Pipe Insulation

Review and Acceptance

Information Submitted:	1) Pipe Insulation Workpaper, EEA Report No. B-REP-06-599-03C, January 2007 2) Attachment #1 – kW Engineering Steam Trap Survey 3) Attachment #2 – Key Parameters for Pipe Insulation 4) Attachment #3 – Enbridge Steam Trap Survey 5) Attachment #4 – 2006 Express Efficiency Program 6) Attachment #5 – Steam Boiler Efficiency 7) Attachment #6 – CPUC Energy Efficiency Policy Manual
Submitted by:	Energy and Environmental Analysis, Inc.
Date:	January 26, 2007

Program Affected:

- [X] Express Efficiency
- [ ] Process Equipment Replacement (PER)
- [ ] Efficient Equipment Replacement (EER)
- [ ] Business Energy Efficiency Program (BEEP)
- [ ] Other (please describe) ________________
- [ ] Energy Efficiency Grant Program (EEGP)
- [ ] Custom Process Improvement (CPI)
- [ ] Recognition Program

The following individuals have reviewed the information cited above, and accept this information for determining energy consumption and/or energy savings related to energy efficiency measures.

Tom DeCarlo, PE Commercial & Industrial Program Manager Southern California Gas Company	(via e-mail) **Approval Date**
Eric Kirchhoff, PE Energy Efficiency Engineering Supervisor Southern California Gas Company	(via e-mail) **Approval Date**

Revision History

Revision No.	Date	Description	Author
---	Jan. 31, 2006	Original release	EEA (S. Knoke)
A	May 9, 2006	1. Added medium-pressure steam pipes 2. Other minor changes	EEA (S. Knoke)
B	July 6, 2006	1. Added Review and Acceptance page 2. Added Revision History page 3. Added Disclaimer page 4. Added discussion addressing reluctance to adopt technology in Executive Summary 5. Added line for steam pressure range to table in Executive Summary 6. Corrected minor error in the annual energy savings calculations 7. Added 3 and 4-inch pipe to Table 4 8. Added annual energy savings chart (Figure 1) in Section 3 and attachment showing calculations 9. Added discussion addressing reluctance to adopt technology in Incentive and Payback chapter 10. Renumbered attachments	EEA (S. Knoke)
C	Jan. 25, 2007	1. Added smaller pipe sizes 2. Added second category for annual operating hours 3. Reduced incentives to two categories 4. Increased annual energy savings to 6 categories 5. Added cost to SCG	EEA (S. Knoke)

ENERGY AND ENVIRONMENTAL ANALYSIS, INC.

B-REP-06-599-03C

Revision C

Pipe Insulation

(Non-space Conditioning)

Workpaper for PY2006-2008

January 2007

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Executive Summary
H12/H13/H17/H18 (Application Code I & J)
Measure(s): Pipe Insulation

Measure Description

Many commercial and industrial customers – particularly smaller, hard to reach businesses – configure piping systems with sub-optimal amounts of insulation. This measure addresses cost-effective energy efficiency opportunities in the pipe insulation area, and encompasses both fiberglass and heavier duty insulation systems such as Perlite and rigid phenolic insulation. Pipe insulation applications in the industrial sector include brine, plating solutions, steam, condensate, hot water, chilled water, and refrigerant; in the commercial sector they include steam, hot water, chilled water, and refrigerant.

Market Applicability

Although the payback is short, experience shows that many customers are not installing pipe insulation, perhaps due to a general lack of awareness of the potential energy savings from pipe insulation. The incentives described in this measure are expected to stimulate adoption primarily due to increased awareness, although the incentives also reduce economic barriers.

These measures are applicable to any small or medium commercial or industrial pipe insulation retrofit (i.e., non new construction) application. They cannot be used for residential purposes.

Terms and Conditions

A minimum of 1 inch of insulation must be added to existing bare commercial or industrial steel pipe system applications. For pipe insulation, the bare pipe size must be 1/2 inch or larger. The following types of applications are not eligible: new construction; new pipe system replacement; fuel switching; residential. The fluid type (hot water, low-pressure steam (≤15 psig), or medium-pressure steam (>15 psig)), the length of insulation installed at each pipe size, annual operating hours, the manufacturer's name, the insulation material type, and the material k-value rating must be provided. If necessary, customers must provide proof of insulating values (e.g., manufacturer's specification sheets).

Cost Effectiveness Modeling Measure Data

Unitized cost effectiveness determinants are summarized in the table below for hot water, low-pressure steam, and medium-pressure steam. The assumed measure lifetime is based on the CPUC Energy Efficiency Policy Manual for insulation measures. The assumed net-to-gross ratio is based on the CPUC Energy Efficiency Policy Manual for the Express Efficiency Program.

Parameter	Hot Water		Low-pressure Steam		Medium-pressure Steam	
Pipe Size (inch)	<1"	≥1"	<1"	≥1"	<1"	≥1"
Steam Pressure Range (psig)	---	---	0 to 15	0 to 15	>15	>15
Fluid Temperature (°F)	120-200	120-200	200-250	200-250	250-500	250-500
Insulation Thickness (inch)	1	1	1	1	1	1
Annual Operating Time (hrs/yr)	2,425	7,752	2,425	7,752	2,425	7,752
Annual Energy Savings (therms per LF)	2.8	18	6.1	40	9.6	63
Incremental Measure Cost, Avg. ($/LF)	$13.85	$16.33	$14.37	$16.57	$14.37	$16.57
Incentive ($/LF)	$2.00	$2.00	$3.00	$3.00	$3.00	$3.00
Measure Lifetime (years)	20	20	20	20	20	20
Net-to-Gross Ratio	0.96	0.96	0.96	0.96	0.96	0.96

MDSS Measure Code	---	---	---	---	---	---
Application Code	I	I	I	I	I	I

Annual Energy Savings

Parameter	**Commercial**	**Industrial**
Pipe Size (inch)	Less than 1"	1" or larger
Operating Time (hrs/yr)	2,425	7,752
Hot Water		
Incentive ($/LF)	$2.00	$2.00
Annual Gas Savings (therms/yr per LF)	**2.8**	**18**
Incentive Cost per Annual Therm Saved (¢/therm/yr) (see note)	72.2	11.1
Low-pressure Steam (0-15 psig)		
Incentive ($/LF)	$3.00	$3.00
Annual Gas Savings (therms/yr per LF)	**6.1**	**40**
Incentive Cost per Annual Therm Saved (¢/therm/yr) (see note)	49.4	7.5
High-pressure Steam (>15 psig)		
Incentive ($/LF)	$3.00	$3.00
Annual Gas Savings (therms/yr per LF)	**9.6**	**63**
Incentive Cost per Annual Therm Saved (¢/therm/yr) (see note)	31.3	4.8

Note: The incentive cost per annual therm saved is the one-time incentive cost divided by the projected annual gas savings (not including net to gross (NTG) ratio). Over the 20-year life of the insulation, the incentive cost per therm saved (not including the NTG) is 5% of the value shown (0.3 – 3.6 cents/therm saved).

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1. Overview

The key parameters for pipe insulation[1] are listed in **Table 1**. A brief overview of these parameters follows:

- **Annual Operating Hours and Other Assumptions** – An annual operating time of 2,425 hours was used for commercial steam and hot water systems with pipe sizes smaller than 1 inch -- based on the average operating time for small commercial dry cleaners establishments from a survey performed in Southern California by kW Engineering[2]. An annual operating time of 7,752 hours was used for industrial steam and hot water systems with pipe sizes 1 inch and larger -- based on the assumption that large steam systems operate under pressure for 24/7, except for six weeks per year for plant maintenance. To determine the energy savings, additional assumptions were made concerning the pressure, temperature, and average velocity of the hot water and steam inside the pipe, the average air temperature, and the average wind speed of air moving past the pipe.
- **Pipe Parameters** – The parameters used to describe the pipe are based on ¾-inch and 2-inch Schedule 40 steel pipe: physical dimensions, thermal conductivity, and surface emittance. The pipe size selected to represent commercial steam and hot water systems, ¾-inch, is a common size in small commercial dry cleaners establishments, where ½-inch and 1-inch pipe sizes are also used. The pipe size selected to represent industrial steam and hot water systems, 2-inch, is a common size, where pipe sizes smaller than 1-inch (except as stubs leading to steam traps) and larger than 4-inches are rare.
- **Insulation Parameters** – The parameters used to describe the insulation are generally based on prefabricated 1-inch thick fiberglass pipe insulation: thermal conductivity, surface emittance, paper or aluminum wrap. Acceptable types of pipe insulation for hot water pipes include polyethylene foam (up to 180 °F), UV-resistant polyethylene foam, and elastomer foam rubber. Acceptable types of insulation for steam pipes include silicone foam rubber (to 425 °F), melamine foam (to 400 °F), rigid urethane-based foam (to 300 °, cellular glass (to 400 °F), fiberglass, and mineral wool. The protection offered by jacketing is also recommended, especially outdoors. Only some jacket materials are suitable for outdoor use, such aluminum, UV-resistant PVC, and paints.
- **Boiler Efficiency** – A boiler efficiency of 80% was used for computing the cost of steam generation.
- **Annual Energy Savings** –The annual energy savings attributed to the installation of pipe insulation was calculated based on the operating time, steam boiler efficiency, and reduction in heat loss due to the insulation.
- **Measure Cost** – Material costs were determined based on the McMaster-Carr catalog. Costs to install the insulation were determined based on telephone conversations with pipe insulation vendors. They provided installed cost per foot for typical jobs, both indoors (paper wrap insulation) and outdoors (aluminum wrap over paper wrap insulation).
- **Incentive/Payback** – Incentive is $2 per linear foot (LF) of insulated hot water pipe and $3/LF of steam pipe (either low-pressure or medium-pressure steam). **Table 1** shows payback values for the pipe insulation with and without the incentive. All estimated payback times are less than about a year.

[1] See **Appendix A** for a description of pipe insulation.
[2] See Attachment #1

Additional comments and calculations follow, and are grouped in the following sections:

- Annual Operating Hours and Other Assumptions
- Pipe Parameters
- Insulation Parameters
- Boiler Efficiency
- Annual Energy Savings
- Measure Cost
- Incentive/Payback
- Other
  - Measure Lifetime
  - Net-to-Gross
  - Qualifying
  - Cost to SCG

Table 1. Key Parameters[3]

Parameter	Hot Water		Low-pressure Steam (0-15 psig)		Medium-pressure Steam (>15 psig)	
Pipe Size (inch)	<1"	≥1"	<1"	≥1"	<1"	≥1"
Insulation Thickness (inch)	1	1	1	1	1	1
Average Steam Pressure (psig)	---	---	10.9	10.9	85.9	85.9
Temperature, Fluid in Pipe (°F)	130	130	241	241	328	328
Operating Time (hrs/yr)	2,425	7,752	2,425	7,752	2,425	7,752
Pipe Parameters						
Pipe Size for Heat Loss Calculations (inch)	0.75	2	0.75	2	0.75	2
Outer Diameter, Pipe, Actual (in.)	1.05	2.375	1.05	2.375	1.05	2.375
Heat Loss, Bare Pipe (Btu/hr-LF)	101	200	214	433	335	678
Heat Loss, Bare Pipe (therm/yr/LF)	2.4	15.5	5.2	34.0	8.2	53.3
Insulation Parameters						
Outer Diameter, Insulation (in.)	3.05	4.38	3.05	4.38	3.05	4.38
Average Heat Loss, Insulation (Btu/hr-LF)	9.0	14.4	16.0	26.7	22.3	38.0
Average Heat Loss, Insulation (therm/yr/LF)	0.2	1.1	0.4	2.1	0.5	2.9
Annual Energy Savings						
Boiler Efficiency (%)	80%	80%	80%	80%	80%	80%
Annual Gas Savings (therms/year/LF)	2.8	18	6.1	40	9.6	63
Annual Cost Savings ($/year/LF)	$2.63	$17.04	$5.77	$37.86	$9.11	$59.75
Measure Cost (MC)						
Average Installed Cost ($/LF)	$13.89	$15.25	$13.89	$15.25	$13.89	$15.25
Incentive						
Incentive Amount ($/LF)	$2.00	$2.00	$3.00	$3.00	$3.00	$3.00
Payback (years)						
(without Rebate)	5.28	0.89	2.41	0.40	1.52	0.26
(with Rebate)	4.52	0.78	1.89	0.32	1.20	0.20
Cost to SCG						
NTG	0.96	0.96	0.96	0.96	0.96	0.96
Cost of First-year Gas Savings to SCG (¢/therm)[4]	75.2	11.6	51.4	7.8	32.6	5.0
Measure Lifetime (yrs)	20	20	20	20	20	20
Cost of Lifetime Gas Savings to SCG (¢/therm)[5]	3.8	0.6	2.6	0.4	1.6	0.2

3 Detailed calculations shown in Attachment #2.
4 Including net to gross (NTG) ratio.
5 Including NTG ratio.

2. Annual Operating Hours and Other Assumptions

Commercial establishments might operate their steam system anywhere from about 2,000 hours per year (8 hours/day, 5 days/week) to about 6,000 hours per year (16 hours/day, 7 days/week). In a survey performed in Southern California by kW Engineering[6], the steam system operating schedule was obtained for each dry cleaner establishment. They report operating their steam system 7.5 to 9 hours per day, 6 days per week, year-round except holidays. The average annual operating time for dry cleaners studied is 2,425 hours per year. In this workpaper, the basis used for annual operating hours for pipe sizes smaller than 1 inch is based on commercial dry cleaner establishments.

An annual operating time of 7,752 hours was used for industrial steam and hot water systems, which generally use pipe sizes 1 inch and larger. Actual operating hours of a steam or hot water system vary depending on end-use applications, boiler size, and seasonal variations. Not every pipe in the system operates for the same number of hours in a year, but most large plants keep the system operating essentially all the time. For example, based on many years of studying steam systems in Enbridge service territory, the average hoursof operation of a typical steam system is 7,500 to 8,000 hours per year[7]. In this workpaper, the basis used for annual operating hours for 1 inch and larger pipe sizes is large plants that nominally operate 24 hour per day, 7 days per week, except that the majority of the hot water or steam system is assumed to be unheated for a total of six weeks per year for scheduled and unscheduled maintenance activities, implying a total of 7,752 hours per year at normal operating temperature.

To determine the annual savings, additional assumptions were made concerning the pressure, temperature, and average velocity of the hot water and steam inside the pipe, the average air temperature, and the average wind speed of air moving past the pipe.

- The average steam pressure was calculated using an Enbridge survey[8] of steam traps. For this workpaper, the Enbridge data was divided into two pressure groups: ≤ 15 psig and > 15 psig. As shown in **Table 2**, the average steam pressure for the two groups was calculated by weighting each pressure by the number of leaking traps. For each pressure category, the weighted average is the sum of the average pressure in the range times the number of traps in the range, divided by the sum of the number of traps in the range. The resulting values for the low-and medium-pressure categories are 10.9 and 85.9 psig, respectively.
- The temperature ranges of the hot water and low-pressure steam are specified in the 2006 Express Efficiency Rebate Program[9] brochure and are listed in **Table 3**. For purposes of the energy savings analysis, the temperature of the hot water was assumed to be 130 °F. The temperatures of the low-pressure and medium-pressure steam correspond to the saturated temperatures of water at the average steam pressures obtained above: 241 °F and 328 °F.
- The flow velocity is needed to calculate the pipe inside wall temperature; it is usually based on considerations of pressure drop due to pipe friction. EEA assumed a typical water flow speed of 10 ft/s and a typical steam flow speed of 100 ft/s. These are not critical parameters, since the heat loss is not very sensitive to fluid velocity inside the pipe.

[6] See Attachment #1.
[7] Bob Griffin, P.Eng., Industrial Energy Consultant, Enbridge Gas Distribution, Toronto, Ontario.
[8] See Attachment #3.
[9] See Attachment #4.

- ASHRAE uses an ambient temperature of 65 °F and 7.5 mph wind speed for their tables of recommended thicknesses for pipe insulation[10]. For reference, in the ASHRAE table just referenced, ASHRAE recommends the insulation thickness listed in **Table 4**.

Table 2. Average Steam Pressure Calculation

Pressure range (psig)	Number of Steam Traps	Average Pressure in Range (psig)	(Average pressure) X (Number in Range)	Average Pressure in Category (psig)
Low Pressure (≤ 15 psig)				
<5	234	2.5	585	10.9
5	0	5	0	
6 to 9	24	7.5	180	
10	515	10	5150	
11 to 14	249	12.5	3112.5	
15	517	15	7755	
Medium Pressure (> 15 psig)				
16 to 19	37	17.5	647.5	85.9
20	28	20	560	
25	33	25	825	
30	73	30	2190	
40	61	40	2440	
50	26	50	1300	
60	60	60	3600	
61 to 99	175	80	14000	
100	45	100	4500	
101 to 124	117	112.5	13162.5	
125	14	125	1750	
150	54	150	8100	
200	2	200	400	
250+	26	425	11050	

Table 3. Fluid Temperature Specifications and Assumptions (°F)

Working Fluid	Fluid Temperature (°F)	
	Specification	Used in Analysis
Hot Water	120-200	130
Low-Pressure Steam	200-250	241
Medium-Pressure Steam	250-500	328

[10] 2001 ASHRAE Handbook Fundamentals, page 25.22, Table 13.

Table 4. ASHRAE Recommended Thickness for Pipe Insulation (inches)

Nominal Pipe Size (inch)	Process Temperature		
	150 °F	250 °F	350 °F
½	1	1½	2
1	1	1½	2
2	1½	2	3
3	1½	2½	3½
4	1½	3	4

3. Pipe Parameters

The energy savings analysis is based on ¾-inch and 2-inch Schedule 40 steel pipe. The pipe size selected to represent commercial steam and hot water systems, ¾-inch, is a common size in small commercial dry cleaners establishments, where ½-inch and 1-inch pipe sizes are also used. The pipe size selected to represent industrial steam and hot water systems, 2-inch, is a common size, where pipe sizes smaller than 1-inch (except as stubs leading to steam traps) and larger than 4-inches are rare.

The energy savings results are expressed per linear foot (LF) of pipe. The thermal conductivity of steel (314.4 Btu-in/hr-ft^2-F or 26.2 Btu/hr-ft/F) is required to calculate the outside wall temperature of the pipe. In addition, the radiation from pipe surface is characterized by emittance, 0.94[11]. **Figure 1** compares the annual gas energy savings from adding one or two inches of insulation to bare hot water and steam pipes which are ¾ and 2 inches in pipe size[12]. Pipe sizes smaller than ½ inch and larger than 4 inch are rare. Because there is little difference between the savings for 1 inch and 2 inches of insulation, the pipe insulation rebate focuses on 1 inch. The impact of the lower annual operating hours assumed for pipe sizes smaller than 1 inch is also apparent in this figure.

Figure 2 compares the incentive cost per therm saved for the full range of fluid types and the two pipe sizes (¾-inch and 2-inch). The incentives used are $2/LF for hot water pipe insulation and $3/LF for steam pipe insulation. The annual hours of operation assumed are 2,425 hr/yr for pipe sizes smaller than 1 inch and 7,752 hr/yr for larger pipe sizes.

[11] One source for the conductivity and emittance of steel pipe is the 2001 ASHRAE Handbook Fundamentals, page 25.20, in the footnotes for Table 11A.
[12] See Attachment #2 – Key Parameters for Pipe Insulation

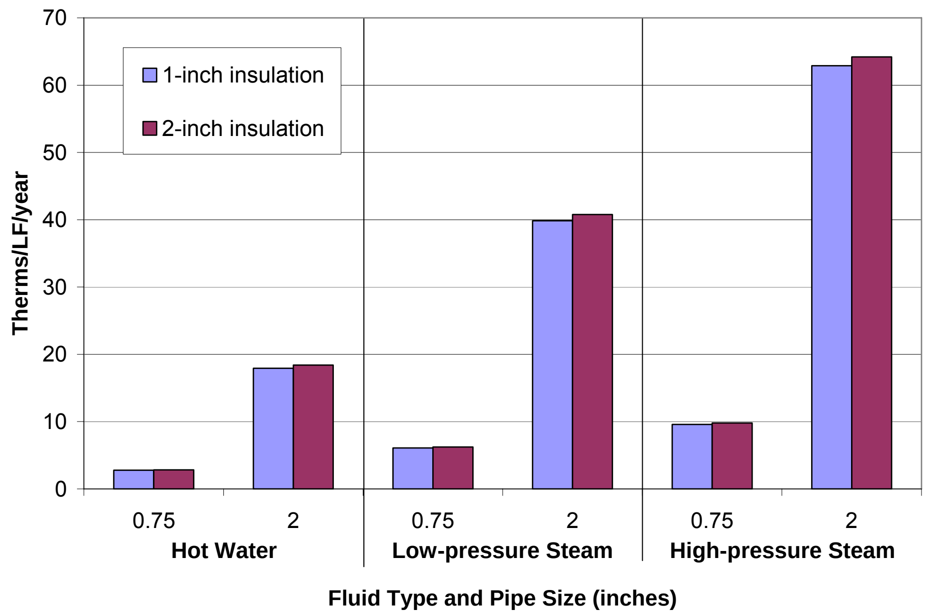

Figure 1. Annual Gas Energy Savings from Adding 1 or 2 Inches of Insulation on Bare Water or Steam Pipes (assuming 2,425 hr/yr for size < 1 inch and 7,752 hr/yr for larger pipe sizes)

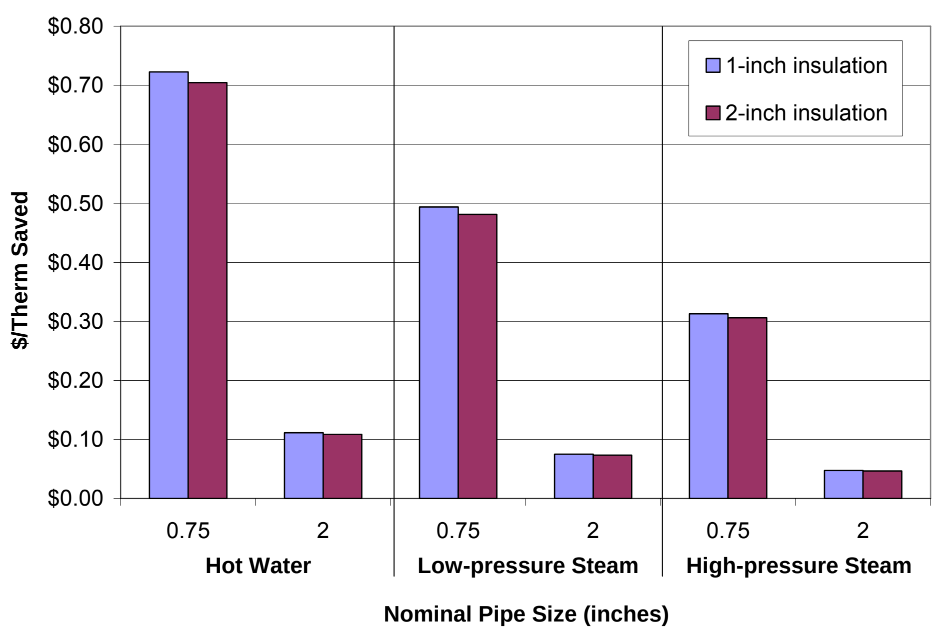

Figure 2. Ratio of Incentive Cost to Annual Therm Savings ($/therm)

4. Insulation Parameters

The energy savings analysis is based on adding 1--inch thick insulation around bare Schedule 40 steel pipe[13]. The thermal conductivity of pipe insulation varies somewhat by material and temperature rating but a value of 0.28 Btu-in/hr-ft^2-F or 0.023 Btu/hr-ft/F) is typical for fiberglass insulation[14]. In addition, the insulation surface participates in radiative heat transfer. Pipe insulation used indoors typically has a paper wrap (with an emittance of about 0.9) and pipe insulation used outdoors typically has an aluminum wrap (with an emittance of about 0.1)[15]. These emittances are not critical parameters, since the heat loss is not very sensitive to radiative heat loss from the rather cool surface of the insulation.

Acceptable types of pipe insulation for hot water pipes include polyethylene foam (up to 180 °F), UV-resistant polyethylene foam, and elastomer foam rubber. Acceptable types of insulation for steam pipes include silicone foam rubber (to 425 °F), melamine foam (to 400 °F), rigid urethane-based foam (to 300 °, cellular glass (to 400 °F), fiberglass, and mineral wool. The protection offered by jacketing is also recommended, especially outdoors. Only some jacket materials are suitable for outdoor use, such aluminum, UV-resistant PVC, and paints.

5. Boiler Efficiency

To calculate the cost of heat lost from bare hot water and steam pipes, it is necessary to have an estimate of the thermal efficiency of the hot water or steam generation boiler. To determine representative boiler efficiencies, data from the California Energy Commission (CEC)[16] was examined. CEC lists several hundred steam boilers, and these boilers were divided into four groups:

- ≤ 2 MMBtuh (hot water only)
- 2-10 MMBtuh (hot water only)
- ≤ 2 MMBtuh (steam only)
- 2-10 MMBtuh (steam only)

The CEC results for hot water boilers are plotted in **Figure 3** and **Figure 4**. As shown in both figures, the boiler listings all start at 80%, with a relatively large number of boilers all rated at 80% efficiency. Based on this data, a baseline efficiency value of 80% was used to compute the cost of hot water generation.

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[13] See Attachment #4 – 2006 Express Efficiency Program Terms and Conditions

[14] Typical thermal conductivities for pipe insulation are listed in the McMaster-Carr catalogue and typical thermal conductivities for a variety of insulation materials are listed in Table 10, 2001 ASHRAE Handbook Fundamentals, page 25.18.

[15] Principles of Heat Transfer, Frank Kreith, Intext Education Publishers, 1973, Table 5-2.

[16] CEC efficiency data included in Attachment #6, and also available online at http://www.energy.ca.gov/appliances/appliance/excel_based_files/boilers/.

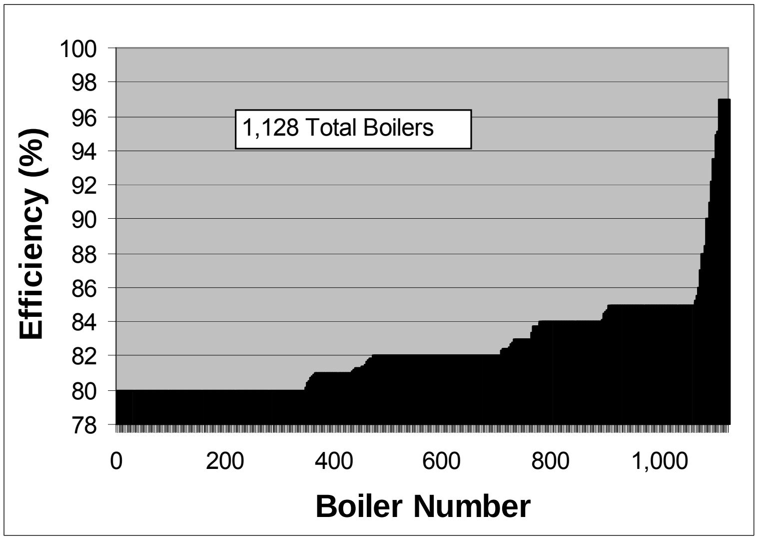

Figure 3. CEC Efficiency Data (Hot Water Boilers ≤ 2 MMBtuh)

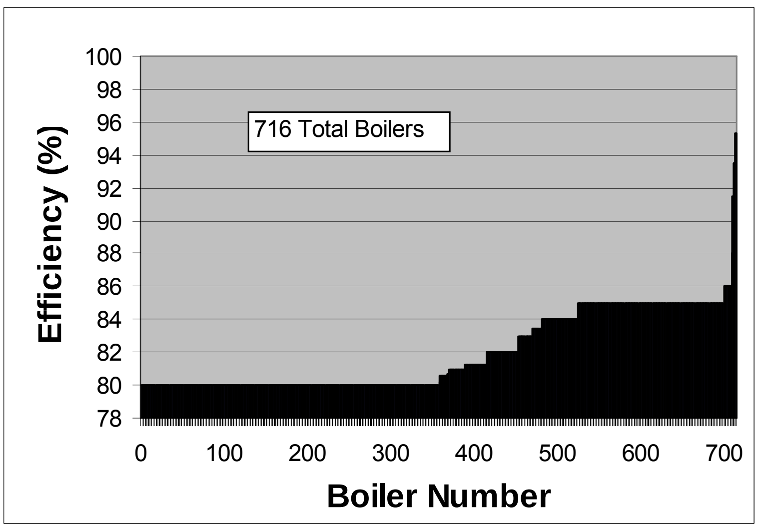

Figure 4. CEC Efficiency Data (Hot Water Boilers 2-10 MMBtuh)

The CEC results for steam boilers are plotted in **Figure 5** and **Figure 6**. As shown in both figures, the boiler listings all start at 80%, with a relatively large number of boilers all rated at 80% efficiency. Based on this data, a baseline efficiency value of 80% was used to compute the cost of steam generation.

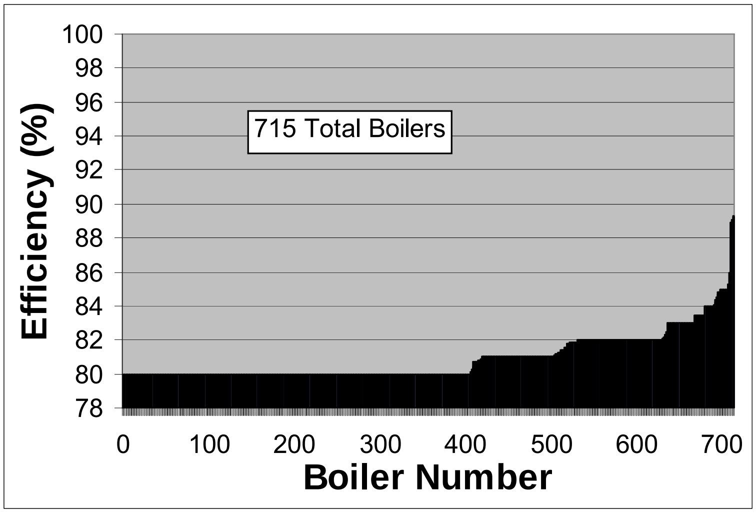

Figure 5. CEC Efficiency Data (Steam Boilers ≤ 2 MMBtuh)

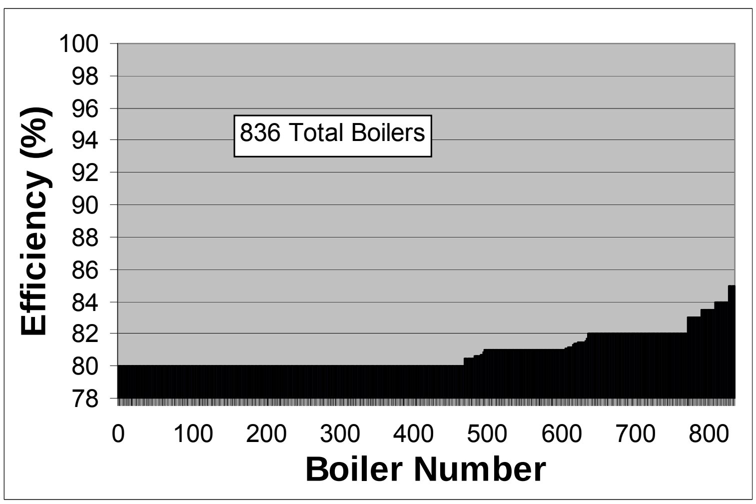

Figure 6. CEC Efficiency Data (Steam Boilers 2-10 MMBtuh)

6. Annual Energy Savings

The annual energy savings attributed to the installation of pipe insulation was calculated based on the operating time, steam boiler efficiency, and reduction in heat loss. The complete heat loss calculations are included in Attachment #2. The calculations included the following heat transfer mechanisms:

- Turbulent forced convection heat transfer inside the pipe[17]
- Steady conduction through the pipe wall and through the insulation[18]
- Forced convection around a horizontal cylindrical pipe if the pipe is bare and around the insulation if the pipe is not bare[19]
- Radiation from the pipe surface if the pipe is bare and from the insulation surface if the pipe is not bare[20]

Due to the radiation, the heat transfer from the bare pipe or from the insulation is a non-linear function of temperature. In the heat transfer calculations in Attachment#2, an iterative scheme was used to converge on the temperature of the outer surface of the bare pipe or insulation. Satisfactory convergence was achieved in six iterations for each.

Table 5 compares the calculated results for the pipe and insulation temperatures with and without insulation. Results are shown for two pipe sizes, three fluid types, and 1-inch insulation. The insulation results in an almost imperceptible change in the pipe outer surface temperature for the hot water cases, but the temperature drop across the pipe wall (and the heat loss) is reduced by a factor of ten. mediumFor steam, the insulation results in a large change in the pipe outer surface temperature (about 50°F for low-pressure steam, and over 80 °F for medium-pressure steam). As with hot water, the temperature drop across the pipe wall (and the heat loss) for steam is reduced by a factor of ten.

Table 5. Comparison of Pipe and Insulation Temperatures

Parameter	Hot Water		Low-pressure Steam (11 psig)		Medium-pressure Steam (86 psig)	
Pipe Size (inch)	<1"	≥1"	<1"	≥1"	<1"	≥1"
Pipe Size for Calculations (inch)	0.75	2	0.75	2	0.75	2
Thickness, insulation (in.)	1	1	1	1	1	1
Fluid Temperature (F)	130.0	130.0	241.0	241.0	328.0	328.0
Temperature inner pipe wall for bare pipe (F)	129.78	129.79	184.81	186.52	235.36	237.94
Temperature inner pipe wall with insulation (F)	129.98	129.99	236.84	237.68	321.91	323.02
Temperature, pipe surface, for bare pipe (F)	129.64	129.63	184.49	186.15	234.86	237.36
Temperature, pipe surface, with insulation (F)	129.97	129.97	236.82	237.66	321.88	322.99
Temperature, insulation surface (F)	69.8	70.5	72.7	74.1	75.1	77.2

[17] Principles of Heat Transfer, Frank Kreith, Intext Education Publishers, 1973, Chapter 8.
[18] Principles of Heat Transfer, Frank Kreith, Intext Education Publishers, 1973, Chapter 2.
[19] 2001 ASHRAE Handbook Fundamentals, page 25.15, Equation (6) and following.
[20] 2001 ASHRAE Handbook Fundamentals, page 25.16, Equation (7) and following.

Temperature, air (F)	65.0	65.0	65.0	65.0	65.0	65.0

The annual energy saved by pipe insulation can be calculated as follows:

$\Delta Q = 0.00001\ X\ t\ X\ (Q_p - Q_i)\ /\ E_b$ **Eqn-1**

where

- ΔQ – Energy Saved (therms/yr/LF), as a result of installing the pipe insulation.
- t – Scheduled Operating Time (hrs/yr). The scheduled operating time represents the time that gas boiler is expected to be in operation. Hours when the equipment is shut down are not included.
- Q_p – Heat Loss from Bare Pipe (Btu/hr/LF)
- Q_i – Heat Loss from Insulated Pipe (Btu/hr/LF)
- E_b – Efficiency (%) of the boiler being used to generate the hot water or steam in the pipe.

The estimated energy savings for all four categories (hot water and steam, 1 inch and 2 inches of insulation) are shown in Error! Reference source not found..

7. Measure Cost

Costs to install the insulation (excluding cost of insulation materials) were determined based on telephone conversations with a pipe insulation vendor. They provided installed cost per foot for typical jobs, as listed in **Table 6**. A price breakdown of indoor installations (with paper wrap) and outdoor installations (with aluminum wrap over the paper wrap) was not obtained. The values in the bottom row of **Table 6** represent an average of typical indoor and outdoor costs of installation.

Table 6. Costs for Installation of Pipe Insulation Provided by Vendor[21]

Parameter		
Insulation thickness (inch)	1	2
Nominal pipe diameter (inch)	2	2
Cost Data ($/LF)		
Cost of installation, indoors	$7.50	$7.55
Cost of installation, outdoors	$14.00	$17.40
Average cost of installation ($/LF)	**$10.75**	**$12.48**

Insulation material costs were determined based on the McMaster-Carr catalog. **Table 7** lists the least expensive 1-inch insulation options for indoor and outdoor, steam and hot water pipe. The bottom two rows combined this data with the average cost of 1-inch installation from **Table 6**:

- Elastomer foam rubber pipe insulation was the least expensive option for hot water pipe sizes 2 inches and smaller

[21] Data source: Cal-Therm Corp., Los Alamitos, CA

- Fiberglass pipe insulation with self-sealing jacket was the least expensive option for larger indoor hot water pipe and indoor steam pipe
- Fiberglass pipe insulation with 0.03-inch PVC self-sealing jacket was the least expensive option for larger outdoor hot water pipe and outdoor steam pipe

Table 7. Pipe Insulation Costs for 1-inch Insulation

Parameter						
Nominal pipe diameter (inch)	0.5	0.75	1	2	3	4
Cost Data ($/LF)						
Hot water, insulation only, indoors or outdoors, lowest cost	$3.05	$3.14	$3.65	$4.50	$7.11	$11.58
Steam, insulation only, indoor, no jacket, lowest cost	$2.63	$2.86	$3.06	$3.86	$4.69	$6.23
Steam, insulation with outdoor jacket, lowest cost	$4.38	$4.60	$5.07	$6.25	$7.68	$9.76
Installation (avg. indoors/ outdoors, 1-inch insulation, from vendor quotes)	$10.75	$10.75	$10.75	$10.75	$10.75	$10.75
Hot water, installed cost, indoors or outdoors	**$13.80**	**$13.89**	**$14.40**	**$15.25**	**$16.93**	**$18.75**
Steam, installed cost, avg. indoors/outdoors, 1-inch)	**$14.25**	**$14.48**	**$14.81**	**$15.81**	**$16.93**	**$18.75**

8. Incentive and Payback

The incentive level for pipe insulation in the 2007 Express Efficiency Rebate Program varies from $2 per linear foot (LF) for at least 1-inch of insulation on hot water pipe, to $3 per LF for at least 1-inch insulation on steam pipe. Using these incentive levels, a comparison of the measure cost and the rebate amount per LF of pipe insulated is shown in **Figure 7**. A payback illustration, based on a gas cost of 95 ¢/therm, is shown in **Figure 8**. As indicated, without an incentive, the payback for pipe insulation on hot water pipe ranges from almost a year for 2-inch pipe and over five years for ¾-inch pipe. The payback for 1-inch insulation on low-pressure steam (11 psig) pipe ranges from a few months for 2-inch pipe to over two years for ¾-inch pipe. The payback for medium-pressure steam (86 psig) ranges from three months for 2-inch pipe to 18 months for ¾-inch pipe. With the incentive, the payback times are slightly shorter. **Table 1** lists payback values for the pipe insulation with and without the incentive.

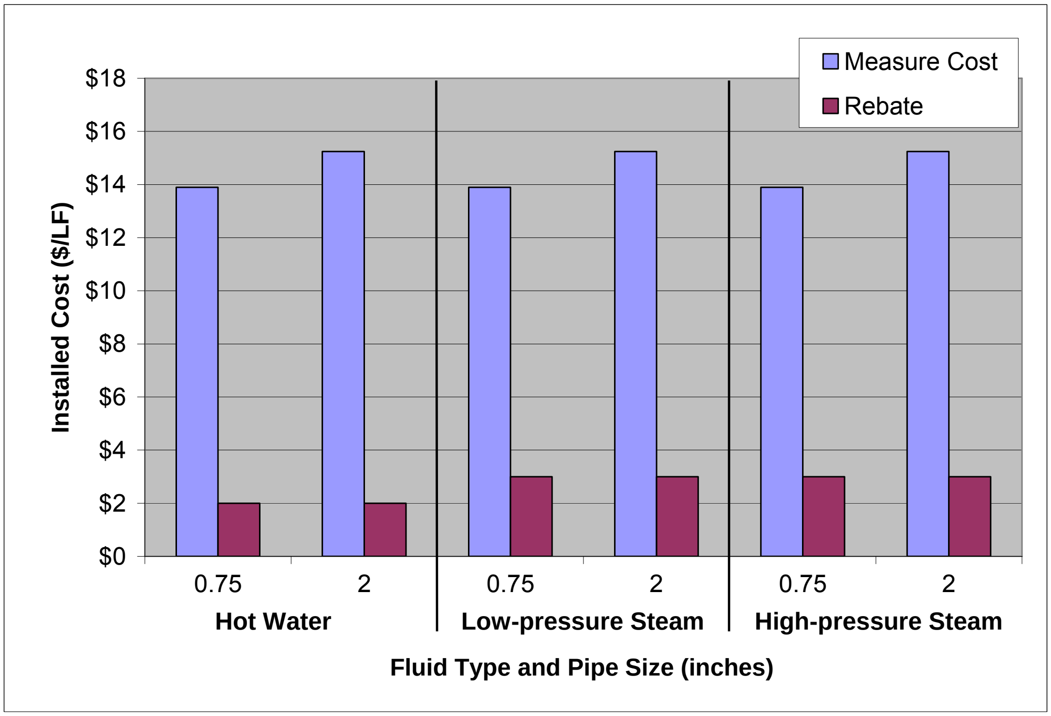

Figure 7. Comparison of Measure Cost and Rebate

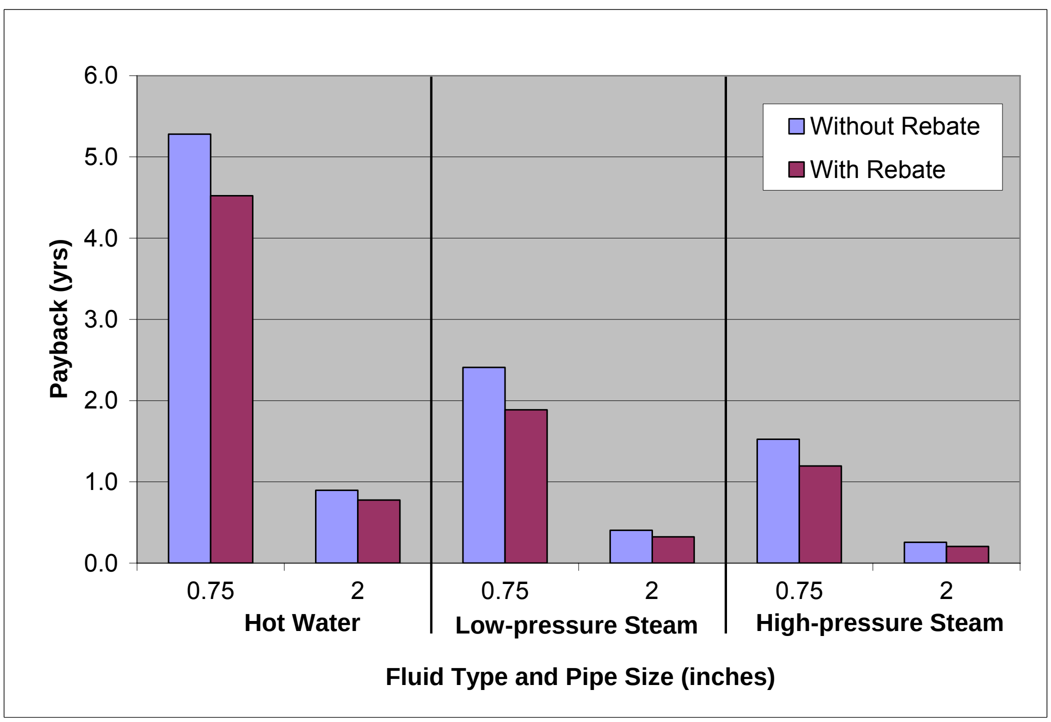

Figure 8. Payback – With and Without Rebate

Even though the payback without the incentives is short, experience shows that many gas customers are not installing pipe insulation. Lack of awareness is believed to be one factor that is limiting more widespread use of pipe insulation, and the incentives described in this workpaper are expected to increase awareness, thereby stimulating the adoption of energy saving pipe insulation. While the primary benefit of this measure is expected to be increased awareness, this measure will also reduce economic barriers, which can be a major obstacle for customers that are cash constrained.

9. Other

Measure Lifetime

Hot water and steam pipe insulation are not specifically identified in the CPUC Energy Efficiency Policy Manual[22]. However, insulation is listed under HVAC measures, which the CPUC identifies as having a 20-year life. A value of 20 years is used in this workpaper as the recommended life of pipe insulation.

Net to Gross Ratio

The net to gross (NTG) ratio is an estimate of free ridership occurring in energy efficiency programs. Free riders are program participants who would have replaced faulty steam traps even if a rebate were not offered. The CPUC Energy Efficiency Policy Manual recommends a value of 0.96 for all equipment covered under the Express Efficiency Program, the value shown in **Table 1**.

Qualifying Parameters

This measure is currently written such that 1 or more inches of insulation must be added to nonresidential bare pipe systems which transfer fluid directly from gas-fired equipment. The minimum qualifying nominal pipe diameter (pipe size) is ½ inch.

Cost to SCG

Table 8 shows the basis for the costs to SCG of the pipe insulation incentive for the various fluids and pipe size categories. The incentive cost is $2/LF for hot water pipe insulation and $3/LF for steam pipe insulation. As shown in **Figure 1**, the annual gas savings varies with fluid type and pipe size. The incentive cost per annual therm saved is the simple ratio of the one-time incentive cost to the annual gas savings from adding insulation. Including the effect of the NTG of 0.96, the cost to SCG of first-year gas savings is the incentive cost per annual therm saved divided by the NTG. Based on the measure lifetime of 20 years, the cost to SCG of the lifetime gas savings is the incentive cost per annual therm saved divided by the NTG and by the measure life. The incentive cost of pipe insulation per therm of gas saved over the lifetime of the insulation is quite low.

[22] See Attachment #7

Table 8. Cost to SCG[23]

Parameter	Hot Water		Low-pressure Steam (0-15 psig)		Medium-pressure Steam (>15 psig)	
Incentive Amount ($/LF)	$2.00	$2.00	$3.00	$3.00	$3.00	$3.00
Annual Gas Savings (therms/yr per LF)	2.8	18	6.1	40	9.6	63
Incentive Cost per Annual Therm Saved ($/therm/yr)	72.2	11.1	49.4	7.5	31.3	4.8
NTG	0.96	0.96	0.96	0.96	0.96	0.96
Cost of First-year Net Gas Savings to SCG (¢/therm)	75.2	11.6	51.4	7.8	32.6	5.0
Measure Lifetime (yrs)	20	20	20	20	20	20
Cost of Lifetime Net Gas Savings to SCG (¢/therm)	3.8	0.6	2.6	0.4	1.6	0.2

23 Detailed calculations shown in Attachment #2.

List of Attachments

The following attachments support this workpaper (supplied as separate electronic files):

- Attachment #1 – kW Engineering Steam Trap Survey
- Attachment #2 – Key Parameters for Pipe Insulation
- Attachment #3 – Enbridge Steam Trap Survey
- Attachment #4 – 2006 Express Efficiency Program
- Attachment #5 – Steam Boiler Efficiency
- Attachment #6 – CPUC Energy Efficiency Policy Manual

Appendix A. Technology Description[24]

A variety of pipe insulation products are commercially available, to provide energy savings and to protect personnel from burns. In addition to hot water and steam, pipe insulation is applied to process fluid piping, HVAC piping, and cryogenic piping. The difficult task is determining not what type of insulation could be used, but what type of insulation should be used in a specific application. The answer depends on why the insulation is needed, its required lifetime, the pipe temperature, and its environment (indoors, outdoors, near food products, near corrosive chemicals, underfoot, overhead, etc.). Equally important to the proper selection of the insulation material is the quality of workmanship involved in the installation, e.g., properly sealing the jacket to keep the insulation dry.

Insulation Materials

Pipe insulation typically consists of the insulation material and a protective jacket (see **Figure 9**). Both are available in a wide variety of materials. Before an insulation material and jacketing system can be chosen, many parameters must be considered. Fiberglass, mineral wool, calcium silicate, ceramic fiber, perlite, cellular glass, removable covers and more recently, high temperature polyisocyanurate, all have maximum operating temperatures good to 450 °F or above. Preformed or fabricated, these insulation materials are readily available.

Courtesy of Accessible Products Company

Figure 9. Pipe Insulation with Flexible Jacket

Material Selection

Criteria for selecting insulation material should include the reason for insulating. Most piping is insulated to protect personnel or to provide an acceptable heat loss. In the high temperature market, the primary reason for insulating a process line is process control. Insulation may be extremely critical to the process.

Each manufacturer publishes test data for the product it makes. They typically list physical properties such as thermal conductivity, compressive strength, density, temperature range and flame and smoke development. Each characteristic has a direct bearing on the insulation product's ability to perform properly during operation of a given process or application at its service temperature.

24 Adapted from "Temperature's Rising, an analysis of insulation options for hot applications," by Robin DeGraff and Mike Irlbacher.

Installation

Common problems associated with failed insulation could be avoided if the substrate could be designed to allow for the proper insulation application. Design features that interfere with the insulator's ability to properly insulate the system include the following:

- Pipes that are not spaced far enough apart and do not allow for the correct insulation thickness to be installed, nor enough room to work and provide a good installation of the insulation.
- Flanges, valves, elbows and other items installed too close together, making it impossible to properly insulate.
- The use of valves that do not have extended bonnets on them to allow for the correct insulation thickness under the valve handle or allow for maintenance of the valve.
- I-beams, braces, brackets and other items coming in contact with the pipe, causing a thermal short.
- Gauges, pipes, and man-way doors installed too close to the vessel or equipment, making it impossible to insulate around or above.
- Improper type of pipe support used.
- Pipes not primed before insulation is installed because it was never specified.

Final Design Considerations

The biggest reason for insulation failure is water; all choices for the system must be reviewed to make sure that the system is breathable, yet water-tight. Additional lines of defense against water should be incorporated into the total design.

Water ingress can be noted under improperly installed or maintained jacket laps, improper spacing of jacket ends, at fittings, flanges, valves and other areas. The minimum insulation surface temperature for personnel protection is approximately 110 °F. Even when considering high-temperature lines of pipe to 450 °F, the thickness of insulation will experience a temperature gradient from 450 ºF to 212 ºF, which is below the temperature of steam, to 110 °F at the surface. The thickness of insulation that lies between 212 °F and 110 °F is where water can be retained in the insulation. If left in operation, this portion can be dried, but the resulting expense is not only an increase in energy required to dry the system, but the added danger of a raised surface temperature. Since water is a conductor, not an insulator, the surface temperature will rise and may exceed that which is safe for personnel. The presence of water also increases in the risk of corrosive under the insulation, which will eventually destroy the piping, at huge expense to the owner.