



PIPE SIZE & PRESSURE DROP CALCULATIONS

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INTRODUCTION

FOR DESIGNING ANY PIPE SYSTEM, THE FIRST ACTIVITY, AFTER FINALISATION OF PROCESS FLOW DIAGRAM, IS *DETERMINING THE SIZE OF THE PIPELINES* OF VARIOUS FLUIDS.

IMPORTANT FACTORS IN PIPE SIZING

- ☒ THE QUANTITY FLOWING
- ☒ THE ALLOWABLE OR RECOMMENDED PRESSURE DROPS
- ☒ THE VELOCITY OF FLOW



STEPS INVOLVED IN PIPE SIZING

STEP 1: CALCULATION OF MINIMUM DIAMETER OF THE PIPE ASSUMING RECOMMENDED VELOCITIES.

STEP 2: FINDING THE STANDARD WALL THICKNESS FOR THE CORRESPONDING NOMINAL BORE.

STEP 3: CALCULATION OF THE PRESSURE DROP FOR THE SELECTED PIPE SIZE FOR THE RECOMMENDED VELOCITY.

STEP 4: CHECKING WHETHER THE PRESSURE DROP IS WITHIN THE ALLOWABLE LIMITS OR NOT. IF NOT REPEAT THE PROCESS.



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STEP 1:



CALCULATION OF MINIMUM DIAMETER OF THE PIPE ASSUMING RECOMMENDED VELOCITIES.

For Main Steam Line

Let us assume,

- 1) Working fluid: Superheated steam
- 2) $T=500^{\circ}\text{C}= 932\text{ F}$
- 3) $P=72.7\text{ Kg/cm}^2$
- 4) Flow rate=117 tones/hr =117000Kg/hr
- 5) Specific weight of superheated steam=21.55 Kg/m³
- 6) Velocity =50m/sec.

SELECTION OF A SUITABLE VELOCITY:

The larger the velocity, the smaller is the pipe size and hence lower is the pipe cost. However, the selection of a suitable velocity is governed by the following system requirements.

1) Pressure Drop:

- a) The calculated pipeline pressure drop should be within the system permissible limits.
- b) Where the system permissible limits have not been pre-determined and where the total cost of the system is significant, the line sizes



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may be determined by optimizing the line drop with the system/equipment parameters so as to result in least capitalized cost, which shall include installed cost, running cost and maintenance or replacement costs.

2) NPSH:

Where applicable, the pipeline velocities and sizes shall be such as to ensure that the NPSH requirements are less than availability.

3) Pipeline Erosion:

High line velocities lead to line erosion particularly in case of wet steam and water.

4) Water Hammer & Surge Pressures:

High line velocities result in significant pressure increases due to water hammer or surge action.

5) Noise:

High line velocities in case of piping carrying compressible fluids lead to high noise levels.

The following table indicates recommended range of velocities for various services and guidelines for selecting a suitable velocity within the range for preliminary line sizing.

S.No	FLUID	RECOMMENDED VELOCITY RANGE
1	<u>STEAM</u>	
1.1	SUPERHEATED STEAM	20 TO 75 m/s
1.2	SATURATED STEAM	20 TO 40 m/s
1.3	WET STEAM / EXHAUST STEAM	20 TO 30 m/s



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2	<u>WATER</u>	
2.1	PUMP SUCTION	0.5 TO 1.5 m/s
2.2	PUMP DELIVERY	1.0 TO 3.0 m/s
2.3	BOILER FEED DELIVERY	3.0 TO 6.0 m/s
2.4	CITY WATER	0.5 TO 1.5 m/s
3	<u>OIL</u>	
3.1	HEAVY OIL (HEATED)	1 TO 2 m/s
3.2	LIGHT OIL	1 TO 2 m/s
4	<u>GASES</u>	
4.1	COMPRESSED AIR	5 TO 15 m/s
4.2	NATURAL GAS	10 TO 30 m/s

The above table indicates ranges of velocity, which in some cases are large. The following additional guidelines may be considered while selecting a suitable value from the range.

- i) For a given velocity, the pressure drop varies inversely with the pipe size. Select lower values of velocities for smaller pipes.
- ii) When line pressures are low, select lower values of velocity to keep pressure drop low. Conversely, at high line pressures, higher velocities should be acceptable.
- iii) In case of short pipe runs, pressure drops are generally inconsequential. Hence high velocities can be selected.



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- iv) For superheated steam lines, the upper limit is from noise considerations. In case of pipelines located outdoor, higher values of velocity are acceptable. In case of indoor piping where background noise is generally low, use an upper limit of 50 m/sec for steam velocity.
- v) In case of high temperature and high-pressure steam piping, pipe expansion will introduce problems of flexibility. Use of high velocity would keep pipe sizes down and minimize flexibility problems.
- vi) Steam lines in intermittent service can be designed with relatively higher velocities since higher noise levels can be tolerated for short durations. In specific cases where pressure drop considerations are unimportant, velocities in excess of 75 m/sec, up to 100 m/sec may also be considered.

The Procedure for line sizing is to first select a preliminary size based on assumed velocity and examine the suitability of the selected size from the point of view of the various system requirements discussed above. The smallest pipe size, which meets all the system requirements, is the **optimum size** for the intended service.

To calculate the minimum Pipe size with out considering pressure,

$$D = \sqrt{(Q \times 354) / (V \times W)}$$

Where,

D → Nominal bore of the pipe (mm)

Q → Flow Rate (Kg/hour)

V → Velocity of the Fluid (m/sec)

W → Specific weight of Fluid (Kg/m³)

$$D = \sqrt{(117000 \times 354) / (50 \times 21.55)}$$



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$$\underline{D = 196\text{mm}}$$

Alternatively,

$$\underline{D = 595 \sqrt{((Q \times V_s) / V)}}$$

Where,

D → Nominal bore of the pipe (mm)

Q → Flow Rate (Tons/hour)

Vs → Specific Volume = 0.04639 m³/Kg

V → Velocity of the Fluid (m/sec)

$$D = 595 \sqrt{((117 \times 0.04639) / 50)}$$

$$\underline{D = 196\text{mm}}$$

STEP 2



FINDING THE STANDARD WALL THICKNESS FOR THE CORRESPONDING NOMINAL BORE.

AS PER ANSI B31.3

For Straight Pipes,

$$\underline{\text{Minimum wall Thickness, } t = PD / 2 (SE + PY)}$$

$$\underline{\text{Required Wall thickness, } t' = (t + \text{Corrosion allowance}) / \text{Mill tolerance}}$$



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Where,

P → Internal Design gage pressure (Kg/cm²)

D → Outside diameter of pipe as listed in tables of standards or specification or as measured (mm)

S → Allowable stress value (Kg/cm²)

E → quality factor.

Y → Values of coefficient, valid for $t < D/6$ and for materials shown. The value of Y may be interpolated for intermediate temperatures. (Refer attachment 1-taken from ANSI B31.3)

For $t \geq D/6$,

$$Y = (d + 2c) / (D + d + 2c)$$

Negative Mill Tolerance = 12.5% (Generally)

Corrosion allowance = 1.5mm (Varies case to case)

Since the minimum diameter of the pipe is 196mm, Let us select 8" pipe (200NB) for calculation,

$$\begin{aligned} \text{Minimum wall Thickness, } t &= (72.7 \times 219.1) / 2 (1055 + 72.7 \times 0.7) \\ &= 7.20 \text{ mm.} \end{aligned}$$

$$\begin{aligned} \text{Nominal Wall thickness, } t' &= (7.20 + 1.5) / 0.875 \\ &= 9.94 \text{ mm.} \end{aligned}$$

Since the Wall thickness is 9.94 mm which is not a standard wall thickness, we can go for the next standard value i.e) 10.31 mm.(Refer attachment 2 for standard wall thickness)



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Thickness = 10.31mm

∴ Schedule → 60

OD = 219.1mm

ID = 198.48 mm.

For Pipe bends,

The minimum required thickness t_m of a bend can be calculated using the following formula,

$$T = PD / 2((SE/I) + PY)$$

Where at the intrados (inside bend radius)

$$I = (4(R_1/D) - 1) / (4(R_1/D) - 2)$$

And at the extrados (outside bend radius)

$$I = (4(R_1/D) + 1) / (4(R_1/D) + 2)$$

Where R_1 = Bend radius of welding elbow or pipe bend.

AS PER ANSI B31.1

Minimum Wall thickness, $t_m = ((PD_o/2(SE+PY) + A)$

SE or SF → Max. Allowable stress in material due to internal pressure and joint efficiency at the design temperature.

A → Additional thickness, (mm)

- To compensate for material removed in threading, grooving etc., required to make a mechanical joint.
- To provide for mechanical strength of pipe
- To provide for corrosion and/or erosion



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- For cast iron pipe the following values of A shall apply:

Centrifugally cast ----- 3.56mm

Statically cast ----- 4.57mm

Y → Refer attachment for coefficient values-taken from ANSI B31.1.

AS PER ANSI B31.4

Nominal Wall thickness, $t_n = t + A$

Where,

t → Pressure design wall thickness (mm)

$$t = P_i D / 2S$$

S → Applicable allowable stress value, psi

$S = 0.72 \times E \times \text{Specified minimum yield strength of the pipe, psi}$

A → Sum of allowances for threading and grooving, corrosion

AS PER ANSI B31.8

Nominal Wall thickness, $t = (P \times D) / 2 \times S \times E \times T$

Where,

S → Specified minimum yield strength, psi

F → Design factor

E → Longitudinal joint factor

T → Temperature derating factor



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VALUE OF COEFFICIENT Y IN VARIOUS CODES

As per IBR, 1977, Regulation 350

$$Y = 0.5$$

As per BS 806, 1980

$$Y = 0.5$$

As per DIN 2413, 1972

$$Y = 0 \text{ for } T < 120^{\circ}\text{C}$$
$$= (1-E/2) \text{ for } T \geq 120^{\circ}\text{C}$$

where T is the design temperature

As per ANSI B31.1, 1977 & As per ANSI B31.3, 1977

Y is a function of temperature and has following values:

Temperature ($^{\circ}\text{C}$)	482	510	538	566	593	621
Ferritic Steels	0.4	0.5	0.7	0.7	0.7	0.7
Austenitic Steels	0.4	0.4	0.4	0.4	0.5	0.7

WELD JOINT EFFICIENCY, E IN VARIOUS CODES

As per IBR, 1977, Regulation 350

$$E = 1 \text{ for seamless ERW steel pipes}$$
$$= 0.9 \text{ for Welded Steel pipes for thickness } \leq 22\text{mm}$$



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- = 0.85 for Welded steel pipes for $22 > \text{thickness} \leq 29\text{mm}$
- = 0.9 for welded steel pipes for thickness $> 29\text{mm}$

As per ANSI B31.1, 1977

- Seamless pipe = 1.0
- Single or double butt-welded pipe with 100% radiography = 1.0
- Double Butt-welded pipe = 0.9
- ERW pipe = 0.85
- Single butt-welded pipe = 0.80
- Special Welded pipe – ASTM A 211 = 0.75
- Furnace Butt-welded pipe = 0.6

As per BS806, 1980

- E = 1.0 for seamless, ERW and pipes complying with the requirements of BS3601, BS3602: Part 1 and BS 3604
- = 1.0 for Submerged arc welded pipes complying with the requirements of BS3602, Part 2, test category-1(100% NDT for welds)
- = 0.95 for submerged Arc welded pipes complying with the requirements of BS3602: Part 2, test category-2.
- = 0.9 for submerged Arc welded pipes complying with the requirements of BS3601.

As per DIN 2413, 1972

- E=1.0 for seamless pipes and for pipes of special quality in steels conforming at least to quality Group-2 in DIN 17100 and subject to special testing including, in particular 100% NDT of welds and with delivery test.
- =0.9 for pipes with test certificate and conforming at least to Quality Group-2 of DIN 17100
- =0.8 for pipes without test certificate but conforming atleast to Quality Group-2 of DIN 17100
- =0.7 for Pipes for General Use in steels conforming to Quality Group-1 of DIN 17100 and not subject to any special testing, licensed works.
- =0.5 as above but for unlicensed works



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STEP 3



CALCULATION OF THE PRESSURE DROP FOR THE SELECTED PIPE SIZE FOR THE RECOMMENDED VELOCITY.

$$\text{Pressure Drop } \Delta P \text{ (Kg/m}^2\text{)} = W ((f \times L \times V^2 / 2gd) + (Z \times V^2 / 2g))$$

Where,

W → Mean Specific weight of the fluid (Kg/m³)

V → Mean Velocity of the fluid (m/sec)

g → Gravitational constant (m/sec²)

f → Co-efficient of friction (Friction factor)

L → Sum of straight pipe Lengths of same size (m)

d → Bore of pipe (m)

Z → Sum of co-efficient of fluid resistance of each fitting such as bend, elbow, tee, reducer, valve, etc.,

CASE-1

To find 'f' ---- we need to find Reynold's number.

Reynolds's number:



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It is a dimensionless number representing the ration of inertial and viscous forces governing a flow.

$$Re = (10^3 \rho \times V \times d) / \mu$$

Where,

V → Mean Velocity of the fluid (m/sec)

d → Bore of pipe (m)

ρ → weight density of fluid (Kg/m³)

μ → Dynamic viscosity, in centipoise.

Refer attachment 3A for Viscosity of water and steam

3B for Viscosity of water and Liquid petroleum Products

3C for Viscosity of various Liquids

3D for Viscosity of gases and vapours

$$Re = ((10^3 \times 21.55 \times 50 \times 0.1985) / 2.936)$$

$$= 72848.689$$

When the Reynold's number for a flow through a closed conduit is less than 2000, the flow is said to be LAMINAR. When the Reynold's number exceeds 4000, the flow is called TURBULENT. In between the values of 2000 and 4000, the flow could be either laminar or turbulent depending upon several factors. Such flows are called TRANSIENT flows.

For laminar flows, friction factor is defined by POISEUILLE'S law as,

$$F = 64/Re.$$

In our case the flow is turbulent we can select the friction factor value from the graph, (Refer attachment 4- taken from CRANE hand book),

$$\underline{\underline{f = 0.02}}$$



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Finding Z:

From a piping isometric,

Let us assume, Total pipe length = 95 m

Pipe fittings:

90 degree elbows = 12nos.

45 degree elbows = 2 nos.

$$Z = K_1 + K_2$$

Where 'K' is defined as the resistance coefficient of the valve or fitting. Values of K for usual valves and fittings are furnished here.

(Refer attachment 5 –taken from CRANE handbook)

$$K_1 = \text{For 90 degree elbow} = 30f_t$$

$$K_2 = \text{for 45 degree elbow} = 16f_t$$

$$Z = (30 \times 0.02 \times 12) + (16 \times 0.02 \times 2)$$

$$Z = 7.84$$

Therefore Pressure drop,

$$\Delta P = (21.55 \times 50^2 / 2 \times 9.8) ((0.02 \times 95)/0.1985) + 7.84$$

$$\Delta P = 47860.209 \text{ Kg/m}^2$$

$$\Delta P = 4.79 \text{ Kg/cm}^2$$

CASE-2

Selecting Higher Pipe Size:



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Let us calculate the pressure drop for a 10" (250NB) line.

Calculation of Wall thickness

$$\begin{aligned}\text{Minimum wall Thickness, } t &= (72.7 \times 273.1) / 2 (1055 + 72.7 \times 0.7) \\ &= 8.98 \text{ mm.}\end{aligned}$$

$$\begin{aligned}\text{Required Wall thickness, } t' &= (8.98 + 1.5) / 0.875 \\ &= 11.97 \text{ mm.}\end{aligned}$$

Since the Wall thickness is 11.97 mm which is not a standard wall thickness, we can go for the next standard value i.e) 12.70 mm.

$$\begin{aligned}\text{Thickness} &= 12.70\text{mm} \\ \therefore \text{Schedule} &\rightarrow 80 \\ \text{OD} &= 273.1\text{mm} \\ \text{ID} &= 247.70 \text{ mm.}\end{aligned}$$

Calculation of Pressure drop

$$\text{Pressure Drop } \Delta P \text{ (Kg/m}^2\text{)} = W ((f \times L \times V^2 / 2gd) + (Z \times V^2 / 2g))$$

$$\text{Re} = (10^3 \times \rho \times V \times d) / \mu$$

$$\begin{aligned}\text{Re} &= ((10^3 \times 21.55 \times 40 \times 0.248) / 2.936) \\ &= 72811.989\end{aligned}$$

From the graph (Refer attachment 4- taken from CRANE hand book),
f = 0.02



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Finding Z:

From a piping isometric,

Let us assume, Total pipe length = 95 m

Pipe fittings:

90 degree elbows = 12nos.

45 degree elbows = 2 nos.

$$Z = K_1 + K_2$$

$$K_1 = \text{For 90 degree elbow} = 30f_t$$

$$K_2 = \text{for 45 degree elbow} = 16f_t$$

$$Z = (30 \times 0.02 \times 12) + (16 \times 0.02 \times 2)$$

$$Z = 7.84$$

Therefore Pressure drop,

$$\Delta P = (21.55 \times 40^2 / 2 \times 9.8) ((0.02 \times 95)/0.248) + 7.84$$

$$\Delta P = 27269.617 \text{ Kg/m}^2$$

$$\underline{\Delta P = 2.73 \text{ Kg/cm}^2}$$



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CASE-1	CASE-2
NB=200	NB=250
Pressure drop = 4.79 Kg/cm ²	Pressure drop=2.73 Kg/cm ²
Steam Velocity = 50 m/s	Steam Velocity = 40 m/s

PRESSURE DROP FROM NOMOGRAPHS:

Pressure drop in liquid lines (for both laminar and turbulent condition) can also be found out from the nomographs. (Refer attachment 6A & 6B- taken from the CRANE handbook).

AGEING:

While sizing pipelines for water service, the likely increase in pressure drop with the ageing of pipe due to increase in pipe roughness, encrustation of pipe with scale, dirt, foreign matter, etc., should be considered. The extent of increase in pressure drop is difficult to predict with any accuracy.

On one hand, inadequate allowances would result in shortfall in capacity at a future date and On the other hand, excessive allowances result in over sizing of piping, which besides increasing piping costs.

The allowance to be provided depends on the following factors:

- a) Size of pipe
- b) Quality of water
- c) Proportion of friction drop to total system resistance
- d) Location of pipe – buried or above ground.