BEE CODE

FLUID PIPING SYSTEMS

Prepared for

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CONTENTS

List of figures

List of Tables

1 OBJECTIVE & SCOPE

1.1 **Objective:**

Objective of this code is to evaluate the following parameters in fluid piping systems.

1) Friction loss
2) Heat gain to cold fluid in piping system from surroundings
3) Heat loss from hot fluid in piping system to surroundings
4) Insulation thickness and method of application

1.2 **Scope:**

This code includes piping systems conveying fluids namely water, brine, compressed air and steam.

Process streams such as petrochemicals, acids, alkalies, slurries are not included in code.

Observations and cost estimates are derived considering piping system in industrial or commercial environment.

1.3. The following codes/standards/publications are used as reference.

1. Optimum Pipe Size Selection – Claude. B. Nolte- Transtechpublications-1978
2. IS 14164: 1994- Industrial Application and finishing of thermal insulation materials at temperatures above –80C and up to 700 C- Code of Practice

2 DEFINITION & DESCRIPTION OF TERMS

2.1 Units and Symbols:

Description of symbols and units are given in table 2.1.

Table 2-1: Units and Symbols

Description	Symbol	Unit
Specific Power consumption	SP	$kW/m^3/h$ for compressed air & kW/TR for chiller
Pressure	P	kPa
Volume flow	Q	m^3/h
Mass flow	M	kg/h
Density	d	kg/m^3
Specific gravity	ρ	p.u.
Velocity	v	m/s
Length of pipeline	L	m
Reynolds Number	Re	-
Friction factor	f	-
Absolute roughness of pipe	e	mm
Temperature	T	ºC
Heat Loss	H	kJ/hr
Heat Transfer coefficient	h	W/m^2-K
Thermal Conductivity	k	W/m-K
Pipe Diameter	D	mm
Cost of power	C	Rs.
Energy cost	R	Rs/kWh

Description of subscripts are given in table 2.2.

Table 2-2: Subscripts

symbol	description
l	liquid
h	Referred to hot face
c	Referred to cold face
air	air
g	gas
st	steam
PD	Pressure drop
HL	Heat loss
HG	Heat gain
d	discharge
s	Referred to surface
eq	equivalent

2.2 Definition of terms

Specific Power Consumption; Specific power consumption is denoted by SP. It is the amount of power consumed per Nm3/h flow of compressed air for compressed air system. For chillers, it is the power consumption per TR cooling.

Pressure: Pressure inside piping is force per unit area in the fluid. It is denoted by Kg/cm^2;or Pa; or can be covered from manometer readings and appropriate density multiplication.

Gauge pressure (psig): A measure of the force per area exerted by a fluid using atmospheric pressure as a zero reference.

Viscosity: The resistance of a fluid to flow when subjected to shear stress.

Reynolds Number. It is defined by the equation $\mathrm{Re} = \frac{vD}{\upsilon}$ where v = Average velocity, D= Characteristic length measured as the pipe inside diameter, υ = kinematic viscosity

Heat loss/Heat gain: Heat loss or gain is measured in kJ/hr. For fluids without change in phase heat loss/gain is difference between heat contents at two points. At each point, heat content is found out by mass flow, specific heat and temperatures. In case phase transfer is taking place heat loss or gain will have to include latent heat or heat of fusion.

Insulation: Insulation is artificial barrier between pipe and ambient, usually outside the pipe. Insulation offers resistance to heat flow due to low thermal conductivity.

Conductivity: Conductivity is defined as heat flux carried by unit length (thickness) at unit temperature difference.

Pipe Size: Pipe sizes are measured as nominal sizes of bore in millimeter & usually these are outside diameters of pipe with inside diameter changing as per class or schedule of piping.

Equivalent Length: That length of straight tubing which has the same pressure drop as the fitting, valve or accessory (of the same nominal size) being considered.

Cost of bought Power: Cost of power is payment to be made for purchase of one unit of power. In case charges are slab wise, appropriate slab needs to be considered.

Cost of Captive Power: Cost of power to be considered in perspective of heat and power demand for captive power generation.

Cost of Heat Loss: Cost of heat is usually incurred in boiler house as rupees per tonne of steam. In Case, waste heat is available for steam generation or back pressure steam is available from turbines, cost of steam will need appropriate correction.

Cost of Heat Gain: Chilled water or brine system gains heat from the surroundings. This gain is overcome by work done by refrigeration compressor or by steam consumed at the absorption machine.

Cost of Pressure Loss in the System of Compressed Air: Cost of power consumption incurred due to flow of compressed air in piping is derived from type of compressor and compressor ratio.

Cost of Pressure Loss in the System of liquids: Cost of power consumption incurred due to flow of liquids in piping is derived from total power consumption in pumping, pump & motor efficiencies.

3 GUIDING PRINCIPLES

3.1 Principle

3.1.1 Pressure drop measurement/estimation

Movement of cooling water, brine, compressed air and steam is essential in any industrial complex. Fluid movement takes place in piping due pressure difference. For carrying out study in these systems, knowledge of pressure at various points is essential.

For a given length of pipe, pressure drop can be measured or calculated. Measurement of pressure drop is recommended if instruments of good accuracy are available and measurement is practically possible. In systems where measurement is not possible, estimation of pressure drop is recommended.

The measurements and estimations enables to take a decision whether the energy cost due to pressure drop in existing piping system is more than the total cost of installing a new pipeline of same size or higher size in order to reduce pressure drop.

Recommended pipe size for steam systems is given in this code to help in proper selection and to verify whether existing piping is properly sized. As a general rule, the pressure drop should not normally exceed 0.1 bar/50 m.

3.1.2 Heat loss/heat gain and insulation thickness calculations

Piping if left bare can lose heat due to temperature difference between pipe surface temperature and ambient temperature. This code describes methods of measurements and calculations for estimation of heat losses and heat gain in piping systems and insulation thickness. Measurements of fluid temperature and pipe surface temperatures are necessary for above calculations.

3.2 Pre-test Requirements

- Pressure gauges are installed at various places for convenience of operation. However, for study, it is recommended that pressures should be measured by calibrated pressure gauge suitable for operating temperature and pressures. It is recommended to use digital pressure gauges.

- Ensure that isolation valves are provided between the pressure gauge and the pipe. Normally isolation valves are provided before gauges.

- When the activity of fitting of pressure gauges is carried out , experienced manpower is needed and due care should be taken.

- Before installing a pressure gauge on a fitting, it is recommended to discharge some fluid to the atmosphere, to ensure that the tapping is clean.

- In DCS or centralized instrumentation plants, trips or alarms are based on feed back given by installed temperature and pressure gauges. Whenever, some measurement point is to be used, disconnection activity should be informed to instrumentation and plant operators.

3.3 Safety Precautions

- The isolation valves between the gauge and pipe may be rarely operated in a plant and are likely to be rusted. If lever or pipe wrench is applied breakage of lever arm or casting itself may take place.
- Pressure gauges have glass dials which are fragile. Extreme care should be taken while fixing/removing pressure gauges.
- Metallic plugs collect dust, metal rust etc. In case these are opened with pressure inside, sudden blow out may hit eyes/face. Chilled water or brine lines can suddenly spray out substantially quantity and panic can result into serious accidents.

4 INSTRUMENTS & METHODS OF MEASUREMENTS

4.1 Measurements/Estimation of Parameters

The following measurements are required in piping systems.

1. Pressure of fluid
2. Temperature of Fluid
3. Flow of fluid
4. Power consumption

4.2 Measurement of pressure

4.2.1 Instruments

Following instruments shall be used for measuring pressure.

(1) For measuring the steam pressure at various points on the steam circuit and Fluid piping, the Bourdon gauges of required ranges shall be used, which shall be calibrated against standard dead weight gauge or a master gauge. The graduations shall permit readings within ± 1 % percent of the expected pressure measurement.

(2) In place of Bourdon gauges, digital pressure gauge with accuracy of 0.25 % or full scale error of 0.01 bar can be used.

(3) The pressures can also be taken for certain parameters from the digital readout on the control panel, which shall be getting signals from the online precision pressure instrumentation such as pressure transmitters.

(4) For measurement of low pressures of less than 0.2 MPa (absolute), manometers shall be used.

4.3 Measurement of Temperature

4.3.1 Instruments

Following instruments shall be used for measuring temperature.

(1) For measuring the temperature of steam at various points on the entire steam circuit, the calibrated thermocouples or resistance temperature detectors (RTDs) installed online or on equipment shall be used. Wherever, the provision of thermo-well is made, calibrated mercury-in-glass thermometers can also be used.

(2) The temperatures can also be taken for certain parameters from the digital readout on the control panel, which shall be getting signals from the online precision temperature instrumentation such as thermocouple or RTD based temperature transmitters.

(3) The instrument for temperature measurement shall be so chosen that it can read with an accuracy of ± 1 % percent of the absolute temperature. Absolute value of full-scale error shall not exceed 0.1^0C.

4.3.2 Method of heat loss calculations from temperature measurements

Heat loss is estimated from the measured pipe surface temperature as given below.

Heat loss from surfaces = Heat transfer coefficient X Area X Temperature difference

Method of calculation of heat transfer coefficient is described in section 5.2.

4.4 Liquid Flow Rate Measuring Instruments / Methods

Liquid flow may be measured with any of the following instruments/methods:

a) Calibrated In-line liquid flow rate meter.
b) Volumetric measurements based on liquid levels from a calibrated tank.
c) Velocity measurement using Transit Time Ultrasonic flow meter. Measurement of pipe internal diameter using ultrasonic thickness guage or estimation of the same using standard tables for the particular class of pipe. Estimation of flow area from the diameter. Estimation of the flow as the multiplication product of the velocity and flow area. In the case of ultrasonic flow meters, care may be taken to ensure that the error is less than 5%.
b) Estimation of pump flow from discharge pressure, electrical power measurements, estimation of pump shaft power and co-relation with performance curves from test certificate or performance characteristics for the particular pump model. The error in flow estimation by this method can be 5 to 10% or even higher, especially when general pump model type performance characteristics are used to estimate the flow. This method is not recommended unless the use of inline or portable flow measuring instruments is ruled out due to site constraints.
c) For steam and compressed air, flow meters are essential.

4.5 Power Consumption

For Electric Motor driven equipments, shaft power shall be estimated as the multiplication product of motor input power, motor operating efficiency and drive transmission efficiency. Motor efficiency should be estimated by any of the following methods.

a. From the manufacturers' test certificates

b. From motor performance data from catalogues of manufacturers

The following data for Drive Transmission Efficiency can be used, in the absence of other reliable information.

Table 4-1: Drive transmission losses

Power transmission by	Efficiency
Properly lubricated precision gear drive	98% for each step
Synthetic Flat belt drive	97%
V- belt drive	95%

Electrical measurements at the motor input shall be done by any of the following methods

a. Calibrated Power meter or Energy meter. In case of Energy measurement for a defined time period, the time period should be measured with a digital chronometer (stop-watch) with least count of 1/100 second.

b. Calibrated Watt meter method, following the 2-Watt meter method.

c. Multiplication product of $\sqrt{3}$, Voltage, Current and Power Factor for 3-phase electric motors.

4.6 Summary of instrument accuracies

The table given below summarises accuracy requirements of various instruments.

For calibrating various instruments, visit www.nabl-india.org for a detailed list of accredited laboratories. Calibration interval suggested for instruments is 6 months.

Table 4-2: Summary of instrument accuracies

Instrument and range	Accuracy
Temperature	1.0%. Precision of 0.1 ºC
Power	0.5%
Fluid Flow, kg/hr or m3/hr	2%
Pressure, kg/cm2	0.5% with 0.01 kg/cm2 precision
Steam flow	3%
Compressed Air flow	1.0%

5 COMPUTATION OF RESULTS

5.1 Pressure drop

5.1.1 Chronological order of measurements

1. Select the piping system to be studied and identify the section of the piping where measurements can be carried out. This piping section should be without any branches
2. Provide pressure measurement tapping with isolation valves of 12.5 to 17 mm, suitable for pressure measurement. Verify whether both ends of pipe, where pressure gauges are installed for measurements, are at same location. If not measure the level difference.
3. Install manometer/pressure gauge of resolution 0.01 kg/cm^2 and measure the pressure drop in the section. Convert the measured pressure drop in kg/cm^2 into meters of liquid column by dividing by liquid density.
4. If the measurement tapping at the end of piping section is at a higher elevation than the point at the starting of the piping section, the level difference between pressure gauges should be subtracted from the differential pressure measured to calculate actual pressure drop in the piping section.

5.1.2 Pressure Drop Calculations

A common and basic expression for the pressure drop occurring during the flow of fluids is expressed as FANNING equation given below:

$$h = \frac{f \times L \times v^2 \times 1000}{2 \times D \times g} \quad \text{---(1)}$$

Where,
h = Head loss in metre of fluid
f = friction factor, related to Reynolds Number
L = Pipe length, metre
v = Velocity of fluid flow, m/s
D = Pipe internal diameter, mm
g = Acceleration due to gravity, m/s^2

Friction factor is calculated by using the following Colebrook's equation.

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon}{3.7\,D} + \frac{2.51}{R_e\sqrt{f}}\right)$$

Where,
f = Friction factor
Re = Reynolds number
ε = Absolute roughness of pipe, mm, typical values are given below. This depends on the type of material.

It may be noted that the above equation can be used for turbulent flow having Re > 4000. For Re < 2100 in laminar region the friction factor is calculated by

f = 64/ Re

Table 5-1: Absolute roughness of pipes

Various materials	e
Glass	0.015 [mm]
Lead	0.015 [mm]
Copper	0.015 [mm]
Brass	0.015 [mm]
Concrete tube	2.0 [mm]
Steel Pipe	
New	0.04 [mm]
After longer use	0.2 [mm]
Slightly rusted	0.4 [mm]
Very rusted	3.35 [mm]
Galvanised	0.15 [mm]
Cast iron	
New	0.5 [mm]
With bitumen layer	0.2 [mm]
Slightly rusted	1.5 [mm]
Very rusted	3.0 [mm]
PVC/HDPE Tube	**0.0015[mm]**

Reynolds Number is calculated as given below.

For liquids,

$$R_e = \frac{353 \times Q_l \times \rho}{D \times \mu}$$

For gases,

$$R_e = \frac{455 \times Q_g \times \rho}{D \times \mu}$$

Where,
Q_l = Rate of flow of liquid, m^3/h
Q_g = Rate of flow of gases, in 1000 Nm^3/h
ρ = Specific gravity of fluid (for water, ρ = 1.0)
D = Pipe inside diameter, mm
μ = Dynamic viscosity, Pa-s.
(Typical viscosity values of air, water and steam are given in Annexure-1)

Equation (1) is modified to obtain pressure drop (kg/cm^2) for liquids and gases as given below.
For liquids,

$$\Delta p = \frac{6442 \times Q_l^2 \times f \times L \times \rho_l}{1000 \times \left(D/10\right)^5}$$

For air,

$$\Delta p = \frac{3.06 \times 10^7 \times Q_{air}^2 \times \rho_g \times f \times T \times Z \times L}{1000 \times P_{air} \times \left(D/10\right)^5}$$

For Steam,

$$\Delta p = \frac{5.53 \times 10^6 \times M_s^2 \times f \times L}{1000 \times P_{st} \times \left(D/10\right)^5}$$

Where,

Δp = Pressure drop, kg/cm^2 per metre length
Q_l = Rate of liquid flow, m^3/h at flow temperature
Q_{air} = Rate of air flow, in 1000 m^3/h at flow temperature
M_s = Mass flow rate of steam , kg/h
μ = Viscosity at fluid flow temperatures, Pa-s
(Refer Annexure-1 for viscosities of water, air and steam)
D = Pipe internal diameter, mm
L = Length of pipeline, metre
ρ_g = Specific gravity of gas (air, steam etc.)
ρ_l = Specific gravity of liquid
T = Temperature, ºKelvin
P = Supply pressure, kPa
Z = Deviation from perfect gas law, called as Compressibility factor, a fraction (depends on pressure)

Typical compressibility factors for air is given below.

Table 5-2: Compressibility factor (Z) for Air

Temperature	Pressure, bar					
K	1	5	10	20	40	60
300	0.9999	0.9987	0.9974	0.9950	0.9917	0.9901
350	1.0000	1.0002	1.0004	1.0014	1.0038	1.0075
400	1.0002	1.0012	1.0025	1.0046	1.0100	1.0159
450	1.0003	1.0016	1.0034	1.0063	1.0133	1.0210
500	1.0003	1.0020	1.0034	1.0074	1.0151	1.0234

Equivalent lengths of pipe fittings, bends etc. need to be taken into account while calculating pressure drop. Table given below shows L/D ratios of pipe fittings. While calculating equivalent length of each fitting, multiply L/D ratio with inside diameter of the pipe.

Table 5-3: Pressure drop in Fittings/bends

180 bend, R=5D	[28 L/Di]
90 bend, R=5D	[16 L/Di]
90 bend (square , R=1.5D)	[20 L/Di]
45 bend (square , R=1.5D)	[16 L/Di]
Tee (flow straight through)	[20 L/Di]
Tee (flow through side outlet)	[65 L/Di]
Gate valve open	[13 L/Di]
½-closed	[195 L/Di]
Membrane valve	[200 L/Di]
Ball valve (spherical plug valve)	[18 L/Di]
Needle valve	[1000 L/Di]
Butterfly valve (larger then 6 inch)	[20 L/Di]
Globe valve	[300 L/Di]
Nozzle (suction nozzle on vessel)	[32 L/Di]
Check valve (in-line ball type)	[150 L/Di]
Check valve (swing type)	[135 L/Di]
Filter (Y-type and bucket type)	[250 L/Di]

5.1.3 Estimation of cost of pressure drop in pumping system

One method of pressure drop reduction in pipelines is to increase pipe diameter. To calculate the cost benefits of using larger diameter pipe is as follows.

Annual Cost of power due to friction loss in pumping systems pipelines,

$$C_{PD-l} = \frac{\Delta p \times \rho_l \times 10 \times Q_l \times 9.81}{3600} \text{ x R x N}$$

Where

C_{PD-l} = Annual cost of pressure drop in liquid pipelines
Δp = pressure drop in kg/cm^2
ρ_l = Specific gravity of liquid (for water, ρ = 1)
Q_l = Rate of flow of liquid, m^3/h
R = Cost of power, Rs/kWh
N = Annual operating hours

The format for data collection and calculation is given in Table 5.4 in MS Excel spreadsheet format. This table can be used if pressure drop is being ***measured***.

Table 5-4: Format for pressure drop measurements on pipe carrying liquids

	A	B	C	
Sl. No.	Description	Equations to be used in column C & Comments	Measurements/ results	Unit
1	Distance between pressure measuring points		100	m
2	Pressure at initial point, P1		30	mWC
3	Pressure at end point of section, P2		20	mWC
4	Height of pressure gauge at P1 above ground		2	mWC
5	Height of pressure gauge at P2 above ground		8	mWC
6	Actual Pressure drop	C2-C3+(C4-C5)	4	MWC
7	Flow		50	M3/h
8	Hydraulic power equivalent to pressure drop	C7*C6*9.8/3600	0.54	KW
9	Cost of energy		4.5	Rs/kWh
10	Operating hours		6000	Hours/year
11	Cost of pressure drop	C8*C9*C10	14,580	Rs/year
12	Existing pipe diameter		102.3	mm
13	New pipe diameter		154.1	mm
14	Cost pressure drop with new pipe	C11*(C12/C13)^5	1,880	Rs/year
15	Energy cost saving	C11-C14	12700	Rs/year

The format for data collection and calculation is given in Table 5.5 in MS Excel spreadsheet format. This table can be used if pressure drop is being ***estimated***.

Table 5-5: Format for pressure drop estimation in pipe carrying liquids

	A	B	C	
Sl No	Parameter	Equations to be used in column C & Comments	Result	Unit
1				
2	Date			
3	Pipe section identification		Cooling tower supply	
4	Liquid in pipe		water	
5	Pipe Nominal diameter		4	inches
6	Pipe inside diameter	From standard piping data	102.3	mm
7	Pipe Length	Total equivalent length of pipeline, including valves, bends etc.	100	m
8	Flow	Measured	50	m^3/h
9	Velocity	C8/3600/(3.14*(C6/1000)^2/4)	1.690	m/s
10	Specific gravity of water		1	p.u
11	Viscosity of water		0.00085	Pa-s
12	Pipe absolute roughness	Take value from Table 5.1 corresponding to the pipe material	0.26	mm
13	Iteration	-2*LOG10(C12/(C6*3.7)+2.51/(C15*SQRT(C14)))+ SQRT(C14)	1.0000	
14	Friction factor	Initially input C14 = 0.02. Go to 'Tools' menu, and select heading 'GOAL SEEK'. Set cell value in C13 equal to 1, by changing cell C14	0.0257	
15	Reynolds Number	353*C8*C10/(C6*C11)	203058	
17				
18	Pressure drop	6442*C8^2*C14*C10/(C6/10)^5/1000*C7	0.3706	kg/cm^2
19	Hydraulic power equivalent to pressure drop	C18*10*C8*9.8/3600	0.50	kW
20	Cost of energy		4.5	Rs/kWh
21	Operating hours		6000	Hours/year
22	Cost of pressure drop	C19*C20*C21	13500	Rs/year
23	New pipe diameter	Inside diameter of pipe	154.1	Mm
24	Cost pressure drop with new pipe	C22*(C6/C23)^5	1,740	Rs/year
25	Energy cost saving	C22-C24	11760	Rs/year

5.1.4 Estimation of cost of pressure drop in Compressed air pipelines

Reduction in pressure drop in compressed air pipelines help reducing the distribution pressure. The compressor discharge pressure setting can be reduced to the extent to reduction in pressure drop.

$$C_{PD\text{-}air} = \left[\left(\frac{P_d}{P_s}\right)^{\left[\frac{n-1}{n}\right]} - \left(\frac{P_d - \Delta p}{P_s}\right)^{\left[\frac{n-1}{n}\right]} \right] \times SP \times Q_{air} \times R \times N$$

Where
C_{PD-l} = Annual cost of pressure drop due to compressed air
P_d = Discharge pressure of compressor, kg/cm^{2}a
P_s = Suction pressure of compressor, kg/cm^{2}a
SP = Specific power consumption of compressor, kW/(Nm^3/h)
Q_{air} = Air flow rate, Nm^3/h
Δp = pressure drop in kg/cm^2
n = Polytropic exponent of compression ≈ 1.4
R = Cost of power, R_s/kWh
N = Annual operating hours

5.1.5 Estimation of savings by using larger diameter pipe

Estimate of cost of power consumption due to pressure drop by changing over to new size can be made as below.

$$C_{PD-new} = C_{PD}\left(\frac{D_{old}}{D_{new}}\right)^5$$

D_{old} = existing diameter, mm
D_{new} = New diameter,mm

Savings due to new pipe = C_{PD} - C_{PD-new}

Investment for new pipe can be estimated from values given in Annexure-5. Using more specific cost of pipes from vendors is recommended.

Recommendation:

Compare investment for new pipe for test length (after getting firm quotation from local contractor and material purchase dept.) with power saving. Estimate of investment for new pipes are given in Annexure-5. Higher pipe size is recommended based on payback period.

5.1.6 Steam piping

Steam piping systems, methods of verifying whether the existing pipe size is adequate can be done by referring to the nomogram given in Annexure-6. This can also be used for proper pipe selection for new projects.

Only in rare cases, change on pipe size can be justified on economic gains due to pressure drop reduction for steam piping.

The main concern due to pressure drop is that a lower pressure may only be available at the point of use. This may hinder equipment performance due to only lower pressure steam being available.

5.2 Heat loss calculations

5.2.1 Heat loss from pipes

Simplified formulae for calculating 'h'(mW/cm^2-K) are given below. This is useful if the temperature difference between the surface and the ambient is less than 150ºC.

For horizontal pipes, h = A + 0.005 (T_h – T_a)

For vertical pipes, $h = B + 0.009\,(T_h - T_a)$

Using the coefficients A, B as given below.

Table 5-6: Coefficients A, B for estimating 'h' (in mW/cm²-C)

Surface	ε	A	B
Aluminium , bright rolled	0.05	0.25	0.27
Aluminium, oxidized	0.13	0.31	0.33
Steel	0.15	0.32	0.34
Galvanised sheet metal, dusty	0.44	0.53	0.55
Non metallic surfaces	0.95	0.85	0.87

If the temperature differential is more than 150ºC, refer Annexure-3 for a more detailed estimation of heat transfer coefficient.

Area of pipe surface, $A = \pi D L_{eff}$, cm^2

Where D = Pipe surface outside diameter

L_{eff} = Effective Length of pipeline

= Length of pipeline + thermal equivalent length of valves & fittings

Heat loss = $h.A.(Ts - Ta) \times 10^{-3}$ Watts

Ts = Pipe surface temperature, ºC

Ta = Ambient temperature, ºC

h = Heat transfer coefficient, mW/cm^2-C

5.2.2 Heat loss calculations for valves/Flanges

For a realistic calculation of heat losses, the following modifications are required to be done.

To account for valves in a pipeline, additional effective length for valves will have to be added to the real length of the pipeline before calculating heat losses. These valves account for the valves and its own flanges.

$L_{eff} = L + \Delta L$

Values in the table assume typical industrial insulation thickness for the temperatures given, and thermal conductivities of k = 0.8 mW/m-C at 100 ºC mean temperature and k = 1.0 mW/m-C at 400 ºC mean temperature.

Table 5-7: Valves & Flanges

Pipe diameter D1, cm		**10.0**		**50.0**	
Pipe Temperature, ºC		100	400	100	400
Pipe located inside ΔL Meters	Non insulated valve	6	16	9	25
	2/3 insulated valve	3.0	6	4.0	10.0
	3/4 insulated valve	2.5	5	3.0	7.5
Pipe located outside ΔL Meters	Non insulated valve	15	22	19	32
	2/3 insulated valve	6	8	7	11
	3/4 insulated valve	4.5	6	6	8.5

For example, a non insulated valve with pipe diameter 10 cm (4"), and the pipe temperature of 100 ºC, additional length to be considered is 6 meter. This is added to the real length to calculate the total length of the pipeline.

To account for the heat losses from a pair of flanges (including the flange pair when a valve is mounted), the following points may be noted.

1. For *Non-insulated Flanges*, use 1/3rd given for a valve of the same diameter. Add this to the real length of piping for calculating heat losses.
2. For *Insulated Flange Boxes,* add one meter for each flange with flange box, before calculating heat losses
3. For *Insulated Flanges*, No adjustment required; calculate heat losses based on real length.

The following points may be noted, to simplify above calculations.

- If the pipe is less than 50 metres long, add an allowance for fittings of 5%.
- If the pipe is over 100 metres long and is a fairly straight run with few fittings, an allowance for fittings of 10% would be made.
- A similar pipe length, but with more fittings, would increase the allowance towards 20%.

5.2.3 Insulation Thickness Calculations

Formulas and procedures for calculating insulation thickness is described below.

T_a = Ambient temperature, ºC
T_s = Desired/actual insulation surface temperature, ºC
T_h = Hot surface temperature (for hot fluid piping), ºC & Cold surface temperature for cold fluids piping)

$$T_m = \frac{(T_h + T_s)}{2}$$

k = Thermal conductivity of insulation at mean temperature of T_m, W/m-C
(Refer Annexure-4 for thermal conductivity values of insulation materials)

h = Surface heat transfer coefficient, (as calculated in section 5.2.1) W/m^2-C

R_s = Surface thermal resistance = $\frac{1}{h}$ ºC-m^2/W

R_l = Thermal resistance of insulation = $\frac{t_k}{k}$ ºC-m^2/W

The heat flow from the pipe surface and the ambient can be expressed as follows

H = Heat flow, Watts

$$(T_h - T_s)/R_l = (T_s - T_a)/R_s \qquad (5)$$

From the above equation, and for a desired T_s, R_l can be calculated. From R_l and known value of thermal conductivity k, thickness of insulation can be calculated.

t_k = Thickness of insulation, mm
r_1 = Actual outer radius of pipe, mm

Equivalent thickness of insulation for pipe, E_{tk} = $(r_1 + t_k) \times \ln\left(\frac{(r_1 + t_k)}{r_1}\right)$

For cold surfaces, T_s is to be substituted with dew point temperature, $T_{dp.}$ This is mainly to prevent condensation on insulation surface. Dew point temperature can be obtained from a dry bulb and wet bulb temperature and using a psychrometric chart or using the following Table 5.8.

Table 5-8: Dew point temperature, ºC

Dry bulb temp., C	% relative humidity												
	20	25	30	35	40	45	50	55	60	65	70	80	90	100
7.2	-12.8	-10.6	-8.3	-6.7	-5.0	-3.9	-2.2	-1.1	0.0	1.1	2.2	3.9	6.1	7.2
10.0	-10.6	-8.3	-6.1	-4.4	-2.8	-1.1	0.0	1.1	2.8	3.9	5.0	6.7	8.3	10.0
12.8	-8.9	-6.1	-3.9	-2.2	0.0	1.1	2.8	3.9	5.0	6.1	7.2	9.4	11.1	12.8
15.6	-6.7	-3.9	-1.7	0.0	1.7	3.9	5.6	6.7	7.8	8.9	10.0	12.2	13.9	15.6
18.3	-4.4	-2.2	0.6	3.3	4.4	6.1	7.8	9.4	10.6	11.7	12.8	15.0	16.7	18.3
21.1	-2.2	0.6	2.8	5.0	7.2	8.9	10.0	11.7	12.8	13.9	15.6	17.8	19.4	21.1
23.9	0.0	2.8	5.6	7.8	9.4	11.1	12.8	13.9	15.6	16.7	17.8	20.6	22.2	23.9
26.7	1.7	5.0	7.8	10.0	12.2	13.9	15.6	16.7	18.3	19.4	20.6	23.3	25.0	26.7
29.4	4.4	7.2	10.0	12.2	14.4	16.1	17.8	19.4	20.6	22.2	23.3	25.6	27.8	29.4
32.2	6.7	9.4	12.2	14.4	16.7	18.9	20.6	22.2	23.3	25.0	26.1	28.3	30.6	32.2
35.0	8.9	12.2	15.0	17.2	19.4	21.1	22.8	24.4	26.1	27.8	28.9	31.1	32.8	35.0
37.8	11.1	14.4	17.2	20.0	21.7	23.9	25.6	27.2	28.9	30.0	31.1	33.3	35.6	37.8
40.6	13.3	16.7	19.4	22.2	24.4	26.1	27.8	29.4	31.1	32.2	33.9	36.1	38.3	40.6
43.3	15.6	18.9	21.7	25.0	26.7	28.9	30.6	32.2	33.3	35.0	36.7	38.9	41.1	43.3

A sample calculation of insulation thickness is made for a 4" dia horizontal pipe having bare surface carrying steam at 4 bar.

T_a = Ambient temperature, ºC = 30
T_s = Actual insulation surface temperature, ºC = 40
T_h = Hot surface temperature (for hot fluid piping), ºC = 120

$$T_m = \frac{(T_h + T_s)}{2} = 80$$

k = Thermal conductivity of insulation at mean temperature of T_m, W/m-C
(Refer Annexure-4 for thermal conductivity values of insulation materials)
= 0.038
r_1 = Actual outer radius of pipe, mm = 100
h = Surface heat transfer coefficient, W/m^2-C
h = A + 0.005 ($T_h - T_a$) , where A = 0.53 for galvanised, dusty pipe surface
= 0.53 + 0.005 x (120 –30) = 0.98mW/cm^2
= 9.8 W/m^{2}C

R_s = Surface thermal resistance = $\frac{1}{h}$ in ºC-m^2/W = 0.102

From the following relationship, R_l , the thermal resistance of insulation can be estimated

$$\frac{(T_h - T_a)}{(R_l + R_s)} = \frac{(T_s - T_a)}{R_s} \text{ ---(5)}$$

$$\frac{(120 - 30)}{(R_l + 0.102)} = \frac{(40 - 30)}{0.102}$$

R_l = 0.816 ºC-m^2/W

Also, $R_l = \frac{t_k}{k}$ ºC-m^2/W

t_k = Thickness of insulation, mm = k x R_l
= 0.038 x 0.816

$= 0.031$ metre = 31 mm

Equivalent thickness of insulation for pipe, $E_{tk} = (r_1 + t_k) \times \ln\left(\frac{(r_1 + t_k)}{r_1}\right)$

$$= (50 + 31) \times \ln\left(\frac{50 + 31}{50}\right) = 39 \text{ mm.}$$

A 39 mm (or 1.5") glass wool insulation is recommended

5.2.4 Heat Loss to Surroundings from steam Piping System

Chronological order of measurements

1. Select a suitable span of about 20 m steam line without branches, valves etc; immediately after a steam trap/valve which can be relied upon for condensate drain.
2. Collect condensate at the end of the span after draining first trap for few minutes.
3. Note pressure, insulation thickness, diameter of pipe

Heat loss = condensate collected x correction for flash steam x Latent heat

Depending on the average steam pressure at the heater a factor F must be used to the condensate collected due to flash steam loss.

$$F = \frac{(h_{s1} - h_{s2})}{L_{s2}} \times 100$$

Where, F = % of condensate lost as flash steam

h_{s1} and h_{s2} = sensible heat in condensate at the upstream pressures Respectively, kJ/kg.

L_{s2} = latent heat of steam at the down stream pressure, kJ/kg.

Typically flash steam loss to atmosphere can be about 9.5% at 4 kg/cm^2.g. and About 13% at 7 kg/ cm^2.g

Savings due to better insulation can be worked out by formula
= {Measured Heat loss – Heat loss theoretical for insulated surface) x Latent heat of steam x (steam Cost x No. of operating hours/yr.)

Local insulation costs should be compared with savings/yr to decide on re-insulation.

Format for heat loss calculations from steam pipes is given below in table 5.9.

Table 5-9: Estimation of heat loss in steam systems

Sl. No	A	B	C
	Description	**Equations/ comments to be used in column C**	
1	Location:		
2	Date of measurement:		
3	Steam pressure, kg/cm2	Measured value	8.0
4	Condensate collected, kg/h	Measured value	30
5	Length of pipeline	Measured/estimated value	50
6	Flash steam correction factor	[1+{SQRT(SQRT(C3)) – 100}/540]	1.126
7	Latent heat of evaporation of steam	From standard data	2260 kJ/kg
8	Total heat loss	C4*C6*C7	76343 kJ/h
9	Boiler efficiency	Estimated value	80%
10	Calorific value of fuel, kJ/kg	From fuel supply data	43.5 MJ/kg
11	Operating hours/year	Observed value	6000
12	Annual fuel consumption due to heat loss, kg/year	C8*C11/(C10*1000*C9)	13162.5
13	Cost of fuel, Rs/kg	From fuel supply data	12
14	Cost of heat loss, Rs/year	C12*C13	1,57,950

5.3 Heat gain to cold fluid in piping system from surroundings

Procedure for measurement of heat gain

1) Select a suitable span of chilled water/brine line.
2) Line should not have any branches.
3) Provide temperature measurement facility of 0.1C accuracy on both ends of the piping
4) Measure temperature at both ends of the section
5) Note flow of fluid or the pump power and pressure developed to estimate flow

Based on observations compute heat gain by formula

Heat gain in liquid, $H = Q_l \times d \times C_p \times \Delta T$

Where, Q = Rate of flow, m^3/h
d = Density of liquid, kg/m^3
C_p = Specific heat capacity of liquid, kJ/kg-C
ΔT= Temperature rise in pipeline, C
H = Heat gain, kJ/h

Cost of heat gain = $\left(\frac{H \times SP}{4.18 \times 3024}\right) \times N \times R$

Where SP = Specific power consumption of chilling plant, kW/TR
R = Cost of power, Rs/kWh
N = Annual operating hours

A format for estimation of heat gain is given in table 5.10 below. This table is in MS Excel programmable format.

Table 5-10: Estimation of heat gain in Chilled water/brine systems

Sl. No	A	B	C
	Description	**Equations/ comments to be used in column C**	
1	Location:		
2	Date of measurement:		
3	Rate of liquid flow, for chilled water/brine , m^3/h	Measured value	
4	Specific heat of liquid, kJ/kg-C	From standard data	
5	Density of liquid, kg/m3	From standard data	
6	Temperature rise, C	Measured value	
7	Length of pipeline	Measured/estimated value	
8	Heat gain, TR	C3*C5*C4*C6/4.18/3024	
9	Specific power consumption of chiller , kW/TR	Measured value	
10	Operating hours/year	Observed value	
11	Annual energy consumption due to heat gain, kWh/year	C8*C9*C10	
12	Cost of energy, Rs/kWh	Observed value	
13	Cost of heat gain, Rs/year	C11*C12	

Calculate insulation thickness for existing surface temperatures as given in section 5.2 and compare with existing insulation thickness. Cost of heat gain and investment for new insulation can be compared to justify investment.

6 REPORT OF TEST RESULTS

6.1 Fluid Piping Pressure drop calculations

Name of Industry:

Test Date:

Time:

Details of instruments used

Sl.No	Description	Measured parameter	Description of accuracy
1	Pressure guage	Line pressure	
2	Flow meter	Liquid flow	
3	Electrical Power Analyser	Electrical parameters	

Measurements and results

Sl. No.	Description	Unit	Result
1	Pressure drop measured	mWC	
2	Flow	M3/h	
3	Hydraulic power equivalent to pressure drop	KW	
4	Cost of energy	Rs/kWh	
5	Operating hours	Hours/year	
6	Cost of pressure drop	Rs/year	
7	Existing pipe diameter	mm	
8	New pipe diameter	mm	
9	Cost pressure drop with new pipe	Rs/year	
10	Energy cost saving	Rs/year	

Test conducted by:
(Energy Auditing Firm)

Test witnessed by:
(Energy Manager)

6.2 Fluid Piping System Evaluation-Heat Gain

Measurements and results of test conducted on piping system are summarised below.
Name of Industry:

Test Date:

Time:

Details of instruments used

Sl.No	Description	Measured parameter	Description of accuracy
1	Pressure guage	Line pressure	
2	Flow meter	Liquid flow	
3	Electrical Power Analyser	Electrical parameters	
4	Thermometer	Fluid temperature	

Estimation of heat gain in Chilled water/brine systems

Sl. No	Description	Value
1	Location:	
2	Date of measurement:	
3	Rate of liquid flow, for chilled water/brine , m^3/h	
6	Temperature rise, C	
7	Length of pipeline	
8	Heat gain, TR	
9	Specific power consumption of chiller , kW/TR	
10	Operating hours/year	
11	Annual energy consumption due to heat gain, kWh/year	
12	Cost of energy, Rs/kWh	
13	Cost of heat gain, Rs/year	

Test conducted by:
(Energy Auditing Firm)

Test witnessed by:
(Energy Manager)

6.3 Fluid Piping System Evaluation-Heat Loss

Measurements and results of test conducted on piping system are summarised below.

Name of Industry:

Test Date:

Time:

Details of instruments used

Sl.No	Description	Measured parameter	Description of accuracy
1	Pressure guage	Line pressure	
2	Flow meter	Liquid flow	
3	Electrical Power Analyser	Electrical parameters	
4	Thermometer	Fluid temperature	

: Estimation of heat loss in steam systems

Sl. No	Description	Value
1	Location:	
2	Date of measurement:	
3	Steam pressure, kg/cm2	
4	Condensate collected, kg/h	
5	Length of pipeline	
8	Total heat loss	
9	Boiler efficiency	
10	Calorific value of fuel, kJ/kg	
11	Operating hours/year	
12	Annual fuel consumption due to heat loss, kg/year	
13	Cost of fuel, Rs/kg	
14	Cost of heat loss, Rs/year	

6.4 Insulation survey format

A format for physical inspection of insulation is given below.

Description	qty
Identification of line	
Location	
Length	
Utility carried through	
Internal temperature	
Indoor/outdoor	
Thickness of insulation	
Insulation supports' condition	
Type of insulation	
a. Foil thickness	
b. Bituminous mastics	
c. Plastic sheets	
d. Vapour seals	
e. Finishing cements	
Surface temperature	
Surface area	
Water seepage possibility	
Need for cover during monsoon	
For line touching ground-possibility of flooding	

7 UNCERTAINTY ANALYSIS

7.1 Introduction

Uncertainty denotes the range of error, i.e. the region in which one guesses the error to be. The purpose of uncertainty analysis is to use information in order to quantify the amount of confidence in the result. The uncertainty analysis tells us how confident one should be in the results obtained from a test.

Guide to the Expression of Uncertainty in Measurement (or GUM as it is now often called) was published in 1993 (corrected and reprinted in 1995) by ISO. The focus of the ISO *Guide* or GUM is the establishment of "general rules for evaluating and expressing uncertainty in measurement that can be followed at various levels of accuracy ".

The following methodology is a simplified version of estimating uncertainty at field conditions, based on GUM.

7.2 Methodology

Uncertainty is expressed as X +/- y where X is the calculated result and y is the estimated standard deviation. As instrument accuracies are increased, y decreases thus increasing the confidence in the results.

A calculated result, r, which is a function of measured variables X_1, X_2, X_3,….., X_n can be expressed as follows:

$r = f(X_1, X_2, X_3, \ldots, X_n)$

The uncertainty for the calculated result, r, is expressed as

$$\partial_r = \left[\left(\frac{\partial r}{\partial X_1} \times \delta x_1 \right)^2 + \left(\frac{\partial r}{\partial X_2} \times \delta x_2 \right)^2 + \left(\frac{\partial r}{\partial X_3} \times \delta x_3 \right)^2 + \ldots\ldots \right]^{0.5} \quad \text{----(1)}$$

Where:

∂_r = Uncertainty in the result

δxi = Uncertainties in the measured variable X_i

$\frac{\partial r}{\partial X_i}$ = Absolute sensitivity coefficient

In order to simplify the uncertainty analysis, so that it can be done on simple spreadsheet applications, each term on RHS of the equation-(1) can be approximated by:

$$\frac{\partial r}{\partial X_1} \times \partial X_1 = r(X_1 + \partial X_1) - r(X_1) \quad \text{----(2)}$$

The basic spreadsheet is set up as follows, assuming that the result r is a function of the four parameters X_1, X_2, X_3 & X_4. Enter the values of X_1, X_2, X_3 & X_4 and the formula for calculating **r** in column A of the spreadsheet. Copy column A across the following columns once for every variable in **r** (see table 7.1). It is convenient to place the values of the uncertainties $\partial(X_1)$, $\partial(X_2)$ and so on in row 1 as shown.

Table 7-1: Uncertainty evaluation sheet-1

	A	B	C	D	E
1		∂X_1	∂X_2	∂X_3	∂X_4
2					
3	X_1	X_1	X_1	X_1	X_1
4	X_2	X_2	X_2	X_2	X_2
5	X_3	X_3	X_3	X_3	X_3
6	X_4	X_4	X_4	X_4	X_4
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$

Add ∂X_1 to X_1 in cell B3 and ∂X_2 to X_2 in cell C4 *etc.*, as in Table 7.2. On recalculating the spreadsheet, the cell B8 becomes $f(X_1+\partial X_1, X_2, X_3, X_4)$.

Table 7-2: Uncertainty evaluation sheet-2

	A	B	C	D	E
1		∂X_1	∂X_2	∂X_3	∂X_4
2					
3	X_1	$X_1+\partial X_1$	X_1	X_1	X_1
4	X_2	X_2	$X_2+\partial X_2$	X_2	X_2
5	X_3	X_3	X_3	$X_3+\partial X_3$	X_3
6	X_4	X_4	X_4	X_4	$X_4+\partial X_4$
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1', X_2, X_3, X_4)$	$r=f(X_1, X_2', X_3, X_4)$	$r=f(X_1, X_2, X_3', X_4)$	$r=f(X_1, X_2, X_3, X_4')$

In row 9 enter row 8 minus A8 (for example, cell B9 becomes B8-A8). This gives the values of ∂ (r, X_1) as shown in table 7.3.

$\partial (r, X_1)=f (X_1 +\partial X_1), X_2, X_3\dots) - f (X_1, X_2, X_3..)$ *etc.*

To obtain the standard uncertainty on *y*, these individual contributions are squared, added together and then the square root taken, by entering $\partial (r, X_1)^2$ in row 10 (Figure 7.3) and putting the square root of their sum in A10. That is, cell A10 is set to the formula, SQRT(SUM(B10+C10+D10+E10)) which gives the standard uncertainty on r, ∂ (r)

Table 7-3: Uncertainty evaluation sheet-3

	A	B	C	D	E
1		∂X_1	∂X_2	∂X_3	∂X_4
2					
3	X_1	$X_1+\partial X_1$	X_1	X_1	X_1
4	X_2	X_2	$X_2+\partial X_2$	X_2	X_2
5	X_3	X_3	X_3	$X_3+\partial X_3$	X_3
6	X_4	X_4	X_4	X_4	$X_4+\partial X_4$
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1', X_2, X_3, X_4)$	$r=f(X_1, X_2', X_3, X_4)$	$r=f(X_1, X_2, X_3', X_4)$	$r=f(X_1, X_2, X_3, X_4')$
9		$\partial (r,X_1)$	$\partial (r,X_2)$	$\partial (r,X_3)$	$\partial (r,X_4)$
10	$\partial (r)$	$\partial (r,X_1)^2$	$\partial (r,X_2)^2$	$\partial (,X_3)^2$	$\partial (r,X_4)^2$

7.3 **Uncertainty evaluation for cost of pressure drop- water pumping:**

Based on above discussions, the methodology for estimating uncertainty is explained below. This example refers to measurements and methodology for calculating the cost of pressure drop for piping in a water pumping system

It is necessary that all instruments are calibrated in the measurement ranges and the error at measurement points be known. If actual calibration certificates are used, error at the measured value should be used in the instrument accuracy table.

Description		**flow**	**pressure**	**pressure**
	Measurements	δ Q	δ p1	δ p2
%	%accuracy	1.00%	0.50%	0.50%
absolute	Absolute	0.50	0.02	0.01
Flow, m3/h	50.0	**50.5**	50.0	50.0
Pressure at point 1, kg/cm2	3.00	3.00	**3.02**	3.00
Pressure at point 2, kg/cm2	2.00	2.00	2.00	**2.01**
Height of pressure gauge at P1 above ground, m	2.0	2.0	2.0	2.0
Height of pressure gauge at P2 above ground, m	8.0	8.0	8.0	8.0
Actual Pressure drop, kg/cm2	0.4	0.4	0.4	0.4
Hydraulic power equivalent to pressure drop, kW	0.54	0.55	0.56	0.53
Cost of energy, Rs/kWh	4.5	4.5	4.5	4.5
Operating hours per year	6000	6000	6000	6000
Cost of pressure drop	14700	14847	15251	14333
Existing pipe diameter, mm	102.3	102.3	102.3	102.3
New pipe diameter	154.1	154.1	154.1	154.1
Cost pressure drop with new pipe	1936	1955	2008	1887
Energy cost saving	12764	12892	13243	12445
Delta		-127.64	-478.66	319.10
Delta square		16292.47	229112.91	101827.96
% uncertainty		4.6%		

Notes:

1) Note that the % error in pressure measurement is 0.5% for the above measurements. This is possible only by using a digital pressure guage of 0.01 bar least count. If a bourdon guage of 2% error is used, the uncertainty would increase from 4.6% to 18%. Hence it is important to have very accurate pressure guages while taking measurements.

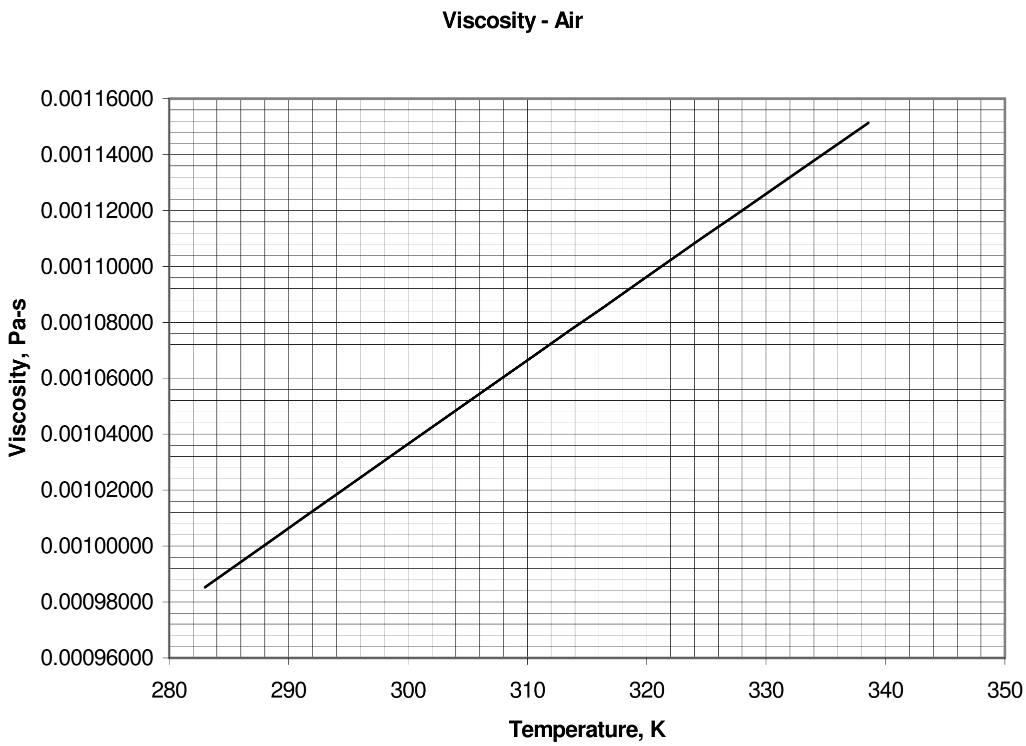
8 GUIDELINES FOR ENERGY CONSERVATION OPPORTUNITIES

Energy losses in a fluid piping system occur due to friction losses and undefined heat gain or heat loss from insulated piping system.

Piping system design is not revised frequently against cost of energy losses and the insulation as designed may also deteriorate over a period of time. The following points should be considered.

1. Assessment of condition of insulation for hot or cold piping and associated elements for spotting areas needing repairs/replacement.
2. Estimation of losses and cost there of for existing system for assessing possibility of improvement in friction losses and insulation losses as applicable.
3. Review and redesign of piping system along with total system for optimizing energy conservation.

ANNEXURE-1: VISCOSITY CHARTS



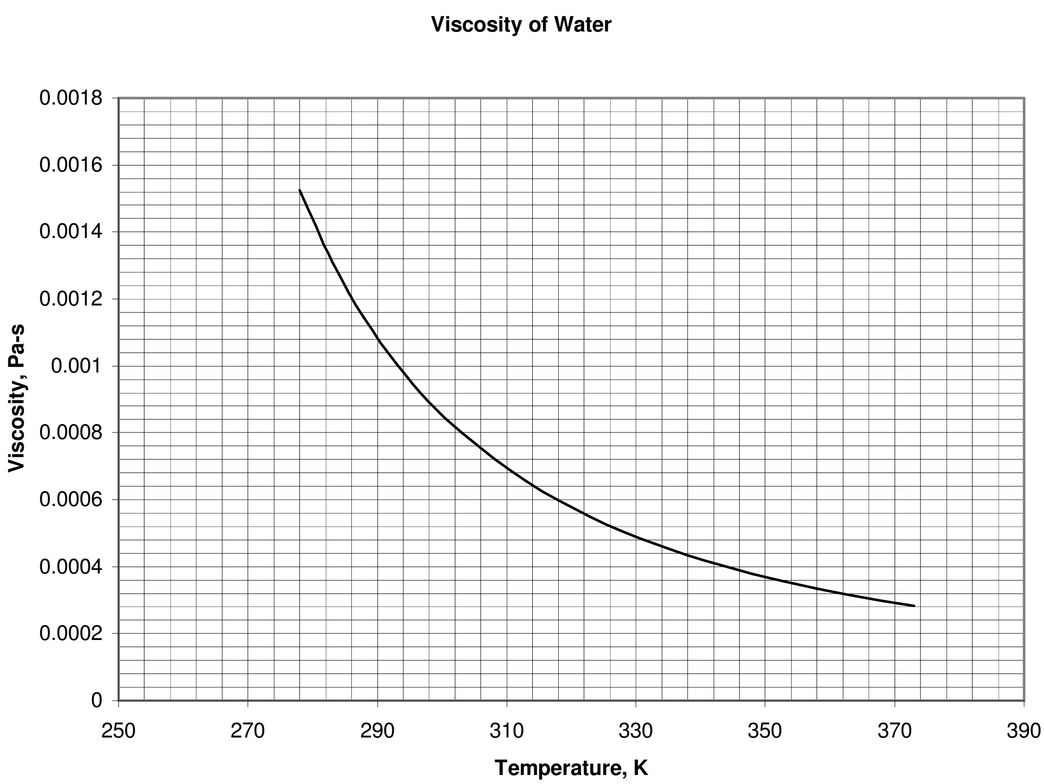


Figure A1.1: Viscosity Chart- Air and water

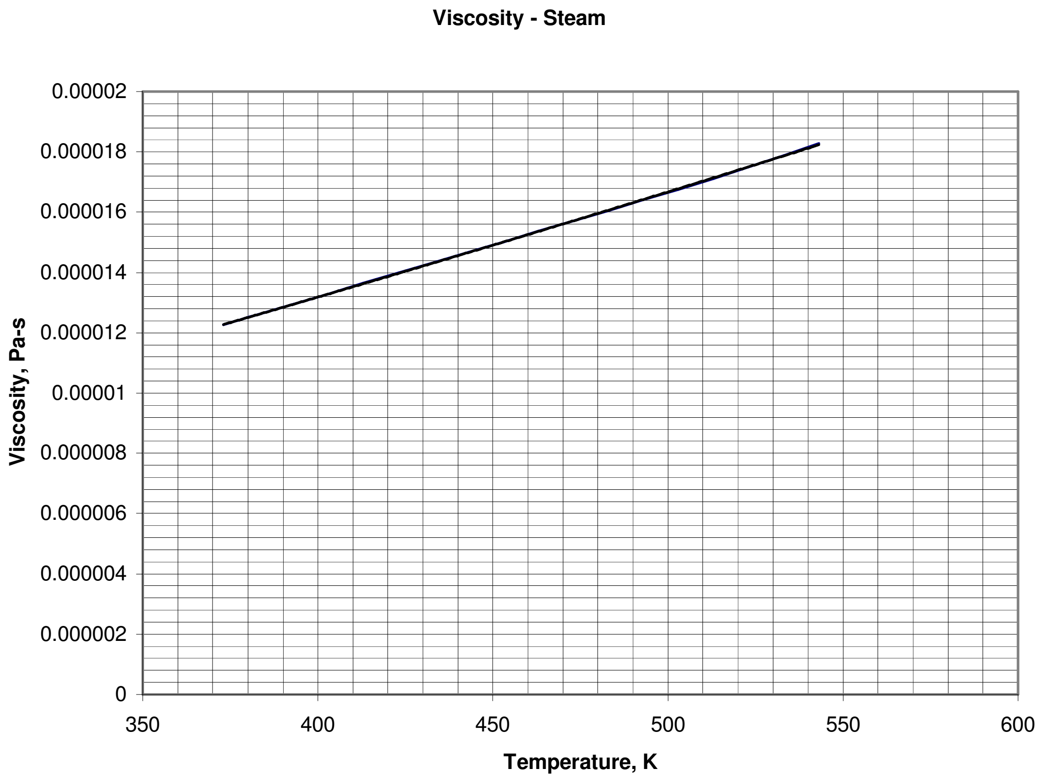


Figure A2.1: Viscosity Charts -steam

ANNEXURE-2: PRESSURE DROP IN WATER PIPING SYSTEMS

Table A2-1: Pressure drop in piping systems

Flow	1"											
m^3/h	Velocity	Pressure drop	1 1/4"									
	m/s	kg/cm^2 per 100 metres	Velocity	Pressure drop	1 1/2"							
0.1	0.05	0.0028	m/s	kg/cm^2 per 100 metres	Velocity	Pressure drop	2"					
0.3	0.15	0.0189	0.09	0.005	m/s	kg/cm^2 per 100 metres	Velocity	Pressure drop	2 1/2"			
0.5	0.25	0.0479	0.14	0.0123	0.11	0.0058	m/s	kg/cm^2 per 100 metres	Velocity	Pressure drop	3"	
0.7	0.35	0.0892	0.20	0.0226	0.15	0.0106	0.09	0.0031	m/s	kg/cm^2 per 100 metres	Velocity	Pressure drop
1	0.50	0.174	0.29	0.0435	0.21	0.0202	0.13	0.0059	0.09	0.0025	m/s	kg/cm^2 per 100 metres
1.3	0.65	0.2862	0.37	0.071	0.27	0.0328	0.17	0.0094	0.12	0.0040	0.08	0.0014
1.6	0.80	0.4259	0.46	0.1048	0.34	0.0482	0.21	0.0138	0.14	0.0058	0.09	0.0020
2	1.00	0.6542	0.58	0.1559	0.42	0.0732	0.26	0.0207	0.18	0.0086	0.12	0.0030
2.5	1.24	1.0075	0.72	0.2447	0.53	0.1114	0.32	0.0314	0.22	0.0130	0.15	0.0045
3	1.49	1.4366	0.86	0.3472	0.63	0.1576	0.38	0.0441	0.27	0.0182	0.17	0.0062
3.6	1.79	2.051	1.04	0.4927	0.76	0.2233	0.46	0.0621	0.32	0.0255	0.21	0.0087
4.2	2.09	2.774	1.21	0.6654	0.89	0.3003	0.54	0.0831	0.38	0.0340	0.24	0.0115
5	2.49	3.901	1.44	0.9345	1.06	0.4204	0.64	0.1158	0.45	0.0473	0.29	0.0159
6			1.73	1.3333	1.27	0.5987	0.77	0.1641	0.54	0.0667	0.35	0.0224
7.2			2.07	1.9053	1.52	0.8539	0.92	0.2331	0.65	0.0944	0.42	0.0315
8.6			2.47	2.7009	1.82	1.2084	1.10	0.3286	0.77	0.1327	0.50	0.0440
10			2.88	3.6346	2.11	1.6241	1.28	0.4403	0.90	0.1773	0.58	0.0587
12					2.54	2.3247	1.54	0.6280	1.08	0.2522	0.70	0.0831
15					3.17	3.6092	1.92	0.9716	1.35	0.3890	0.87	0.1275
18							2.31	1.3894	1.62	0.5551	1.05	0.1813
23							2.95	2.2538	2.07	0.8970	1.34	0.2918
28									2.52	1.3204	1.63	0.4283
35									3.15	2.0496	2.04	0.6630
42											2.45	0.9492
47											2.74	1.1838
52											3.03	1.4459

ANNEXURE-2: PRESSURE DROP IN WATER PIPING SYSTEMS cont'd..

Flow	3 1/2"											
m^3/h	Velocity	Pressure drop	4"									
	m/s	kg/cm^2 per 100 metres	Velocity	Pressure drop	5"							
2	0.09	0.0015	m/s	kg/cm^2 per 100 metres	Velocity	Pressure drop	6"					
4	0.17	0.0051	0.14	0.0028	m/s	kg/cm^2 per 100 metres	Velocity	Pressure drop	8"			
7	0.30	0.0144	0.24	0.0077	0.15	0.0025	m/s	kg/cm^2 per 100 metres	Velocity	Pressure drop	10"	
10	0.43	0.0280	0.34	0.0149	0.22	0.0048	0.15	0.0020	m/s	kg/cm^2 per 100 metres	Velocity	Pressure drop
14	0.61	0.0531	0.47	0.0281	0.30	0.0090	0.21	0.0036	0.12	0.0009	m/s	kg/cm^2 per 100 metres
18	0.78	0.0859	0.61	0.0453	0.39	0.0145	0.27	0.0058	0.15	0.0015	0.10	0.0005
23	1.00	0.1378	0.78	0.0724	0.49	0.0230	0.34	0.0091	0.20	0.0023	0.13	0.0008
28	1.22	0.2018	0.95	0.1058	0.60	0.0334	0.42	0.0132	0.24	0.0034	0.15	0.0011
34	1.48	0.2940	1.15	0.1540	0.73	0.0485	0.51	0.0191	0.29	0.0048	0.19	0.0016
40	1.74	0.4042	1.35	0.2113	0.86	0.0663	0.60	0.0261	0.34	0.0066	0.22	0.0021
48	2.09	0.5781	1.62	0.3015	1.03	0.0943	0.72	0.0369	0.41	0.0092	0.26	0.0030
56	2.43	0.7829	1.89	0.4077	1.20	0.1271	0.83	0.0498	0.48	0.0124	0.31	0.0040
66	2.87	1.0823	2.23	0.5629	1.42	0.1750	0.98	0.0683	0.57	0.0169	0.36	0.0054
80	3.48	1.5821	2.70	0.8219	1.72	0.2548	1.19	0.0992	0.69	0.0244	0.44	0.0077
95			3.21	1.1536	2.04	0.3569	1.42	0.1382	0.82	0.0339	0.52	0.0107
108			3.65	1.4853	2.32	0.4592	1.61	0.1777	0.93	0.0435	0.59	0.0137
122					2.62	0.5837	1.82	0.2256	1.05	0.0550	0.67	0.0173
136					2.93	0.7230	2.03	0.2792	1.17	0.0680	0.74	0.0213
150					3.23	0.8772	2.23	0.3384	1.29	0.0822	0.82	0.0257
170							2.53	0.4329	1.46	0.1049	0.93	0.0328
195							2.90	0.5673	1.68	0.1372	1.06	0.0427
230							3.43	0.7858	1.98	0.1896	1.26	0.0589
270									2.32	0.2597	1.47	0.0804
315									2.71	0.3518	1.72	0.1087
365									3.14	0.4703	1.99	0.1451
425									3.66	0.6353	2.32	0.1957
500									4.30	0.8772	2.73	0.2695
590											3.22	0.3736
700											3.82	0.5237
820											4.48	0.7163

ANNEXURE-3: HEAT LOSS FROM BARE PIPE SURFACES

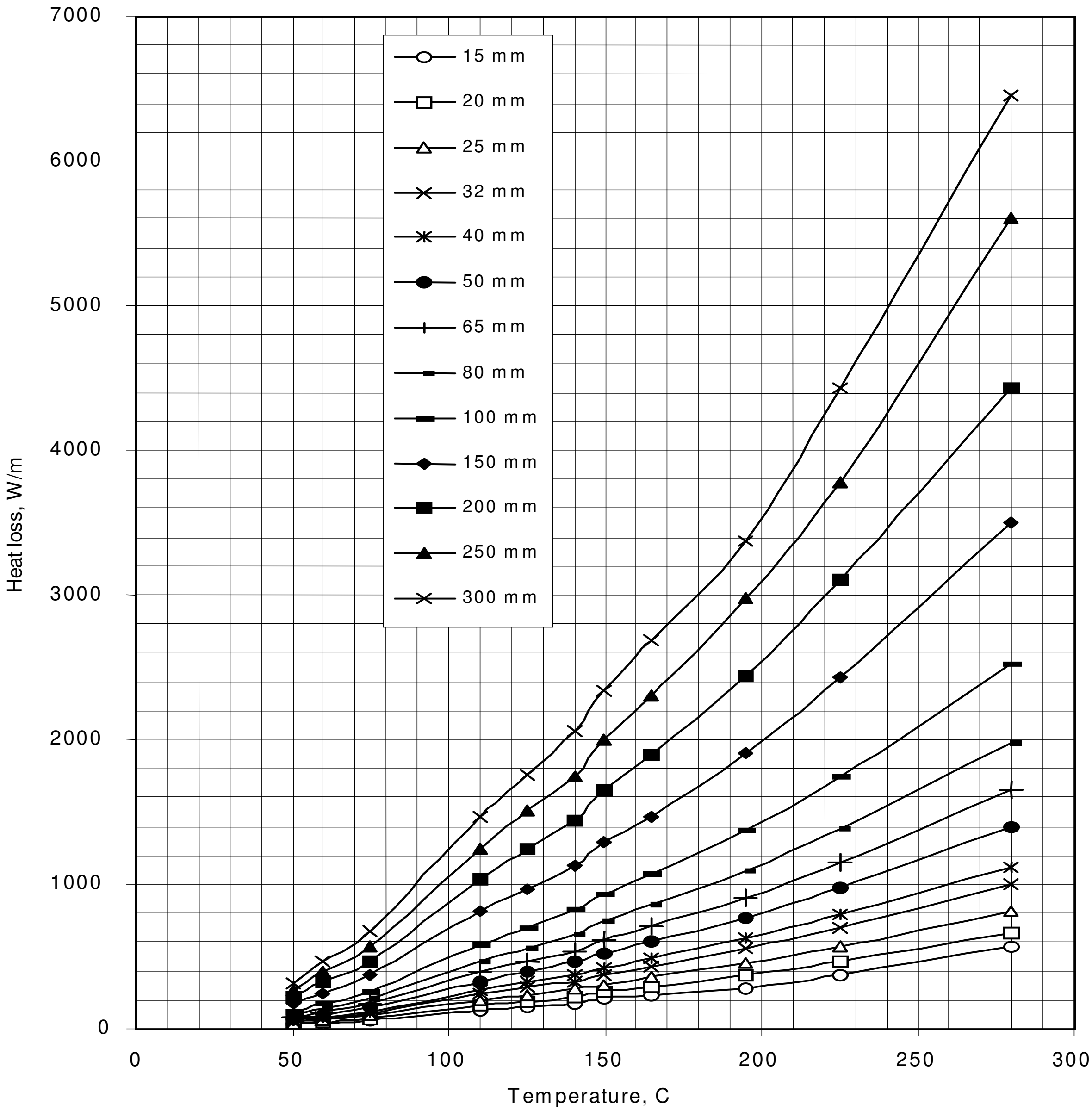


Figure A3-1: Heat losses from bare pipe surfaces

Average ambient temperature = 30 C

Heat transfer coefficient is estimated from the following equation.

$$h = \frac{\left[5.76\times10^{-8}\times\varepsilon\times\left(T_h{}^4 - T_a{}^4\right)+1.95\times\left(T_h - T_a\right)^{1.25}\times\left(\frac{(v+0.35)}{0.35}\right)^{0.5}\right]}{\left[T_h - T_a\right]}$$

$H = h \text{ X } A \text{ x } (T_h\text{-}T_a)$ ---(4)

Where

h = Heat transfer coefficient, W/m^2-K, H = Heat loss, Watts, T_h = Average hot surface temperature, K , T_a = Average ambient temperature, K, v = Average air velocity, m/s, ε = Emissivity of surface, a fraction, A = Surface area = $\pi\times D_o\times L$,D_o = External diameter of pipe, m L = Length of pipe, m

ANNEXURE-4: THERMAL CONDUCTIVITY OF INSULATION

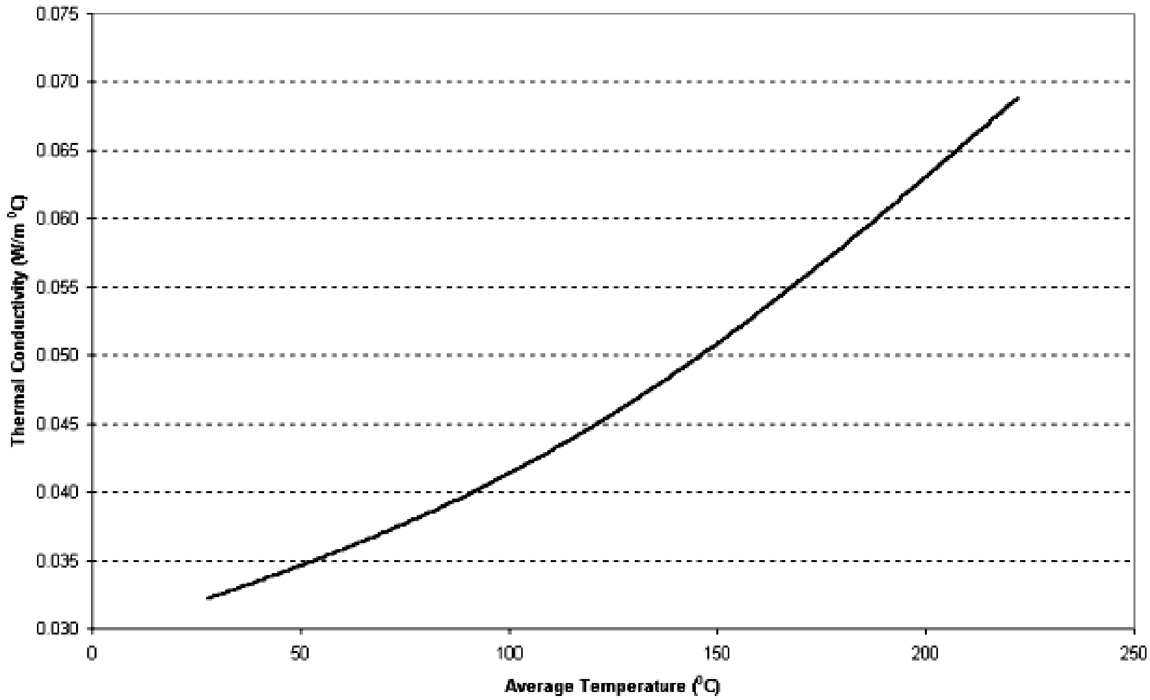


Figure A4-1: Thermal conductivity of Glass wool insulation

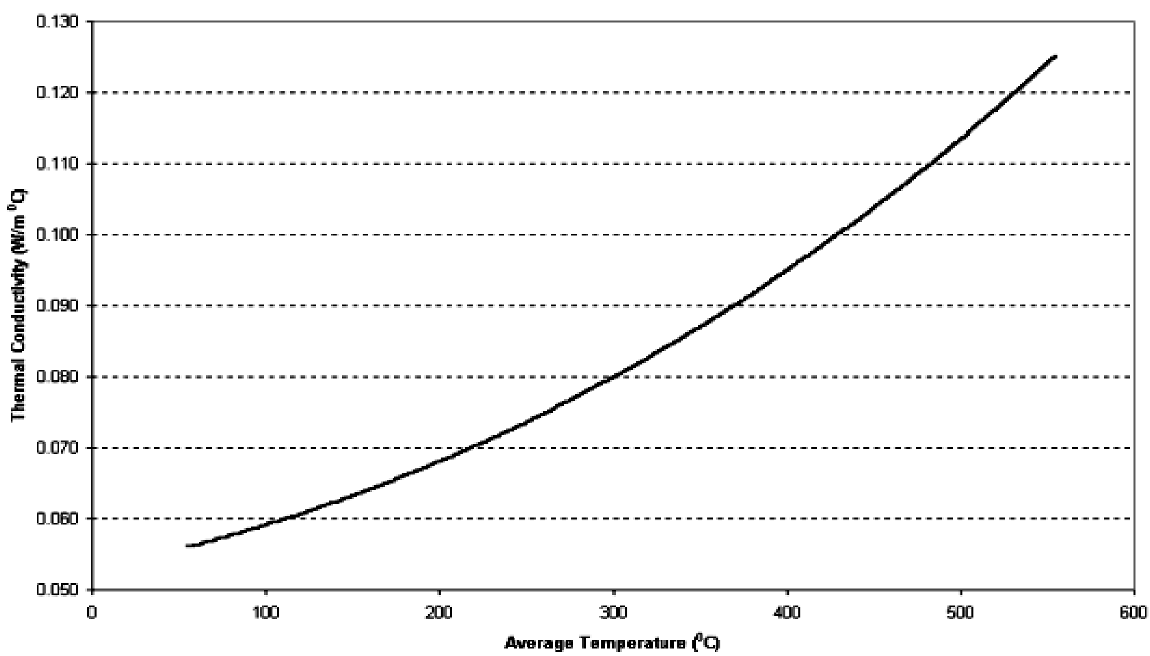


Figure A4-2Thermal conductivity of Calcium silicate insulation

ANNEXURE-5: COST OF NEW PIPES

Dia, mm	Thickness, mm	Weight, kg	Piping Cost, Rs/m	Cost of erection, Rs/m	Total cost, Rs/m
100	6	10	1000	1000	2000
150	6	15	1500	1500	3000
200	8	20	2000	2000	4000
250	8	31	3100	3100	6200
300	10	45	4500	4500	9000
500	10	75	7530	5000	12530
1000	15	150	15000	10000	25000

ANNEXURE-6: STEAM PIPELINE SIZING CHART – VELOCITY

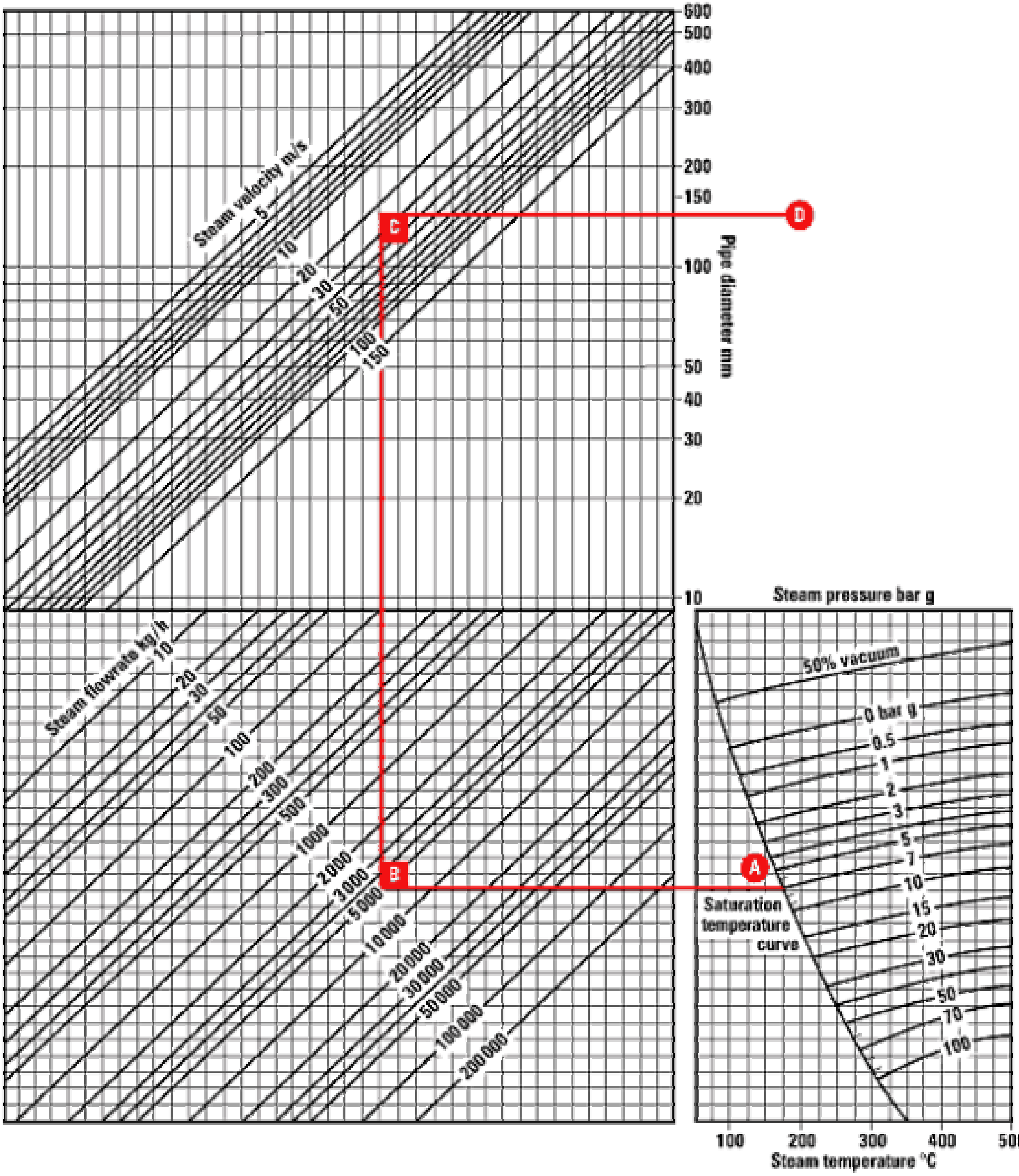


Figure A6-1: Steam line sizing chart (source: Spirax Sarco)

Draw a horizontal line from the saturation temperature line at operating pressure (A) to steam mass flow rate lines (B). From point **B**, draw a vertical line to the steam velocity of 25 m/s (Point **C**). From point **C**, draw a horizontal line across the pipe diameter scale (Point **D**) to obtain pipe diameter.