PIPING DESIGN

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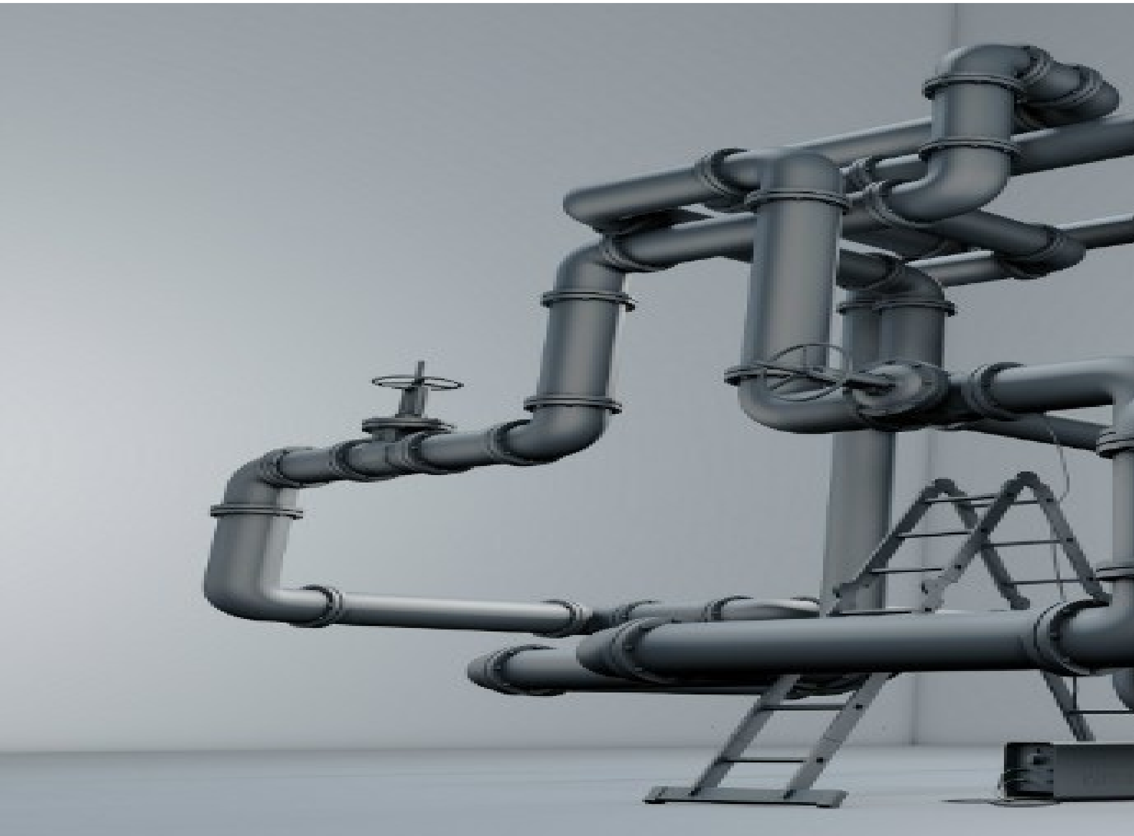
PIPING SYSTEM DESIGN

OBJECTIVES



To identify and briefly discuss the parts of a piping system

To determine design consideration of an engineer in an piping system

To enumerate and identify several underlying principles in an piping system through its parts

To design a water piping system

DESIGN OF PIPING SYSTEMS

INTRODUCTION. CONSIDERATION.

- The flow rate of fluids is a critical variable in most chemical engineering applications especially in flows in the process industries

- Flow is defined as mass flow or volume flow per unit of time at specified temperature and pressure conditions for a given fluid.

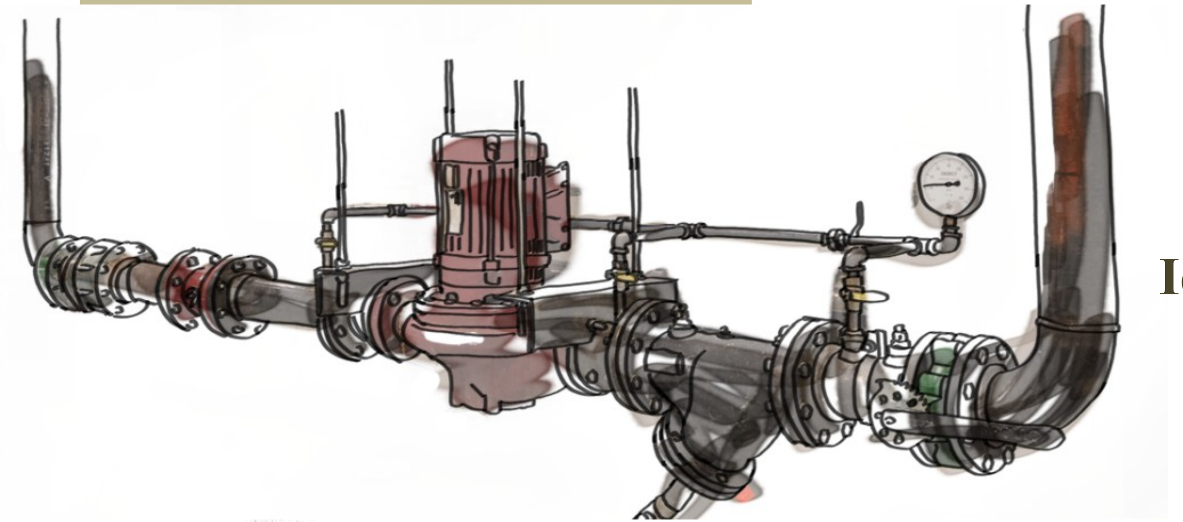
The following items should be considered by the engineer when developing the design for a piping system:

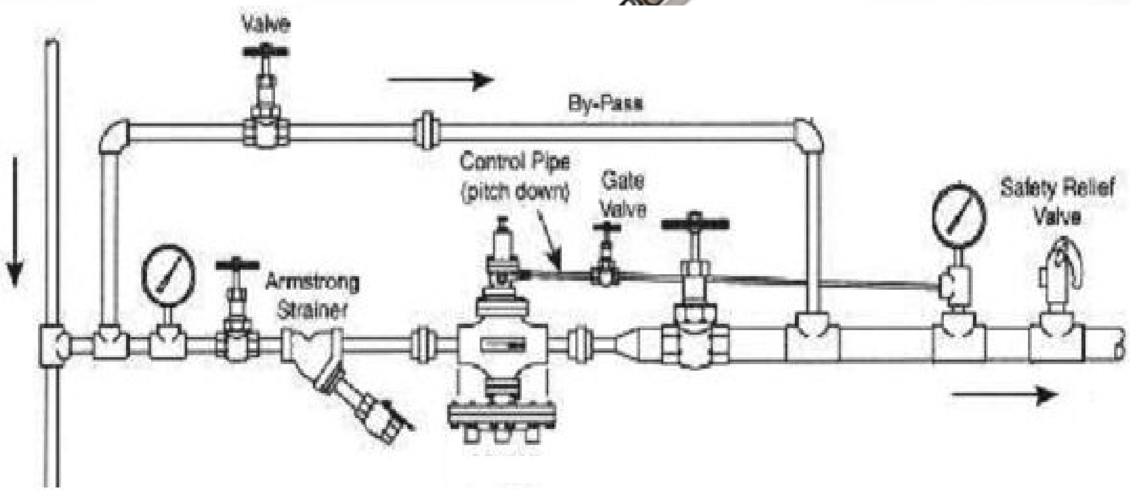
- Choice of Materials and Sizes
- Effects of Temperature Level and Temperature Changes
- Flexibility of the System for Physical or Thermal Shocks
- Adequate Support and Anchorage
- Alterations in the System and the Service

CONSIDERATIONS 01

PARTS OF PIPING

IDENTIFICATION. DESCRIPTION



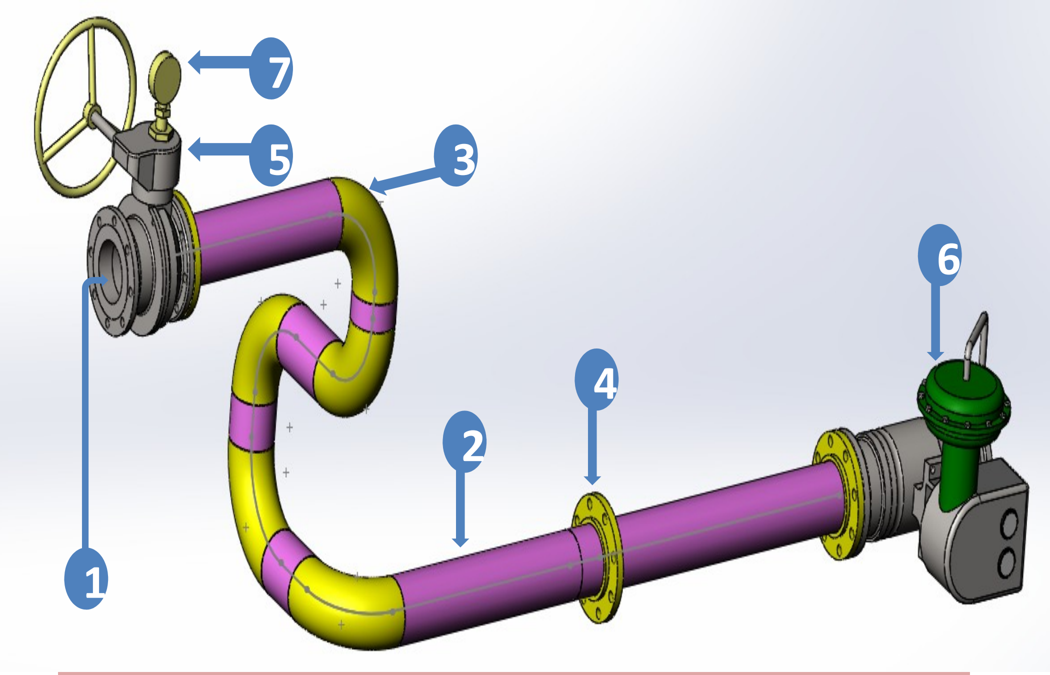


Identification of parts needed for design will generally give you an outlook on what you are about to design.

This will incorporate chemical engineering principles.

Determining the parts will also set your focus on what parameter must be firstly acquired.

PARTS	DESCRIPTION
1. Fluid	Material that is being transported
2. Pipe	Material where the fluid is being transported
3. Fittings	Provides connections and turns for pipes
4. Fasteners	Holds the pipes in place
5. Valves	Used to control the flow
6. Pumps	Apply pressure difference for fluid flow
7. Measuring Devices	Used for measuring the parameters needed



DESCRIPTION

02

PRINCIPLE IN PIPING DESIGN

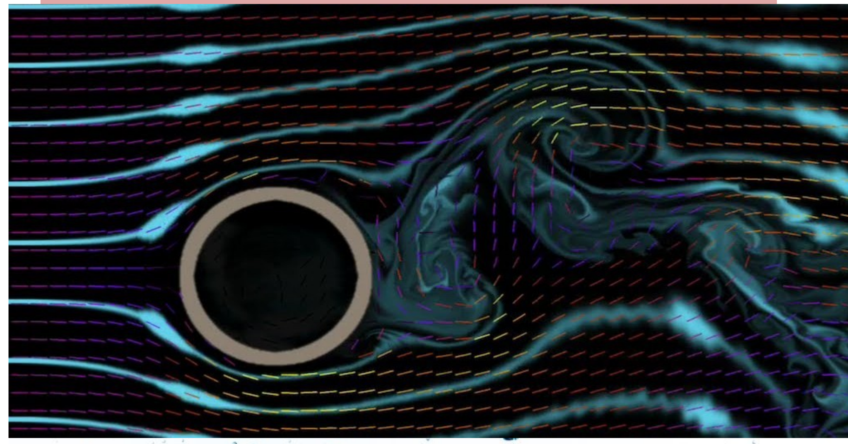
FLUID. PIPE. AUXILIARIES.

Properties and Behavior

Transportation and the storage of fluids (gases and liquids) involve the understanding of the properties and behavior of fluids.

Flows can be classified into two major categories: *(a) incompressible* and *(b) compressible flow.*

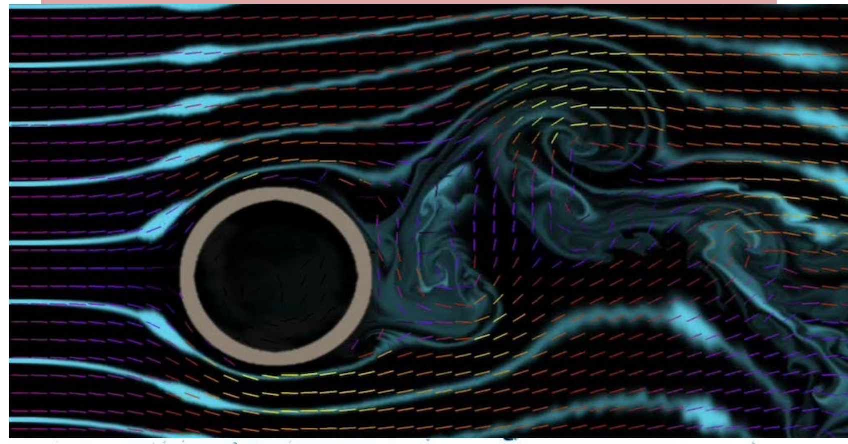
Most liquids fall into the incompressible flow category, while most gases are compressible in nature.



FLUID 03

Properties and Behavior

Fluid flow, compressible or incompressible, can be classified by the ratio of the inertial forces to the viscous forces. This ratio is represented by the Reynolds number (NRe).



$$N_{Re} = \frac{Dv\rho}{\mu}$$

where, ρ is the density of the fluid, V the velocity, D the diameter, and μ the viscosity of the fluid

Properties and Behavior

TABLE 10-1 Density, Viscosity, and Kinematic Viscosity of Water and Air in Terms of Temperature

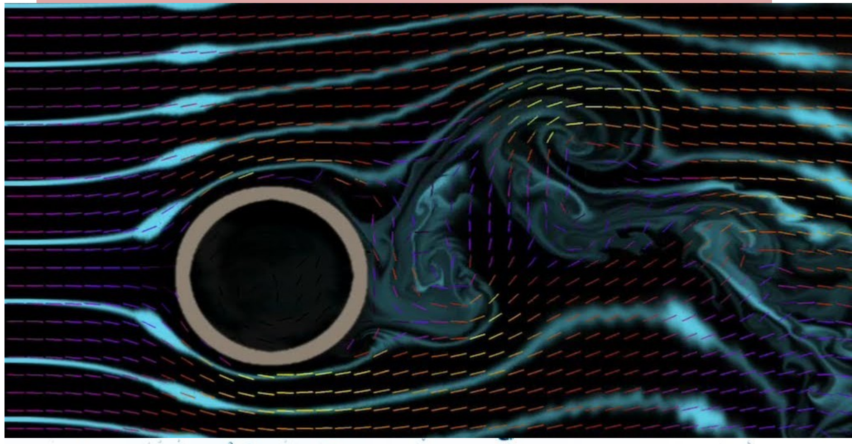
Temperature (°C)	Temperature (°F)	Water: Density ρ (lbf sec²/ft⁴)	Water: Viscosity $\mu \times 10^6$ (lbf sec/ft²)	Water: Kinematic viscosity $\nu \times 10^6$ (ft²/sec)	Air at a pressure of 760 mm Hg (14.696 lbf/in²): Density ρ (lbf sec²/ft⁴)	Air: Viscosity $\mu \times 10^6$ (lbf sec/ft²)	Air: Kinematic viscosity $\nu \times 10^6$ (ft²/sec)
−20	−4	—	—	—	0.00270	0.326	122
−10	14	—	—	—	0.00261	0.338	130
0	32	1.939	37.5	19.4	0.00251	0.350	140
10	50	1.939	27.2	14.0	0.00242	0.362	150
20	68	1.935	21.1	10.9	0.00234	0.375	160
40	104	1.924	13.68	7.11	0.00217	0.399	183
60	140	1.907	9.89	5.19	0.00205	0.424	207
80	176	1.886	7.45	3.96	0.00192	0.449	234
100	212	1.861	5.92	3.19	0.00183	0.477	264

Conversion factors: 1 kp sec²/m⁴ = 0.01903 lbf sec²/ft⁴ (= slug/ft³)
1 lbf sec²/ft⁴ = 32.1719 lb/ft³ (lb = lb mass; lbf = lb force)
1 kp sec²/m⁴ = 9.80665 kg/m³ (kg = kg mass; kp = kg force)
1 kg/m³ = 16.02 lb/ft³

TABLE 10-2 Kinematic Viscosity

Liquid	Temperature °C	Temperature °F	$\nu \times 10^6$ (ft²/s)
Glycerine	20	68	7319
Mercury	0	32	1.35
Mercury	100	212	0.980
Lubricating oil	20	68	4306
Lubricating oil	40	104	1076
Lubricating oil	60	140	323

Materials of Construction



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Flows can be classified into two major categories: *(a) incompressible* and *(b) compressible flow.*

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FLUID 03

Materials of Construction

- **Materials of construction will determine the required property of the pipe that will not allow any damage in terms of corrosion, thermal expansion and even internal and external stress.**

- **Standards allow designers and users of materials to work with confidence that the materials supplied will have the expected minimum properties.**

TABLE 25-4 Melting Temperatures of Common Alloys*

	UNS	Melting range °F	Melting range °C
Aluminum alloy AA1100	A91100	1190–1215	640–660
Aluminum alloy AA5052	A95052	1125–1200	610–650
Aluminum cast alloy 43	A24430	1065–1170	570–630
Copper	C11000	1980	1083
Red brass	C23000	1810–1880	990–1025
Admiralty brass	C44300	1650–1720	900–935
Muntz Metal	C28000	1650–1660	900–905
Aluminum bronze D	C61400	1910–1940	1045–1060
Ounce metal	C83600	1510–1840	854–1010
Manganese bronze	C86500	1583–1616	862–880
90-10 copper nickel	C70600	2010–2100	1100–1150
70-30 copper nickel	C71500	2140–2260	1170–1240
Carbon steel, AISI 1020	G10200	2760	1520
Gray cast iron	F10006	2100–2200	1150–1200
4-6 Cr, ½ Mo Street	S50100	2700–2800	1480–1540
Stainless steel, AISI 410	S41000	2700–2790	1480–1530
Stainless steel, AISI 446	S44600	2600–2750	1430–1510
Stainless steel, AISI 304	S30400	2550–2650	1400–1450
Stainless steel, AISI 310	S31000	2500–2650	1400–1450
Stainless steel, ACI HK	J94224	2550	1400
Nickel alloy 200	N02200	2615–2635	1440–1450
Nickel alloy 400	N04400	2370–2460	1300–1350
Nickel alloy 600	N06600	2470–2575	1350–1410
Nickel-molybdenum alloy B-2	N10665	2375–2495	1300–1370
Nickel-molybdenum alloy C-276	N10276	2420–2500	1320–1370
Titanium, commercially pure	R50250	3100	1705
Titanium alloy T1-6A1-4V	R56400	2920–3020	1600–1660
Magnesium alloy AZ 31B	M11311	1120–1170	605–632
Magnesium alloy HK 31A	M13310	1092–1204	589–651
Chemical lead		618	326
50-50 solder	L05500	361–421	183–216
Zinc	Z13001	787	420
Tin	Z13002	450	232
Zirconium	R60702	3380	1860
Molybdenum	R03600	4730	2610
Tantalum	R05200	5425	2996

*Courtesy of National Association of Corrosion Engineers.

FLUID 03

Materials of Construction

A few of the organizations which generate standards of major importance to the chemical-process industries

American National Standards Institute

American Society of Mechanical Engineers

American Society for Testing and Materials

International Organization for Standardization

Materials of Construction

TABLE 25-5 Carbon and Low-Alloy Steels[a]

Steel type	ASTM	UNS	Composition, %[b]	Mechanical properties[c]		
				Yield strength, kip/in² (MPa)	Tensile strength, kip/in² (MPa)	Elongation, %
C-Mn	A53B	K03005	0.30 C, 1.20 Mn	35 (241)	60 (415)	
C-Mn	A106B	K03006	0.30 C, 0.29–1.06 Mn, 0.10 min. Si	35 (241)	60 (415)	30
C	A285A	K01700	0.17 C, 0.90 Mn	24 (165)	45–55 (310–380)	30
HSLA	A517F	K11576	0.08–0.22 C, 0.55–1.05 Mn, 0.13–0.37 Si, 0.36–0.79 Cr, 0.67–1.03 Ni, 0.36–0.64 Mo, 0.002–0.006 B, 0.12–0.53 Cu, 0.02–0.09 V	100 (689)	115–135 (795–930)	16
HSLA	A242(1)	K11510	0.15 C, 1.00 Mn, 0.20 min Cu, 0.15 P	42–50 (290–345)	63–70 (435–480)	21
2¼ Cr, 1 Mo	A387(22)	K21590	0.15 C, 0.30–0.60 Mn, 0.5 Si, 2.00–2.50 Cr, 0.90–1.10 Mo	30 (205)[d] 45 (310)[e]	60–85 (415–585)[d] 75–100 (515–690)[e]	18[e] 18[d]
4–6 Cr, ½ Mo	A335 (P5)	K41545	0.15 C, 0.30–0.60 Mn, 0.5 Si, 4.00–6.00 Cr, 0.45–0.65 Mo	30 (205)	60 (415)	
9 Cr, 1 Mo	A335 (P9)	K81590	0.15 C, 0.30–0.6 Mn, 0.25–1.00 Si, 8.00–10.00 Cr, 0.90–1.10 Mo	30 (205)	60 (415)	
9 Ni	A333(8), A353(1)	K81340	0.13 C, 0.90 Mn, 0.13–0.32 Si, 8.40–9.60 Ni	75 (515)	100–120 (690–825)	20
	AISI 4130	G41300	0.28–0.33 C, 0.80–1.10 Mn, 0.15–0.3 Si, 0.8–1.10 Cr, 0.15–0.25 Mo	120 (830)[f]	140 (965)[f]	22[f]
	AISI 4340	G43400	0.38–0.43 C, 0.60–0.80 Mn, 0.15–0.3 Si, 0.70–0.90 Cr, 1.65–2.00 Ni, 0.20–0.30 Mo	125 (860)[g]	148 (1020)[g]	20[g]

[a]Courtesy of National Association of Corrosion Engineers. To convert MPa to lbf/in², multiply by 145.04.
[b]Single values are maximum values unless otherwise noted.
[c]Room-temperature properties. Single values are minimum values.
[d]Class 1.
[e]Class 2.
[f]1-in-diameter bars water-quenched from 1,575°F (860°C) and tempered at 1,200°F (650°C).
[g]1-in-diameter bars oil-quenched from 1,550°F (845°C) and tempered at 1,200°F (650°C).

FLUID 03

Sizing

The design engineer must specify the diameter of pipe that will be used in given piping system, and economic factors must be considered in determining the optimum pipe diameter.

For turbulent flow (N_{Re} > 2100) in steel pipes

$$D_{i,opt} = 3.9 q_f^{0.36} \rho^{0.18}$$

where, Di.opt = optimum inside pipe diameter, in.

q_f = fluid flow rate, ft3/s

ρ = fluid density, lb/ft3

μc= fluid viscosity, centipoises

FLUID 03

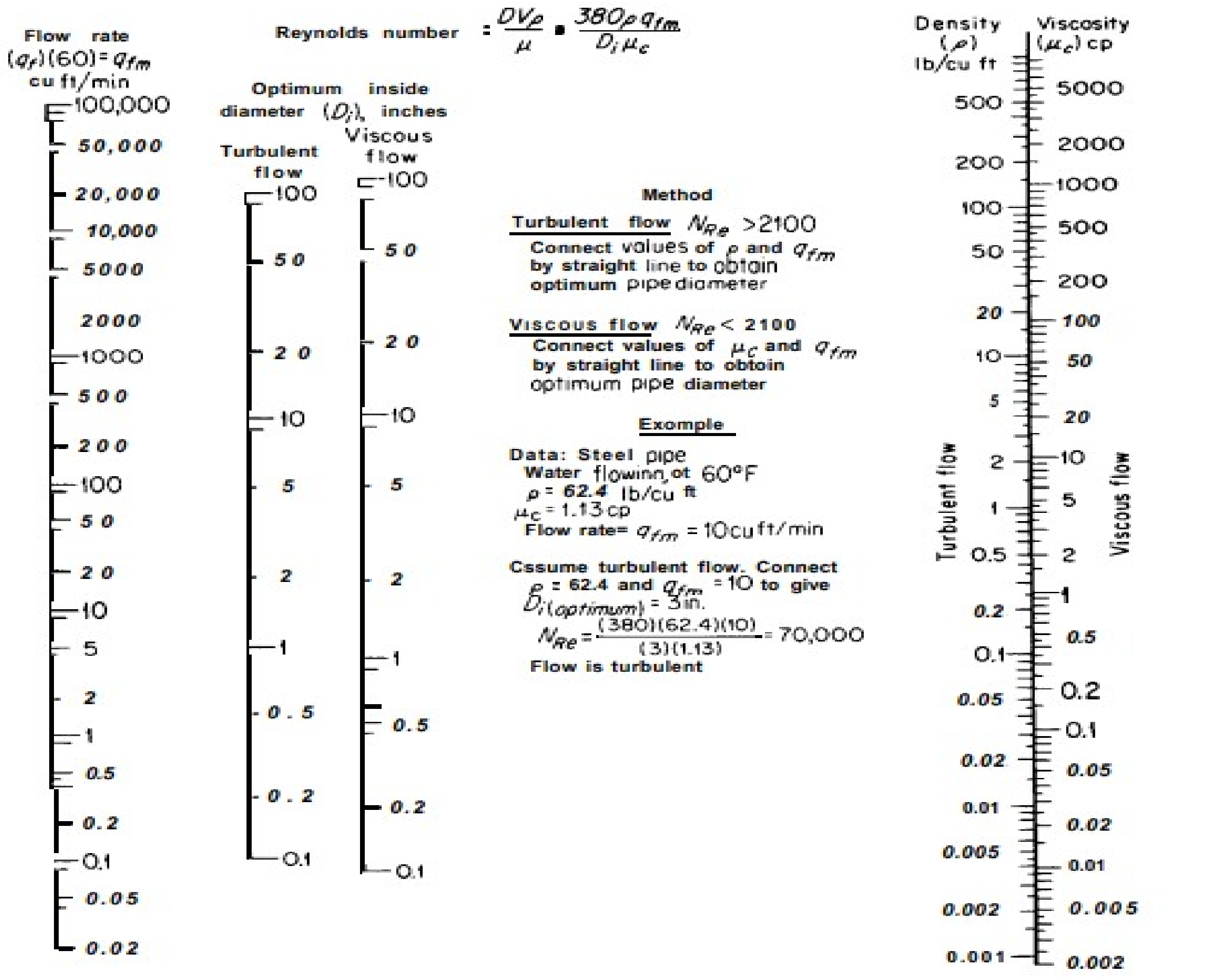


FIGURE 14-2
Nomograph for estimation of optimum economic pipe diameters with turbulent or viscous flow based on Eqs. (15) and (16).

SOURCE: ***Peters, Timmerhaus and West, Plant Design and Economics for Chemical Engineers.***

FLUID **03**

Strength

Pipes are now specified according to wall thickness by a standard formula for schedule number as designated by the American Standards Association.

The bursting pressure of a thin-walled cylinder:

$$P_b = \frac{2 S_T t_m}{D_m}$$

where, P_b = bursting pressures (difference between internal and external pressures),psi

S_T = tensile strength, psi

t_m= minimum wall thickness, in.

D_m = mean diameter, in.

FLUID 03

Strength

TABLE 10-22 Properties of Steel Pipe

Nominal pipe size, in	Outside diameter, in	Schedule no.	Wall thickness, in	Inside diameter, in	Cross-sectional area		Circumference, ft, or surface, ft²/ft of length		Capacity at 1-ft/s velocity		Weight of plain-end pipe, lb/ft
					Metal, in²	Flow, ft²	Outside	Inside	U.S. gal/min	lb/h water	
⅛	0.405	10S	0.049	0.307	0.055	0.00051	0.106	0.0804	0.231	115.5	0.19
		40ST, 40S	.068	.269	.072	.00040	.106	.0705	.179	89.5	.24
		80XS, 80S	.095	.215	.093	.00025	.106	.0563	.113	56.5	.31
¼	0.540	10S	.065	.410	.097	.00092	.141	.107	.412	206.5	.33
		40ST, 40S	.088	.364	.125	.00072	.141	.095	.323	161.5	.42
		80XS, 80S	.119	.302	.157	.00050	.141	.079	.224	112.0	.54
⅜	0.675	10S	.065	.545	.125	.00162	.177	.143	.727	363.5	.42
		40ST, 40S	.091	.493	.167	.00133	.177	.129	.596	298.0	.57
		80XS, 80S	.126	.423	.217	.00098	.177	.111	.440	220.0	.74
½	0.840	5S	.065	.710	.158	.00275	.220	.186	1.234	617.0	.54
		10S	.083	.674	.197	.00248	.220	.176	1.112	556.0	.67
		40ST, 40S	.109	.622	.250	.00211	.220	.163	0.945	472.0	.85
		80XS, 80S	.147	.546	.320	.00163	.220	.143	0.730	365.0	1.09
		160	.188	.464	.385	.00117	.220	.122	0.527	263.5	1.31
		XX	.294	.252	.504	.00035	.220	.066	0.155	77.5	1.71
¾	1.050	5S	.065	.920	.201	.00461	.275	.241	2.072	1036.0	0.69
		10S	.083	.884	.252	.00426	.275	.231	1.903	951.5	0.86
		40ST, 40S	.113	.824	.333	.00371	.275	.216	1.665	832.5	1.13
		80XS, 80S	.154	.742	.433	.00300	.275	.194	1.345	672.5	1.47
		160	.219	.612	.572	.00204	.275	.160	0.917	458.5	1.94
		XX	.308	.434	.718	.00103	.275	.114	0.461	230.5	2.44

SOURCE: ***Green and Perry, Perry's Chemical Engineers' Handbook..***

FUNCTIONS

Valves are mechanical devices that control the flow and pressure within a system or process. They are essential components of a piping system that conveys liquids, gases, vapors, slurries etc.

- **To slow down or stop the flow of a fluid**
- **To reduce or increase the flow rate of a fluid.**
- **To control the direction of a flow**
- **To regulate process pressure.**

FUNCTIONS

Pipe fittings are widely demanded for any piping and plumbing systems used in industrial and commercial applications.

Fittings allow pipes to be joined or installed in the appropriate place and terminated or closed where necessary.

FUNCTIONS

A fastener is a hardware device that mechanically joins or affixes two or more objects together.

Fasteners are used to create joints that can be removed or dismantled without damaging the joining components.

FUNCTIONS

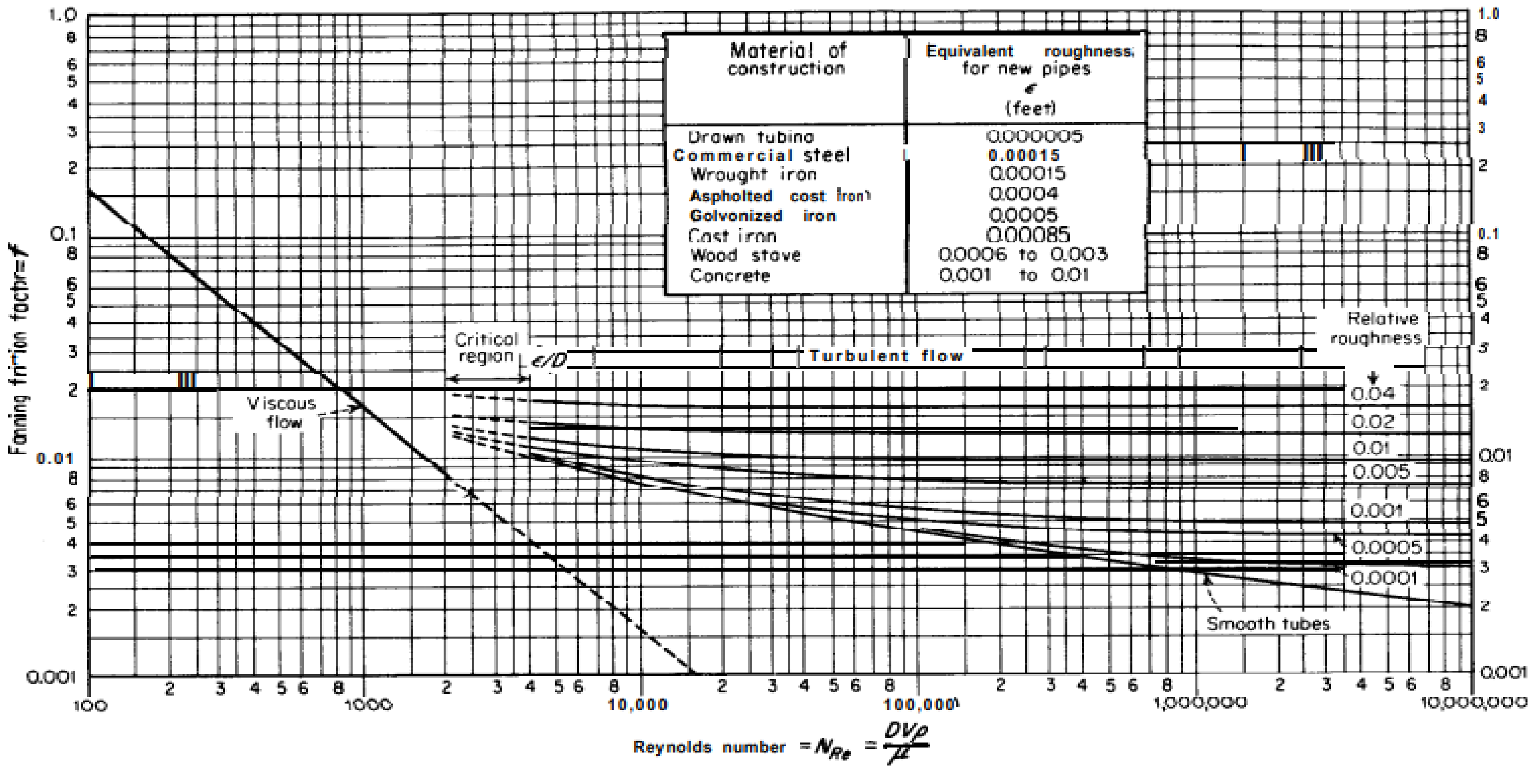
When choosing a fastener for a given application, it is important to know the specifics of that application to help select the proper material for the intended use.

Factors that should be considered include:

- **Accessibility**
- **Environment, including temperature, water exposure, and potentially corrosive elements**
- **Installation process**
- **Materials to be joined**
- **Reusability**
- **Weight restrictions**

FRICTIONAL LOSS

Frictional effects are extremely important in flow processes. Friction is main cause for resistance to the flow of a fluid through given system.



FRICTION LOSS

Approximate equations showing the relationship between the friction factor and the Reynolds number in the turbulent-flow region have been developed. Two of these equations follow:

For smooth pipe or tubes,

$$f = \frac{0.046}{(N_{Re})^{0.2}}$$

For new iron or steel pipe,

$$f = \frac{0.04}{(N_{Re})^{0.16}}$$

FANNING EQUATION

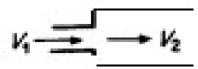
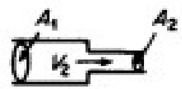
If the linear velocity, density, and viscosity of the flowing fluid remain constant and the pipe diameter is uniform over a total pipe length L, the equation will give:

$$F = \frac{-\Delta p_f}{\rho} = \frac{2fV^2L}{g_c D}$$

TABLE 1

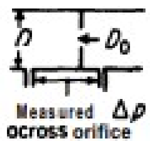
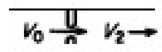
Expressions for evaluating frictional losses in the flow of fluids through conduits

For noncircular, cross-sectional area and turbulent flow, replace D by $4R_H = 4$ (cross-sectional flow area/wetted perimeter).

Friction caused by	General expression for frictional loss	Limited expression and remarks
Flow through long straight pipe of constant cross-sectional area	$dF = \frac{2fV^2\,dL}{g_cD}$	For case in which fluid is essentially noncompressible and temperature is constant $F = \frac{2fV^2L}{g_cD}$
Sudden enlargement	$F_e = \frac{(V_1 - V_2)^2}{2\alpha g_c}$	The following values for α may be used in design calculations: turbulent flow, $\alpha = 1$; streamline flow, $\alpha = 0.5$ 
Sudden contraction	$F_c = \frac{K_cV_2^2}{2\alpha g_c}$	The following values for α may be used in design calculations: turbulent flow, a = 1; streamline flow, $\alpha = 0.5$  For $\frac{A_2}{A_1} < 0.715$, $K_c = 0.4\left(1.25 - \frac{A_2}{A_1}\right)$ For $\frac{A_2}{A_1} > 0.715$, $K_c = 0.75\left(1 - \frac{A_2}{A_1}\right)$ For conical or rounded shape, $K_c = 0.05$
Fittings, valves, etc.	$F = \frac{2fV^2L_e}{g_cD}$	L_e/D per fitting (dimensionless) 45° elbows — 15 90° elbows, std. radius — 32 90° elbows, medium radius — 26 90° elbows, long sweep — 20 90° square elbows — 60 180° close-return bends — 75

SOURCE: *Peters, Timmerhaus and West, Plant Design and Economics for Chemical Engineers.*

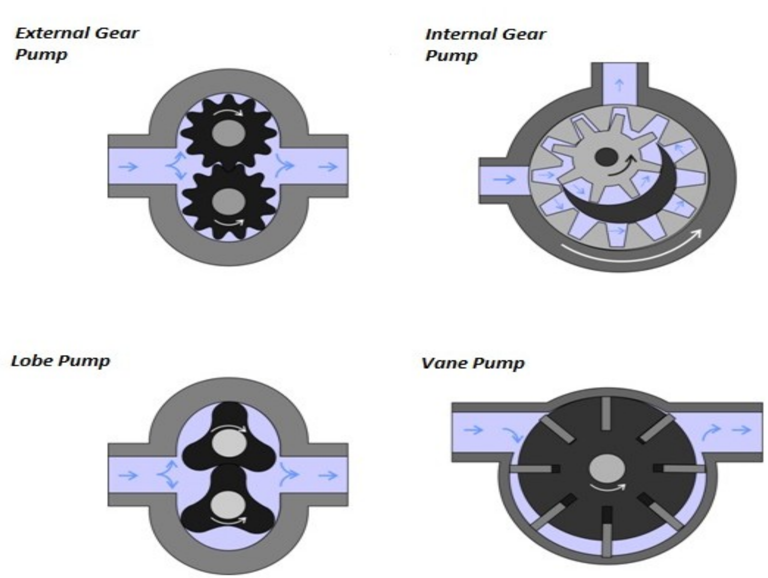
TABLE 1
Expressions for evaluating frictional losses in the flow of fluids through conduits (*Continued*)

Friction caused by	General expression for frictional loss	Limited expression and remarks	
Fittings, valves, etc.	$F = \dfrac{2fV^2L_e}{g_cD}$		L_e/D per fitting (dimensionless)
		180° medium-radius return bends	50
		Tee (used as elbow, entering run)	60
		Tee (used as elbow, entering branch)	90
		Couplings	Negligible
		Unions	Negligible
		Gate valves, open	7
		Globe valves, open	300
		Angle valves, open	170
		Water meters, disk	400
		Water meters, piston	600
		Water meters, impulse wheel	300
Sharp-edged orifice	$-\Delta p_f = F_\rho$	$\dfrac{D_o}{D}$	$\dfrac{\Delta p_f(100)}{\Delta p \text{ across orifice}} = \%$
		0.8	40
		0.7	52
		0.8	63
		0.5	73
		0.4	81
		0.3	89
		0.2	95
			
Rounded orifice	$F = \dfrac{(V_o - V_2)^2}{2\alpha g_c}$	The following values for α may be used in design calculations: turbulent flow, $\alpha = 1$; streamline flow, $\alpha = 0.5$ 	
Venturi	$-\Delta p_f = F_\rho$	$-\Delta p_f = \frac{1}{8}$ to $\frac{1}{10}$ of total pressure drop from upstream section to venturi throat	

SOURCE: Peters, *Timmerhaus and West, Plant Design and Economics for Chemical Engineers.*

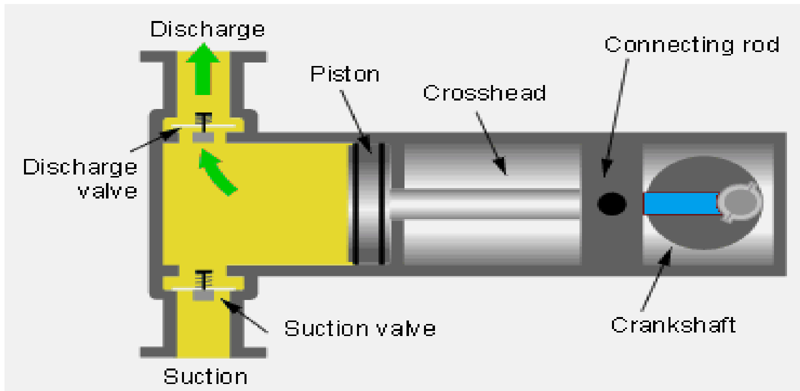
PUMP SELECTION

Pumps are used to transfer fluids from one location to another. The pump accomplishes this transfer by increasing the pressure of the fluid and, thereby, supplying the driving force necessary for flow.



Pump Types

- **Reciprocating or positive-displacement pumps with valve action**
- **Rotary positive-displacement pumps with no valve action**

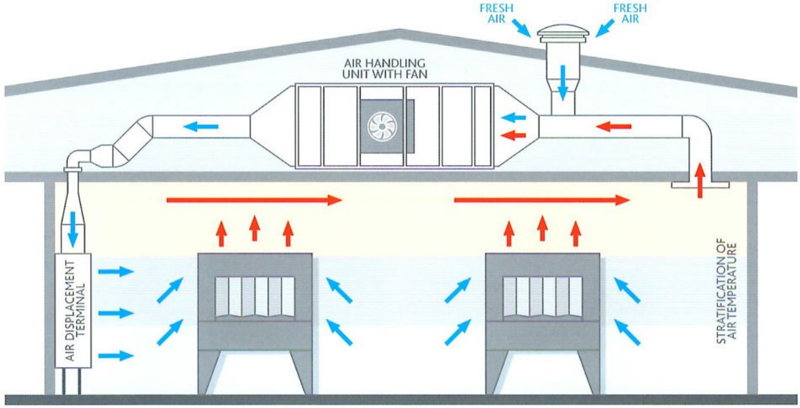


PUMP SELECTION

Pumps are used to transfer fluids from one location to another. The pump accomplishes this transfer by increasing the pressure of the fluid and, thereby, supplying the driving force necessary for flow.

Pump Types

- **Rotary centrifugal pumps with no valve action**
- **Air-displacement systems**



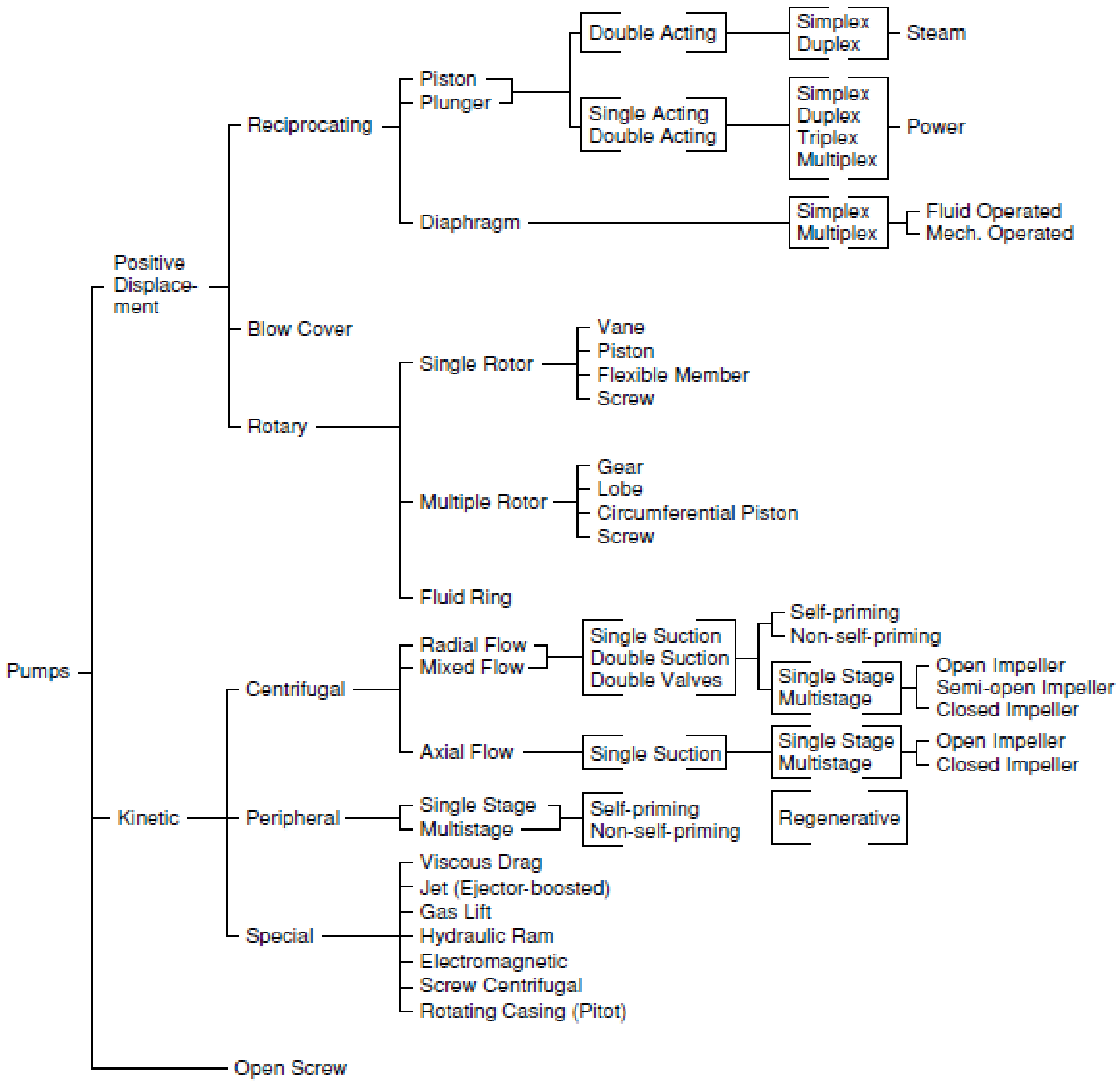


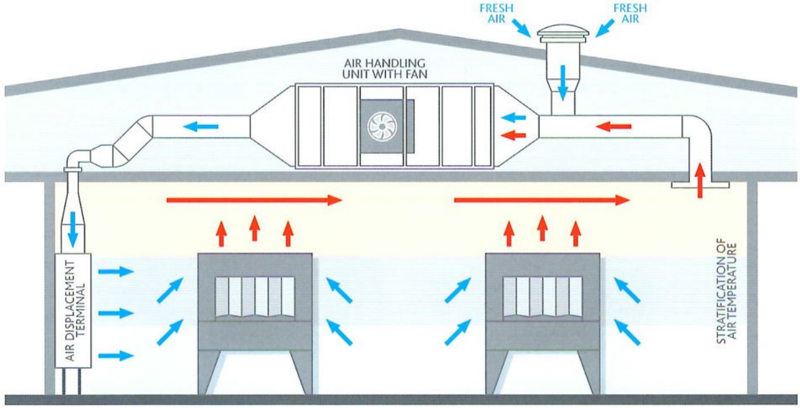
FIG. 10-23 Classification of pumps. (*Courtesty of Hydraulic Institute.*)

PUMPS **03**

PUMP SELECTION

Major factors that govern pump selection

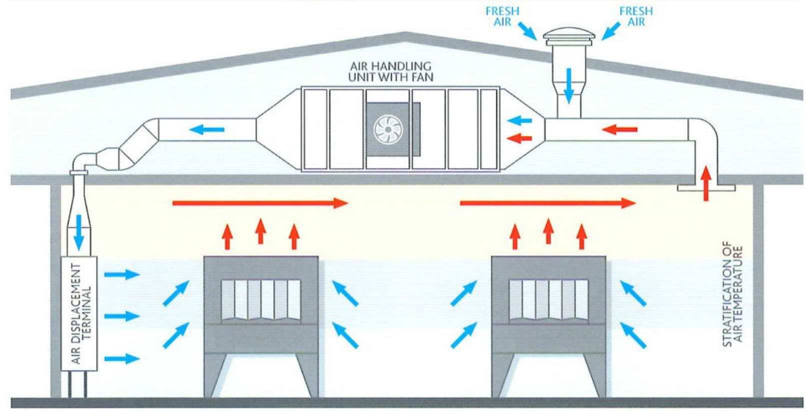
- **The amount of fluid that must be pumped.**
- **The properties of the fluid.**
- **The increase in pressure of the fluid due to the work input of the pumps.**
- **Type of flow distribution.**



PUMP SELECTION

Major factors that govern pump selection

- Type of power supply.
- Cost and mechanical efficiency of the pump.



PUMP SELECTION

Major factors that govern pump selection

TABLE 2
"Rule-of thumb" economic velocities for sizing steel pipelines

Turbulent flow

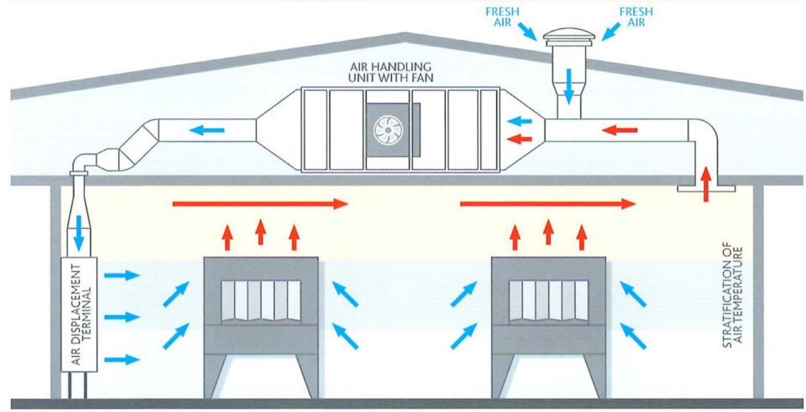
Type of fluid	Reasonable velocity, ft/s
Water or fluid similar to water	3-10
Low-pressure steam (25 psig)	50-100
High-pressure steam (100 psig and up)	100-200
Air at ordinary pressures (25-50 psig)	50-100

The preceding values apply for motor drives. Multiply indicated velocities bv 0.6 to eive reasonable velocities when steam turbine drives are used.

Viscous flow (liquids)

Nominal pipe diameter, in.	Reasonable velocity, ft/s		
	μ_c† = 50	μ_c = 100	μ_c = 1000
1	1.5-3	1-2	0.3-0.6
2	2.5-3.5	1.5-2.5	0.5-0.8
4	3.5-5.0	2.5-3.5	0.8-1.2
8		4.0-5.0	1.3-1.8

† μ_c = viscosity, centipoises.



POWER REQUIREMENTS

A major factor involved in the design of pumping and piping systems is the amount of power that is required for the particular operation.

In differential form,

$$\frac{g}{g_c}dZ + vdP + \frac{V_i dV_i}{g_c} = SW_s - \delta F$$

where, g = local gravitational acceleration, usually taken as 32.17 ft/s²

g_c = conversion factor in Newton's law of motion, 32.17 ft * $lbm_{mass}/(s^2)(lb_f)$

Z = vertical distance above an arbitrarily chosen datum plane, ft

v = specific volume of the fluid ft3/lbm

p = absolute pressure, Ibf/ft*

POWER REQUIREMENTS

where, I = instantaneous or point velocity, ft/s

u = internal energy, ft *Ibf/lbm

Q = heat energy imparted as such to the fluid system from an outside source, ft *Ibf/lbm

W = shaft work, gross work input to the fluid system from an outside source, ft *Ibf/lbm

W, = mechanical work imparted to the fluid system from an outside source,* ft *lbf/lbm

F = mechanical-energy loss due to friction, ft. Ibf/lbm

For Total Head,

$$h_A = h_L + \left(\frac{P_2}{\rho} - \frac{P_1}{\rho}\right) + (z_2 - z_1) + \left(\frac{v_2^2 - v_1^2}{2g}\right)$$

POWER REQUIREMENTS

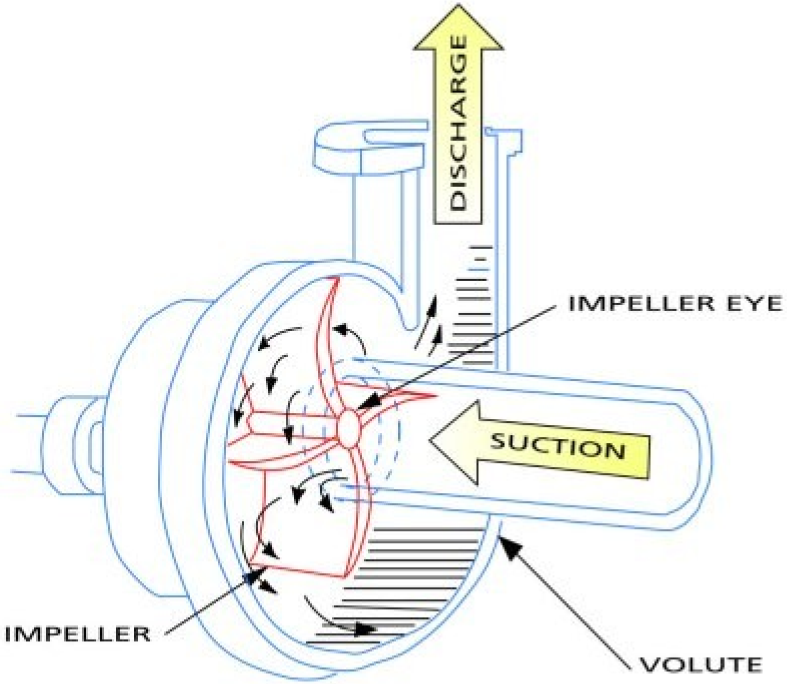
Centrifugal Pumps

$$kW = HQ\rho/3.670 \times 10^5$$

where, kW is the pump power output, kW;
H = total dynamic head, N·m/kg (column of liquid);
Q = capacity, m3/h; and ρ = liquid density, kg/m3.

$$hp = HQ_s/3.960 \times 10^3$$

where, hp is the pump-power output, hp;
H = total dynamic head, lbf·ft/lbm (column of liquid);
Q = capacity, U.S. gal/min; and
s = liquid specific gravity.



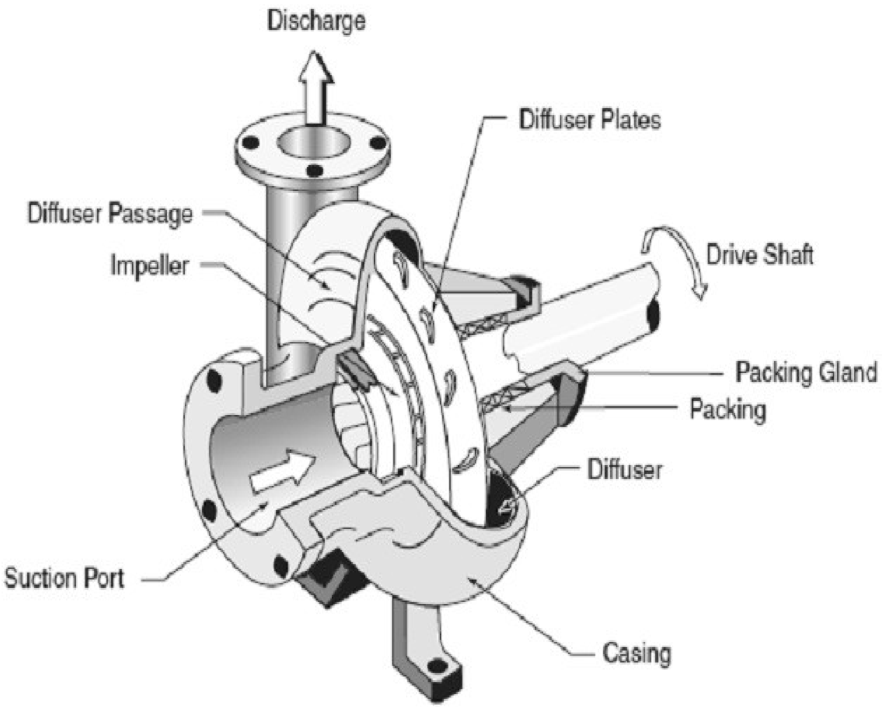
POWER REQUIREMENTS

Compressors

$$Power = p_1 v_1 \ln \frac{p_2}{p_1}$$

$$hp = 3.03x10^{-5}\, p_1 q_{fm_1} \ln \frac{p_2}{p_1}$$

where, power = power requirement, ft . lbf/lbm
p1 = intake pressure, lbf/ft*
v1 = specific volume of gas at intake conditions, ft3/lbm
p2 = final delivery pressure, lbf/ft*
qfml = cubic feet of gas per minute at intake conditions



POWER REQUIREMENTS

Compressors

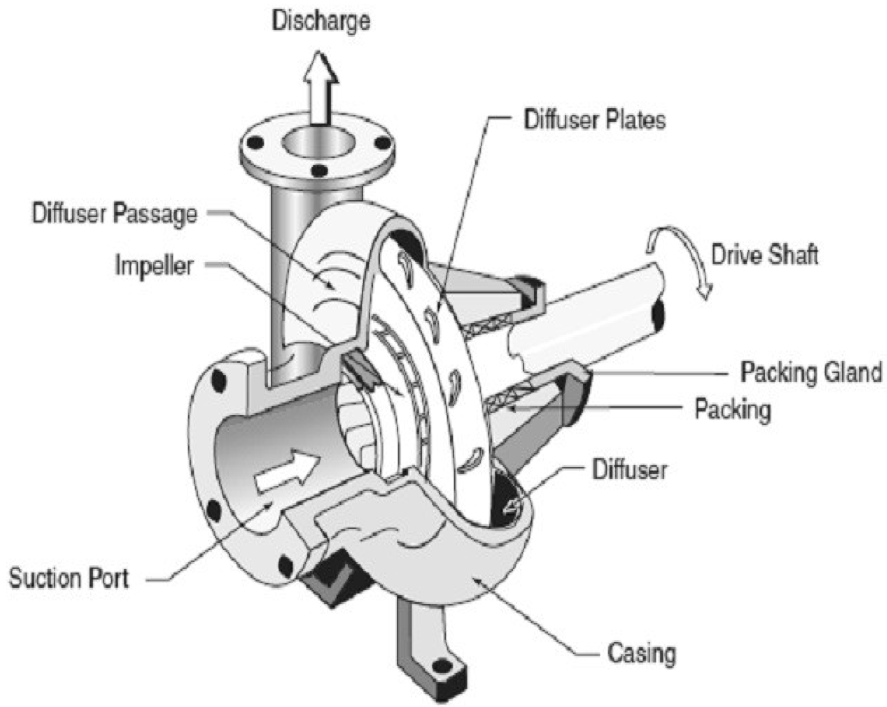
Similarly, for an ideal gas undergoing an isentropic compression (pvk = constant), the following equations apply:

$$\text{Power} = \frac{k}{k-1} p_1 v_1 \left[\left(\frac{p_2}{p_1} \right)^{(k-1)/k} - 1 \right]$$

$$\text{hp} = \frac{3.03 \times 10^{-5} k}{k-1} p_1 q_{fm_1} \left[\left(\frac{p_2}{p_1} \right)^{(k-1)/k} - 1 \right]$$

$$p_2 = p_1 \left(\frac{v_1}{v_2} \right)^{k} = p_1 \left(\frac{T_2}{T_1} \right)^{k/(k-1)}$$

$$T_2 = T_1 \left(\frac{v_1}{v_2} \right)^{k-1} = T_1 \left(\frac{p_2}{p_1} \right)^{(k-1)/k}$$



FLOW

Orifice meters, venturi meters, rotameters, and displacement meters are used extensively in industrial operations for measuring the rate of fluid flow.

For orifice meters and venturi meters

$$q_f = C_d S_c \sqrt{\frac{2g_c v(p_1 - p_c)}{1 - (S_c/S_1)^2}}$$

For rotameters

$$q_f = C_d S_c \sqrt{\frac{V_p 2g(\rho_p - 1/v)v}{S_p\left[1 - (S_c/S_1)^2\right]}}$$

FLOW

where, qf = flow rate, ft”/s

Cd= coefficient of discharge

Sc = cross-sectional flow area at point of minimum cross-sectional flow area, ft’

S1= cross-sectional flow area in upstream section of duct before constriction, ft2

gc = gravitational constant in Newton’s law of motion, 32.17 ft *Ibm/WsXlbf)

g = local gravitational acceleration, ft/(s2)

FLOW

where v = average specific volume of fluid, ft3/lb

p_1 = static pressure in upstream section of duct before constriction, psf

p_c = static pressure at point of minimum cross-sectional flow area, psf

VP = volume of plummet, ft3

SP = maximum cross-sectional area of plummet, ft2

p, = density of plummet, lb/ft3

TEMPERATURE

Thermocouples

It is suitable for measuring temperatures from −330 to 5000°F (−201 to 2760°C).

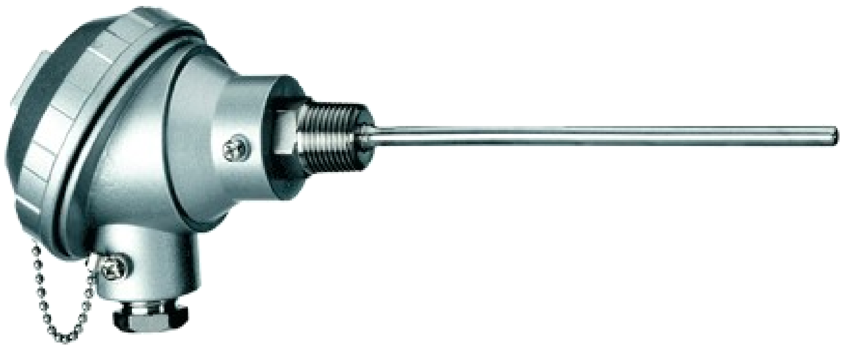
Thermocouples function by producing a voltage proportional to the temperature differences between two junctions of dissimilar metals.

TEMPERATURE

Resistive Thermal Detectors (RTDs)

RTDs determine temperature by measuring the change in resistance of an element due to temperature.

Platinum is generally utilized in RTDs because it remains mechanically and electrically stable, resists contaminations, and can be highly refined. The useful range of platinum RTDs is −454–1832°F (−270−1000°C).



SAMPLE DESIGN OF PIPING SYSTEMS

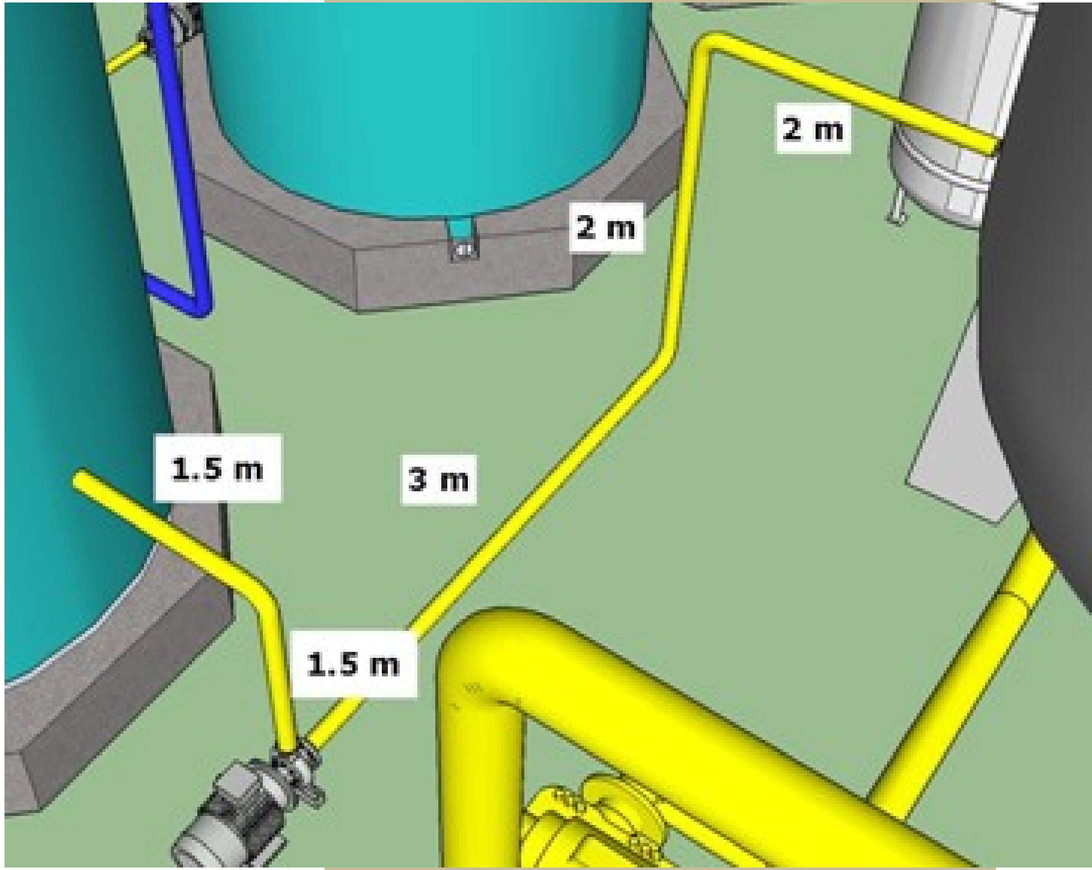
PROBLEM. DESCRIPTION. PARTS. DATA AND ASSUMPTIONS. CONSIDERATIONS. REQUIREMENTS. CALCULATIONS. SPECIFICATIONS.

DESIGN PROBLEM

A pump must deliver the 10,000 kg/batch of 15% Sodium Hydroxide from storage tank to an Digester

DESIGN DESCRIPTION

Process piping system is designed to transport 15% (w/v) Sodium Hydroxide from its dilution tank to the digester.

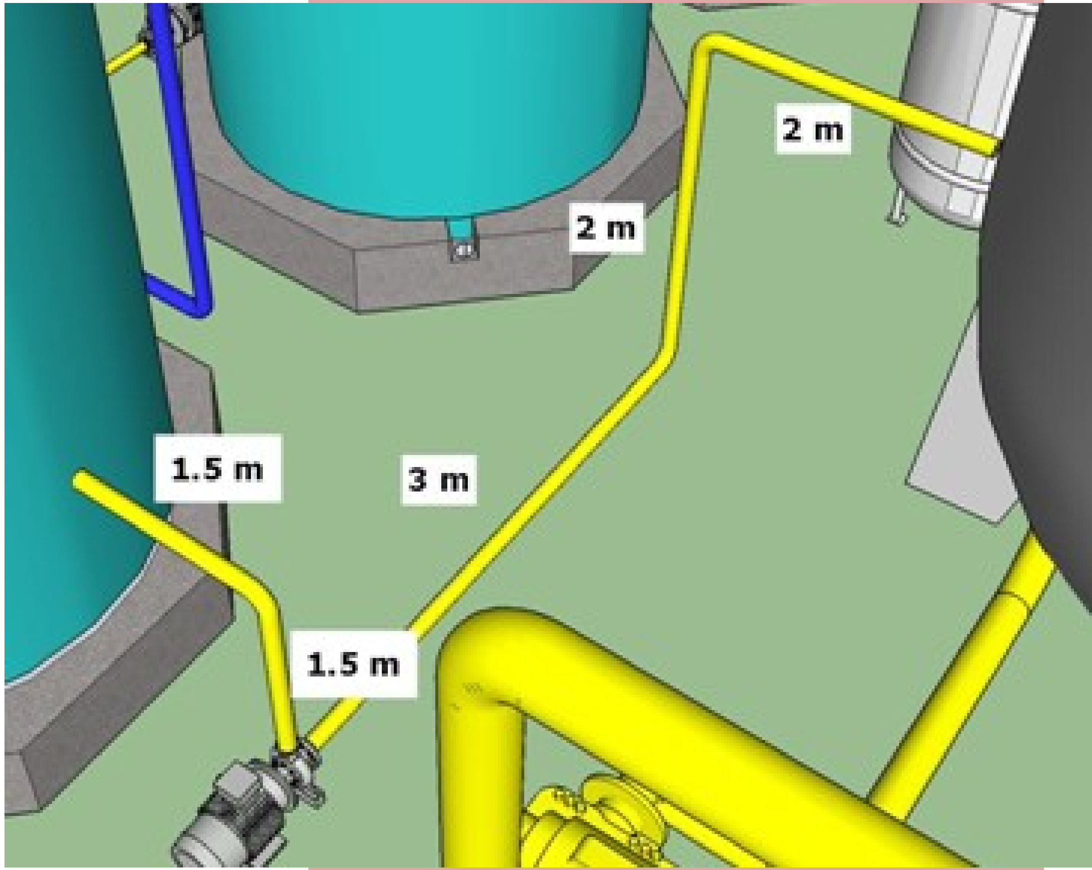


DESIGN PARTS

1. Pipe
2. 3 standard 90deg elbows
3. 1 gate valve
4. 1 centrifugal pump

DATA AND ASSUMPTIONS

1. The mass of entering solution is 11,179.8726 kg. (Based on Material Balance).
2. The density of sodium hydroxide is 1166.99 kg/m3. (Based on Qualitative Flowchart)



SAMPLE DESIGN

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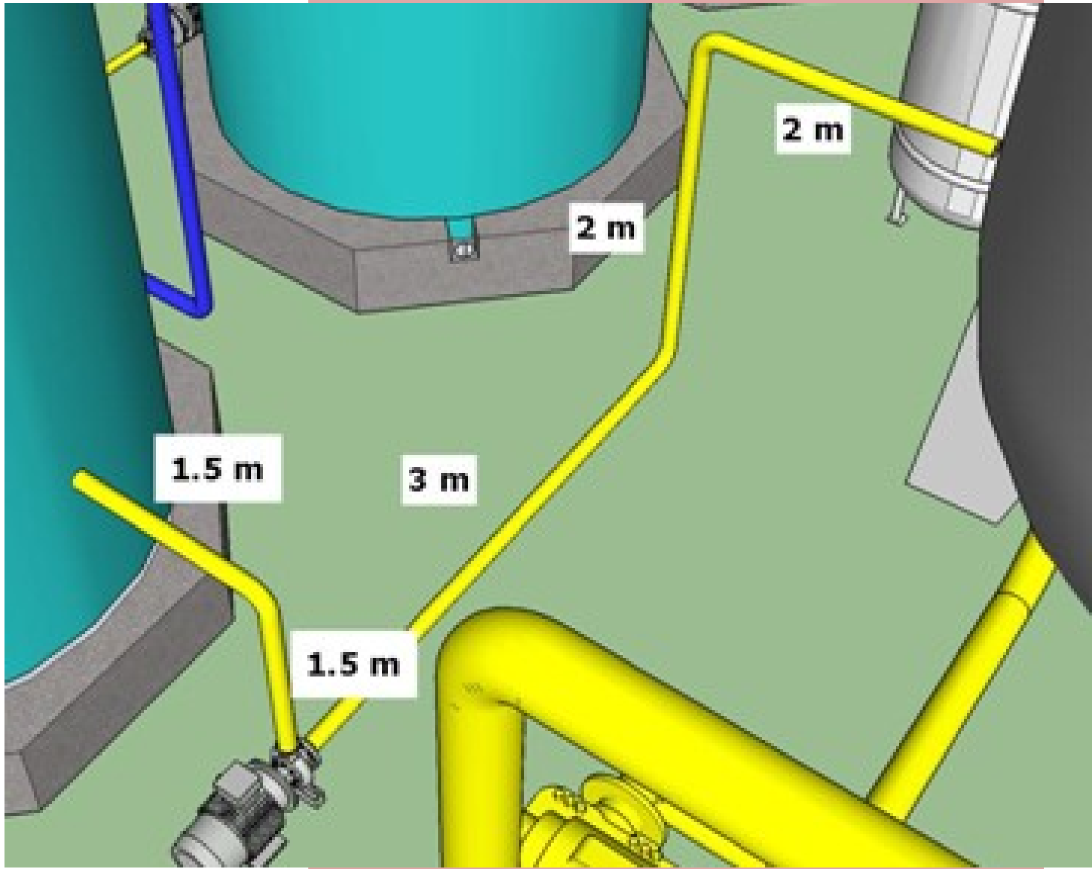
3. The viscosity of sodium hydroxide is 2.17cp (Based on Qualitative Flowchart)
4. The length of the straight pipe is 10 meters.
5. Fittings are standards with full openings.



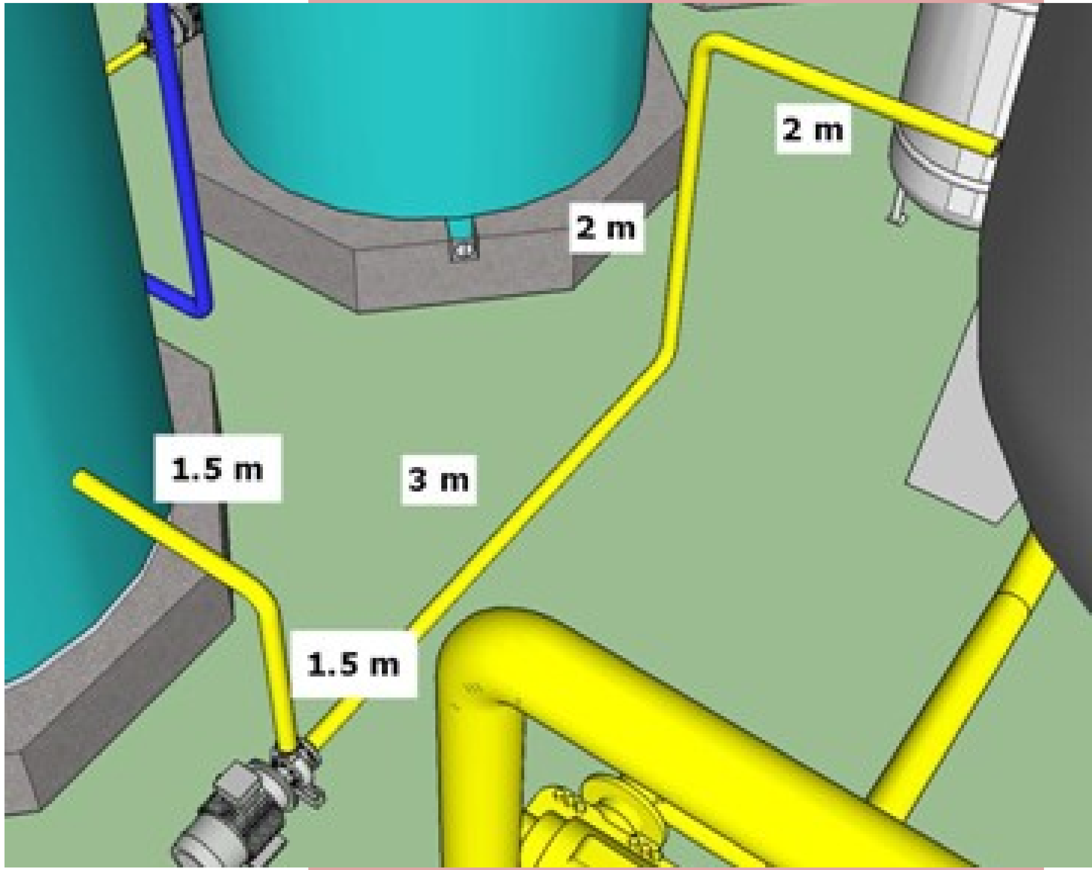
DESIGN CONSIDERATION

1. The material of construction of the pipe is stainless steel type 302. (Plant Design and Economics for Chemical Engineers, 4th ed., by Peters and Timmerhaus).

2. Maximum allowable pressure for temperature up to 650oF is 7,300 psi (Process Equipment Design by Hesse and Rushton).

3. The mechanical strength and corrosion for plain end pipe over 1 in nominal size is 0.065 inches. (Process Equipment Design by Hesse and Rushton)

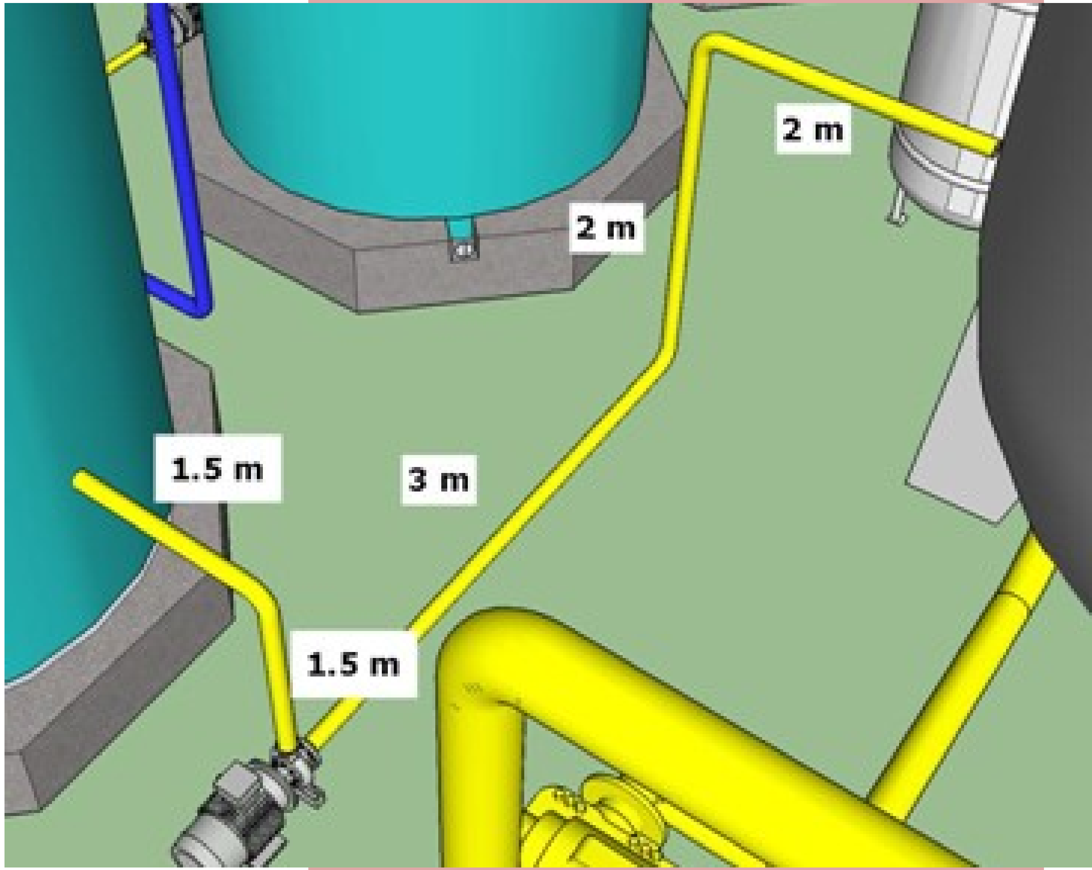
4. Centrifugal Pump is used with an efficiency of 80%.
NaOH solution is assumed to incompressible and isothermal.



5. Time of transportation is 10 minutes.

DESIGN REQUIREMENTS

1. Pipe Diameter
2. Pipe Thickness
3. Area
4. Velocity
5. Fanning friction factor
6. Losses
7. Pipe Length
8. Total Head
9. Power Requirement



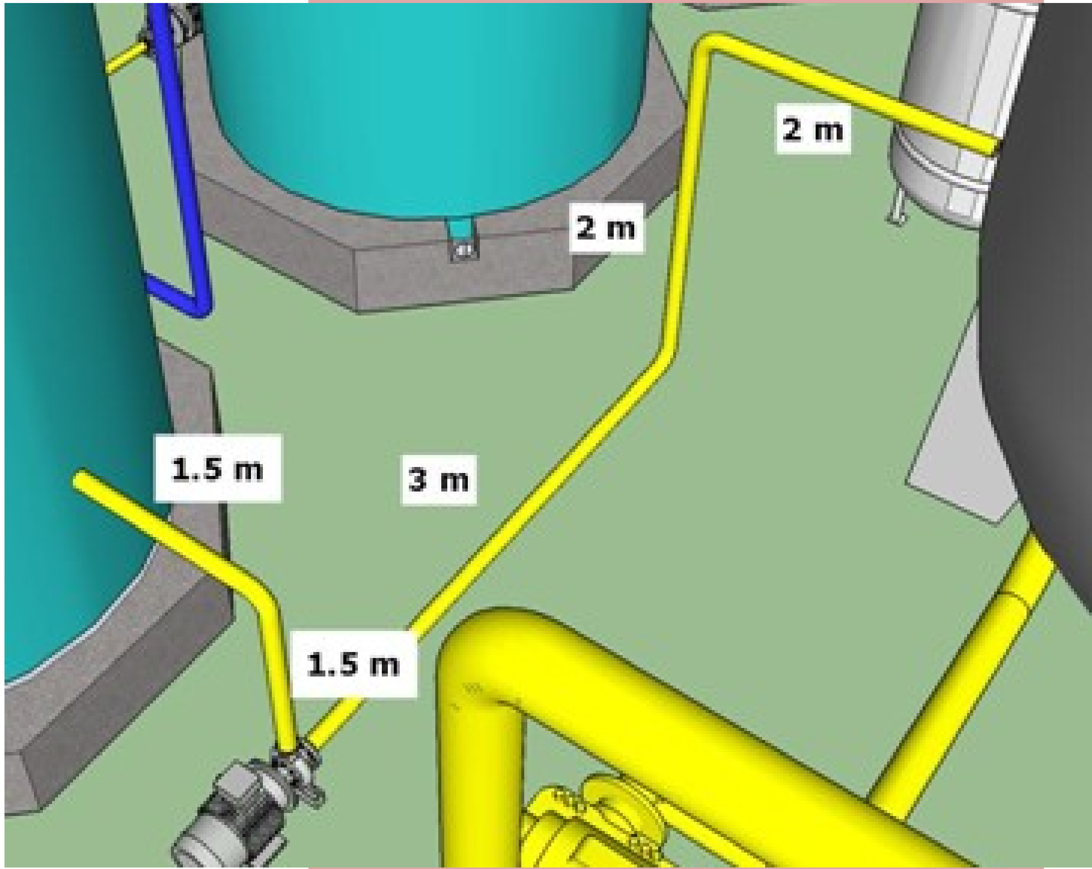
DESIGN CALCULATIONS

1. Pipe Diameter

$$q_f = \frac{mass\ flowrate}{density}$$

$$q_f = \frac{\frac{11{,}179.8726\ kg}{10 * 60\ seconds}}{\frac{1166.99\ kg}{m^3}}$$

$$q_f = 0.0589\ \frac{m^3}{s} * \frac{3.2808^3 ft^3}{m^3} = 2.08\ \frac{ft^3}{s}$$



DESIGN CALCULATIONS

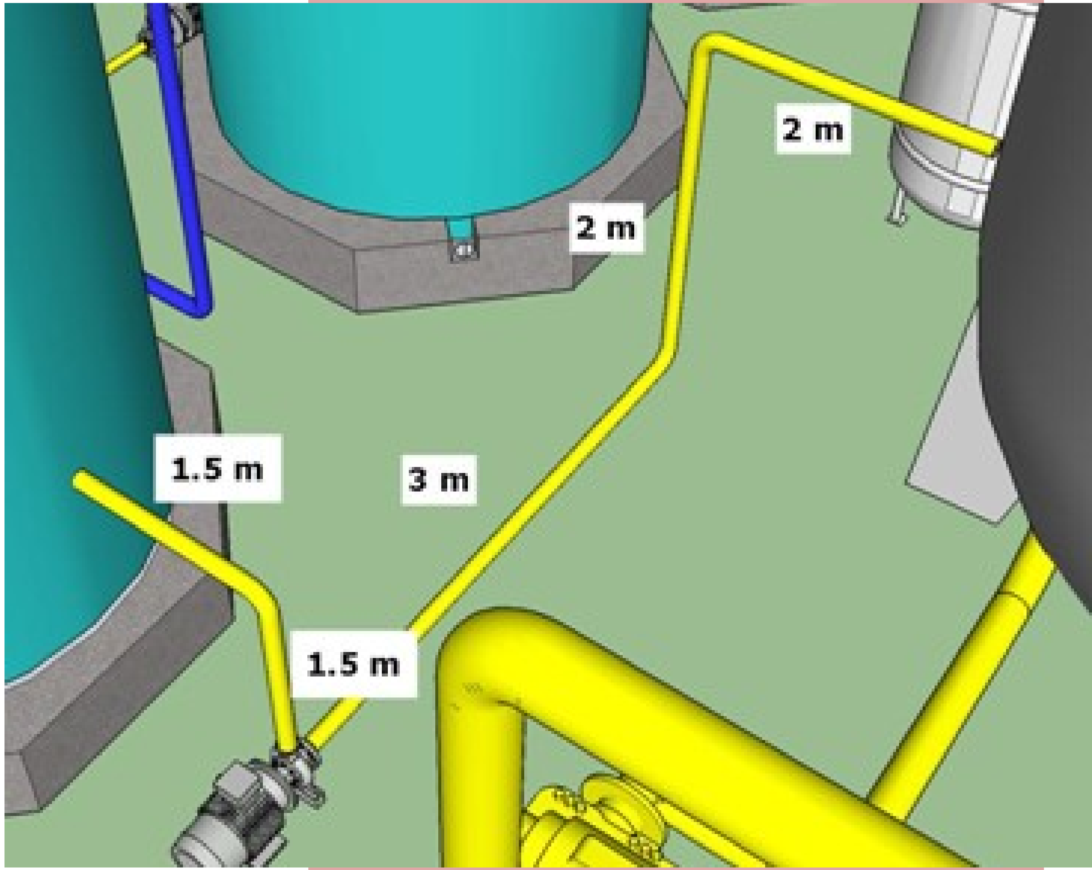
1. Pipe Diameter

For turbulent flow, the equation for pipe diameter is given by (*Plant Design and Economics by Peters and Timmerhaus*)

$$D_{i,opt} = 3.9 q_f^{0.45} \rho^{0.13}$$

$$= 3.9 \times (2.08 ft^3/s)^{0.45} \left(\frac{1133.93\ kg}{m^3} * \frac{1m}{3.2808^3 ft} * 2.205\right)^{0.13}$$

$$D_{i,opt} = 9.43\ inches = 239.52\ mm$$



SAMPLE DESIGN

DESIGN CALCULATIONS

STAINLESS STEEL PIPES/ PLATES

NOM. BORE	PIPE O.D.	WALL THICKNESS				RADIUS				A	B	C	E	G	L		H	D	h
		5S	10S	40S	80S	1D	1.5D	2D	3D						SHORT	LONG			
1/2"	21.34	1.65	2.11	2.77	3.73	12.7	19.05	25.4	38.1	12.7	15.9	25.4	25.4	34.9	50.8	76.2	50.8	45	8
3/4"	26.67	1.65	2.11	2.87	3.91	19.05	28.57	38.10	57.15	19.05	11.1	28.6	25.4	42.8	50.8	76.2	50.8	50	8
1"	33.40	1.65	2.77	3.38	4.55	25.4	38.1	50.8	76.2	25.4	22.2	38.1	38.1	50.8	50.8	101.6	50.8	60	10
11/4"	42.16	1.65	2.77	3.56	4.85	31.75	47.6	63.5	95.25	31.75	25.0	47.6	28.1	63.5	50.8	101.6	50.8	70	12
11/2"	48.26	1.65	2.77	3.68	5.08	38.1	57.15	76.2	114.3	38.10	28.6	57.2	38.1	73.0	50.8	101.6	63.5	80	12
2"	60.32	1.65	2.77	3.91	5.54	50.8	76.2	101.6	152.4	50.8	34.0	63.5	38.1	92.0	63.5	152.4	76.2	94	16
21/2"	73.02	2.11	3.05	5.16	7.01	63.5	95.25	127.0	190.5	63.5	44.0	76.2	38.1	104.8	63.5	152.4	88.9	110	16
3"	88.90	2.11	3.05	5.49	7.62	76.2	114.30	152.4	228.6	76.2	50.8	85.7	50.8	127.0	63.5	152.4	88.9	130	18
3 1/2"	101.60	2.11	3.05	5.74	8.08	88.9	133.35	177.8	266.7	88.9	57.2	95.3	63.5	139.7	76.2	152.4	101.6	140	18
4"	114.30	2.11	3.05	6.02	8.56	101.6	152.4	203.2	304.8	101.6	63.5	104.8	63.5	157.2	76.2	152.4	101.6	158	20
5"	141.30	2.77	3.40	6.55	9.52	127.0	190.5	254.0	381.0	127.0	82.6	123.8	76.2	185.7	76.2	203.2	127.0	188	25
6"	168.27	2.77	3.40	7.11	10.97	152.4	228.6	304.8	457.2	152.4	95.3	158.7	88.9	203.2	139.7	212	25		
8"	219.07	2.77	3.76	8.18	12.7	203.2	304.8	406.4	609.6	203.2	127.0	190.5	101.6	270.0	101.6	203.2	152.4	268	30
10"	273.05	3.40	4.19	9.27	12.7	254.0	381.0	508.0	762.0	254.0	158.7	215.9	127.0	324.0	127.0	254.0	177.8	330	35
12"	323.85	3.96	4.57	9.52	12.7	304.0	457.2	609.6	914.4	304.0	190.5	254.0	152.4	381.0	152.4	254.0	203.2	400	40
14"	355.60	3.96	4.76	9.52	12.7	355.6	533.4	711.2	1066.8	355.6	22.2	280.0	165.1	412.8	152.4	305.0	330.2		
16"	406.40	4.19	4.76	9.52	12.7	406.4	609.6	812.8	1219.2	496.4	254.0	304.8	177.8	470.0	152.4	305.0	355.6		
18"	457.20	4.19	4.76	9.52	12.7	457.2	685.8	914.4	1371.6	457.1	285.7	343.0	203.2	533.4	152.4	152.40	305.0		
20"	508.00	4.76	5.54	9.52	12.7	508.0	762.0	101.6	1524.0	508.0	317.6	381.0	228.6	584.2	152.4	305.0	508.0		

DESIGN CALCULATIONS

1. **Pipe Diameter**

Use: Nominal Pipe Size of 10 inches schedule 40

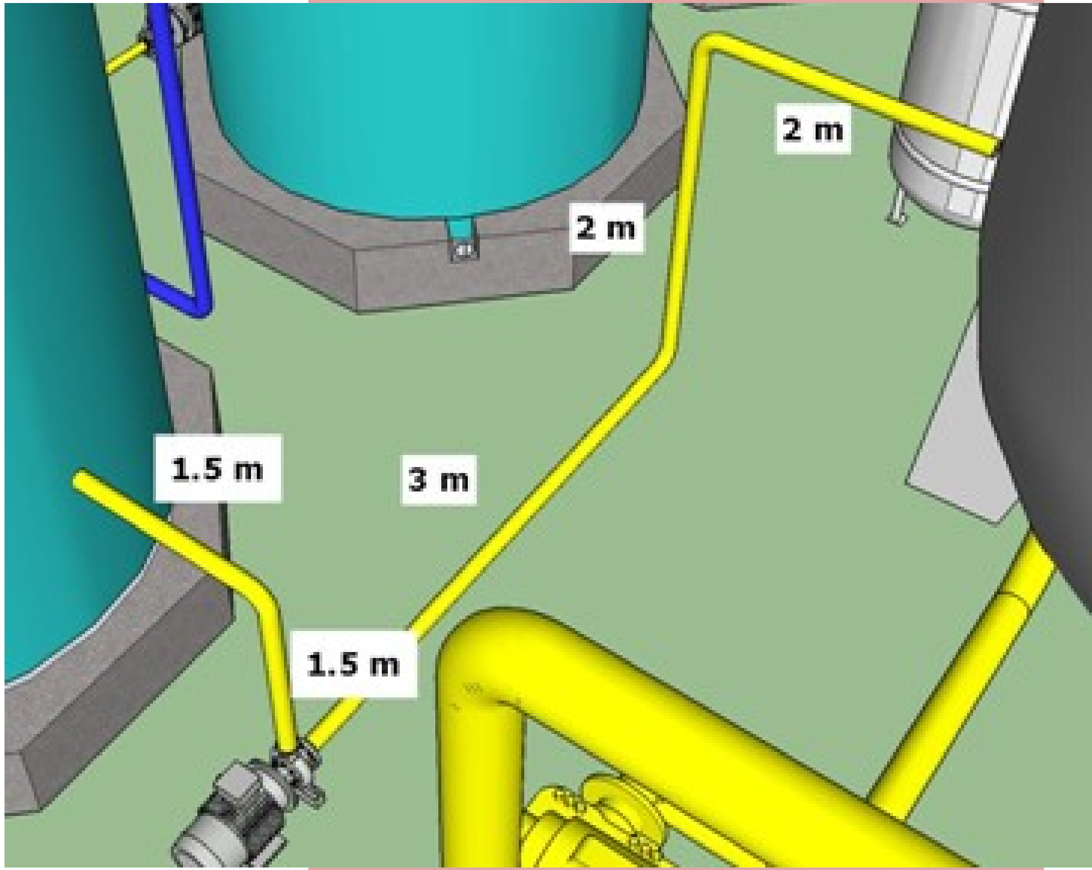
D_0= 273.05 mm

D_i= 254.51mm

2. **Pipe Thickness**

From ANSI B36. 19, For Nominal Pipe Size of 10 inches schedule 40

$$t = 9.271\ mm = 0.365\ in$$



DESIGN CALCULATIONS

3. Area

$$A = \frac{\pi}{4} D_I^{\,2}$$

$$A = \frac{\pi}{4}(0.25451)^2$$

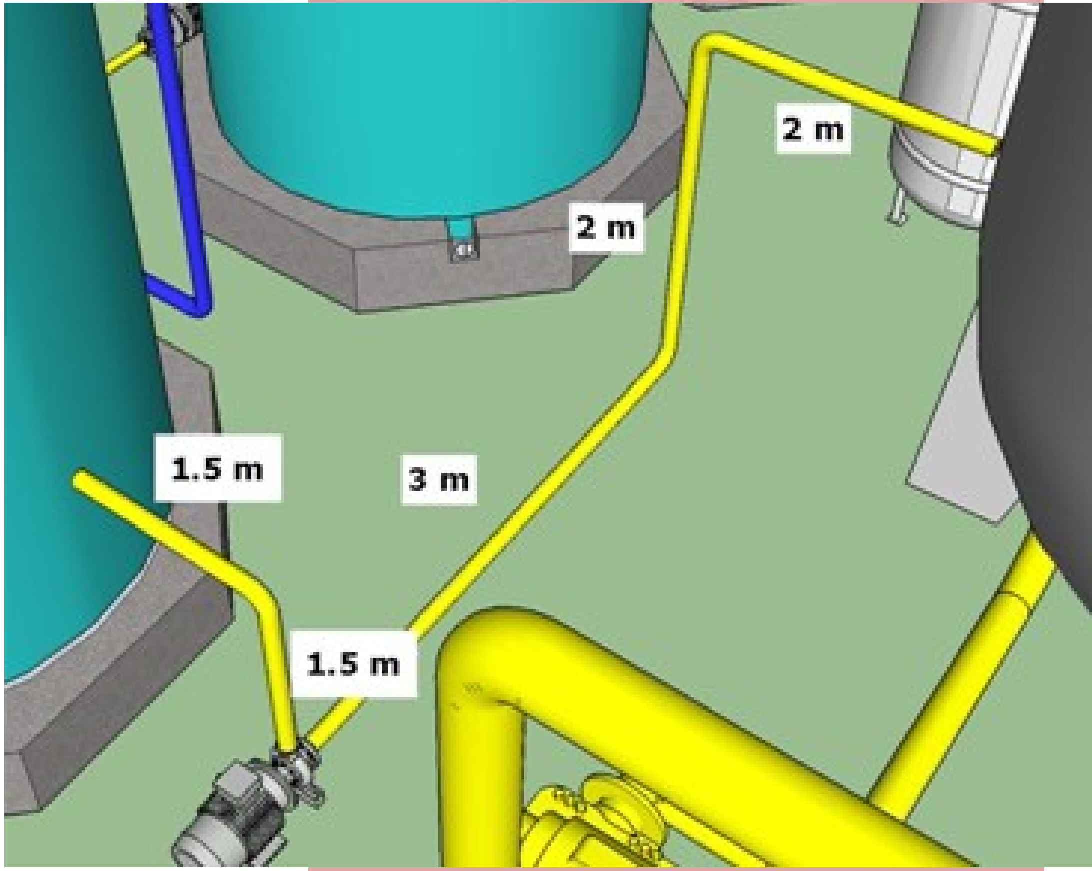
Area = 0.051 m²

4. Velocity

$$v = \frac{mass}{travel\ time} * \frac{1}{density} * \frac{1}{area}$$

$$v = \frac{11{,}179.8726 kg}{10 * 60\ s} * \frac{1}{1166.99 \frac{kg}{m^3}} * \frac{1}{0.051\ m^2}$$

Velocity = 1.15 m/s



SAMPLE DESIGN

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DESIGN CALCULATIONS

5. Friction factor

$$N_{Re} = \frac{Dv\rho}{\mu}$$

$$N_{Re} = \frac{(.25451)(1.15)(1166.99)}{2.17x10^{-3}}$$

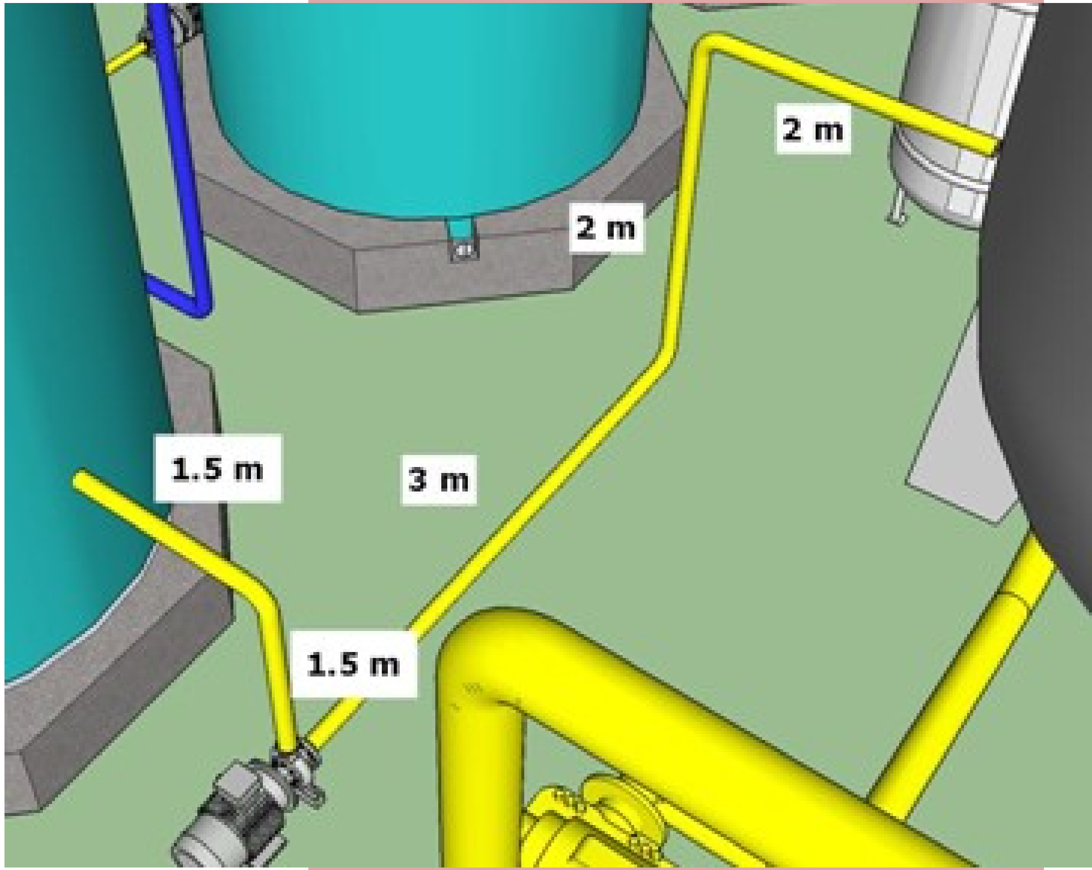
$$N_{Re} = 152{,}942.86; Turbulent\ Flow$$

$$Relative\ Roughness = \frac{\varepsilon}{D_I}$$

Where:

$\varepsilon = Equivalent\ Roughness, m$

$Di = Inside\ \ diameter, m$



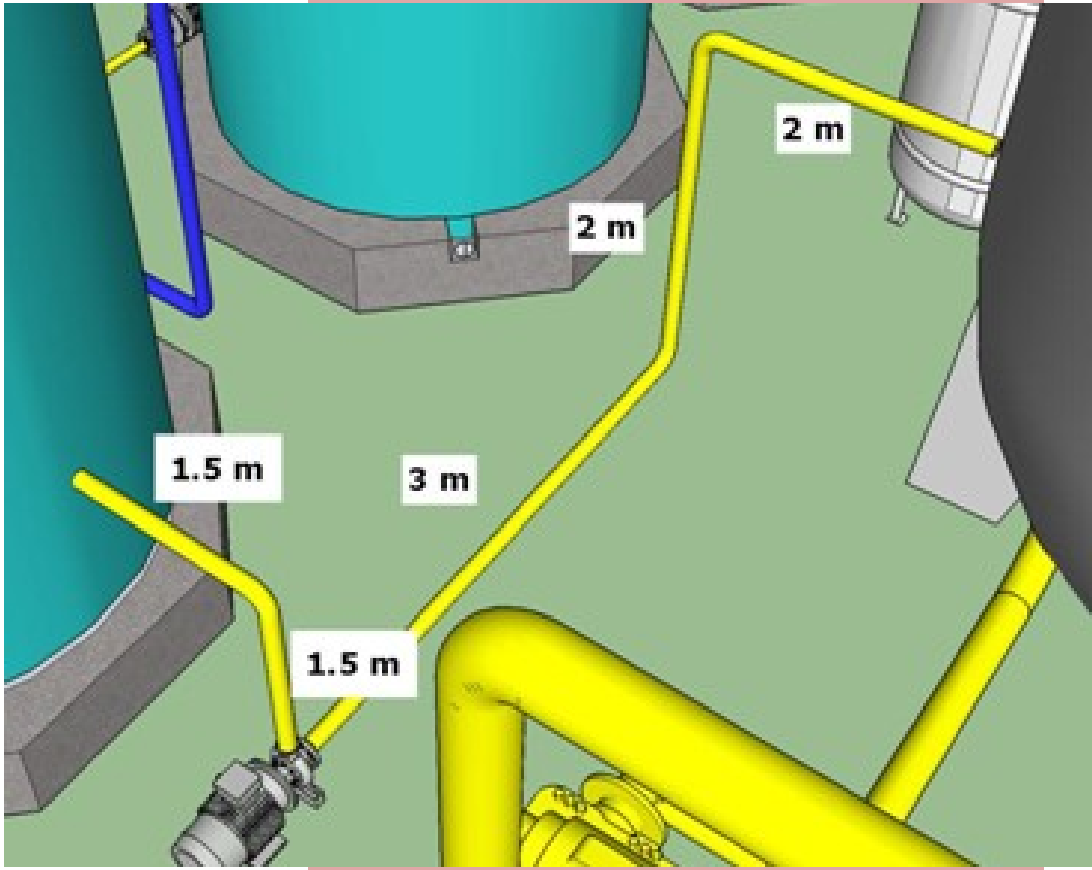
DESIGN CALCULATIONS

5. Friction factor

$$Relative\ Roughness = \frac{4.6x10^{-5}}{0.25451} = 1.81x10^{-4}$$

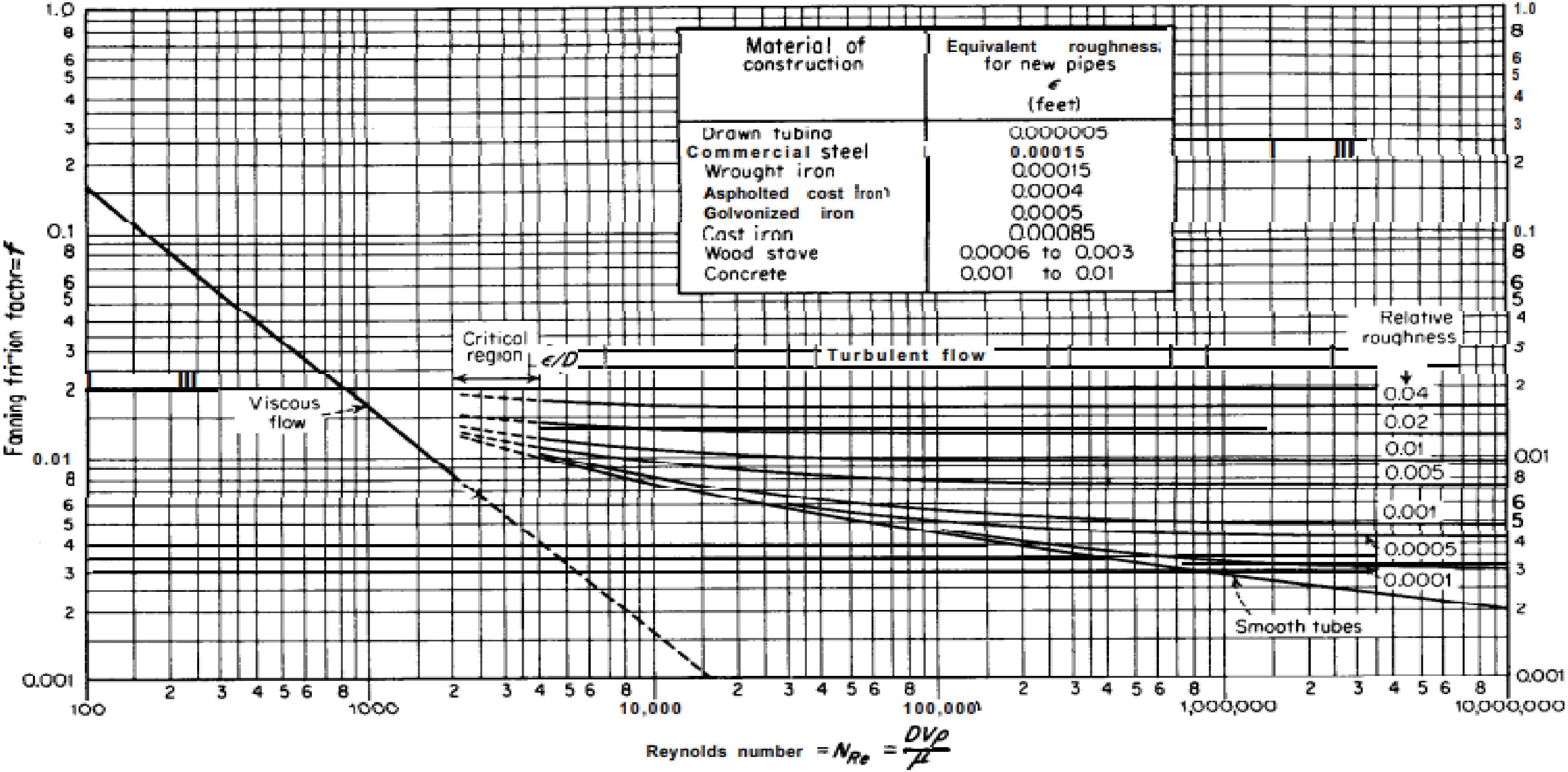
From Moody Diagram (*Principles of Transport Processes and Separation of Processes by Geonkoplis*, using relative toughness and Reynolds number;

$$Friction\ Factor = 0.004$$



DESIGN CALCULATIONS

5. Friction factor

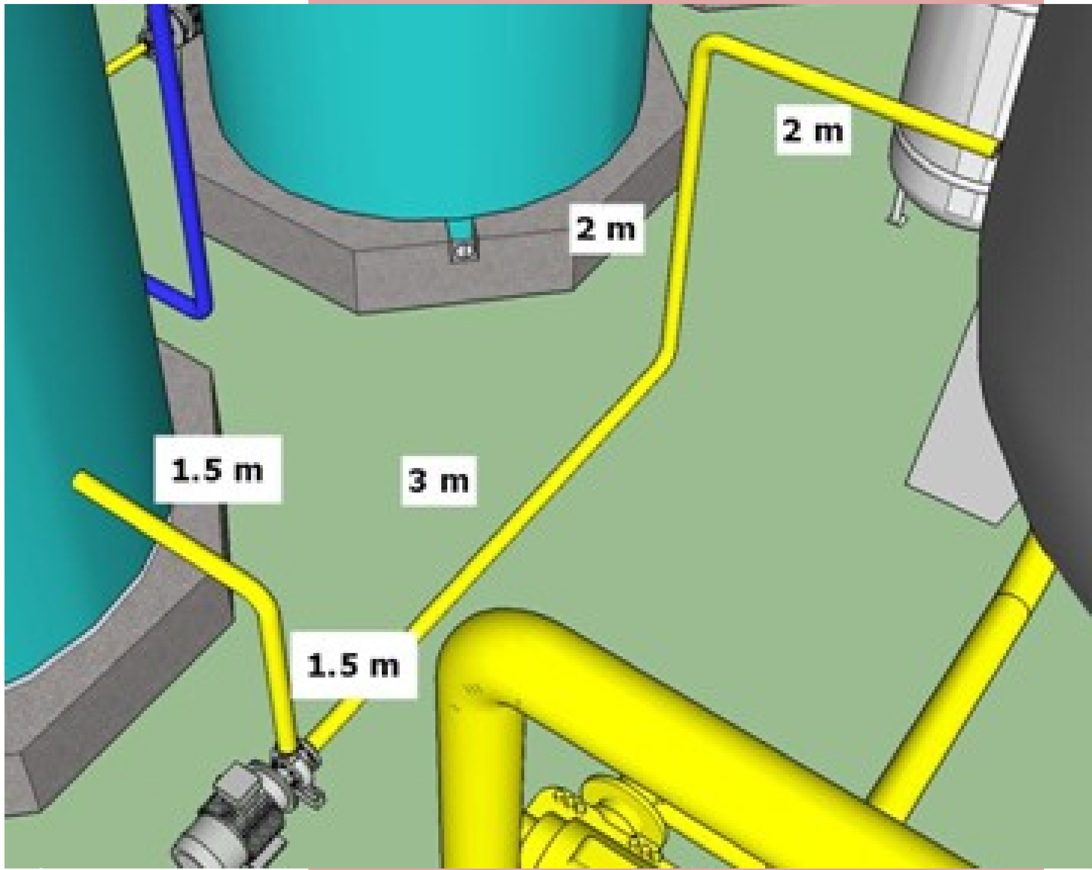


DESIGN CALCULATIONS

6. Losses

$$\frac{Length}{Diameter} = \frac{10m}{0.25451} = 39.29\ m$$

$$\frac{V^2}{2g} = \frac{1.15^2}{2(9.81)} = 0.067\ m$$



For skin friction in pipes, the equation is given by (Unit Operations of Chemical Engineering by McCabe)

$$h_{pipe} = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) = (0.003)(39.29)(0.067) = 0.0184m$$

DESIGN CALCULATIONS

6. Losses

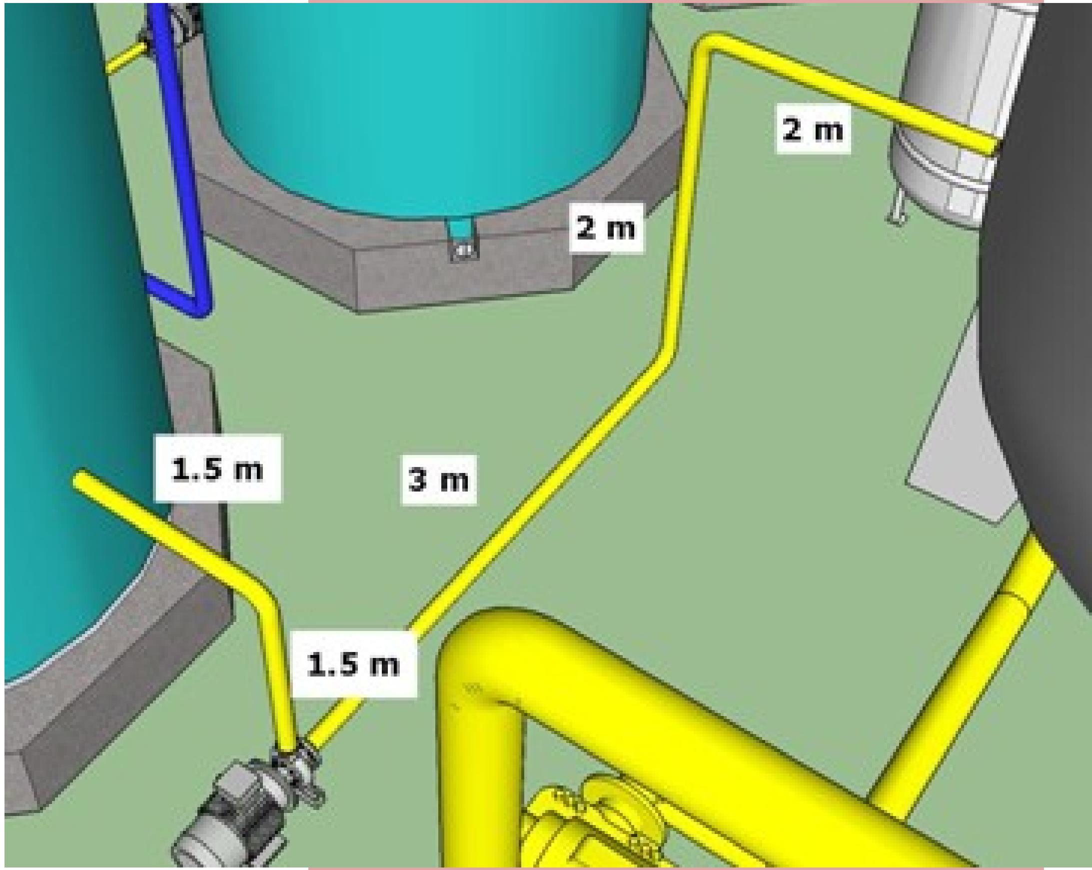
To solve for losses for gate valve, and elbow. Following equations are given: (Principles of Transport Processes and Separation Processes). Kf value for wide open gate valve is 0.17; kf value for standard 90o elbow is 0.75

$$h_{gate} = K_f\left(\frac{V^2}{2g}\right) = 0.17(0.067) = 0.01139\ m$$

$$h_{elbow} = K_f\left(\frac{V^2}{2g}\right) = (0.75 * 3)(.067) = 0.151\ m$$

$$h_{LOSSES}TOTAL = 0.181\ m$$

Total Losses: 0.181 m



SAMPLE DESIGN

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DESIGN CALCULATIONS

6. Losses

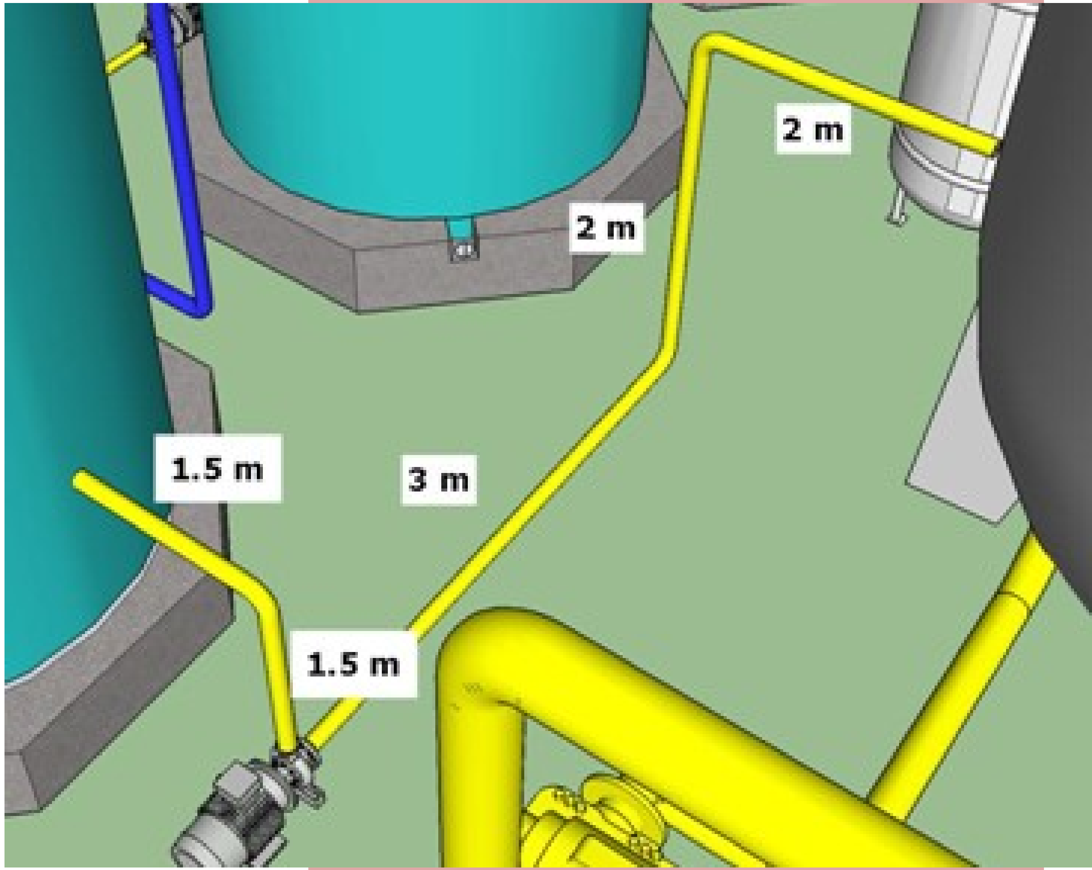
To solve for losses for gate valve, and elbow. Following equations are given: (Principles of Transport Processes and Separation Processes). Kf value for wide open gate valve is 0.17; kf value for standard 90o elbow is 0.75

$$h_{gate} = K_f\left(\frac{V^2}{2g}\right) = 0.17(0.067) = 0.01139\ m$$

$$h_{elbow} = K_f\left(\frac{V^2}{2g}\right) = (0.75 * 3)(.067) = 0.151\ m$$

$$h_{LOSSES}TOTAL = 0.181\ m$$

Total Losses: 0.181 m



DESIGN CALCULATIONS

7. Pipe Length

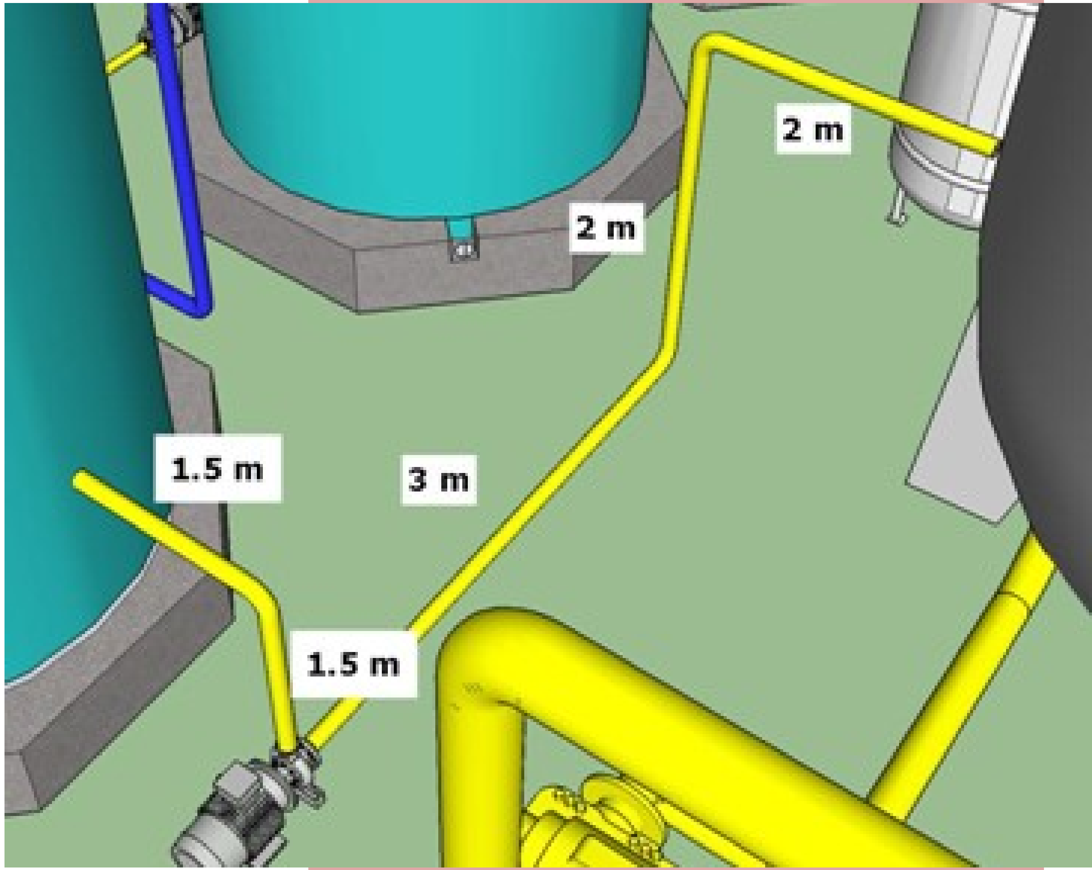
From table 2.10-1 in Principles for Transport Processes and Separation Processes
The equivalent pipe length for Elbow and valves are as follows:

$$L_{elbow} = (3)(35)(0.25451) = 26.724\ m$$

$$L_{gate\ valve} = (9)(0.25451) = 2.291\ m$$

$$L_{TOTAL} = 26.724 + 2.291 + 10 = 39.015\ m$$

Use: 39.1 m



DESIGN CALCULATIONS

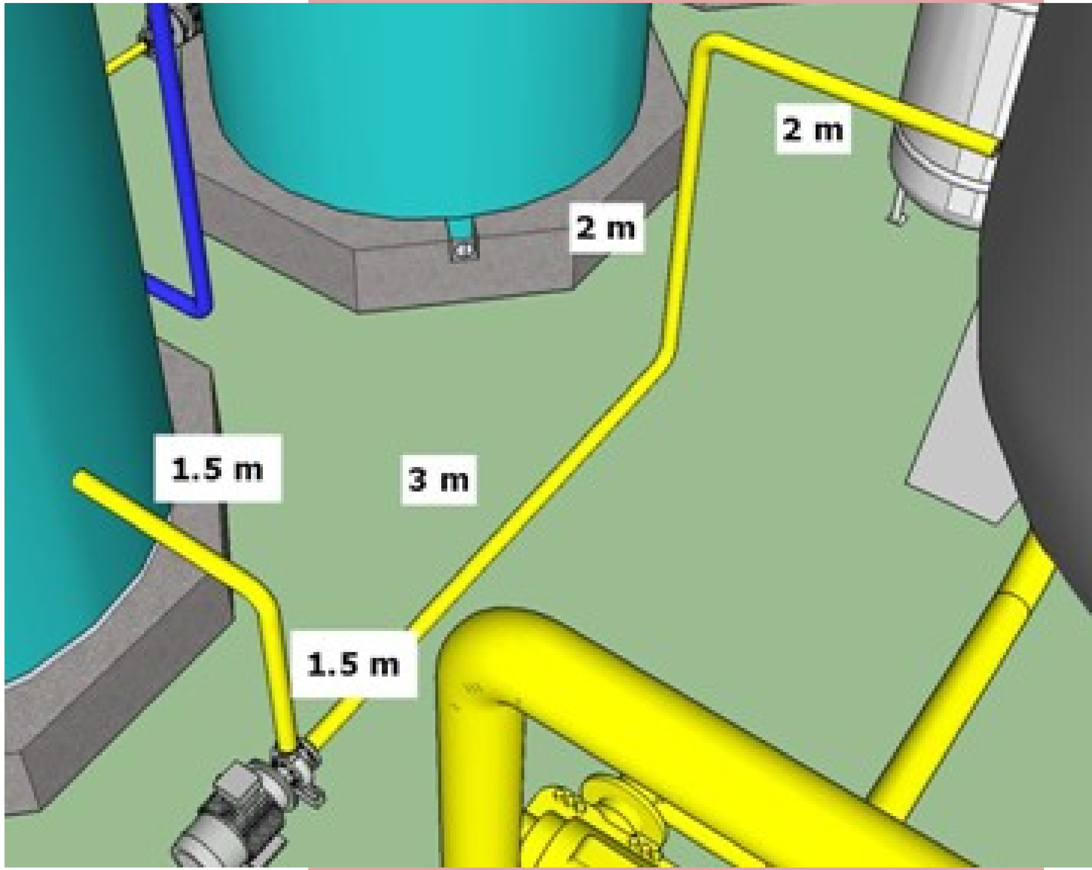
8. Total Head

Equation for the computation of total head is given by: (Unit Operations of Chemical Engineering by McCabe)

$$h_A = h_L + \left(\frac{P_2}{y} - \frac{P_1}{y}\right) + (Z_2 - Z_1) + \left(\frac{{v_2}^2 - {v_1}^2}{2g}\right)$$

$$h_A = 0.181 + \left(\frac{101{,}325}{1166.99} - \frac{101{,}325}{1166.99}\right) + (0.5 - 0) + (0)$$

$$h_A = 0.681\ m$$



DESIGN CALCULATIONS

9. Power Requirement

Pump power requirement is given by the equation (Perry's Chemical Engineering Handbook, 8th ed.,)

$$kW = HQ\rho/3.670 \times 10^5$$

or

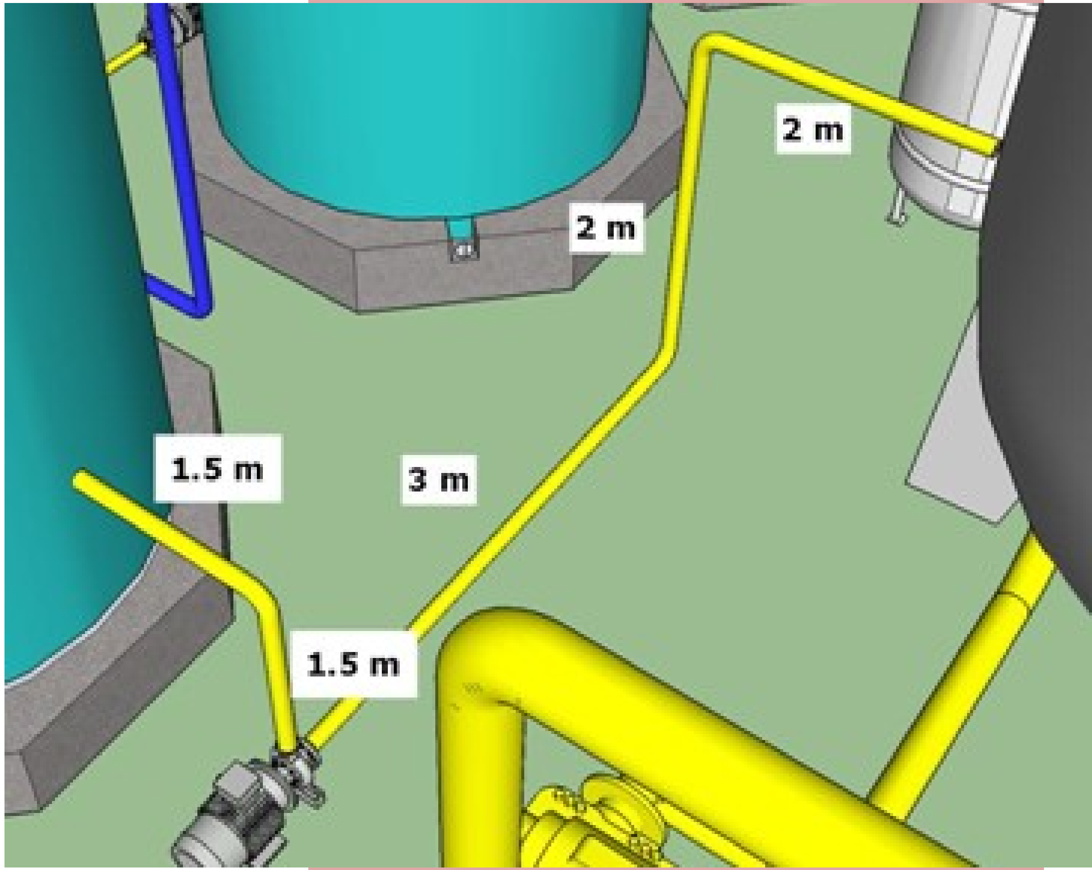
$$P = \frac{h_A q_f \rho g}{e}$$

Assuming 80% pump efficiency

$$P = \frac{(0.681)(0.0589)(1166.99)(9.81)}{0.80} * \left(\frac{1}{1000}\right)$$

$$P = 0.5577\ kW = 0.7479 hp$$

Use: 1.00 hp



SAMPLE DESIGN

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DESIGN SPECIFICATION

Piping Connection	**From NaOH Dilution Tanks to Alkali Digester**
Function	To transfer 15% (w/v) NaOH to Alkali Digester
Material of construction:	Stainless Steel type 302
Design Data:	
Auxiliaries	3- 90º Standard Elbow 1GateValve 1 Centrifugal Pump
Schedule Number	40
Outside Diameter	273.05 mm
Inside Diameter	254.51 mm
Nominal Diameter	10 in
Wall Thickness	9.271 mm
Total Length	39.1 m
Power Requirement	1.00 hp