ME444 ENGINEERING PIPING SYSTEM DESIGN

CHAPTER 1: INTRODUCTION

TENTATIVE SCHEDULE

- BEFORE MIDTERM: THEORY OF FLOW IN PIPE, PIPE SIZING, PIPING MATERIALS, PUMP SELECTION

- AFTER MIDTERM: DESIGN OF VARIOUS PIPING SYSTEMS FOR BUILDINGS AND INDUSTRIES

Web: http://dulyachot.me.engr.tu.ac.th/me444/me444.htm

CONTENTS

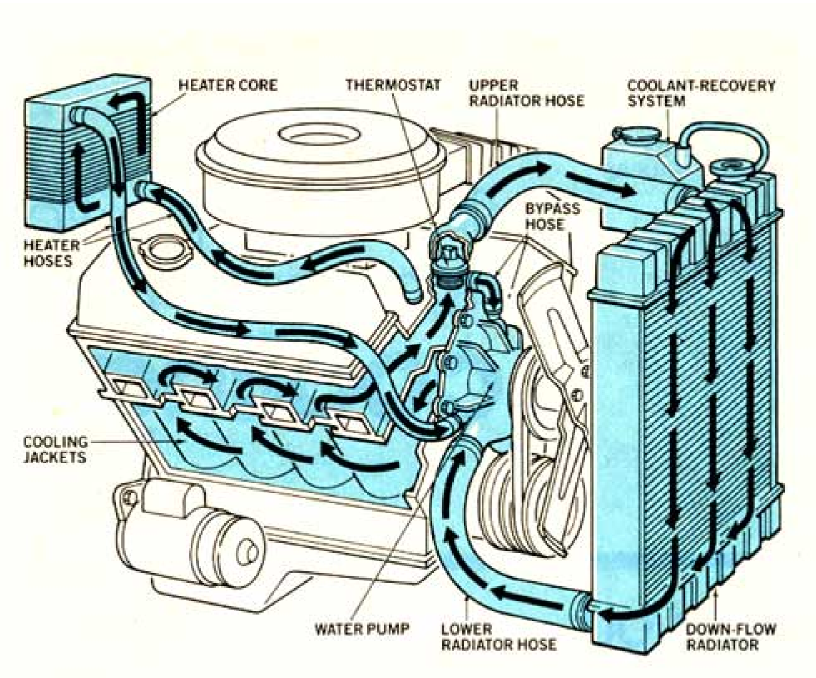
1. INTRODUCTION

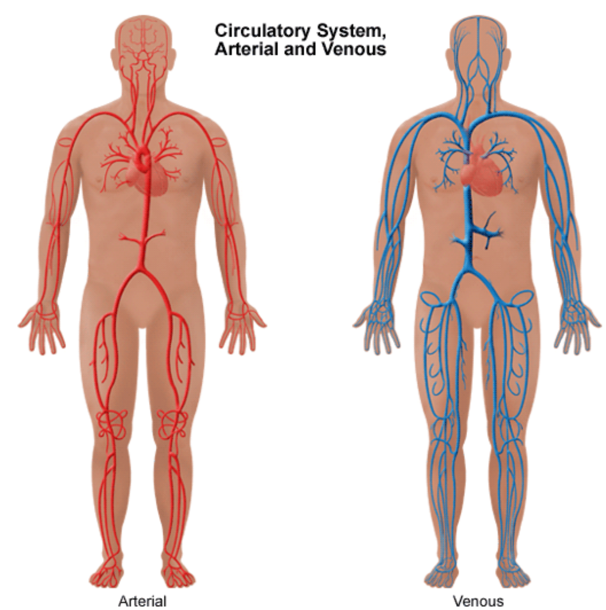
PIPING SYSTEMS EXIST IN EVERY ENGINEERING APPLICATION.

APPLICATIONS:
PLUMBING, FIRE PROTECTION, PROCESS, AIR-CONDITIONING, REFRIGERATION, VENTILATION, COMPRESSED GAS, STEAM

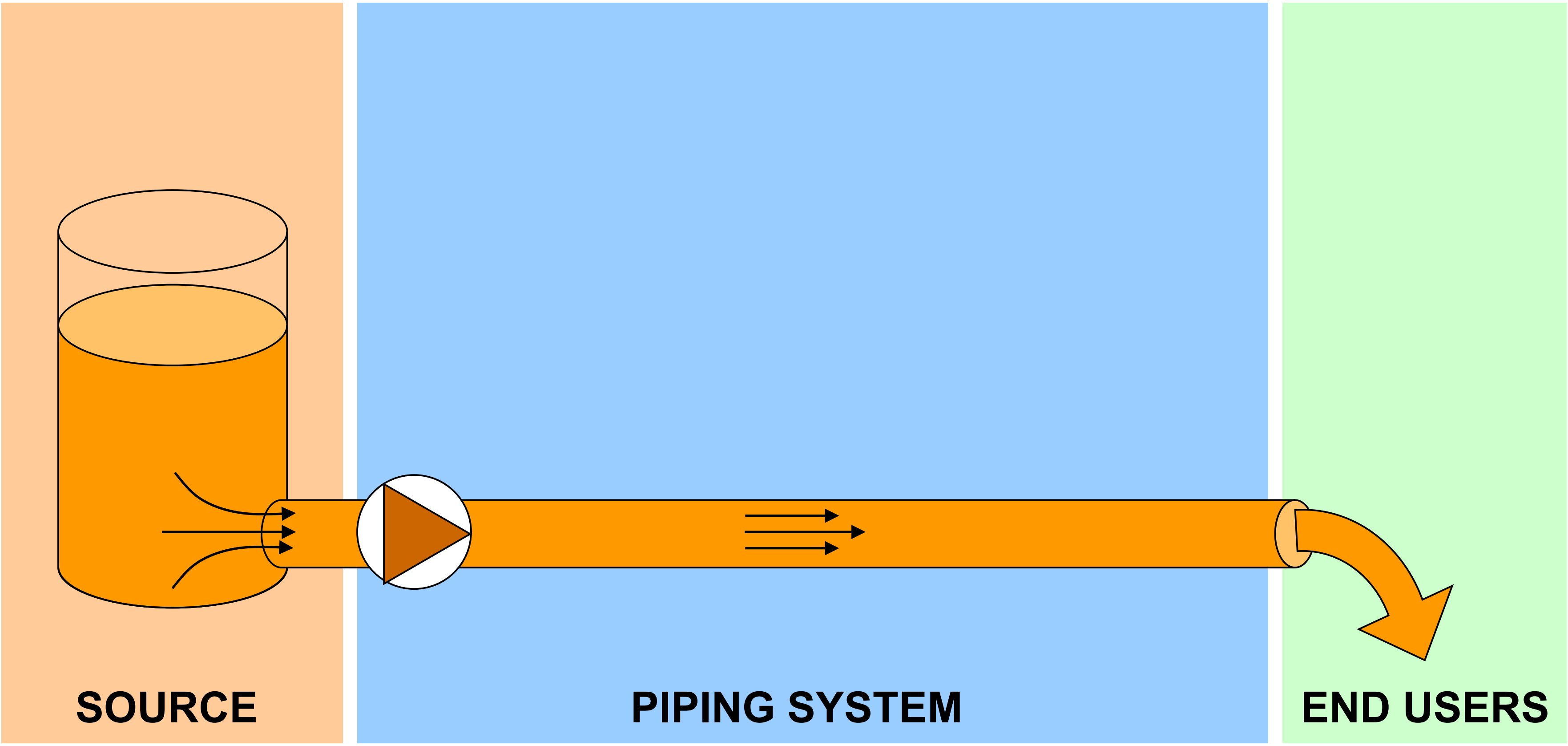
FUNCTION:
TRANSMIT FLUID AT A PREFERED RATE TO THE DESTINATIONS WITH PREFERRED PROPERTIES
(I.E. PRESSURE, TEMPERATURE)

SESSION 1 MAIN REFERENCE: PUMPING STATION DESIGN

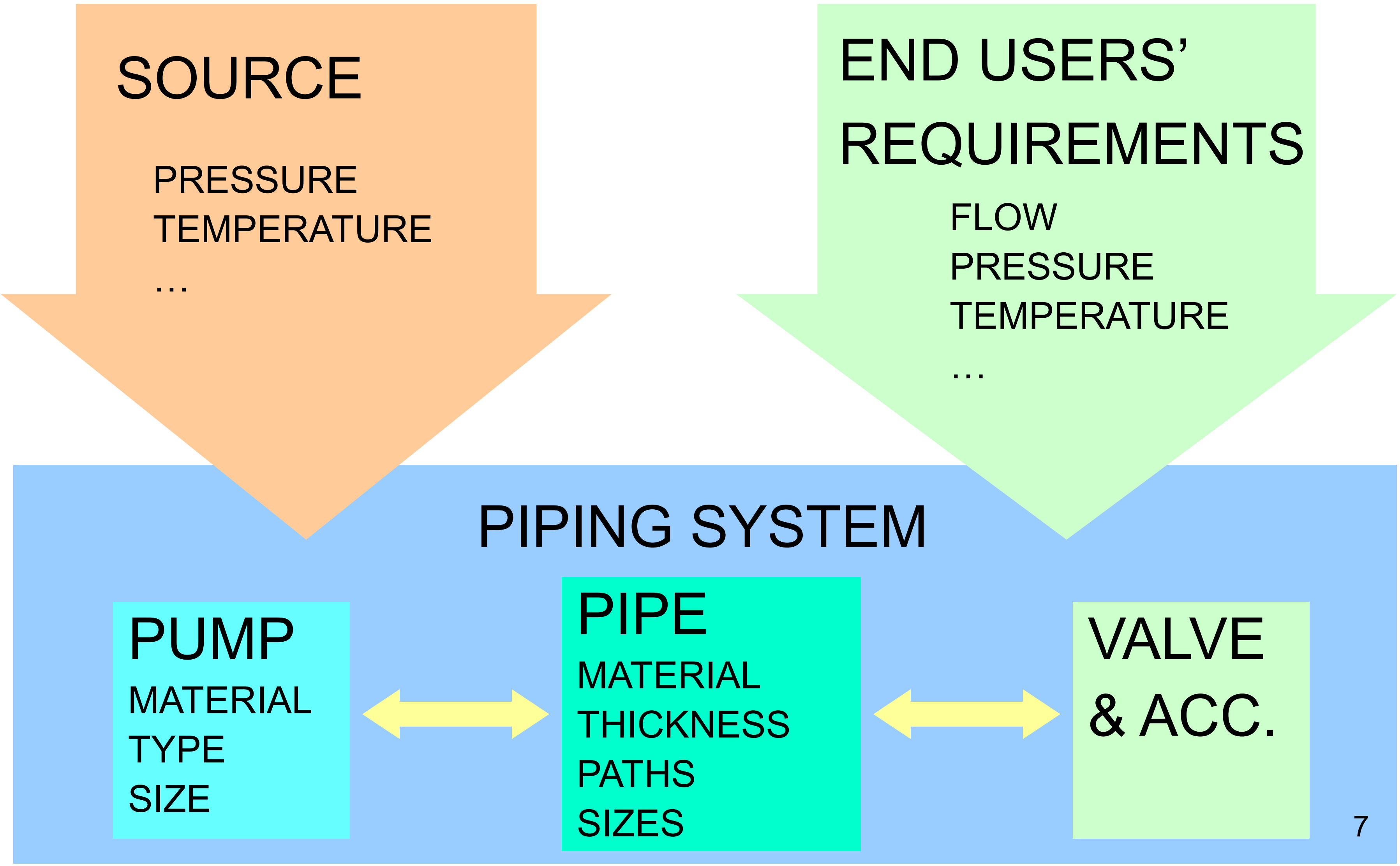

HEATER CORE
THERMOSTAT
UPPER RADIATOR HOSE
COOLANT-RECOVERY SYSTEM
BYPASS HOSE
HEATER HOSES
COOLING JACKETS
WATER PUMP
LOWER RADIATOR HOSE
DOWN-FLOW RADIATOR


Circulatory System, Arterial and Venous
Arterial
Venous

DESIGN CONCEPT



PIPING SYSTEM DESIGN



2. STANDARDS

American National Standard Institute (ANSI)

American Petroleum Institute (API)

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

American Society of Mechanical Engineers (ASME)

ASME STANDARDS

B31.1. Power Piping

B31.2. Fuel Gas Piping

B31.3. Process Piping

B31.4. Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids

B31.5. Refrigeration Piping

B31.8. Gas Transmission and Distribution Piping

B31.9. Building Services Piping

B31.11. Slurry Transportation Piping

STANDARDS

American Society of Testing and Materials (ASTM)

International Organization for Standardization (ISO)

American Water Works Association (AWWA)

National Sanitation Foundation (NSF)

STANDARDS

National Fire Protection Association (NFPA)

Factory Mutual Research Corporation (FM)

Underwriters Laboratories (UL)

STANDARDS

British Standard

Deutsches Institut für Normung

Japanese Industrial Standard

Old mark
(expired)

วิศวกรรมสถานแห่งประเทศไทย ในพระบรมราชูปถัมภ์

3. BASIC UNITS

PIPE SIZE: INCHES, mm.

PIPE LENGTH: FEET, METRES

VOLUME: CU.M., CU.FT., LITRES, GALLONS

FLOWRATE: GPM, CU.M./H, LPS, LPM, CFM

PRESSURE: PSI, BAR, m.WG., KG/CM^2

POWER: KW, HP

STUDENTS MUST HAVE THE CONVERSION FACTORS

7 basic quantities

ปริมาณ	หน่วยวัดในระบบเอสไอ	ตัวย่อ
ความยาว	เมตร	m
มวล	กิโลกรัม	kg
เวลา	วินาที	s
กระแสไฟฟ้า	แอมแปร์	A
อุณหภูมิ	เคลวิน	K
ปริมาณของสะสาร	โมล	m
ความส่องสว่าง	แรงเทียน (candela)	cd

Basic conversion

Length

1 in (inch) = 25.4 mm = 2.54 cm = 0.0254 m = 0.08333 ft

1 ft (foot) = 0.3048 m

1 m (meter) = 3.2808 ft = 39.37 in

1 km = 0.6214 mile = 3281 ft

Mass

1 kg = 1,000 g = 2.2046 lb

1 lb = 16 oz = 0.4536 kg =

Temperature

celsius, rankine, kelvin, centigrade, fahrenheit,

- $1\ ^{o}C = 1.8\ ^{o}F$
- $1\ ^{o}F = 0.555\ ^{o}C$
- $0\ ^{o}C$ corresponds to $32\ ^{o}F$, 273.16 K and 491.69 R
- $T(^{o}R) = (9/5)T(K)$
- $T(^{o}F) = [T(^{o}C)](9/5) + 32$
- $T(^{o}F) = [T(K) - 273.15](9/5) + 32$
- $T(^{o}C) = 5/9[T(^{o}F) - 32]$

Area

Length

1 in (inch) = 25.4 mm = 2.54 cm = 0.0254 m = 0.08333 ft

1 ft (foot) = 0.3048 m

1 m (meter) = 3.2808 ft = 39.37 in

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Mass

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Volume

barrel, gallon, cubic centimeter (cm^3), cubic feet ($foot^3$), cubic inch ($inch^3$), cubic meter ($meter^3$), cubic yard ($yard^3$), quarts, liters, acre foot, board foot, bushel, cord, cup, dram, fluid ounce, peck, pint, quart, tablespoon, teaspoon,

- 1 Gallon (U.S.) = 3.785×10^{-3} m^3 = 3.785 dm^3 (liter) = 0.13368 ft^3 = 4.951×10^{-3} yd^3 = 0.8327 Imp. gal (UK) = 4 Quarts = 8 Pints
- 1 Imp. gal (UK) = 4.546×10^{-3} m^3 = 4.546 dm^3 = 0.1605 ft^3 = 5.946×10^{-3} yd^3 = 1.201 gal (US)
- 1 dm^3 (Liter) = 10^{-3} m^3 = 0.03532 ft^3 = 1.308×10^{-3} yd^3 = 0.220 Imp gal (UK) = 0.2642 Gallons (US) = 1.057 Quarts = 2.113 Pints
- 1 ft^3 = 0.02832 m^3= 28.32 dm^3 = 0.03704 yd^3 = 6.229 Imp. gal (UK) = 7.481 gal (US) = 1,728 Cu.In.

Volume Flowrate

- $1\ m^3/h = 2.7778x10^{-4}\ m^3/s = 0.2778\ dm^3$(litre)/s $= 9.810x10^{-3}\ ft^3/s = 0.5886\ ft^3/min$ (cfm) = 3.667 Imp.gal (UK)/min = 4.403 gal (US)/min

- 1 gal (US)/min $=6.30888x10^{-5}\ m^3/s = 0.227\ m^3/h = 0.06309\ dm^3$(litre)/s $= 2.228x10^{-3}\ ft^3/s = 0.1337\ ft^3/min$ = 0.8327 Imperial gal (UK)/min

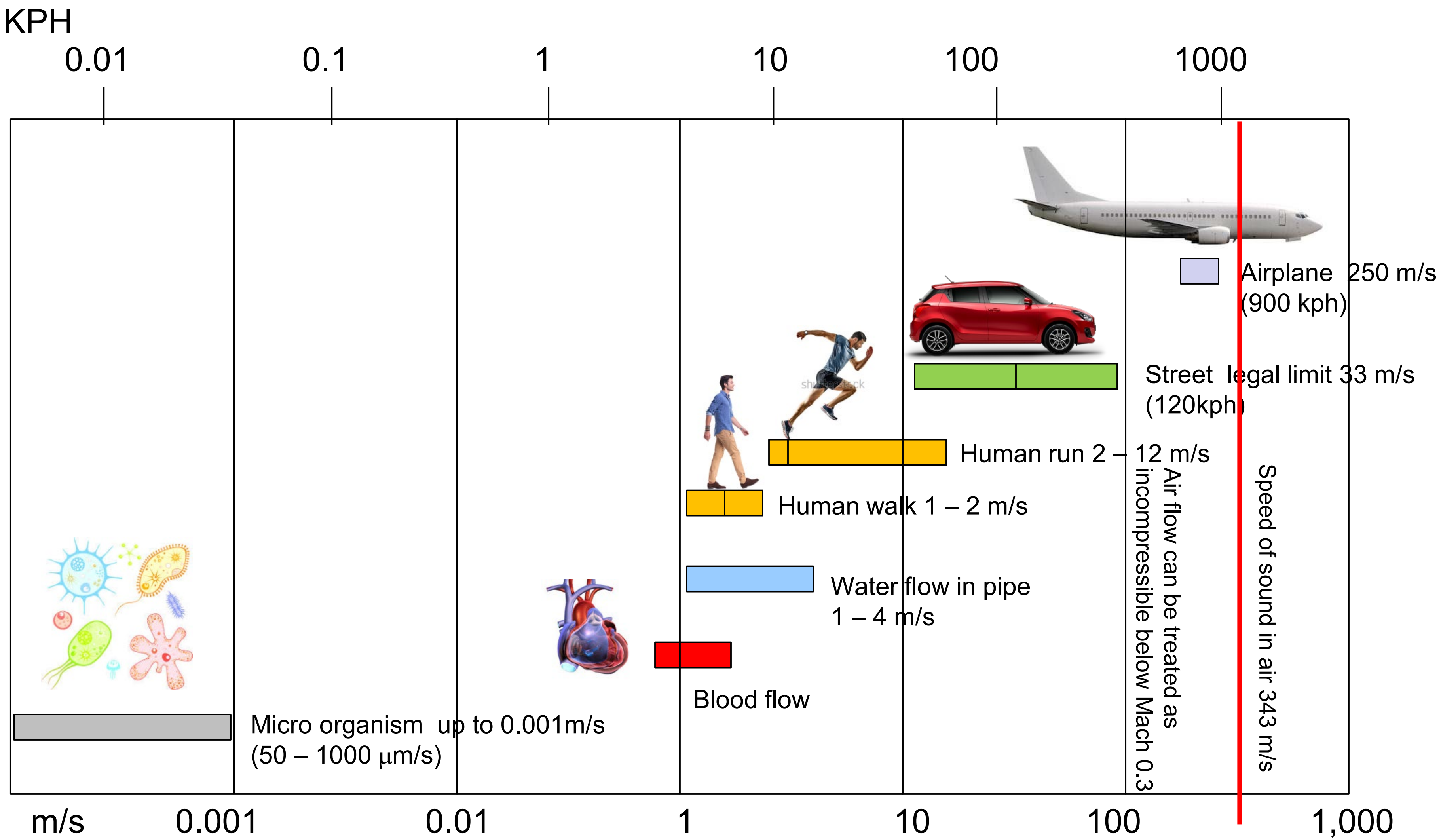
- $1\ ft^3/min = 1.7\ m^3/h = 0.47$ l/s

Velocity

foot/second, inch/second, meter/second, kilometer/hour, knot, mile/hour,nautical mile per hour

- 1 ft/s = 0.3048 m/s
- 1 ft/min = 5.08×10^{-3} m/s = 0.0183 km/h = 0.0114 mph
- 1 mph = 0.44703 m/s = 1.609 km/h = 88 ft/min = 5280 ft/hr = 1.467 Ft./sec. = 0.8684 knots
- 1 m/s = 3.6 km/h = 196.85 ft/min = 2.237 mph
- 1 km/h = 0.2778 m/s = 54.68 ft/min = 0.6214 mph = 0.5396 knot
- 1 knot (nautical mile per hour)= 0.514444444 m/s = 1.852 kilometers per hour = 1.1515 miles per hour= 1 nautical miles per hour

Velocity



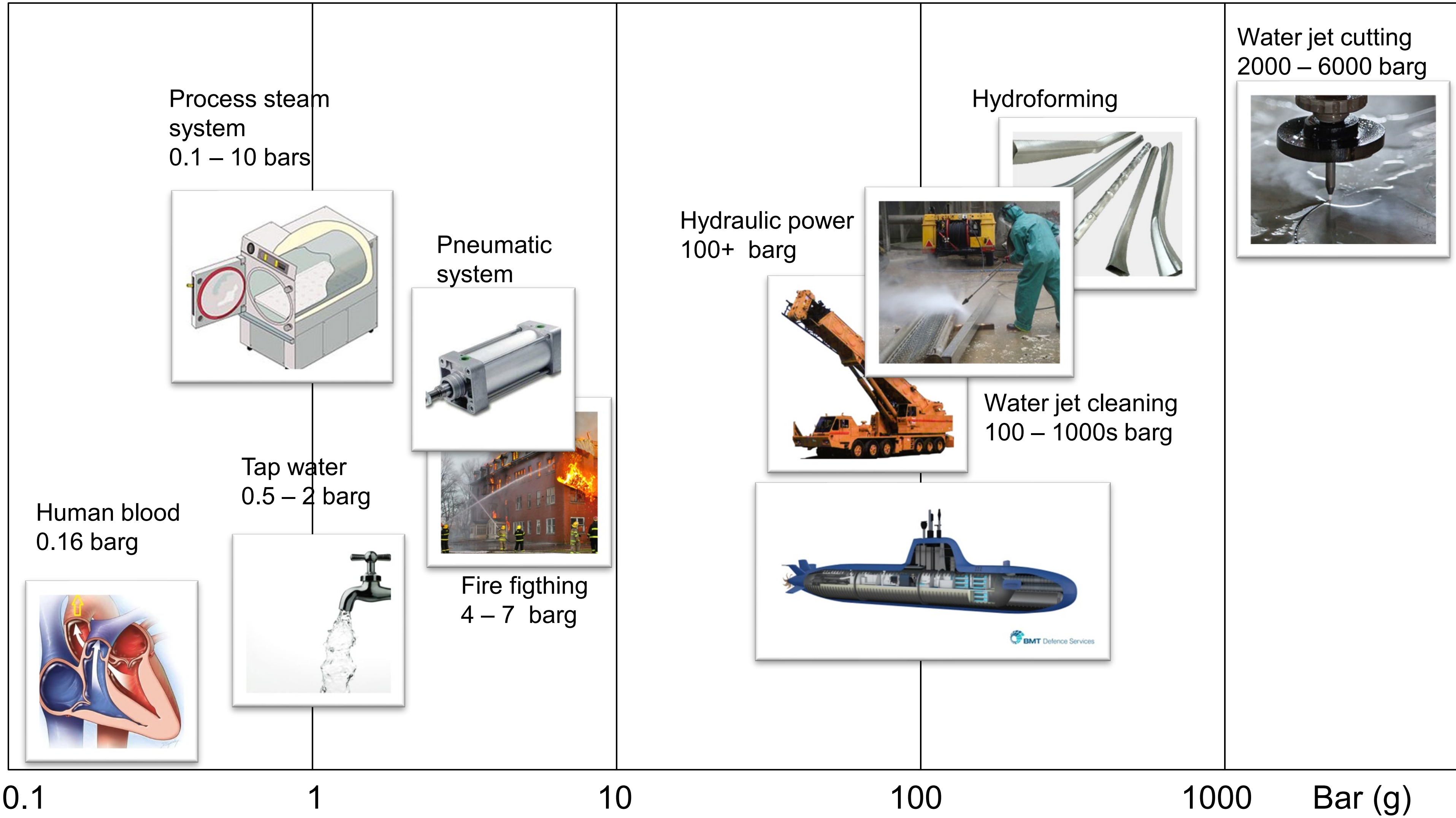
KPH
0.01
0.1
1
10
100
1000
Airplane 250 m/s
(900 kph)
Street legal limit 33 m/s
(120kph)
Human run 2 – 12 m/s
Human walk 1 – 2 m/s
Water flow in pipe
1 – 4 m/s
Blood flow
Micro organism up to 0.001m/s
(50 – 1000 μm/s)
Air flow can be treated as incompressible below Mach 0.3
Speed of sound in air 343 m/s
m/s
0.001
0.01
1
10
100
1,000

Pressure

atmosphere, centimeters of mercury, foot of water, bar, barye, centimeter of water, dyne/centimeter^2, inch of mercury, inch of water, kgf/centimeter^2, kgf/meter^2, lbf/foot^2, lbf/inch^2 (psi), millibar, millimeter of mercury, pascal, torr, newton/meter^2

- Standard Atmospheric Pressure 1 atm = 101.325 kN/m^2 = 101.325 kPa = 14.7 psia = 0 psig = 29.92 in Hg = 760 torr = 33.95 Ft.H_2O = 407.2 In.W.G (Water Gauge) = 10.33 m.WG. = 2116.8 Lbs./Sq.Ft.
- 1 bar = 10^5 Pa (N/m^2) = 0.1 N/mm^2 = 10,197 kp/m^2 = 10.20 m H_2O = 0.9869 atm = 14.50 psi (lb_f/in^2) = 10^6 dyn/cm^2 = 750 mmHg
- 1 psi (lb/in^2) = 144 psf (lb_f/ft^2) = 6,894.8 Pa (N/m^2) = 6.895×10^{-3} N/mm^2 = 6.895×10^{-2} bar

Pressure Level (GAGE)



Energy

British Thermal Unit (Btu), calorie, joule, kilojoule, electron volt, erg, foot lb_f, foot poundal, kilocalorie, kilowatt hour, watt hour

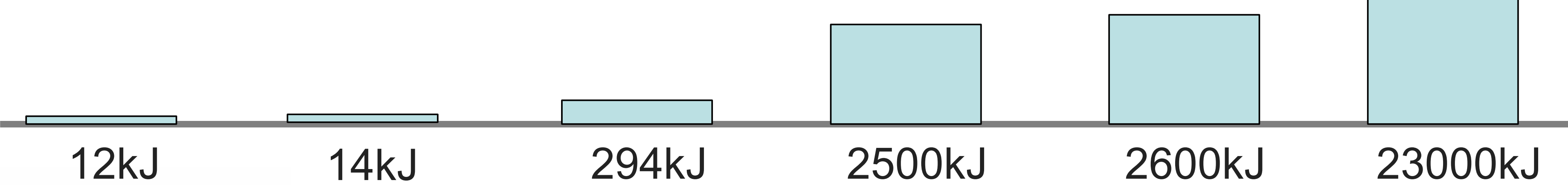
1 Btu = ความร้อนที่ต้องใช้ในการเพิ่มอุณหภูมิของน้ำ 1 ปอนด์ ขึ้น 1°F (58.5 °F ถึง 59.5 °F) ที่ระดับน้ำทะเล (ความดัน30 in.HG.).

1 calorie = ความร้อนที่ต้องใช้ในการเพิ่มอุณหภูมิของน้ำ 1 กรัม ขึ้น 1°C

- 1 kWh = 3.6×10^6 J = 3.671×10^5 kpm = 859.9 kcal = 2.656×10^6 ft lb_f = 3.412×10^3 Btu
- 1 kJ = 1 kNm = 1kWs = 10^3 J = 0.947813 Btu = 737.6 ft lb_f = 0.23884 kcal
- 1 Btu (British thermal unit) = 1,055.06 J = 107.6 kpm = 2.931×10^{-4} kWh = 0.252 kcal = 778.16 ft lb_f = 1.055×10^{10} ergs = 252 cal = 0.293 watt hour
- 1 cal = 4.186 J

Energy

Power is the time rate of energy.
In SI unit, Joule/second.



Up stair to 7th floor
(18m., 70kg)

AA alkaline
(24grams)
3.90 Wh

1km Run
70kcal / km

Boil 1L of water

630kcal

LHV of 1L of
Alcohol 23MJ

Heat Flowrate and Power

- 1 kW = 1,000 Watts = 3,412 Btu/h = 737.6/550 British hp = 1.341 British hp = 10^3/9.80665 kg_f m/s = 737.6 ft lb_f/s = 10^3/(9.80665 75) metric hp
- 1 hp (English horse power) = 745.7 W = 0.746 kW = 550 ft lb/s = 2,545 Btu/h = 33.000 ft lb/m = 1.0139 metric horse power ~= 1.0 KVA
- 1 metric horse power = 736 W = 75 kg m/s = 0.986 English horse power
- 1 refrigeration Ton = 12,000 Btu/h cooling = 3.516 kW = 3,025.9 k Calories/h

- 1 Therm = 100,000 Btu/h
- 1 ft lb/s = 1.3558 W
- 1 Btu/s = 1055.1 W
- 1 Btu/h = 1 Btuh = 0.293 W = 0.001 MBH
- 1 Boiler Horse Power = 33,475.35 Bth/h = 9.81 kW

Viscosity

Viscosity dynamic (ความหนืด) – μ ความหนืดสัมบูรณ์

- 1 lb/(ft s) = 1.4879 Pa s = 14.88 P = 1,488 cP = 0.1517 kp s/m^2
- 1 cP (Centipoise) = 10^{-3} Pa s = 0.01 P = 1.020x10^{-4} kp s/m^2 = 6.721x10^{-4} lb/(ft s) = 0.00100 (N s)/m^2
- 1 kg/(m s) = 1 (N s)/m^2 = 0.6720 lb_m/(ft s) = 10 Poise
- 1 P (Poise) = 0.1 Pa s = 100 cP = 1.020x10^{-2} kp s/m^2 = 6.721x10^{-2} lb/(ft s) = 0.1 kg/ms
- 1 Pa s (N s/m^2) = 10 P (Poise) = 10^3 cP = 0.1020 kp s/m^2 = 0.6721 lb/(ft s)
- 1 kp s/m^2 = 9.80665 Pa s = 98.07 P = 9,807 cP = 6.591 lb/(ft s)
- 1 reyns = 1 $1b_f$ s/in^2 = 6894.76 Pa s

Unit of Viscosity

Absolute or Dynamics viscosity, μ

$$\tau = \mu \frac{du}{dy} \Rightarrow \mu = \frac{\overbrace{\tau}^{\text{Pa}}}{\left(\frac{\overbrace{du}^{\text{m/s}}}{\underbrace{dy}_{\text{m}}}\right)} \Rightarrow \text{Pa.s}$$

10^{-3} Pa.s = 1 cP (centipoise)

Properties of Some Fluids (approx.)

Fluids (Temp.)	Density (kg/m^3)	Absolute Viscosity (Pa-s)
Air (30C)	1.16	18.6×10^{-6}
Water (30C)	996	0.798×10^{-3}
Sea water (30C)	1022	0.86×10^{-3}
Bloods (37C)	1060	2.8×10^{-3}
Ethanol (30C)	781	0.983×10^{-3}
Kerosine (30C)	820	1.4×10^{-3}
SAE 10W-30 Oil (30C)	840	0.09
Glycerin (30C)	1260	0.6
Mercury (30C)	13496	1.45×10^{-3}

Kinematic Viscosity

Kinematic viscosity (nu) $$\nu = \frac{\mu}{\rho}$$

Units of kinematic viscosity are in m^2/s or Stoke

1 St (Stokes) = 10^{-4} m^2/s = 1 cm^2/s

Since the *Stoke* is a large unit it is often divided by *100* into the smaller unit ***centiStoke (cSt)*** - where

- *1 St = 100 cSt*
- *1 cSt (centiStoke) = 10^{-6} m^2/s = 1 mm^2/s*
- *1 m^2/s = 10^6 centiStokes*

Viscosity

Viscosity kinematic (ความหนืดเชิงจลนศาสตร์) – $\nu = (\mu / \rho)$

- $1\ ft^2/s = 0.0929\ m^2/s$
- $1\ ft^2/\ h = 2.581 x 10^{-5} m^2/s$
- $1\ St\ (Stokes) = 1x10^{-4}\ m^2/s = 100\ cSt = 1.076x10^{-3}\ ft^2/s$
- $1\ m^2/s = 10^4\ St = 10^6\ cSt = 10.764\ ft^2/s = 38750\ ft^2/h$
- $1\ cSt\ (Centistokes) = 10^{-6}\ m^2/s = 0.01\ St = 1.076x10^{-5}\ ft^2/s$

Water Properties

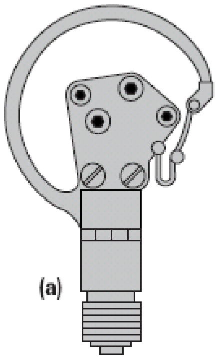
อุณหภูมิ T (°C)	ความหนาแน่น ρ kg/m^3	Dynamic Viscosity μ $(N.s/m^2) \times 10^{-3}$	Kinematic Viscosity ν $(\times 10^{-6}\ m^2/s)$ *	ความดันไอ (kPa)**
0 (น้ำแข็ง)	916.2			
0	999.9	1.787	1.787	0.87
5	1000	1.519	1.519	0.92
10	999.7	1.307	1.307	1.18
20	998.2	1.002	1.004	2.29
30	995.7	0.798	0.801	4.27
40	992.2	0.653	0.658	7.43
50	988.1	0.547	0.553	12.36
60	983.2	0.467	0.475	19.89
70	977.8	0.404	0.413	31.10
80	971.8	0.355	0.365	47.32
90	965.3	0.315	0.326	70.16
100	958.4	0.282	0.294	101.3
100 (ไอน้ำ)	0.598			

* $1 \times 10^{-6}\ m^2/s$ = 1 Centistroke
** 1 bar = 100 kPa

GUAGE PRESSURE

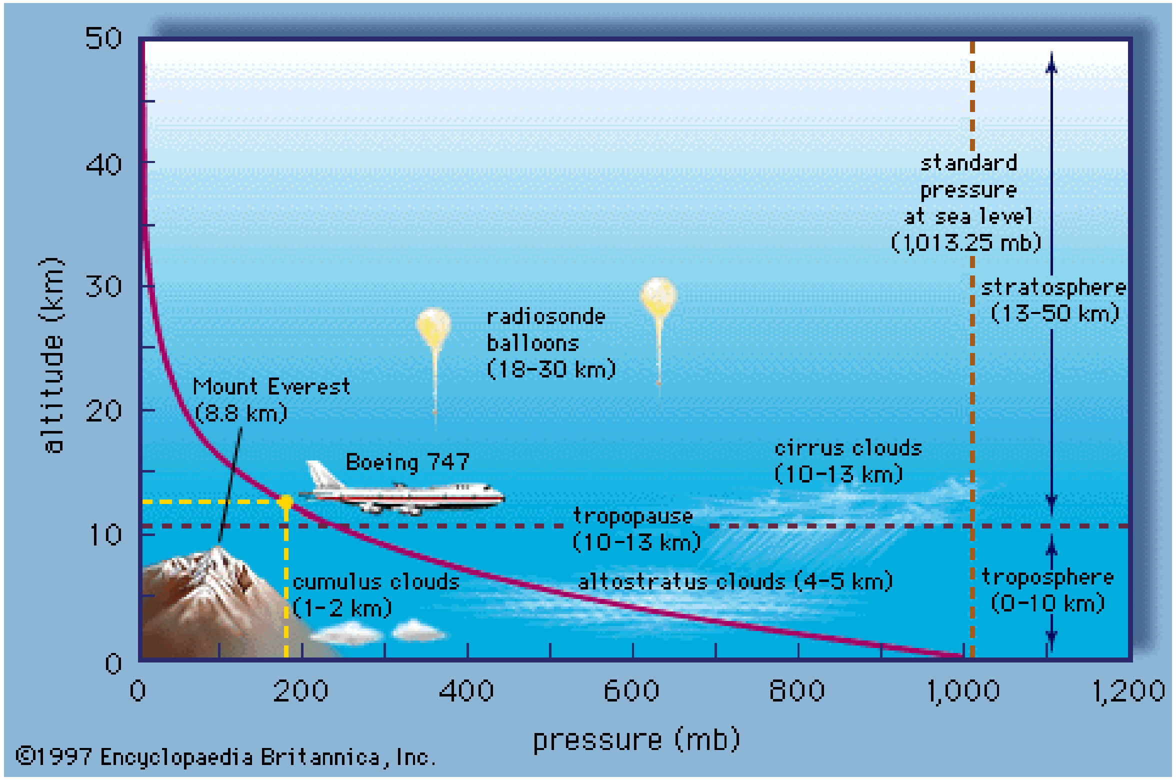
$$P_{guage} = P_{absolute} - P_{atm}$$

P_{guage} is obtained from pressure measuring device.



Atmospheric pressure

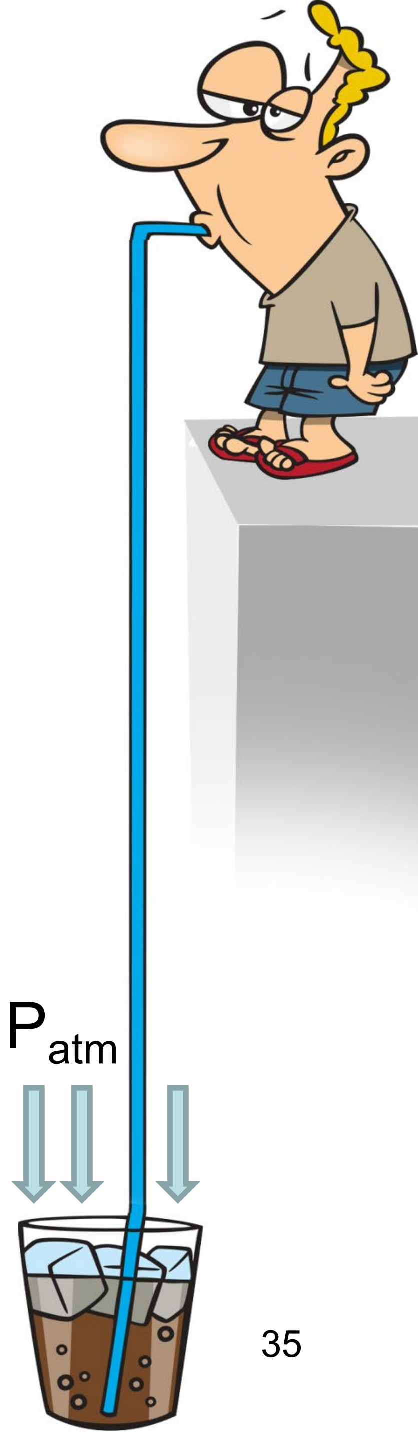
P_{atm} varies with altitude



Pressure at sea level

At sea level P_{atm} = 101.3 kPa $P = \rho g h$

Water can be drawn upto
$h = P_{atm}/\rho_{water}g$ = ?? m



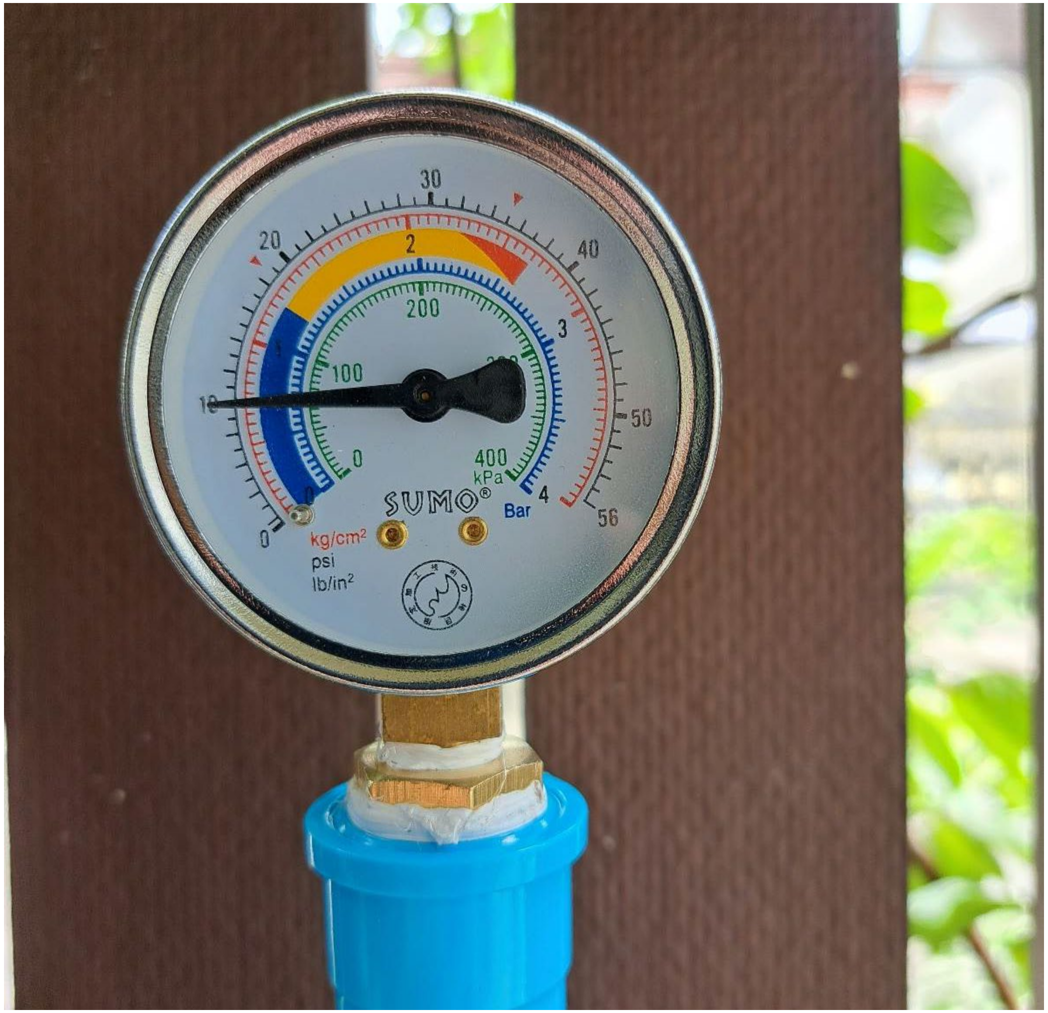
Pressure and elevation

- In theory 1 barg of pressure can drive water up 10.2 m with zero flow.
- Waterworks Authority (MWA/PWA) attempt to deliver water at 1-2 barg.
- 2 barg = 20.4 m.WG. → = 6 Floors !!
- In practical situations, pressure drops in main and branch pipes, water hardly reach 2nd floor, so people use pump.

City Water Pressure

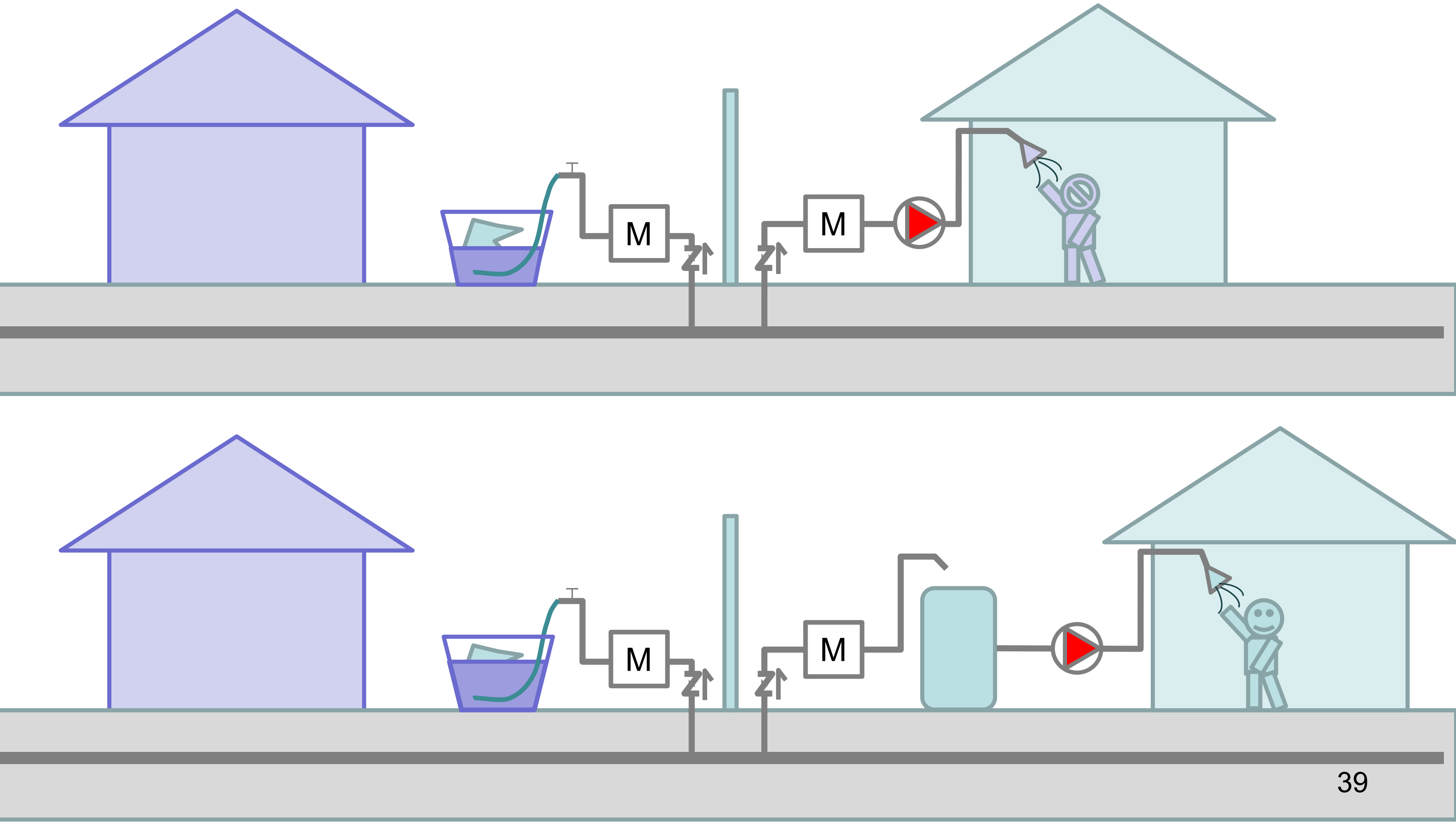
https://prachatai.com/journal/2021/05/93256

Water pressure from PWA

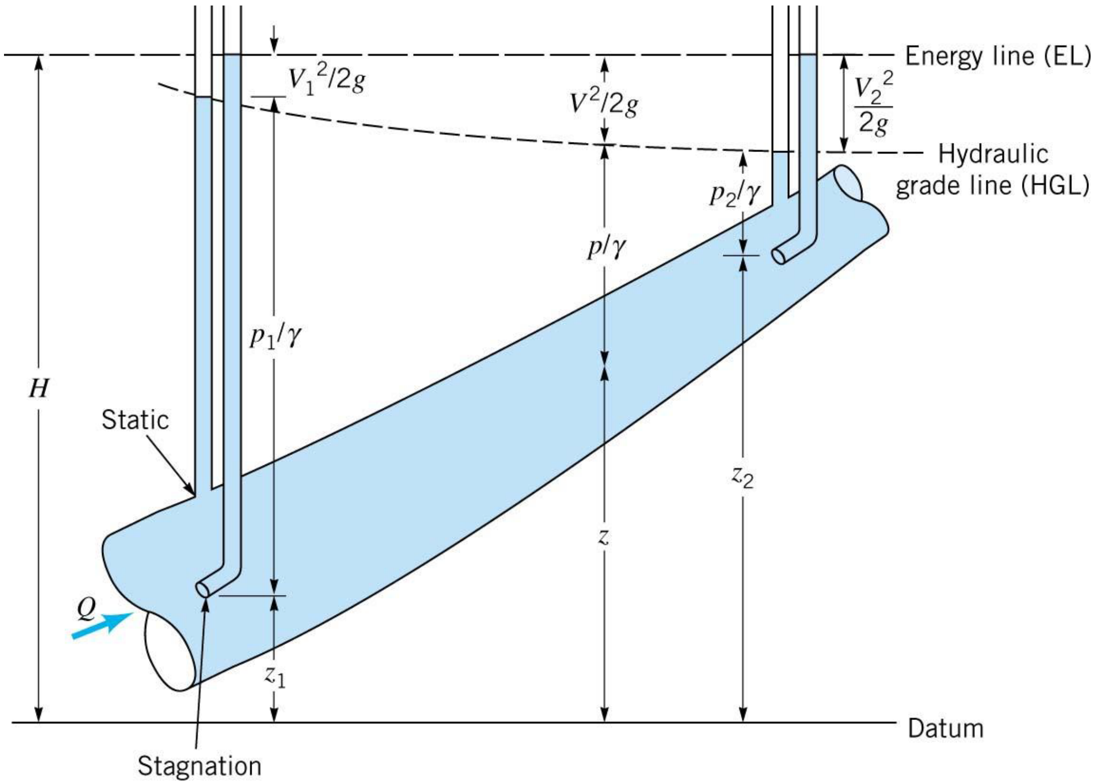


8 Aug 2022
Klong Luang
Patumthani

It’s illegal to pump water from city main



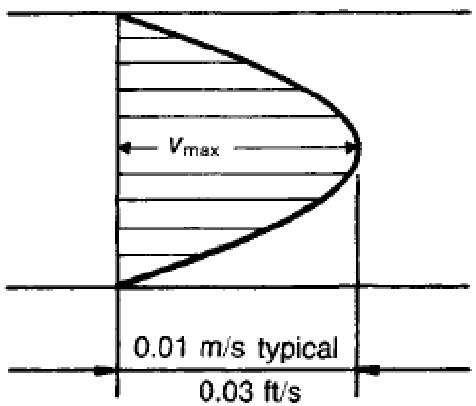
4. BASIC FLOW IN PIPE



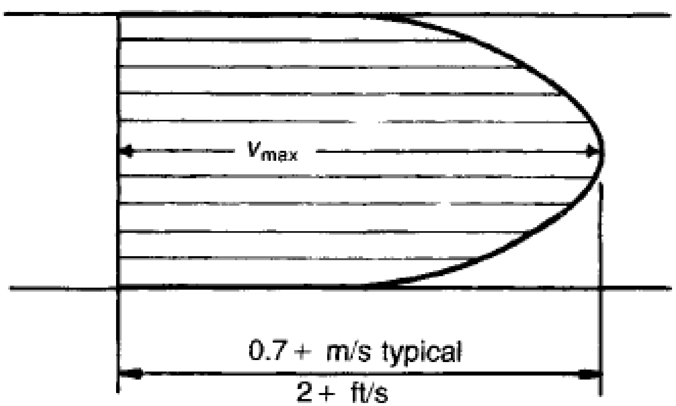
$$\frac{p_1}{\rho g}+\frac{V_1^{\,2}}{2g}+z_1=\frac{p_2}{\rho g}+\frac{V_2^{\,2}}{2g}+z_2+LOSS$$

Flow Pattern

LAMINAR or TURBULENCE ?



Re < 2000



Re > 10000

REYNOLDS NUMBER

$$\mathrm{Re} = \frac{vD}{\nu}$$

Inertia vs. Viscous Effect

WATER FLOW AT 1.2 m/s IN A ½" PIPE

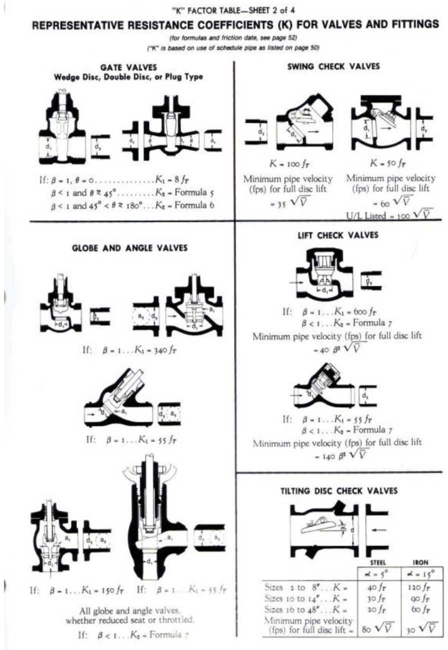
$$\mathrm{Re} = \frac{1.2 \cdot 0.0125}{10^{-6}} = 15000$$

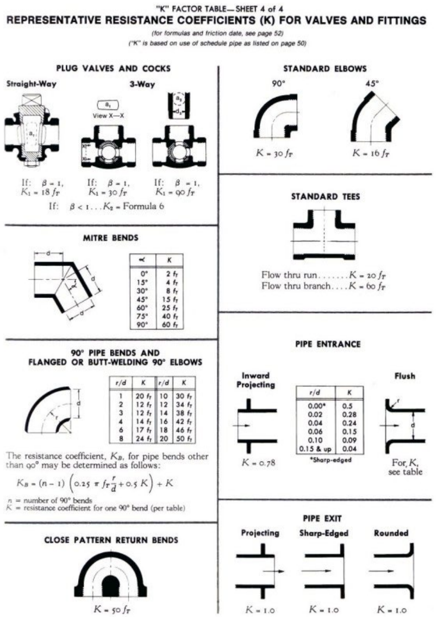
=TURBULENT

LOSS

MAJOR LOSS: LOSS IN PIPE

MINOR LOSS: LOSS IN FITTINGS AND VALVES

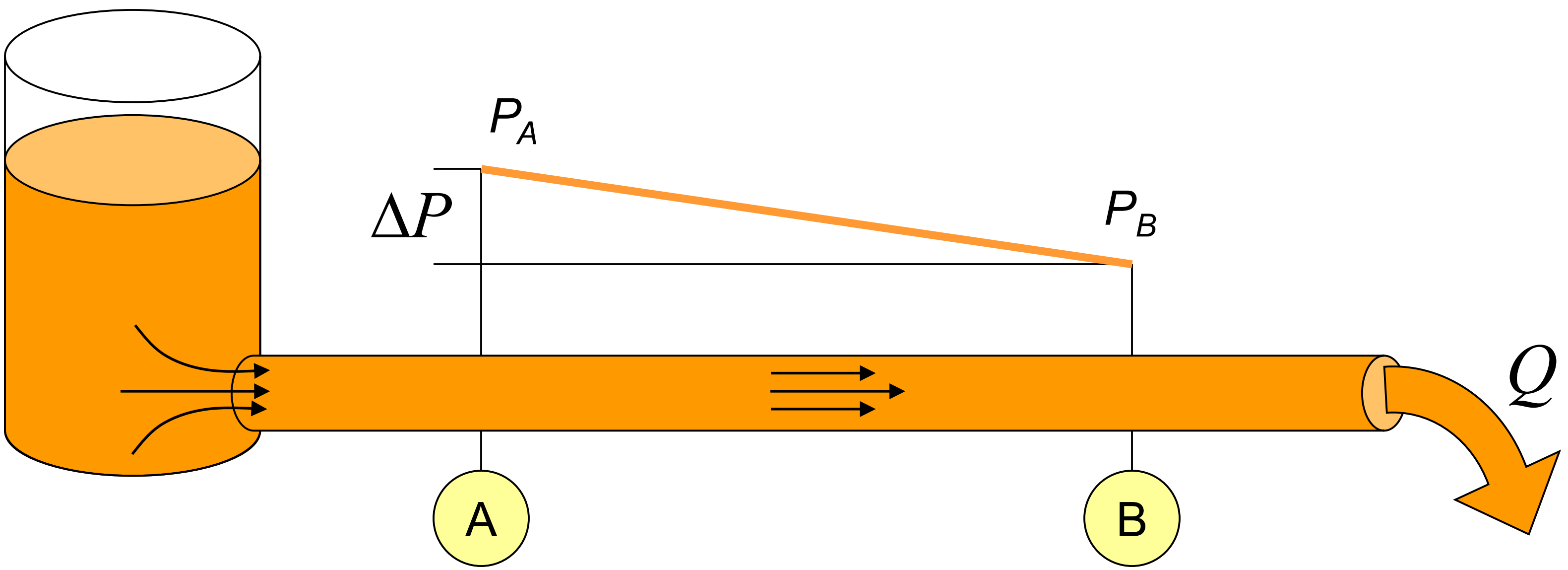




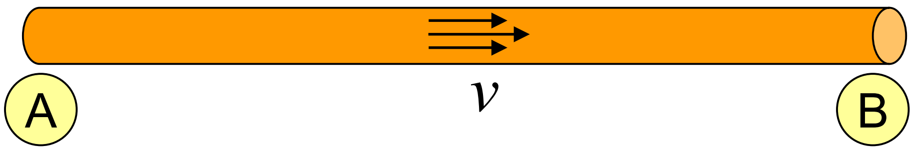
LOSS IN PIPE

LOSS IN PIPE CAUSED BY FRICTION BETWEEN FLUID AND PIPE SURFACE. FRICTION CAN BE RELATED TO SHEAR STRESS.

$$\tau = \mu \frac{du}{dy}$$

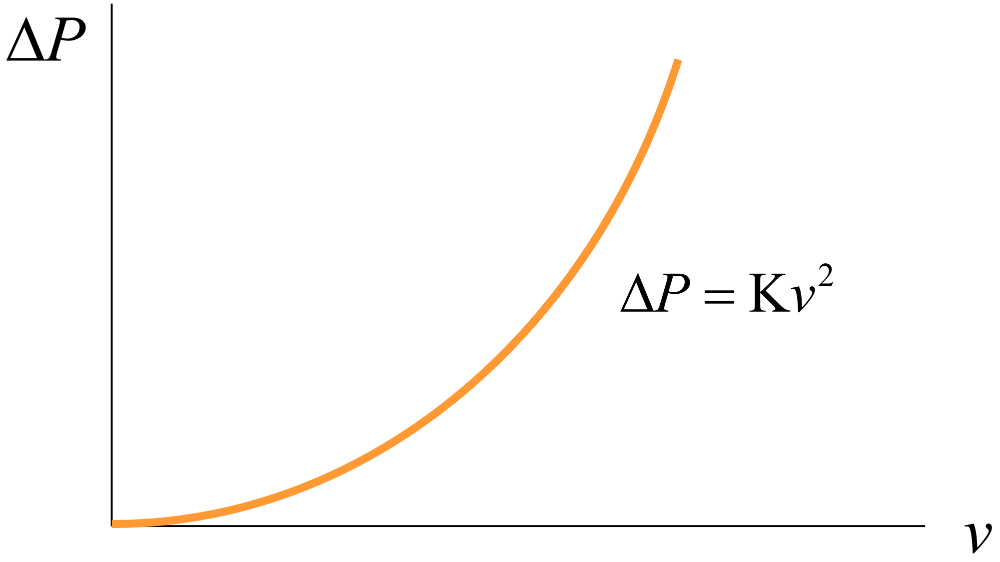


VELOCITY AND LOSS



LOSS IN PIPE VARIES WITH SQUARE OF FLUID VELOCITY

$$\Delta P \propto v^2$$

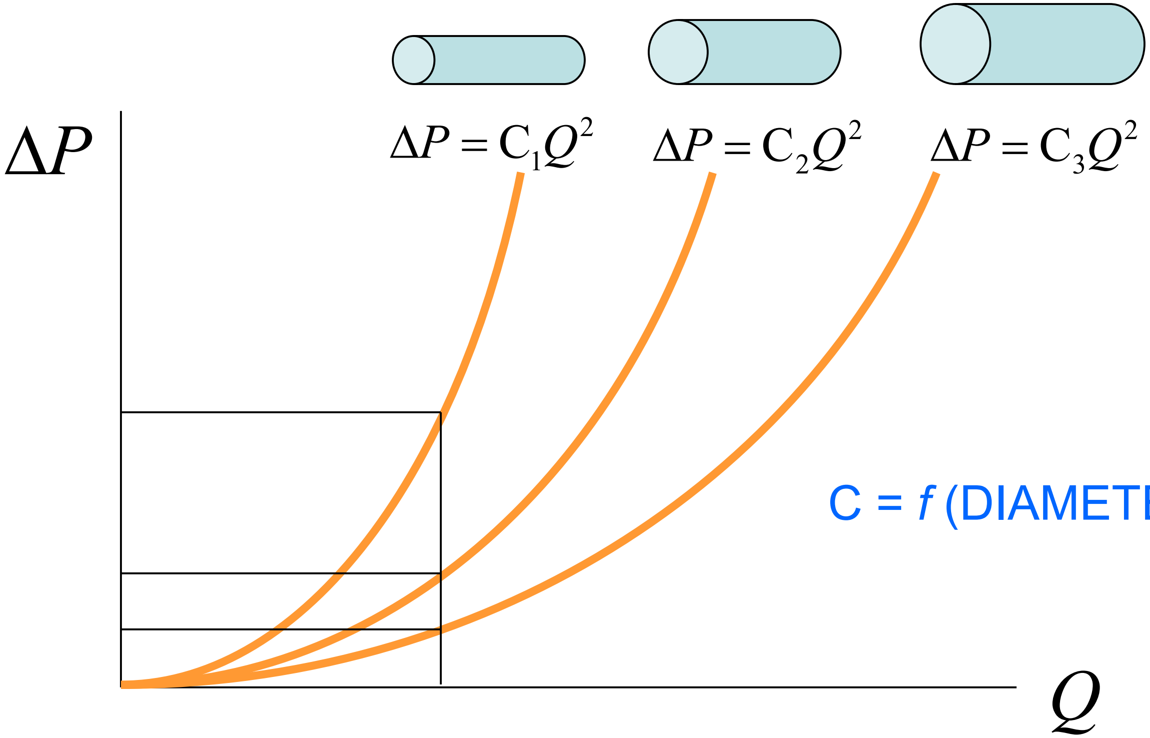


FLOW AND LOSS

FLUID VELOCITY IS RELATED TO THE FLOW RATE VIA PIPE SIZE

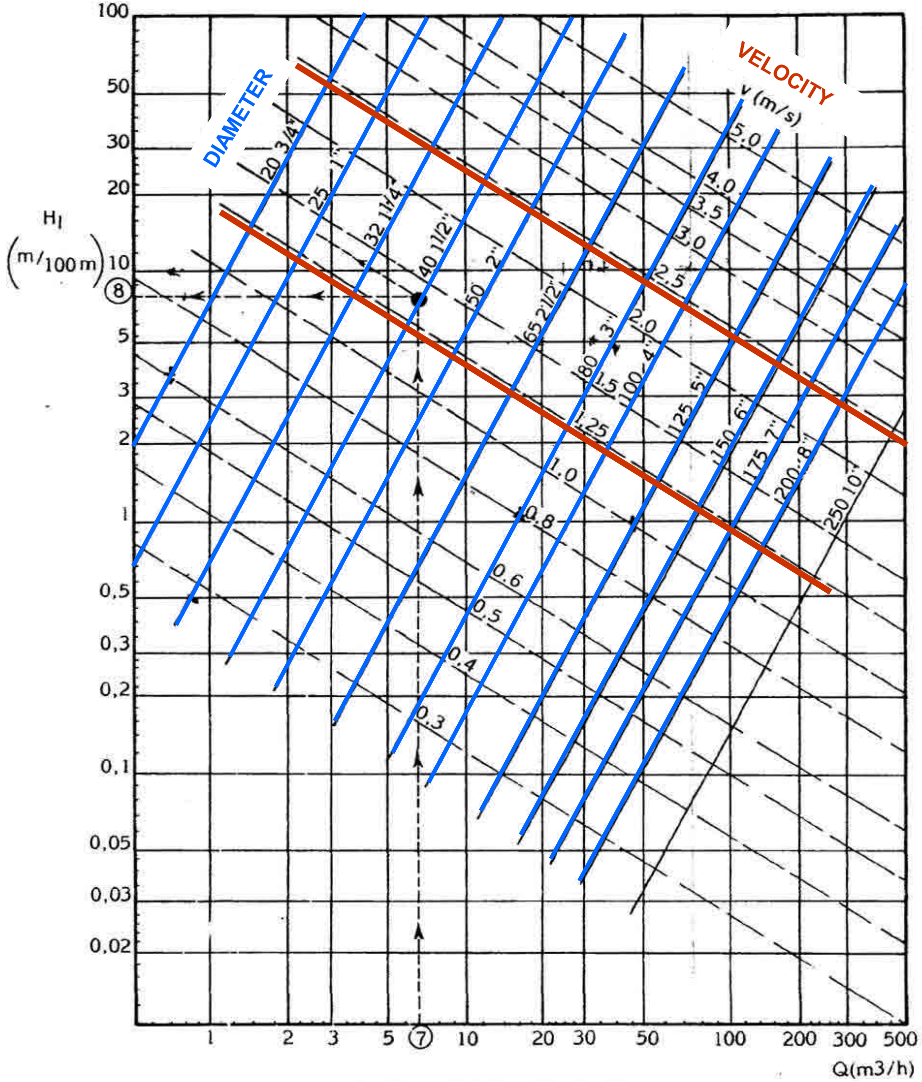
$$v = \frac{Q}{\left(\frac{\pi D^2}{4}\right)}$$

THUS.. $\Delta P \propto Q^2$



C = *f* (DIAMETER, ROUGHNESS)

FRICTION LOSS CHART



DESIGN VELOCITY
1.2 TO 2.4 m/s

FRICTION LOSS EQUATION

HAZEN-WILLIAMS EQUATION (SI UNIT)

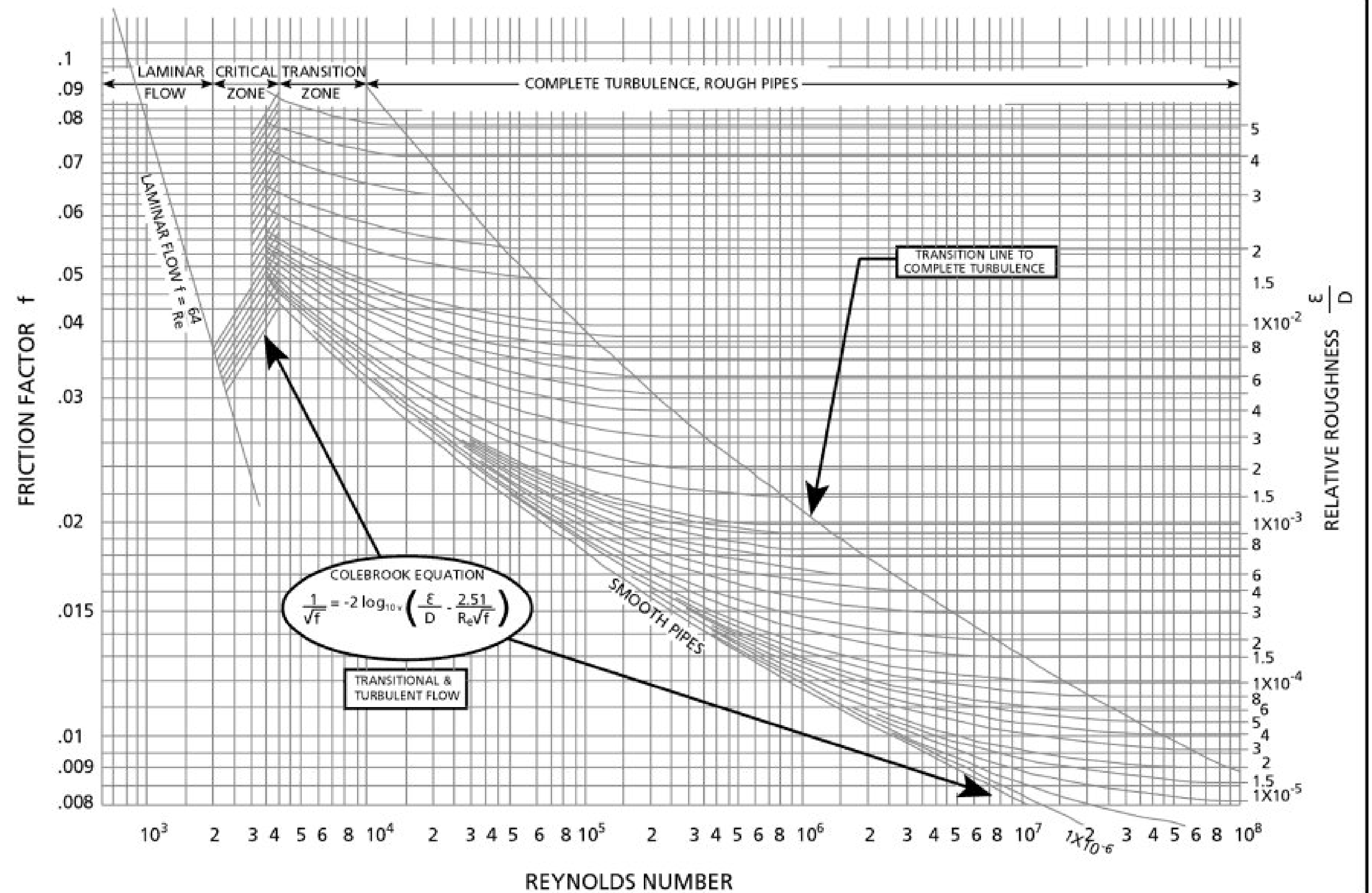
$$h_f = \left(\frac{151Q}{CD^{2.63}} \right)^{1.85}$$

DARCY WEISBACH EQUATION

$$h = f \frac{L}{D} \frac{v^2}{2g}$$

READING ASSIGNMENT: 3-2 FRICTION LOSS IN PIPE

MOODY DIAGRAM

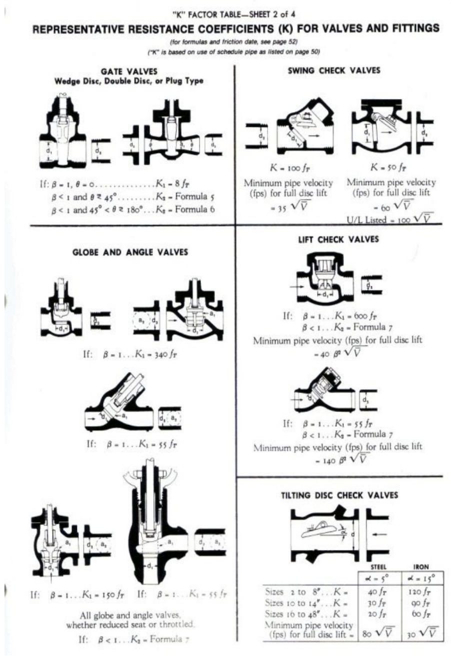


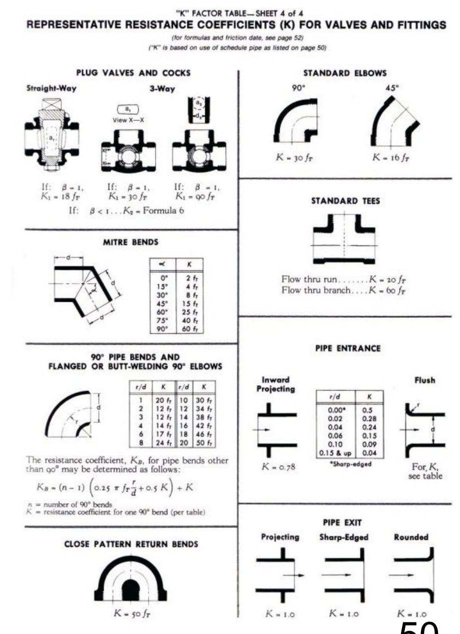
MINOR LOSS

LOSS IN FITTING: USE EQUIVALENT LENGTH

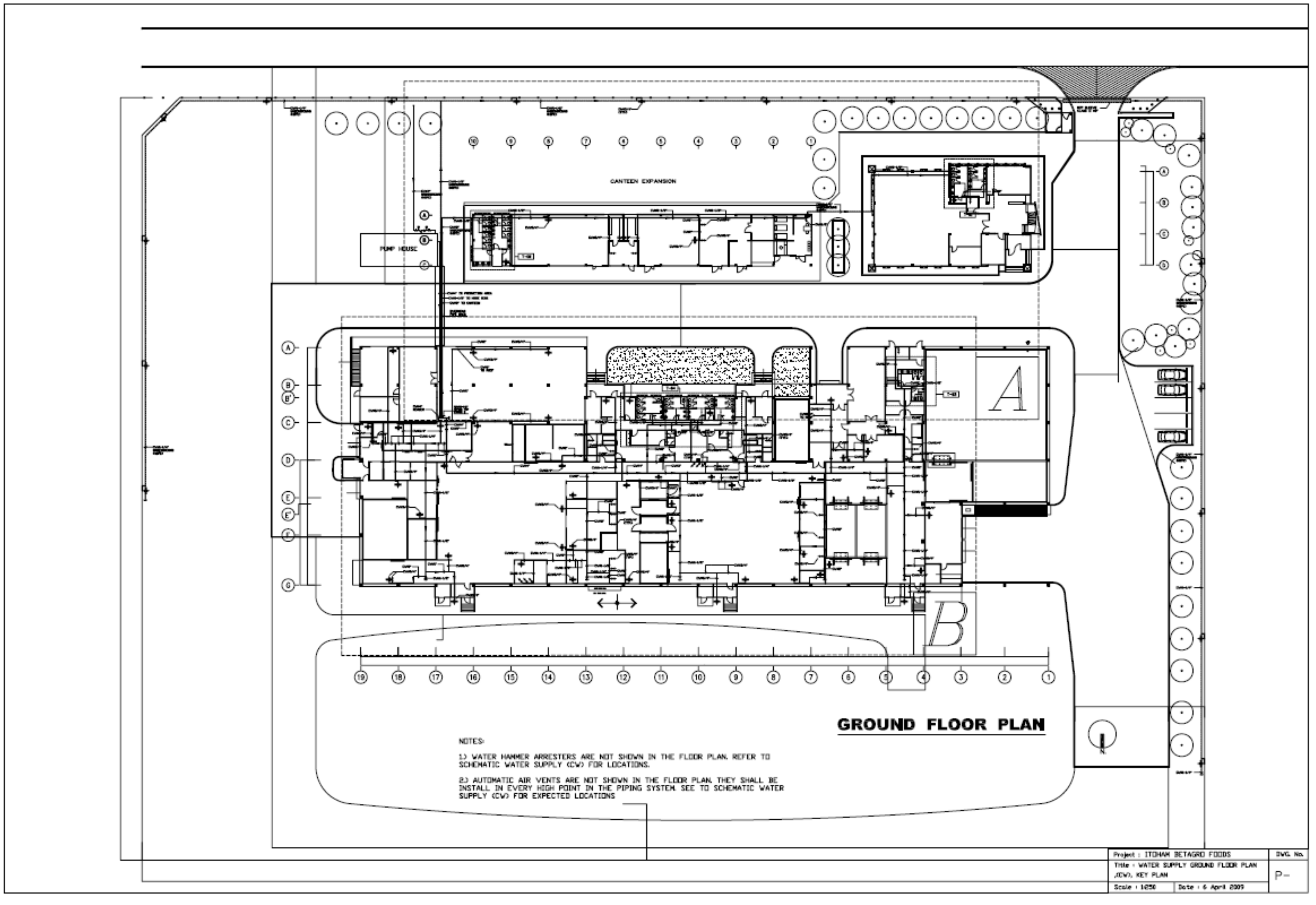
LOSS IN VALVE: USE C_V OR K_V

(DISCUSS LATER)





5. QUICK LOOK AT PIPE DRAWINGS



NEXT SESSION

PIPING MATERIALS AND EQUIPMENTS

VALVES

PUMPS

HOMEWORK 1

- Find a water valve (for example, in a toilet, a kitchen or the backyard).
- Measure inlet pipe size. Draw or photograph the valve.
- Measure the flow rate in LPM from the valve at various valve opening positions (for exmple 25%, 50%, 75% and 100%).
- Find out the supply pressure (in m.WG.)
- Plot flowrate vs % open