface temperature. At 600 F, it would even be economically sound to add 3" more insulation. At 900 F, more than 3" additional insulation is indicated than would be required for 140 F surface temperature. Even at so low a temperature as 200 F, it would save money to add almost 2" more.

If cost of capital equipment and cost of money to buy the capital equipment had been taken into account, the conclusion would have been similar but even more startling. An investment of dollars in engineered insulation should bring a return comparable to that from a more efficient generator or other specific equipment.



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