Plumbing Theory
MANUSCRIPT

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January 26, 2026

Contents

Chapter 1

Plumbing Theory

Plumbing theory refers to any nonphysical aspect of plumbing. Any time spent in the classroom, looking at blueprints, estimating developed length, sketching pipes on a napkin, etc. - falls under plumbing theory.

1 Introduction

Plumbers in working Massachusetts learn plumbing theory predominantly from the State *Plumbing Code* to ensure the safe and adequate operation of finished plumbing systems. Formally called *Chapter 10 of Massachusetts Regulations*, also known as *248 CMR 10*, also known as the *Uniform State Plumbing Code*, is available via *mass.gov* as PDF. Edition 12/8/23 is used for the majority of this study.

1.1 248 CMR 10 – Sections

CMR 10 contains 22 sections and spans roughly 120 pages, depending on formatting. The sections of CMR 10 are as follows:

1. **Scope and Jurisdiction.** Plumbing must be done by plumbers. Plumbers don't deal with HVAC.
2. **Basic Principles.** Common-sense 'gotcha' questions for memorization.
3. **Definitions.** Glossary for CMR 10.
4. **Testing and Safety.** Testing, defects, repairs, alteration for rough and finish plumbing.
5. **General Regulations.** Pitch, allowed fittings, underground, connections.
6. **Materials.** Allowed materials.
7. **Joints and Connections.** Term-heavy section all about joints.
8. **Traps and Cleanouts.** Trap/cleanout parts, rules, materials. SLAMOBEC.
9. **Interceptors, Separators, and Holding Tanks.** Flow rate, capacity, sizing. 3-bay sinks.
10. **Plumbing Fixtures.** Bathroom fixtures, incl. fountains, laundry. Minimum facilities Tables.
11. **Hangers and Supports.** Material, adherence, horizontal/vertical separation, base of stack.
12. **Indirect Waste Piping.** Requirements, safe waste pan, air gap v.s. air break, sump.
13. **Piping and Treatment of Special Wastes.** Requires involvement of engineer.
14. **Water Supply and the Water Distribution System.** Water pipe sizing, pressure, flow rates.
15. **Sanitary Drainage System.** Waste pipe sizing (horizontal and vertical). Kitchen sink drainage. Backwater prevention.
16. **Vents and Venting.** Battery, bow, combination, circuit, common, crown, ejector, extension, fixture, future, individual, loop, relief, stack, wet, 5-6-8-10.
17. **Storm Drains.** No traps required if connecting exclusively to storm.
18. **Hospital Fixtures.** Special definitions and fixtures.
19. **Manufactured/Mobile Homes, Construction, and Temporary Use Trailers.** Mobile home means 320 or more square feet when erected. Modular means built off-site.
20. **Swimming Pools.** Public/residential/wading. Cross-connection control, discharge.
21. **Vacuum Powered Sanitary Drainage Systems.** Requires involvement of engineer.
22. **Boiler Discharge into Building Drainage System.** No greater than 120 degrees at 5 psi. No steam into the system.

1.2 248 CMR 10 – Basic Principles

There are 27 plumbing principles in the present version of CMR 10.02. The following is an attempt to condense these to something more memorable.

1. **Potable.** All occupied premises must have potable water.
2. **Adequate.** Adequate water required.
3. **Hot.** Hot water required.
4. **Conservation.** Water conservation.
5. **Overheating.** Dangers of explosion or overheating.
6. **Fixtures.** Required plumbing fixtures (five).
7. **Cleanouts.** Protection of drainage systems.
8. **Workmanship.** Durable materials and good workmanship.
9. **Traps.** Need for traps in the drainage systems.
10. **Oil.** Special precautions for oily and/or flammable liquid wastes.
11. **Venting.** Need for venting in the plumbing system.
12. **Tested.** Plumbing systems must be tested.
13. **Substances.** Harmful substances must be excluded from the plumbing system.
14. **Indirect.** Need for indirect waste piping in the plumbing drainage system.
15. **Ventilation.** Light and ventilation.
16. **Disposal.** Need for disposal of sewage.
17. **Flooding.** Prevent sewer flooding.
18. **Maintenance.** Proper maintenance.
19. **Accessible.** Fixtures shall be accessible.
20. **Integrity.** Structural integrity.
21. **Ground.** Protect ground and surface water.
22. **Treatment.** Piping and treatment of hazardous wastes.
23. **Privacy.** Need for privacy.
24. **Drinking.** Drinking water station.
25. **Temporary.** Structures or trailers for temporary use.
26. **Design.** Materials and design.
27. **Emergency.** Emergency/temporary use.

1.3 Additional Requirements

In addition to all of CMR 10, journeyman plumbers are required to be familiar with:

Comply with General Laws

- State Water Conservation laws in plumbing regulations and for property owners.
- ANSI requirements.
- Energy Policy Act and maximum water usage.
- UPC requirements for materials.
- Licencing and specialization, reinstatement, renewal, revokation.
- State Construction Industry Licensing Board.
- Excavation, utility location/identification/marking.
- ADA.

Comply with Regulations

- Standard Gas Code (concealed indoor).
- Standard Building Code Congress Gas Code.
- Code of Federal Regulations, Title 29, 1926.
- National Fuel Gas Code.
- Federal-Aid Highway Act.
- OSHA for first aid/medical, housekeeping.
- Safety and education - trainer's responsibilities.
- Plumbing permit, installation permit.
- State Boiler Code, registration, permit.
- State Trenching Law.
- Inspections (and internal inspections).
- Insurance.
- Pressure and temperature relief controls.
- Plumbing Divisions of State Health Departments.
- State Boards of Health, water contamination.
- Materials: piping, joints,
- Written specifications, bill of materials, blueprints

Work Planning/Organizing

- Takeoff sheet, takeoff form, takeoff sequence.
- Nameplate: T&P relief valve, water heater, lift station.
- Backflow prevention.
- Precedence of codes and regulations.
- Bar chart schedule.
- Isometric drawings.
- Mensuration.
- Measurements: tools, end-to-end

Perform Pipe Cutting and Joining

- Tools: pipe cutters, hacksaw.
- Fittings: cast-iron (no-hub, bell-and-spigot), insert fitting for plastic.
- Joints: caulked soil pipe, cement method and bituminous method on bell-and-spigot vitrified clay, compression gasket, bumping method, folding method, galvanized steel threaded, polyethylene, mechanical compression, steel threaded, iron, steel pipe grooved, asbestos, clay.
- Joining vent and flue pipes.
- Cutting: concrete pipe (hammer and cold chisel), cast-iron pipe, plastic, steel
- Solder: selection, paste-type, joints.
- Flares: impact, screw-type.
- Solvent weld joint, process and safety, codes for joining plastic tubing, rules for handling.
- Polyethylene pipe in trenches.
- Threaded and reamed pipe.
- Working with lead, glass, ductile iron.
- Cutting in confined spaces.

Perform Plumbing Systems Installation

- Rough work, locations of holes.
- Parts of potable water system.
- Definition of fixture unit.
- Insulation: types, role of fiberglass. Insulation of water lines. State Energy Code.
- Cleanouts: principles, location.
- Trenches, installing pipe.
- Gas piping, residential.
- Gas pipe sizing via National Fuel Gas Code.
- Parts: bushing, lead wall shield, etc.
- Tools for installing through concrete walls, ceilings, floors.
- Floor/area drains, installation.
- Laundry tray waste.
- Closet bends.
- Underground gas pipe installation.
- Installation of pipe hanger through floor: metal, wood.
- Fire standpipe systems.
- Safe pipe installation.
- Sprinkler systems: types (5), hazard classification.
- Water supply: sizing, fixtures.
- Water velocity: method of sizing, friction loss.
- Single-family dwelling: kitchen stack, building drain, lav, bathroom, tub/vent, shower.
- Supporting pipe/glass: horizontal, vertical.
- Wood screws.
- Sanitary drainage/venting.
- Drain sizing: methods (horizontal branches).
- Change of direction, grade.

2 Materials & Connections

ABS Plastic Pipe and Drainage Pattern Fittings

1. 10.05.5.a.7 — Where PVC or ABS is installed underground
2. 10.06.1.a–f — Materials – General rules
3. 10.06.2.g — PVC and ABS DWV pipe and fittings
4. 10.06.Table.1 — Storm and Sanitary Waste and Vent Piping
5. 10.06.Example.1 — PVC limited allowances in mixed-use building 10 stories and under
6. 10.07.4.a — Joining methods for plastic pipe and fittings
7. 10.07.8.d — Plastic to other materials
8. 10.07.8.f — PVC to ABS connection
9. 10.07.8.g — Special joints and connections (unlike materials)
10. 10.08.3.b.l — Cleanout plugs brass or plastic
11. 10.08.3.b.5 — Cleanout material compatibility
12. 10.11.4.a.4 — Vertical supports for plastic pipe (includes ABS; at each story height, not more than ten-foot intervals)
13. 10.11.4.b.5 — Horizontal supports for plastic pipe (includes ABS; 1-1/2 inch or less at three-foot intervals, 2 inch or over at four-foot intervals)

ABS Cellular Core Plastic Pipe

1. 10.05.5.a.7 — Underground Installation of PVC or ABS (approved for storm and sanitary waste and vent piping below ground)
2. 10.06.2.g — PVC and ABS DWV Pipe and Fittings (cellular-core ABS; installed per manufacturer instructions)
3. 10.06.Table.1 — Storm and Sanitary Waste and Vent Piping (ABS Cellular Core Plastic Pipe; above and below ground)
4. 10.07.4.a — Joining Methods for Plastic Pipe and Fittings (solvent-weld, mechanical, threaded, or shielded stainless-steel clamps)
5. 10.07.8.f — PVC to ABS Joints (mechanical or transition fittings required; direct solvent welding prohibited)
6. 10.11.4.a.4 — Vertical Supports for Plastic Pipe (includes ABS; at each story height, not more than ten-foot intervals)
7. 10.11.4.b.5 — Horizontal Supports for Plastic Pipe (includes ABS; 1-1/2 inch or less at three-foot intervals, 2 inch or over at four-foot intervals)

Aluminum DWV Pipe with Drainage Pattern Fittings

1. 10.06.Table.1 — Storm and Sanitary Waste and Vent Piping
2. 10.07.3 — Aluminum DWV Pipe and Fittings
3. 10.11.4.a.6 — Vertical Supports (at each story height or at intervals not exceeding ten feet)
4. 10.11.4.b.9 — Horizontal Supports (at ten-foot intervals)

Cast Iron (Extra Heavy)

1. 10.06.Table.1 — Storm and Sanitary Waste and Vent Piping (Extra Heavy Cast Iron Soil Pipe and Fittings)
2. 10.06.2.i.1 — Urinal Waste: Extra Heavy or Service Weight Cast Iron Soil Pipe and Fittings (Caulked Joints)
3. 10.07.8.a — Cast Iron to Copper or Brass (DWV) Joints
4. 10.07.8.c — Threaded Pipe to Cast Iron (Caulked, Threaded, or Transition Fittings)
5. 10.07.8.d.1 — Cast Iron to PVC or ABS (Lead and Oakum or Compression Gasket)
6. 10.07.8.d.2 — Cast Iron to PVC or ABS (No-Hub Transition Clamps)
7. 10.11.4.a.1 — Vertical Supports for Cast Iron Soil Pipe (at base and at each story height)
8. 10.11.4.b.1 — Horizontal Supports for Cast Iron Soil Pipe (at five-foot intervals; where ten-foot lengths are used, ten-foot intervals are acceptable)

Cast Iron (Service Weight)

1. 10.06.Table.1 — Storm and Sanitary Waste and Vent Piping (Service Weight Cast Iron Soil Pipe and Fittings)
2. 10.06.2.i.1 — Urinal Waste: Extra Heavy or Service Weight Cast Iron Soil Pipe and Fittings (Caulked Joints)
3. 10.06.2.i.2 — Urinal Waste: Extra Heavy, Service Weight, or No-Hub Cast Iron Soil Pipe (Resilient Gaskets or No-Hub Clamps)
4. 10.07.8.a — Cast Iron to Copper or Brass (DWV) Joints
5. 10.07.8.c — Threaded Pipe to Cast Iron (Caulked, Threaded, or Transition Fittings)
6. 10.07.8.d.1 — Cast Iron to PVC or ABS (Lead and Oakum or Compression Gasket)
7. 10.07.8.d.2 — Cast Iron to PVC or ABS (No-Hub Transition Clamps)
8. 10.11.4.a.1 — Vertical Supports for Cast Iron Soil Pipe (at base and at each story height)
9. 10.11.4.b.1 — Horizontal Supports for Cast Iron Soil Pipe (at five-foot intervals; where ten-foot lengths are used, ten-foot intervals are acceptable)

Cast Iron (No-Hub)

1. 10.06.Table.1 — Storm and Sanitary Waste and Vent Piping (No-Hub Cast Iron Soil Pipe and Fittings)
2. 10.06.2.i.2 — Urinal Waste: Extra Heavy, Service Weight, or No-Hub Cast Iron Soil Pipe (Resilient Gaskets or No-Hub Clamps)
3. 10.07.8.a — Cast Iron to Copper or Brass (DWV) Joints
4. 10.07.8.c — Threaded Pipe to Cast Iron (Caulked, Threaded, or Transition Fittings)
5. 10.07.8.d.1 — Cast Iron to PVC or ABS (Lead and Oakum or Compression Gasket)
6. 10.07.8.d.2 — Cast Iron to PVC or ABS (No-Hub Transition Clamps)
7. 10.07.8.e — Aluminum DWV to Hubless Cast Iron Pipe (Transition Clamps)
8. 10.11.4.a.1 — Vertical Supports for Cast Iron Soil Pipe (at base and at each story height)
9. 10.11.4.b.1 — Horizontal Supports for Cast Iron Soil Pipe (at five-foot intervals; where ten-foot lengths are used, ten-foot intervals are acceptable)

Copper DWV (Color Coded Yellow)

1. 10.06.Table.1 — Copper DWV Tubing and Fittings (Hard Drawn, Wrot, or Cast Brass; Color Coded Yellow; approved for storm and sanitary waste and vent piping)
2. 10.07.8.a — Cast Iron to Copper or Brass (DWV) Joints (use approved mechanical or compression adapters)
3. 10.07.8.b — Copper Tubing to Threaded Pipe (adapter fittings; soldered per manufacturer instructions)
4. 10.11.4.a.3 — Vertical Supports for Copper Tubing (each story height, not more than ten-foot intervals)
5. 10.11.4.b.3 — Horizontal Supports for Copper Tubing (1-1/4 inch or less at six-foot intervals; 1-1/2 inch or over at ten-foot intervals)

Copper Tubing (Types M, L, and K)

1. 10.06.Table.2 — Copper Tubing Hard Drawn & Copper Alloy (Type M) Color Coded Red
2. 10.06.Table.2 — Copper Tubing Hard Drawn & Copper Alloy (Type L) Color Coded Blue
3. 10.06.Table.2 — Copper Tubing Hard Drawn & Copper Alloy (Type K) Color Coded Green
4. 10.11.4.a.3 — Vertical Supports for Copper Tubing (each story height, not more than ten-foot intervals)
5. 10.11.4.b.3 — Horizontal Supports for Copper Tubing (1-1/4 inch or less at six-foot intervals; 1-1/2 inch or over at ten-foot intervals)

Copper DWV Fittings (Wrot and Cast Brass)

1. 10.06.Table.1 — Copper DWV Fittings (Wrot) (allowed for above- and below-ground drainage, waste, and vent systems)
2. 10.06.Table.1 — Copper DWV Fittings (Cast Brass) (allowed for above- and below-ground drainage, waste, and vent systems)
3. 10.07.8.b — Copper Tubing to Threaded Pipe (use brass or wrought copper adapter fittings; joints soldered per manufacturer instructions)

Copper Pipe (IPS)

1. 10.06.Table.1 — Copper Pipe (IPS) (allowed for storm and sanitary waste and vent piping, above and below ground)
2. 10.07.8.b — Copper Tubing to Threaded Pipe (use brass or wrought copper adapter fittings; joints soldered per manufacturer instructions)
3. 10.11.4.a.3 — Vertical Supports for Copper Tubing (each story height, not more than ten-foot intervals)
4. 10.11.4.b.3 — Horizontal Supports for Copper Tubing (1-1/4 inch or less at six-foot intervals; 1-1/2 inch or over at ten-foot intervals)

Ductile Iron and Drainage Pattern Fittings

1. 10.06.Table.1 — Ductile Iron Pipe and Drainage Pattern Fittings (approved for storm and sanitary waste and vent piping, above and below ground)
2. 10.07.2.g — Ductile Iron (approved joining methods include press-connect, push-fit, compression, grooved, flanged, and tee forming)
3. 10.11.4.a.2 — Vertical Supports for Ductile Iron Pipe (at base and each story height)
4. 10.11.4.b.2 — Horizontal Supports for Ductile Iron Pipe (at ten-foot intervals)

Galvanized Schedule 40 Steel Pipe with Drainage Pattern Fittings

1. 10.06.Table.1 — Galvanized Schedule 40 Steel Pipe with Drainage Pattern Fittings (approved for storm and sanitary waste and vent piping below ground only)
2. 10.07.8.c — Threaded Pipe to Cast Iron (galvanized steel may be caulked, threaded, or joined with approved adapter or transition fittings)
3. 10.11.4.a.2 — Vertical Supports for Galvanized Steel Pipe (at base and each story height)
4. 10.11.4.b.2 — Horizontal Supports for Galvanized Steel Pipe (at ten-foot intervals)

Polypropylene Pipe with Drainage Pattern Fittings

1. 10.06.Table.1 — Polypropylene Pipe with Drainage Pattern Fittings (approved for storm and sanitary waste and vent piping, above and below ground)
2. 10.07.4.c — Polypropylene (PP) Pipe and Fittings (joints shall be made using heat-fusion, mechanical/compression, or threaded methods)
3. 10.11.4.a.4 — Vertical Supports for Plastic Pipe (includes PP; at each story height, not more than ten-foot intervals)
4. 10.11.4.b.5 — Horizontal Supports for Plastic Pipe (includes PP; 1-1/2 inch or less at three-foot intervals, 2 inch or over at four-foot intervals)

Polyethylene Pipe with Drainage Pattern Fittings

1. 10.06.Table.1 — Polyethylene Pipe with Drainage Pattern Fittings (approved for storm and sanitary waste and vent piping, above and below ground)
2. 10.07.4.c — Polyethylene (PE) Pipe and Fittings (joints shall be made using heat-fusion, mechanical/compression, or threaded methods)
3. 10.11.4.a.4 — Vertical Supports for Plastic Pipe (includes PE; at each story height, not more than ten-foot intervals)
4. 10.11.4.b.5 — Horizontal Supports for Plastic Pipe (includes PE; 1-1/2 inch or less at three-foot intervals, 2 inch or over at four-foot intervals)

PVC Plastic Pipe and Drainage Pattern Fittings

1. 10.06.Table.1 — PVC Plastic Pipe and Drainage Pattern Fittings (approved for storm and sanitary waste and vent piping, above and below ground; see 10.06.2.g and 10.12.1.a.5.b)
2. 10.06.Table.1.Note — Commercial Limitation (PVC and other combustible plastics not permitted in buildings exceeding three stories or requiring fire-rated construction unless protected by an approved firestop system)
3. 10.06.Example.1 — Fire Separation (illustrates protection requirements for combustible piping through rated assemblies)
4. 10.06.2.g — PVC and ABS DWV Pipe and Fittings (installed per manufacturer instructions; solvent-weld, mechanical, threaded, or shielded stainless-steel clamps)
5. 10.07.4.a — Joining Methods for Plastic Pipe and Fittings (solvent-weld, mechanical, threaded, or shielded stainless-steel clamps)

6. 10.07.4.a — Threaded Joints (permitted only for Schedule 80 PVC or other product-accepted threaded components; not used for standard DWV solvent-weld systems)

PVC Cellular Core Plastic Pipe

1. 10.06.Table.1 — PVC Cellular Core Plastic Pipe (approved for storm and sanitary waste and vent piping, above and below ground; see 10.06.2.g and 10.12.1.a.5.b)
2. 10.06.Table.1.Note — Commercial Limitation (PVC Cellular Core not permitted in buildings exceeding three stories or requiring fire-rated construction unless protected by an approved firestop system)
3. 10.06.Example.1 — Fire Separation (illustrates protection requirements for combustible piping through rated assemblies)
4. 10.06.2.g — PVC and ABS DWV Pipe and Fittings (installed per manufacturer instructions; solvent-weld, mechanical, threaded, or shielded stainless-steel clamps)
5. 10.07.4.a — Joining Methods for Plastic Pipe and Fittings (solvent-weld, mechanical, threaded, or shielded stainless-steel clamps)

PVC Support Requirements

1. 10.05.5.a.7 — Underground Installation of PVC or ABS (requires proper bedding, backfill, and allowance for expansion and contraction)
2. 10.07.4.a — Joining Methods for Plastic Pipe and Fittings (solvent-welded joints must be fully seated and cured before testing or backfilling)
3. 10.09.1.d — Sleeving Through Walls or Slabs (PVC passing through foundations or structural members must be sleeved or otherwise protected from stress and abrasion)
4. 10.11.4.a.4 — Vertical Supports for Plastic Pipe (at each story height, not more than ten-foot intervals)
5. 10.11.4.b.5 — Horizontal Supports for Plastic Pipe (1-1/2 inch or less at three-foot intervals, 2 inch or over at four-foot intervals)
6. 10.11.4 — Alignment and Anchorage (hangers shall maintain grade, prevent sagging, and accommodate thermal movement)

Type 304 Stainless Steel Tubing with Drainage Pattern Fittings

1. 10.06.Table.1 — Type 304 Stainless Steel Tubing with Drainage Pattern Fittings (approved for storm and sanitary waste and vent piping below ground only)
2. 10.07.2.h — Stainless Steel (Type 304) (joints may be press-connect, grooved, flanged, compression, or mechanical coupling as recommended by manufacturer)
3. 10.11.4.a.2 — Vertical Supports for Stainless Steel Tubing (at base and each story height)
4. 10.11.4.b.2 — Horizontal Supports for Stainless Steel Tubing (at ten-foot intervals)
5. 10.06.2.h — Stainless steel pipe and fittings shall be permanently marked with manufacturer, type (304 or 316), and ASTM/ANSI standard.

Type 316 Stainless Steel Tubing with Drainage Pattern Fittings

1. 10.06.Table.1 — Type 316 Stainless Steel Tubing with Drainage Pattern Fittings (approved for storm and sanitary waste and vent piping, above and below ground)
2. 10.07.2.h — Stainless Steel (Type 316) (joints may be press-connect, grooved, flanged, compression, or mechanical coupling as recommended by manufacturer)
3. 10.11.4.a.2 — Vertical Supports for Stainless Steel Tubing (at base and each story height)
4. 10.11.4.b.2 — Horizontal Supports for Stainless Steel Tubing (at ten-foot intervals)
5. 10.06.2.h — Stainless steel pipe and fittings shall be permanently marked with manufacturer, type (304 or 316), and ASTM/ANSI standard.

Epoxy Reinforced Fiberglass Pipe and Fittings

1. 10.06.Table.1 — Epoxy Reinforced Fiberglass Pipe and Fittings (approved for storm water drainage only; see table note)
2. 10.07.2.g — Fiberglass-Reinforced Plastic (FRP) Piping (joints shall be made using compression, flanged, or other manufacturer-approved mechanical couplings)

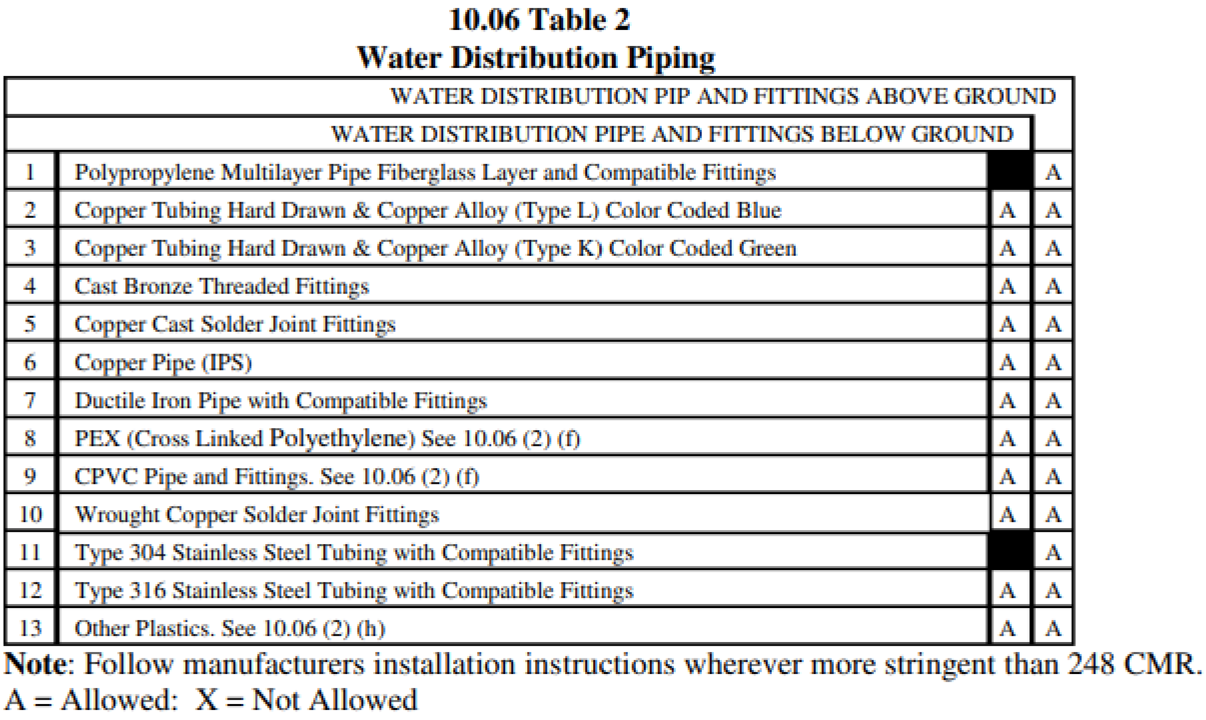
3. 10.11.4.a.4 — Vertical Supports for Plastic Pipe (includes FRP; at each story height, not more than ten-foot intervals)
4. 10.11.4.b.5 — Horizontal Supports for Plastic Pipe (includes FRP; 1-1/2 inch or less at three-foot intervals, 2 inch or over at four-foot intervals)

2.1 Use of PVC and ABS Piping

PVC and ABS piping are approved materials under 10.06.2.g for drain, waste, and vent systems when installed in accordance with manufacturer standards and the joining methods of 10.07.4. Their use is subject to distinct limitations based on building type and installation location.

- **Residential dwellings.** PVC and ABS Schedule 40 pipe and fittings may be used for sanitary waste, vent, and storm drainage systems in one- and two-family dwellings, hotels, motels, inns, condominiums, and in the residential portions of assisted-living facilities not exceeding ten stories (10.06.2.g).
- **Commercial structures.** Above-ground use of PVC and ABS in commercial buildings is generally prohibited except in explicitly approved cases such as chemical waste systems, isolated mechanical spaces, or repair of existing systems. Below ground, both materials are permitted for sanitary and storm drainage piping provided they are installed per trenching and backfilling requirements (10.05.5.a.7).
- **Underground installation.** When PVC or ABS is installed below grade, the trench bottom shall be smooth, uniformly compacted, and provide continuous bearing along the bottom quadrant of the pipe. Granular fill shall be placed and compacted to a minimum of six inches above the crown of the pipe, and large stones or debris shall be excluded (10.05.5.a.7.a–d).
- **Fire-rated construction.** Neither PVC nor ABS may be installed within fire-rated walls, ceilings, or floors unless protected or enclosed in compliance with 10.06.Example.1 (Fire Separation). These materials are combustible and not suitable for plenum or air-handling spaces.
- **Transitions and joints.** Direct solvent welding between PVC and ABS is prohibited. Transitions between the two materials shall use mechanical couplings, shielded stainless-steel clamps, or other product-accepted transition fittings (10.07.8.f).
- **Joining methods.** PVC and ABS joints shall be made using solvent welding, mechanical joints, or threaded or shielded stainless-steel clamps, consistent with 10.07.4.a.
- **Material repair and replacement.** ABS may be used in commercial work only for the repair or extension of existing ABS systems where replacement with another approved material is impractical and specifically authorized by the Authority Having Jurisdiction (10.06.Table.1).

2.2 Water Distribution Piping



10.06 Table 2
Water Distribution Piping

		WATER DISTRIBUTION PIPE AND FITTINGS BELOW GROUND	WATER DISTRIBUTION PIP AND FITTINGS ABOVE GROUND
1	Polypropylene Multilayer Pipe Fiberglass Layer and Compatible Fittings	■	A
2	Copper Tubing Hard Drawn & Copper Alloy (Type L) Color Coded Blue	A	A
3	Copper Tubing Hard Drawn & Copper Alloy (Type K) Color Coded Green	A	A
4	Cast Bronze Threaded Fittings	A	A
5	Copper Cast Solder Joint Fittings	A	A
6	Copper Pipe (IPS)	A	A
7	Ductile Iron Pipe with Compatible Fittings	A	A
8	PEX (Cross Linked Polyethylene) See 10.06 (2) (f)	A	A
9	CPVC Pipe and Fittings. See 10.06 (2) (f)	A	A
10	Wrought Copper Solder Joint Fittings	A	A
11	Type 304 Stainless Steel Tubing with Compatible Fittings	■	A
12	Type 316 Stainless Steel Tubing with Compatible Fittings	A	A
13	Other Plastics. See 10.06 (2) (h)	A	A

Note: Follow manufacturers installation instructions wherever more stringent than 248 CMR.
A = Allowed: X = Not Allowed

Figure 1.1. CMR 10.06 Table 2

Polypropylene Multilayer Pipe (Fiberglass Layer) and Compatible Fittings

1. 10.06.Table.2 — Polypropylene Multilayer Pipe with Fiberglass Layer and Compatible Fittings (approved for hot and cold water distribution)
2. 10.07.4.c — Polypropylene (PP) Pipe and Fittings (joints shall be made using heat-fusion, mechanical/compression, or threaded methods)
3. 10.11.4.a.4 — Vertical Supports for Plastic Pipe (includes PP; at each story height, not more than ten-foot intervals)
4. 10.11.4.b.5 — Horizontal Supports for Plastic Pipe (includes PP; 1-1/2 inch or less at three-foot intervals, 2 inch or over at four-foot intervals)

Copper Tubing Hard Drawn and Copper Alloy (Type L, Blue)

1. 10.06.Table.2 — Copper Tubing Hard Drawn and Copper Alloy (Type L, Color Coded Blue) (approved for hot and cold water distribution)
2. 10.07.8.b — Copper Tubing to Threaded Pipe (use brass or wrought copper adapter fittings; joints soldered per manufacturer instructions)
3. 10.11.4.a.3 — Vertical Supports for Copper Tubing (each story height, not more than ten-foot intervals)
4. 10.11.4.b.3 — Horizontal Supports for Copper Tubing (1-1/4 inch or less at six-foot intervals; 1-1/2 inch or over at ten-foot intervals)

Copper Tubing Hard Drawn and Copper Alloy (Type K, Green)

1. 10.06.Table.2 — Copper Tubing Hard Drawn and Copper Alloy (Type K, Color Coded Green) (approved for hot and cold water distribution)
2. 10.07.8.b — Copper Tubing to Threaded Pipe (use brass or wrought copper adapter fittings; joints soldered per manufacturer instructions)
3. 10.11.4.a.3 — Vertical Supports for Copper Tubing (each story height, not more than ten-foot intervals)
4. 10.11.4.b.3 — Horizontal Supports for Copper Tubing (1-1/4 inch or less at six-foot intervals; 1-1/2 inch or over at ten-foot intervals)

Cast Bronze Threaded Fittings

1. 10.06.Table.2 — Cast Bronze Threaded Fittings (approved for hot and cold water distribution)
2. 10.07.8.c — Threaded Pipe to Cast Iron or Bronze (joined by threaded, caulked, or mechanical transition fittings as approved)

3. 10.11.4.a.2 — Vertical Supports for Metal Pipe (at base and each story height)

4. 10.11.4.b.2 — Horizontal Supports for Metal Pipe (at ten-foot intervals)

Copper Cast Solder Joint Fittings

1. 10.06.Table.2 — Copper Cast Solder Joint Fittings (approved for hot and cold water distribution)

2. 10.07.8.b — Copper Tubing to Threaded Pipe (use brass or wrought copper adapter fittings; joints soldered per manufacturer instructions)

3. 10.11.4.a.3 — Vertical Supports for Copper Tubing (each story height, not more than ten-foot intervals)

4. 10.11.4.b.3 — Horizontal Supports for Copper Tubing (1-1/4 inch or less at six-foot intervals; 1-1/2 inch or over at ten-foot intervals)

Copper Pipe (IPS)

1. 10.06.Table.2 — Copper Pipe (IPS) (approved for hot and cold water distribution)

2. 10.07.8.b — Copper Tubing to Threaded Pipe (use brass or wrought copper adapter fittings; joints soldered per manufacturer instructions)

3. 10.11.4.a.3 — Vertical Supports for Copper Tubing (each story height, not more than ten-foot intervals)

4. 10.11.4.b.3 — Horizontal Supports for Copper Tubing (1-1/4 inch or less at six-foot intervals; 1-1/2 inch or over at ten-foot intervals)

Ductile Iron with Compatible Fittings

1. 10.06.Table.2 — Ductile Iron Pipe with Compatible Fittings (approved for hot and cold water distribution)

2. 10.07.2.g — Ductile Iron (approved joining methods include press-connect, push-fit, compression, grooved, flanged, and tee forming)

3. 10.11.4.a.2 — Vertical Supports for Ductile Iron Pipe (at base and each story height)

4. 10.11.4.b.2 — Horizontal Supports for Ductile Iron Pipe (at ten-foot intervals)

Cross-Linked Polyethylene (PEX) and Compatible Fittings

1. 10.06.Table.2 — Cross-Linked Polyethylene (PEX) and Compatible Fittings (approved for hot and cold water distribution)

2. 10.06.Table.2.Note — Height Limitation (PEX permitted for water distribution in buildings not exceeding six stories unless specifically product-accepted for higher use)

3. 10.07.4.d — Cross-Linked Polyethylene (PEX) Pipe and Fittings (joints shall be made using insert and compression fittings or other manufacturer-approved methods)

4. 10.11.4.a.4 — Vertical Supports for Plastic Pipe (includes PEX; at each story height, not more than ten-foot intervals)

5. 10.11.4.b.5 — Horizontal Supports for Plastic Pipe (includes PEX; 1-1/2 inch or less at three-foot intervals, 2 inch or over at four-foot intervals)

Chlorinated Polyvinyl Chloride (CPVC) and Compatible Fittings

1. 10.06.Table.2 — Chlorinated Polyvinyl Chloride (CPVC) and Compatible Fittings (approved for hot and cold water distribution)

2. 10.07.4.b — Chlorinated Polyvinyl Chloride (CPVC) Pipe and Fittings (joints shall be made using solvent-weld, threaded, or mechanical methods per manufacturer instructions)

3. 10.11.4.a.4 — Vertical Supports for Plastic Pipe (includes CPVC; at each story height, not more than ten-foot intervals)

4. 10.11.4.b.5 — Horizontal Supports for Plastic Pipe (includes CPVC; 1-1/2 inch or less at three-foot intervals, 2 inch or over at four-foot intervals)

Wrought Iron Solder Joint Pipe and Fittings

1. 10.06.Table.2 — Wrought Iron Solder Joint Pipe and Fittings (approved for hot and cold water distribution)

2. 10.07.8.c — Threaded Pipe to Wrought Iron or Other Metal (joined by threaded, soldered, or mechanical transition fittings as approved)

3. 10.11.4.a.2 — Vertical Supports for Metal Pipe (at base and each story height)

4. 10.11.4.b.2 — Horizontal Supports for Metal Pipe (at ten-foot intervals)

Type 304 Stainless Steel Tubing with Compatible Fittings

1. 10.06.Table.2 — Type 304 Stainless Steel Tubing with Compatible Fittings (approved for hot and cold water distribution)
2. 10.07.2.h — Stainless Steel (Type 304) (joints may be press-connect, grooved, flanged, compression, or mechanical coupling as recommended by manufacturer)
3. 10.11.4.a.2 — Vertical Supports for Stainless Steel Tubing (at base and each story height)
4. 10.11.4.b.2 — Horizontal Supports for Stainless Steel Tubing (at ten-foot intervals)
5. 10.06.2.h — Stainless steel pipe and fittings shall be permanently marked with manufacturer, type (304 or 316), and ASTM/ANSI standard.

Type 316 Stainless Steel Tubing with Compatible Fittings

1. 10.06.Table.2 — Type 316 Stainless Steel Tubing with Compatible Fittings (approved for hot and cold water distribution)
2. 10.07.2.h — Stainless Steel (Type 316) (joints may be press-connect, grooved, flanged, compression, or mechanical coupling as recommended by manufacturer)
3. 10.11.4.a.2 — Vertical Supports for Stainless Steel Tubing (at base and each story height)
4. 10.11.4.b.2 — Horizontal Supports for Stainless Steel Tubing (at ten-foot intervals)
5. 10.06.2.h — Stainless steel pipe and fittings shall be permanently marked with manufacturer, type (304 or 316), and ASTM/ANSI standard.

Other Plastics

1. 10.06.2.h — Other Plastics (plastic materials not specifically named in 10.06 may be approved for plumbing systems if product-accepted by the Board)
2. 10.07.4 — Plastic Pipe and Fittings (joints shall be made using solvent-weld, mechanical, compression, heat-fusion, or threaded methods per manufacturer instructions)
3. 10.11.4.a.4 — Vertical Supports for Plastic Pipe (at each story height, not more than ten-foot intervals)
4. 10.11.4.b.5 — Horizontal Supports for Plastic Pipe (1-1/2 inch or less at three-foot intervals, 2 inch or over at four-foot intervals)

2.3 Use of PEX and CPVC Piping

Cross-linked polyethylene (PEX) and chlorinated polyvinyl chloride (CPVC) are approved materials under 10.06.2.e and 10.06.Table.2 for potable hot and cold water distribution when installed per manufacturer instructions and the jointing requirements of 10.07.4. Their use is limited by temperature, pressure, and building height.

- **Residential dwellings.** PEX and CPVC tubing and fittings are approved for hot and cold water distribution in one- and two-family dwellings, condominiums, hotels, motels, and similar residential occupancies up to six stories in height (10.06.2.e, 10.12.1.a.5).
- **Commercial structures.** Above-ground use in commercial buildings is limited to non-plenum areas and locations not subject to continuous exposure to temperatures exceeding 180 degrees Fahrenheit. Installation in return-air plenums or high-temperature mechanical rooms is prohibited (10.06.Table.2, 10.06.Example.1).
- **Building height.** PEX and CPVC are approved only for buildings not exceeding six stories in height unless otherwise product-accepted by the Board. Multi-story use must comply with pressure ratings and manufacturer limitations (10.06.2.e, 10.12.1.a.5).
- **Joining methods.**
  - PEX joints shall be made using insert and compression fittings, or other product-accepted crimp, clamp, or expansion-type connectors (10.07.4.d).
  - CPVC joints shall be solvent-cemented or mechanically joined per manufacturer's product acceptance and 10.07.4.a.
- **Transitions.** PEX and CPVC may be joined to copper, brass, or other metallic piping only by means of mechanical adapters, threaded connectors, or manufacturer-approved transition fittings. Direct solvent welding or soldering to dissimilar materials is prohibited (10.07.8.d, 10.07.8.g).
- **Supports.** Both materials shall be supported at each story height for vertical runs and at intervals not exceeding three feet for tubing 1-1/2 inches or less, or four feet for tubing 2 inches and larger (10.11.4.a.4, 10.11.4.b.5).

- **Temperature limitations.** PEX and CPVC shall not be installed in areas exposed to temperatures exceeding their rated design temperature. PEX tubing shall not be used for steam or high-temperature process lines (10.06.Table.2).
- **Fire-rated construction.** PEX and CPVC are combustible materials and shall not be installed in or through fire-rated walls, floors, or ceilings unless enclosed or otherwise protected in accordance with 10.06.Example.1 (Fire Separation).

3 Permanent Joints

3.1 Solvent Welding

Solvent-welded joints for plastic piping systems are governed by 248 CMR 10.07.4 and related provisions in 10.06.2.g and 10.07.8. These sections establish the approved methods for joining PVC and ABS drain, waste, and vent piping using chemical solvent cements that soften and fuse the mating surfaces.

All solvent welding shall be performed in accordance with the manufacturer's instructions and the applicable ASTM standard for the material being joined. The joint must be made with a compatible primer (if required) and solvent cement specifically formulated for the pipe material. Solvent cements for PVC and ABS are not interchangeable unless the product is specifically listed for both materials.

Pipe ends shall be cut square, chamfered, and thoroughly cleaned of dirt, grease, and moisture before cementing. When primer is required, it shall be applied evenly to both mating surfaces until the surface is softened. While the surfaces are still wet, a uniform coat of solvent cement shall be applied to both parts, after which the pipe shall be inserted fully into the fitting with a quarter-turn twist to evenly distribute the cement. The joint shall be held stationary for several seconds to prevent pushback.

Excess cement shall be removed from the exterior of the joint, and the assembly shall remain undisturbed until set. The system shall not be tested or backfilled until the solvent cement has fully cured in accordance with the manufacturer's minimum set time based on temperature and pipe size.

For installations involving dissimilar materials, such as transitions between PVC and ABS, solvent-welded joints shall not be used unless the solvent cement is specifically rated for that combination. Otherwise, a mechanical transition coupling or listed adapter shall be installed in accordance with 10.07.8.f. Direct joining of unlike plastics with ordinary cement is prohibited.

When installed in underground locations, solvent-welded PVC and ABS piping shall be protected from physical stress by proper bedding and backfill as required by 10.05.5.a.7. In above-ground installations, the piping shall be supported per 10.11.4.a.4 and 10.11.4.b.5 to prevent joint strain or deflection during curing and service.

All materials used for solvent welding, including primers and cements, shall conform to the standards referenced in 248 CMR 3.04 for product acceptance. Containers shall be labeled with the manufacturer, material type, and ASTM designation. Open containers shall be closed when not in use to prevent evaporation or contamination.

3.2 Lead Content and Solder Types

Solders used in plumbing work are regulated under 10.07.5.b and 10.06.1.e. These sections incorporate the lead-free requirements of the Federal Safe Drinking Water Act (42 U.S.C. Section 300f) and define the acceptable compositions for use in potable and non-potable systems.

- **Lead-free requirement.** Solders and fluxes used in potable water systems shall contain not more than 0.2 percent lead, and the weighted average lead content of wetted surfaces in pipe, fittings, and fixtures shall not exceed 0.25 percent (10.07.5.b, 10.06.1.e).
- **Potable water systems.** Only lead-free solders such as tin-antimony, tin-silver, or tin-copper alloys may be used for joining copper, brass, or bronze piping intended to carry drinking water. These solders must be listed or product-accepted for potable service (10.07.5.b).
- **Non-potable systems.** Traditional tin-lead solders (such as 50/50 or 60/40 alloys) may be used only in non-potable systems such as drain, waste, vent, or closed-loop hydronic heating piping where drinking water is not conveyed (10.07.5.b).
- **Flux requirements.** Fluxes shall be non-corrosive, non-toxic, and compatible with the solder alloy used. Acidic or petroleum-based fluxes shall not be used on potable systems (10.07.5.a.1–2).
- **Verification.** Installers shall ensure that all solders, fluxes, and related joining materials are clearly labeled as "lead-free" when used on any potable water piping.

3.3 Solder Joints

Soldered joints are governed by 10.07.5.a and 10.07.5.b. The process joins copper, brass, or bronze tubing using soft or silver-bearing solder and an approved flux that promotes wetting and prevents oxidation. All soldered joints shall form a watertight, durable connection consistent with the material provisions of 10.06 and workmanship standards of 10.07.

- **Preparation.** Joint surfaces shall be cleaned bright and free from oil, scale, or dirt. Flux shall be applied uniformly and sparingly to mating surfaces only (10.07.5.a.1–3).
- **Assembly.** Tubing and fittings shall be properly aligned before heating. The joint shall be heated uniformly to the melting temperature of the solder, allowing capillary flow into the joint (10.07.5.a.4).

- **Filler metals.** Solders shall be lead-free when used in potable water systems in accordance with the Federal Safe Drinking Water Act. Tin-antimony, tin-silver, or equivalent lead-free alloys are acceptable (10.07.5.b).
- **Temperature limits.** Soldered joints are suitable for service temperatures not exceeding 180 degrees F for water distribution and 250 degrees F for heating systems (10.07.5.b).
- **Inspection.** After cooling, all soldered joints shall be wiped clean and visually examined to ensure full capillary fill and a smooth bead. Defective joints shall be removed and remade (10.07.5.a.5).

3.4 Brazed Joints

Brazed joints are governed by 10.07.5.c and are used where greater mechanical strength or higher temperature resistance is required. The brazing process uses filler metals with a melting point above 840 degrees F but below the melting point of the base metal. All brazed joints shall meet the permanent joint requirements of 10.06 and 10.07.

- **Preparation.** Surfaces shall be cleaned bright and free from scale, grease, or oxidation. A flux suitable for the filler metal shall be applied to ensure proper wetting (10.07.5.c.1).
- **Filler metals.** Brazing alloys shall conform to AWS A5.8 or equivalent standards and be compatible with the base metal. Acceptable alloys include copper-phosphorus, silver-phosphorus, and silver-copper (10.07.5.c.2).
- **Temperature limits.** Brazed joints are required where service temperatures exceed 250 degrees F, such as in hot-water, refrigeration, or medical-gas systems (10.07.5.c.3).
- **Protection.** Combustible materials near the joint shall be protected from flame and heat. Joints shall not be brazed in contact with walls or framing unless noncombustible shields are used (10.07.5.c.4).
- **Inspection.** Completed brazed joints shall be cleaned of flux residue and examined for full penetration and a smooth fillet. Porous or incomplete joints shall be cut out and re-brazed (10.07.5.c.5).

3.5 Lead Joints

Lead joints are regulated by 248 CMR 10.07.6. These provisions cover the use of molten lead, lead wool, and related methods for joining cast iron, brass, or copper piping. The code permits lead joints only where specifically approved and where the materials joined are suitable for such connection.

Molten lead joints shall be made by first caulking oakum or other approved packing material into the joint to the proper depth. The remaining space shall then be filled with molten lead to a depth of not less than one inch. The lead shall be poured in one continuous operation and allowed to cool naturally without quenching. After cooling, the joint shall be firmly caulked tight with caulking tools to ensure a dense, watertight seal.

Lead wool joints shall be packed by hand in small, even strands and thoroughly compacted with caulking irons to achieve a uniform, tight joint. The use of putty, paint, or other surface sealants is not permitted as a substitute for proper packing and caulking.

All lead joints shall be made using clean, sound lead free of foreign matter or oxide scale. Joints shall be smooth, without cracks, and watertight under test. The use of lead joints in contact with potable water or food-handling systems is prohibited. Lead joints may be used only for sanitary drainage, waste, vent, or storm piping where expressly allowed by 10.06.Table.1 and related product standards.

When joining dissimilar metals such as cast iron and copper or brass, lead joints shall be made in accordance with 10.07.8.c using approved mechanical or compression adapters where direct lead joining would be impractical or unsafe. All workmanship shall conform to good trade practice and the applicable ASTM or ANSI standards for cast iron jointing materials.

3.6 Welding of Steel and Ductile Iron

Welded joints in steel or ductile iron pipe are regulated by 248 CMR 10.07.7. All welding shall conform to recognized standards and be performed by qualified personnel using compatible filler materials.

3.7 Press-Connect Fittings

Press-connect fittings, including copper, stainless steel, and carbon steel systems such as ProPress, MegaPress, and similar products, are governed by 10.07.4 and 10.06.1.d–e. These joints form permanent mechanical seals through radial compression of a fitting onto the pipe using an approved pressing tool. Their use is limited to materials and applications approved through Product Acceptance.

- **Approval.** Press-connect systems shall be product-accepted under 248 CMR 3.04 and conform to the applicable ASTM or ASME standards listed in 10.06.Table 2 for water distribution or in 10.06.Table 1 for drainage and vent piping (10.06.1.d–e).
- **Materials.** Press fittings are approved for copper, stainless steel (Types 304 and 316), and carbon steel

pipe conforming to ASTM A53 or A106. Fittings and O-rings must be listed for the intended service (10.07.4.d).

- **O-ring seals.** Elastomeric sealing elements shall be compatible with the intended fluid and service temperature. EPDM rings are typical for potable water, while HNBR or FKM are used for hydronic and gas piping (10.07.4.d).
- **Applications.** Press-connect joints may be used for potable water, heating, and gas piping where specifically listed. They shall not be used in systems exceeding the pressure or temperature ratings specified by the manufacturer (10.07.4.d, 10.06.Table 2).
- **Prohibited uses.** Press fittings shall not be used in fire-rated assemblies unless the system has a Product Acceptance certifying such use. Unlisted fittings shall not be used for chemical waste or corrosive drainage systems (10.06.Example.1).
- **Installation.** Pipe ends shall be clean, deburred, and fully inserted into the fitting before pressing. Pressing tools shall be calibrated and maintained in accordance with manufacturer instructions to ensure proper seal compression (10.07.4.d).
- **Testing.** All press systems shall be tested per 10.13. The test shall be performed prior to concealment and at pressures specified by the manufacturer, not less than the code test pressure for the system type (10.13.2).

3.8 Transitions Between Materials

Transitions between different piping materials are covered under 248 CMR 10.07.8. This section details approved methods for joining dissimilar materials, including mechanical, threaded, soldered, and solvent-welded transition fittings.

4 Traps

Traps are regulated primarily under 248 CMR 10.08, with additional installation and seal-protection requirements in 10.10(6) for floor and trough drains. Traps prevent the passage of sewer gases by maintaining a water seal and must be installed and vented in accordance with this code (10.08, 10.10.6).

4.1 Five Parts

Every trap, regardless of material or design, consists of five essential parts. Together they maintain a water seal and prevent the passage of sewer gas while allowing the fixture to drain freely. These parts are named and described as follows.

1. **Inlet.** The point at which wastewater from a fixture enters the trap and is directed into the trap body.
2. **Seal.** The retained water forming the liquid barrier between the fixture and the sanitary drainage system.
3. **Dip.** The lowest portion of the trap where water collects. The height difference between the dip and the weir establishes the effective seal depth. Unless otherwise permitted, the seal depth shall be not less than 2 inches and not more than 4 inches (10.08.2).
4. **Weir.** The internal high point at the outlet side of the trap that water must flow over to exit. The vertical distance between the dip and the weir determines the water seal depth.
5. **Outlet.** The point at which water leaves the trap and flows into the trap arm or waste line. The outlet elevation relative to the inlet helps maintain the standing seal.

These five elements are present in all standard trap designs, including P-traps, S-traps, and drum traps. The geometry may differ, but each design must preserve a continuous liquid seal between the fixture and the waste system.

4.2 SLAMOBEC

Trap seals may fail through eight distinct mechanisms summarized by the mnemonic **SLAMOBEC**. Each represents a physical or environmental condition that can compromise the water seal required to prevent sewer gases from entering the occupied space (10.08, 10.10.6).

1. **Siphonage.** The trap seal may be destroyed by self-siphonage or induced siphonage when negative pressure develops in the drainage system. This occurs when a fixture discharges rapidly without proper venting or where an S-trap is installed (10.08, 10.16.10).
2. **Leakage.** The trap seal may be lost through defective joints, cracks, or improperly assembled fittings that allow the water seal to escape (10.06, 10.07).
3. **Aspiration.** High-velocity air passing over a branch or fixture connection can induce flow through the trap arm, drawing water out of the trap seal. This condition is prevented by correct vent placement (10.16).
4. **Momentum.** The momentum of discharge from a fixture can carry part of the trap's water seal past the weir if the trap is installed too far from the vent or with excessive slope (10.16.10.Table.1).
5. **Oscillation.** Rapid pressure fluctuations within the drainage system can cause the trap seal to oscillate, gradually lowering the water level and breaking the seal (10.08).
6. **Back pressure.** Positive pressure within the system, often from surging or inadequate venting, can blow air through the trap and force water out of the seal (10.16.2).
7. **Evaporation.** Infrequently used traps, such as those in floor drains or emergency fixtures, may lose their seal through evaporation. Trap-priming or resealing devices are required in such locations (10.10.6.e.2).
8. **Capillary action.** Hair, lint, or fibrous material bridging across the trap weir can wick water from the seal by surface tension, eventually breaking the seal (10.08).

4.3 General Knowledge

- **Separate trap.** Each plumbing fixture, except as otherwise permitted, shall be separately trapped by an approved water-seal trap located as close as practicable to the fixture outlet (10.08.1.a).
- **Seal depth.** The water seal of any trap shall be not less than two inches and not more than four inches. No trap shall depend on a moving part, mechanical seal, or check valve for its seal (10.08.2).
- **Trap design.** All traps shall be self-scouring and shall have smooth interior surfaces. Bell traps and traps with interior partitions or moving parts are prohibited (10.08.3).

- **Trap material.** Traps shall be constructed of approved materials conforming to 10.06. The material of each trap shall be compatible with the piping to which it connects (10.08.3.k, 10.06).
- **Trap setting.** Each trap shall be located as close to the fixture outlet as conditions permit, and all trap arms shall be installed with uniform grade toward the drain. The developed length from the fixture outlet to the trap weir shall not exceed 24 inches measured horizontally (10.08.1.b).
- **Trap venting.** Each fixture trap shall be protected from siphonage or backpressure by means of a vent sized and installed in accordance with 10.16 and 10.16.Table.1 (10.08.4, 10.16.10).
- **Seal protection.** Where loss of trap seal may occur through evaporation or siphonage, an approved automatic trap-sealing or trap-priming device shall be installed. Such devices shall be readily accessible for maintenance (10.10.6.e.2).
- **Floor drains.** Floor and trough drains shall incorporate integral or separate traps providing a minimum three-inch water seal and a removable strainer. Drains subject to backflow shall include a backwater valve (10.10.6.a-c).
- **Resealing devices.** Floor and trough drains installed in commercial or industrial areas shall be equipped with an automatic trap-resealing device or, where permitted, a product-accepted barrier-type seal protection device (10.10.6.e.2, 10.10.6.e.3).
- **Trap sizing.** The trap diameter shall correspond to the outlet of the fixture served, and no trap shall be larger than the fixture outlet except where required to prevent clogging (10.08.2).
- **Trap accessibility.** All traps shall be installed so as to be accessible for cleaning and replacement. Concealed traps are prohibited except where access panels are provided (10.08.3.l).
- **Prohibited traps.** The following are not permitted: S-traps, drum traps (except for special fixtures where approved), and traps subject to unvented siphonage (10.08.3.h-j).
- **Multiple fixtures.** Fixtures joined to a common waste line shall each be provided with an individual trap except where a single trap is permitted for two or three fixtures in accordance with 10.08.5 (such as in certain laundry or laboratory sinks).
- **Maintenance.** Damaged, corroded, or improperly sealing traps shall be replaced with traps of approved design and material consistent with 10.06 (10.08.3.n).

4.4 Common Traps

Certain combination fixtures, such as double-compartment sinks, three-bowl laundry tubs, or similar multi-outlet fixtures, may be served by a single trap when installed in accordance with the limitations of 10.08(2)(d). This provision recognizes that compartments forming a single fixture body may discharge through one common outlet and trap, provided the arrangement does not create excessive distance or drop between the outlets and the trap seal.

- **Common trap allowance.** A single trap may serve a combination fixture if all compartments discharge through a single outlet into that trap (10.08.2.d).
- **Horizontal spacing.** The horizontal distance between fixture outlets and the trap weir shall not exceed 30 inches measured along the centerline of the waste pipe (10.08.2.d).
- **Center-to-center separation.** The maximum horizontal distance between the centers of any two fixture outlets connected to one trap shall not exceed 30 inches (10.08.2.d).
- **Vertical drop.** The vertical distance from the fixture outlet to the trap weir shall not exceed six inches. This ensures that the seal is maintained and prevents self-siphonage (10.08.2.d).
- **Trap alignment.** The trap shall be located directly beneath the fixture outlets and arranged symmetrically to receive discharge from each compartment (10.08.2.d).
- **Trap sizing.** The trap shall be of the same nominal size as the largest compartment outlet it serves, but not smaller than 1-1/2 inches (10.08.2.d).
- **Separate fixtures prohibited.** Fixtures that are not integral parts of a combination fixture shall not be connected to a common trap (10.08.2.c, 10.08.2.d).

5 Cleanouts

All materials must conform to 248 CMR 10.06. Every product, system, and piece of equipment used in plumbing work shall meet the material requirements stated in this section and comply with 248 CMR 3.04: Product, Design, and Testing Standards (10.6.1.a).

5.1 General Knowledge

- **Extensions and alterations.** When extending, adding to, or relocating existing piping, the Inspector may allow materials of like grade or quality to those originally installed if the prior installation met the code in effect at that time (10.06.1.b).
- **Material equivalency.** The Board may accept materials that do not strictly meet 10.06.1 if it determines they are substantially equivalent to normally accepted materials and not detrimental to health, safety, or welfare (10.06.1.c).
- **Alternate materials.** Materials not specifically named in the code may be used if they meet the standards, use, and intent of 10.06 and have received Board approval through Product Acceptance, Variance, or Test-site status (10.06.1.d).
- **Cleanout materials.** Cleanout fittings and plugs shall be constructed of approved materials consistent with the piping to which they connect. Plastic cleanout plugs shall be of the same material as the pipe or fitting they serve (10.08.b.5).
- **Cleanout access.** Cleanouts shall be installed to ensure direct accessibility and shall not be permanently concealed. When located in finished floors or walls, an access plate or door of sufficient size must be provided (10.08.e, 10.08.l).
- **Direction of flow.** Every cleanout shall open in the direction of flow of the drainage line or at right angles thereto (10.08.i).
- **Cleanout clearances.** Cleanouts on three-inch and larger piping shall have at least 18 inches of clearance for cleaning; smaller than three-inch piping shall have at least 12 inches of clearance (10.08.k).
- **Cleanout sizing.** Cleanouts shall be of the same nominal size as the pipe served up to four inches and not less than four inches for larger piping (10.08.j).
- **Concealed piping.** Cleanouts on concealed piping shall terminate flush with the finished surface and remain accessible via removable covers or access panels (10.08.e).
- **Equivalent fittings.** A cleanout requirement may be satisfied by a fixture trap incorporating a union connection, a fixture with an integral trap, or a removable roof drain cover (10.08.m).
- **Prohibited use.** Cleanout openings shall not be used for installation of any new or additional plumbing except where another end-cleanout of equal access and capacity is provided (10.08.n).

5.2 Cleanout Locations

- **Front wall cleanout.** The front wall cleanout shall be full-sized, equal to the nominal size of the building drain up to four inches, and not less than four inches for larger piping (10.08.1.j).
- **Base of stack.** A cleanout shall be provided at or near the base of every vertical storm-water conductor, waste, or soil stack (10.08.f).
- **Building drain.** A cleanout shall be installed on the building drain to provide accessibility in direct line through the drain to the building sewer. An additional full-sized cleanout may be installed outside the building but not more than five feet beyond the foundation wall (10.08.g).
- **Inaccessible locations.** For buildings with slabs or limited crawl space, the cleanout for the building drain may be installed outside but not more than five feet beyond the foundation wall (10.08.h).
- **Four-inch and smaller piping.** Cleanouts shall be installed in every horizontal drainage line four inches and smaller in diameter at each change of direction greater than 45 degrees and at intervals not exceeding 50 feet. This ensures that smaller-diameter piping remains readily cleanable as required by 10.08.3.a and Example 4 (10.08.3.a, Example 4).
- **Five- and six-inch piping.** Cleanouts serving horizontal drainage lines five or six inches in diameter shall be located at each change of direction greater than 45 degrees and at intervals not exceeding 100 feet (10.08.3.a, Example 4).
- **Seven- through ten-inch piping.** Cleanouts shall be installed at each change of direction greater than 45 degrees and at intervals sufficient to maintain full accessibility. For these diameters, spacing may exceed 100 feet only where direct cleaning access exists from both ends of the run (10.08.3.a).
- **Large-diameter exterior piping.** For exterior underground piping over ten inches in diameter, manholes shall be provided at every change in alignment,

grade, or size, and at intervals not exceeding 350 feet. If the total developed length is less than 150 feet, cleanouts may be used every 75 feet instead of manholes (10.08.o).

5.3 Cleanout Equivalents

A *cleanout equivalent* is any approved access point that provides the same functional rodding and cleaning capability as a standard cleanout fitting. These are used where direct cleanouts are impractical or where a fixture or component already provides sufficient access to the drainage system (10.08.3.m).

- **Equivalent access.** A cleanout requirement may be satisfied by a fixture trap with a removable trap seal, a fixture with an integral trap, or a removable roof drain cover providing equivalent access to the drainage system (10.08.3.m).
- **Accessibility.** Equivalent cleanout points shall be located so that rodding and cleaning can be performed in the direction of flow without removing permanent construction (10.08.3.m).
- **Material compatibility.** When a fixture trap or roof drain is used as a cleanout equivalent, the materials shall be consistent with the piping served in accordance with 10.06 (10.08.3.m, 10.06).
- **Limitations.** Cleanout equivalents shall not be used where direct cleanout access is specifically required by 10.08.3.f through 10.08.3.k, including bases of stacks and exterior building drains (10.08.3.m).

5.4 Cleanout Plugs

Cleanout plugs serve as removable closures for access openings in drainage and vent piping systems. They are regulated primarily under 248 CMR 10.08 and must comply with the general material provisions of 10.06 and the joining requirements of 10.07. Each cleanout shall be installed so that it is accessible, watertight, and capable of being opened for maintenance or inspection without damage to the building structure or piping.

- **Material compatibility.** Each cleanout plug shall be constructed of approved materials consistent with the pipe or fitting to which it connects. Plastic plugs shall be made of the same plastic resin as the pipe or fitting they serve; metallic plugs shall be of a compatible alloy such as brass, bronze, or stainless steel (10.08.b.5, 10.06.1.a-e).
- **Removability.** Cleanout plugs shall be provided with raised square heads, recessed slots, or other means for removal using standard tools. Threads shall be right-handed unless otherwise specified, allowing counterclockwise removal in normal practice (10.08.b.5).
- **Watertight seal.** Threads or gaskets shall form a tight, durable seal under test conditions. Approved sealants, gaskets, or thread compounds may be used if compatible with the pipe material and not detrimental to the joint (10.08.b.5, 10.07.4).
- **Accessibility.** Cleanout plugs shall be located so as to be directly accessible for removal. When located in finished walls or floors, access panels or removable covers of sufficient size shall be provided (10.08.e, 10.08.l).
- **Prohibited use.** Cleanout openings shall not be used for the installation of new or additional plumbing except where another full-sized cleanout of equal access is provided (10.08.n).

Lead Fit-All Type Plugs

Older installations sometimes used hammered-in lead fit-all plugs as closures for cast-iron hubs or cleanout tees. These plugs were friction-fitted and relied on the softness of lead to create a seal. Under 248 CMR 10.08, such devices are no longer considered acceptable for new or replacement work.

Lead fit-all plugs do not meet the requirements of 10.08.b.5 because they lack a positive mechanical means of removal and are not considered *readily accessible*. They also fail the material and product-acceptance criteria of 10.06 and 248 CMR 3.04. Modern code practice requires that all cleanout plugs be mechanically removable and product-accepted.

Approved alternatives include:

- Threaded brass, bronze, or PVC plugs with raised or recessed heads.
- Gasketed expansion-type plugs or caps where Product-accepted.
- Removable mechanical caps integrated into cleanout fittings.

Lead plugs may be found in existing systems, but when a cleanout is serviced or replaced, the lead closure shall be removed and replaced with an approved threaded or mechanical plug consistent with the material of the fitting (10.06, 10.08.b.5).

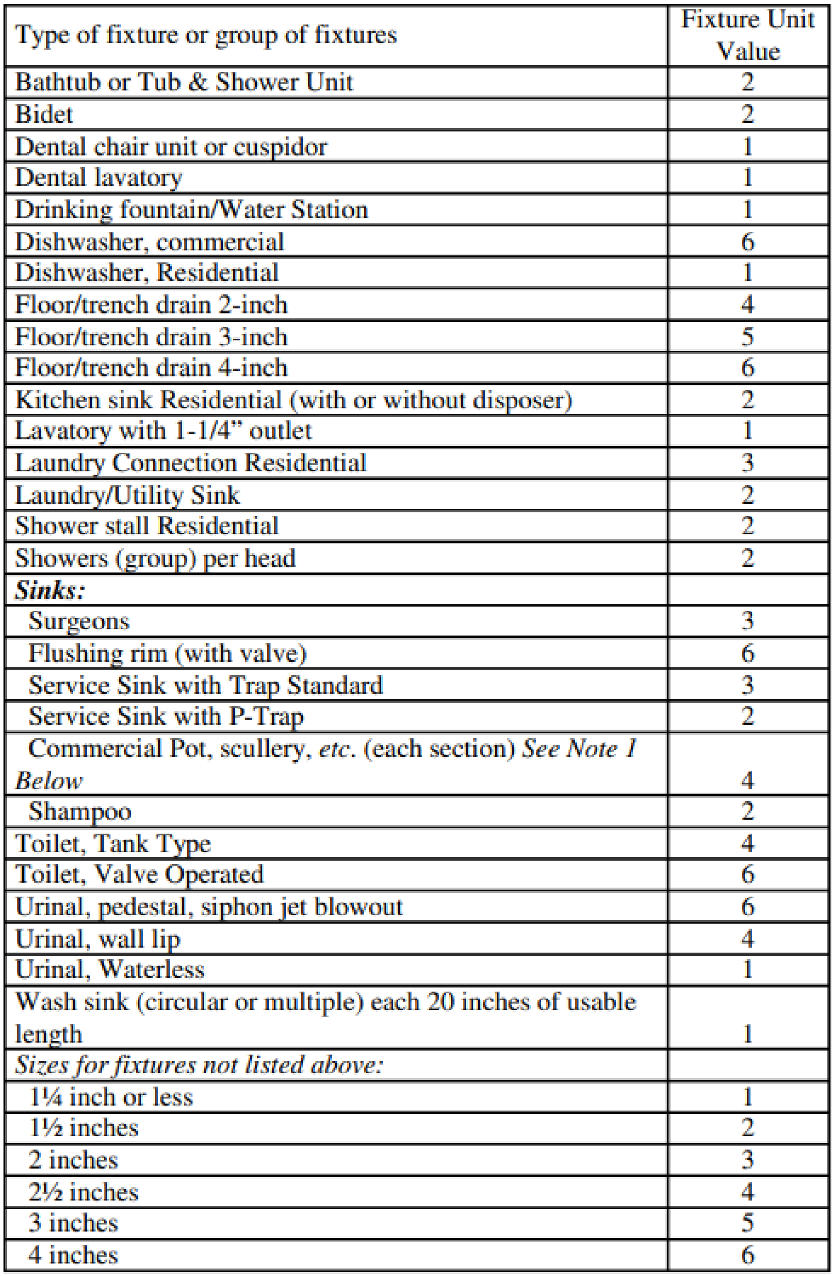
6 Drainage and Waste

6.1 General Knowledge

1. 10.05.2 — Horizontal drainage piping three inches in diameter or smaller shall be installed with a minimum uniform pitch of one-quarter inch per foot. Piping larger than three inches shall have a minimum uniform pitch of one-eighth inch per foot.
2. 10.08.1.j — The front wall cleanout shall be full-sized, equal to the nominal size of the building drain up to four inches, and not less than four inches for larger piping.
3. 10.08.2.a.1 — The waste for a domestic dishwasher may be separately trapped, connected to the manufactured inlet side opening of a food waste disposer, or connected between the outlet of the kitchen sink and the inlet of the trap using a wye fitting.
4. 10.15.10.a — A combination plumbing fixture may be installed on one trap provided that one compartment is not more than six inches deeper than the other and the waste outlets are not more than 30 inches apart. Each compartment shall otherwise comply with trap and vent requirements.
5. 10.15.6.b — Sanitary piping penetrating an exterior foundation wall shall be no less than four inches in diameter. Exceptions include certain residential laundry drains, baptistry wastes, or semi-positive displacement grinder pump discharges, which may be smaller where permitted.
6. 10.16.2.a — A full-size stack shall be not less than three inches in diameter. All building drains shall have at least one full-size main stack vent or vent stack of not less than three inches.

6.2 Waste Pipe Sizing

Waste pipe sizing makes use of the term *fixture unit* to quantify the ‘amount of drainage’ from any given fixture. Figure 1.3 shows CMR 10.15 Table 1 for a variety of common fixtures.



Type of fixture or group of fixtures	Fixture Unit Value
Bathtub or Tub & Shower Unit	2
Bidet	2
Dental chair unit or cuspidor	1
Dental lavatory	1
Drinking fountain/Water Station	1
Dishwasher, commercial	6
Dishwasher, Residential	1
Floor/trench drain 2-inch	4
Floor/trench drain 3-inch	5
Floor/trench drain 4-inch	6
Kitchen sink Residential (with or without disposer)	2
Lavatory with 1-1/4" outlet	1
Laundry Connection Residential	3
Laundry/Utility Sink	2
Shower stall Residential	2
Showers (group) per head	2
Sinks:	
Surgeons	3
Flushing rim (with valve)	6
Service Sink with Trap Standard	3
Service Sink with P-Trap	2
Commercial Pot, scullery, *etc.* (each section) *See Note 1 Below*	4
Shampoo	2
Toilet, Tank Type	4
Toilet, Valve Operated	6
Urinal, pedestal, siphon jet blowout	6
Urinal, wall lip	4
Urinal, Waterless	1
Wash sink (circular or multiple) each 20 inches of usable length	1
Sizes for fixtures not listed above:	
1¼ inch or less	1
1½ inches	2
2 inches	3
2½ inches	4
3 inches	5
4 inches	6

Figure 1.2. CMR 10.15 Table 1: Fixture Unit Values for Various Plumbing Fixtures.

There are several notes (not explicitly listed here) to go along with the Table pertaining to grease interceptors, devices with (semi-)continuous flow, and floor drains handling varying surface areas.

As per usual with fixture units, one must take the sum of all fixture units in a particular branch or building and sizing the pipe(s) accordingly.

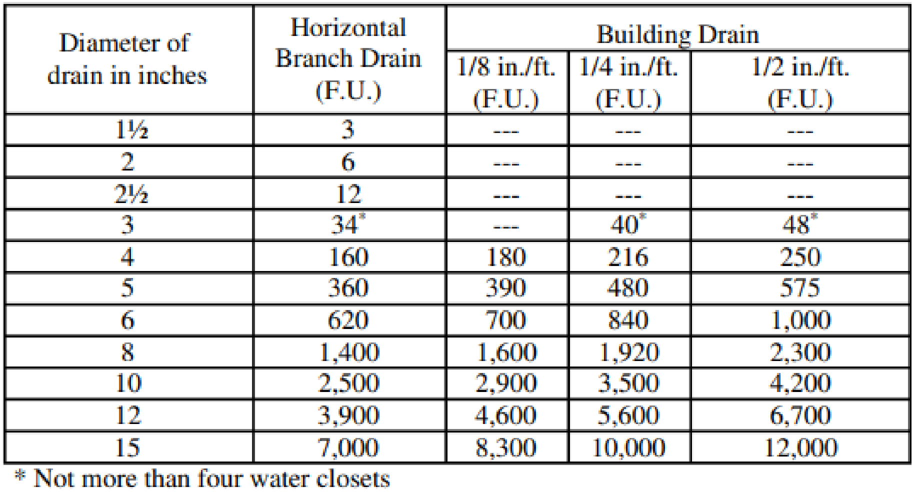
There are four configurations for the slope of a pipe suggested in CMR 10.15. Measured from the horizontal, these are:

- 1/8 inch per foot (0.597°)
- 1/4 inch per foot (1.19°)
- 1/2 inch per foot (2.39°)
- Vertical: ≥ 45°

Note that any slope less than 45 degrees is considered horizontal.

Horizontal Waste Pipes

When it comes to waste pipes, CMR 10.15 differentiates between a horizontal branch drain (handling some things) versus a horizontal building drain (handling everything). This leads to CMR 10.15 Table 2 as shown in Figure 1.4. Note the number of fixture units a pipe can handle has to do not only with the pipe's diameter, but also the *slope* of the pipe. (This wasn't a concern for pressurized water supply lines.)



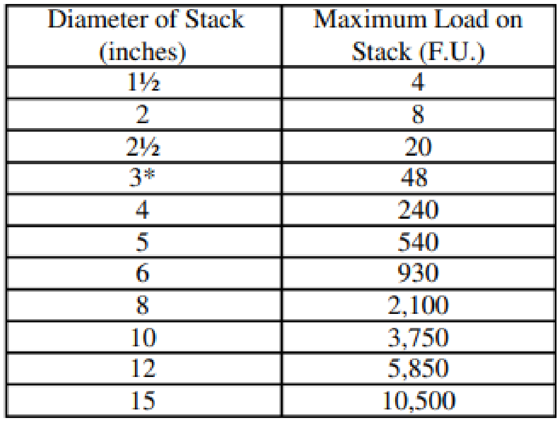
Diameter of drain in inches	Horizontal Branch Drain (F.U.)	Building Drain		
		1/8 in./ft. (F.U.)	1/4 in./ft. (F.U.)	1/2 in./ft. (F.U.)
1½	3	---	---	---
2	6	---	---	---
2½	12	---	---	---
3	34*	---	40*	48*
4	160	180	216	250
5	360	390	480	575
6	620	700	840	1,000
8	1,400	1,600	1,920	2,300
10	2,500	2,900	3,500	4,200
12	3,900	4,600	5,600	6,700
15	7,000	8,300	10,000	12,000

* Not more than four water closets

Figure 1.3. CMR 10.15 Table 2: Maximum Loads in Fixture Units for Horizontal Drains.

Stacks (1 or 2 Intervals)

The story is different for vertical pipes. CMR 10.15 offers CMR 10.15 Table 3 as shown in Figure 1.5 for stacks having one or two branch intervals. The data in CMR 10.15 Table 3 seems to occur empiracally, which is to say the numbers were found by experiment rather than by formula. Thus the precise relationship between the stack diameter and the maximum load is not obvious without some work.



Diameter of Stack (inches)	Maximum Load on Stack (F.U.)
1½	4
2	8
2½	20
3*	48
4	240
5	540
6	930
8	2,100
10	3,750
12	5,850
15	10,500

Figure 1.4. CMR 10.15 Table 3: Maximum Loads in Fixture Units for Soil and Waste Stacks Having One or Two Branch Intervals.

Let y denote the maximum load on the stack in fixture units, and let x denote the pipe diameter in inches. Proposing

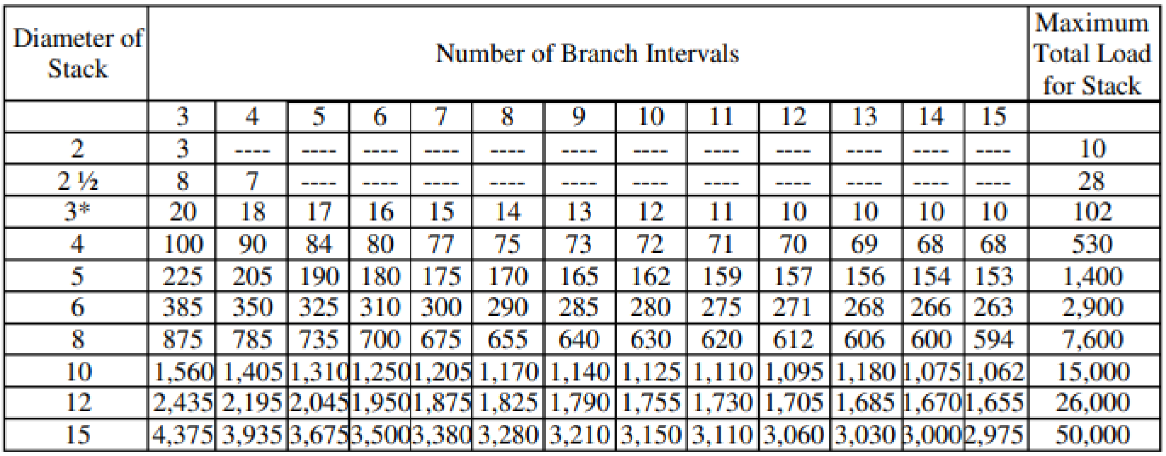
$$y = Ax^B\,,$$

and running a piecewise power law analysis using the information from CMR 10.15 Table 3 leads to:

$$y = \begin{cases} x \leq 3: & (0.81698)\,x^{3.5783} \\ x > 3: & (5.5947)\,x^{2.8106} \end{cases}$$

Stacks (3+ Intervals)

For stacks having more than two branch intervals, we are provided with CMR 10.15 Table 4 as Figure 1.6.



Diameter of Stack	Number of Branch Intervals													Maximum Total Load for Stack
	3	4	5	6	7	8	9	10	11	12	13	14	15	
2	3	----	----	----	----	----	----	----	----	----	----	----	----	10
2 ½	8	7	----	----	----	----	----	----	----	----	----	----	----	28
3*	20	18	17	16	15	14	13	12	11	10	10	10	10	102
4	100	90	84	80	77	75	73	72	71	70	69	68	68	530
5	225	205	190	180	175	170	165	162	159	157	156	154	153	1,400
6	385	350	325	310	300	290	285	280	275	271	268	266	263	2,900
8	875	785	735	700	675	655	640	630	620	612	606	600	594	7,600
10	1,560	1,405	1,310	1,250	1,205	1,170	1,140	1,125	1,110	1,095	1,180	1,075	1,062	15,000
12	2,435	2,195	2,045	1,950	1,875	1,825	1,790	1,755	1,730	1,705	1,685	1,670	1,655	26,000
15	4,375	3,935	3,675	3,500	3,380	3,280	3,210	3,150	3,110	3,060	3,030	3,000	2,975	50,000

Figure 1.5. CMR 10.15 Table 4: Maximum Loads in Fixture Units for Any One Branch Interval on Multi-story Soil and Waste Stacks.

The lower body of CMR 10.15 Table 4, along with the data for stacks taller than 15 branch intervals, is generated from one formula. For a given stack diameter, we write

$$\text{Load (DFU)} = N\left(\frac{1}{2n} + \frac{1}{4}\right) ,$$

where N is the maximum load on the one- or two-interval stack reported in CMR 10.15 Table 3. The variable n is the number of branch intervals on the stack to be sized.

For example, for a stack size of 4-inch diameter with $n = 10$ branch intervals, use CMR 10.15 Table 3 to find $N = 240$ in drainage fixture units. The corresponding load is

$$L = 240\left(\frac{1}{2 \times 10} + \frac{1}{4}\right) = 72 ,$$

as properly found in CMR 10.15 Table 4.

For very tall buildings, the term $1/4$ dominates $1/2n$ and the above simplifies to

$$L \approx \frac{N}{4} ,$$

which says the fixture unit load for any one branch in a very tall stack is about a quarter of the stack maximum in the one- or two-story case.

The right-most column in CMR 10.15 Table 4 is somewehat mysterious. To illustrate, suppose we have a building with 15 branch intervals using a stack diameter of 4 inches. According to the table, there are up to 68 fixture units allowed on any one branch. Planning optimistically, what if we want all 15 branches to handle 68 fixture units? Multiply the two to find $15 \times 68 = 1020$, which is about twice the maximum stack load according to the last column.

This descrepency lessens as we go down the table. Trying the 10 inch case, we see 1062×15 roughly matches the value in the last column. Beyond what's been demonstrated, however, there isn't an obvious pattern in the last column. Going for another power law analysis while and considering pipe diameters above three inches, the maximum total load as a function of diameter is approximately:

$$y = (5.7853)\, x^{3.3935}$$

7 Storm Drains

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8 Venting

8.1 General Knowledge

- **Vent connection height.** The connection between a vent pipe and a vent stack shall be at least 6 inches above the flood-level rim of the highest fixture served (10.16.3.a).

- **Crown venting.** A vent located within two pipe diameters of the trap weir is considered a crown vent and is prohibited (10.16.1.b).

- **Vent through roof (VTR).** Each vent terminal shall extend not less than 18 inches and not more than 24 inches above the roof surface (10.16.3.a).

- **Minimum VTR diameter.** No vent through roof shall be less than 2 inches in diameter (10.16.3.a).

- **Wet venting.** The minimum wet-vent diameter is 2 inches. Wet venting is not permitted for kitchen sinks, garbage disposers, dishwashers, washing machines, or other culinary fixtures (10.16.5).

- **Common vents.** A common vent serves two or more fixtures. An individual vent may serve as a common vent if it is vertical and the connected fixtures enter at the same level (10.16.7.a).

- **Bow vents.** A bow vent may be installed where a sink or lavatory vent cannot rise 6 inches above the flood-level rim before turning horizontal (10.16.9).

- **Trap arm distance.** The distance from the trap weir to the vent opening shall comply with the 5-6-8-10 rule based on pipe diameter (10.16.10).

- **Vent sizing.** The nominal size of a vent shall be one-half the diameter of the drain it serves but not less than 1.25 inches (10.16.11.a).

- **Underground vents.** The minimum diameter for underground venting is 2 inches, and materials shall match those approved for the associated drain (10.16.11.a).

- **Future vents.** A future vent shall be installed at the lowest level of a building and labeled at least every ten feet and at each change of direction (10.16.12.a).

- **Combination waste-and-vent.** Waste-vent combinations are prohibited except where specifically approved. Limited exceptions apply to floor drains, sinks, and similar fixtures with drains larger than 2 inches that are not individually vented (10.16.1.a).

- **Stack vents.** A stack vent shall connect to its header at the top of the stack and not less than 6 inches above the flood-level rim of the highest fixture served (10.16.5.b).

- **Exterior vent extensions.** Soil and waste vent extensions shall not be run on the exterior of a building (10.16.3.d).

- **Air admittance valves.** Air admittance valves are prohibited unless special permission is granted by the Board (10.16.1.e).

- **Horizontal extensions.** Extension of a horizontal drain for the purpose of venting is not permitted (10.16.1).

- **Frost closure.** Where frost closure is likely, each vent through roof shall be increased to not less than 3 inches in diameter (10.16.3.e).

- **Battery venting.** A single vent may serve a battery of up to eight floor-outlet fixtures (10.16.8).

- **Vent grade.** Every vent pipe shall be graded and connected above the centerline of the drain it serves to ensure proper air circulation and to prevent condensate accumulation (10.16.3.c).

- **Clearance to openings.** Each vent terminal shall terminate at least 10 feet horizontally, or 2 feet vertically, from any window, door, air intake, or ventilating opening within that radius (10.16.3.d–f).

- **Vent headers.** Multiple stack vents may be connected to a common horizontal vent header, provided the header is sized for the combined fixture load and is pitched to drain back to the stacks (10.16.2.e).

- **Vent materials.** Vent piping shall be of the same material and grade as the associated drainage piping in accordance with 10.06.Table 1.

- **Circuit venting.** A circuit vent may serve up to eight similar floor-outlet fixtures on a single horizontal branch, provided the vent connects between the two most downstream traps (10.16.6).

- **Relief vents.** Where a circuit vent serves multiple branches or fixtures at different elevations, a relief vent shall be installed to equalize air pressure (10.16.6.b).

- **Dead-end vents.** Vent pipes shall not terminate in dead ends or unventilated branches (10.16.1.d).

- **Testing.** All vent piping shall be tested as part of the drainage and vent system, using either a water test or air test, prior to concealment and before fixtures are connected (10.13.2).

8.2 The 5-6-8-10 Rule

When attaching a plumbing fixture to a vent pipe, the distance from that fixture's trap weir to the vent connection cannot exceed a certain length, depending on the diameter of the pipe being used.

CMR 10.16 provides information on the matter as shown in Figure 1.7. Despite the typo in Table 1, we glean that, for instance, a pipe diameter of two inches cannot exceed six feet in length as sketched. Reading down the right column, this has been named the 5-6-8-10 rule.

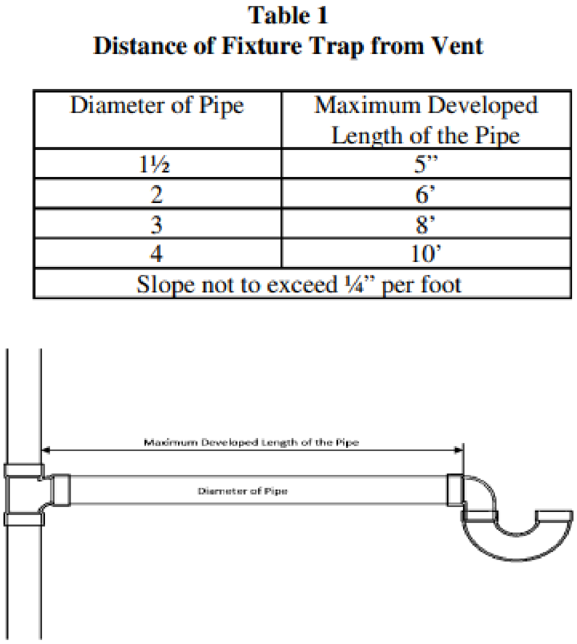

Table 1
Distance of Fixture Trap from Vent

Diameter of Pipe	Maximum Developed Length of the Pipe
1½	5"
2	6'
3	8'
4	10'
Slope not to exceed ¼" per foot	

Figure 1.6. CMR 10.16 Table 1 with provided sketch.

While the sketch provided under Table 1 means well, the drain pipe shown is perfectly horizontal and does not illustrate the point of the rule. To remedy this, imagine tilting the pipe toward the vent by an angle θ with respect to the horizontal as shown in Figure 1.8.

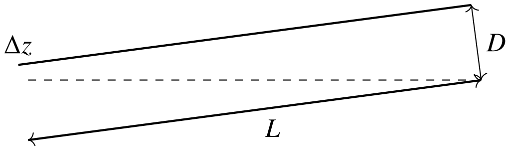

Figure 1.7. Sloped pipe.

By convention, the angle θ for pipes of diameter ≤ 3 in corresponds to a minimum uniform pitch of $1/4$ in per foot. For pipes greater than three inches, the minimum uniform pitch is $1/8$ in per foot. Figure 1.8 exaggerates this angle for clarity.

Paying attention to the dashed horizontal line, one sees that adjusting the angle θ of the pipe will change the height Δz. This is the vertical distance from the trap weir to the top of the vent connection.

For simultaneous drainage and venting through the pipe, it makes sense that Δz should never be zero or negative. Moreover, Δz should be far enough from zero so that venting is maintained.

From trigonometry, observe in Figure 1.8 that

$$L \sin(\theta) = D - \Delta z \,,$$

where L is the pipe length and D is the diameter. As mentioned, θ takes one of two branches:

$$\theta = \begin{cases} 1/4 \text{ in} \cdot \text{ft}^{-1} & \arctan(1/48) \approx 0.0208 \\ 1/8 \text{ in} \cdot \text{ft}^{-1} & \arctan(1/96) \approx 0.0104 \end{cases}$$

With this, we set up four calculations for Δz (converting feet so Δz comes out in inches):

$$\begin{aligned} \Delta z_{1.5} &= (1.5 - 60 \sin(0.0208)) \text{ in} \\ \Delta z_2 &= (2 - 72 \sin(0.0208)) \text{ in} \\ \Delta z_3 &= (3 - 96 \sin(0.0208)) \text{ in} \\ \Delta z_4 &= (4 - 120 \sin(0.0104)) \text{ in} \end{aligned}$$

Crunching the numbers, one finds:

$$\begin{aligned} \Delta z_{1.5} &= 0.2521 \text{ in} \\ \Delta z_2 &= 0.5025 \text{ in} \\ \Delta z_3 &= 1.003 \text{ in} \\ \Delta z_4 &= 2.752 \text{ in} \end{aligned}$$

Looking for some order in the above, we see the first three Δz roughly doubling with each increase in pipe size. The four-inch case breaks this pattern, as $2\Delta z_3$ is not 2.752 inches.

As a ratio to pipe diameter, we also learn:

$$\begin{aligned} \Delta z_{1.5}/1.5 \text{ in} &\approx 17\% \\ \Delta z_2/2 \text{ in} &\approx 25\% \\ \Delta z_3/3 \text{ in} &\approx 33\% \\ \Delta z_4/4 \text{ in} &\approx 69\% \end{aligned}$$

These figures are a bit deceiving in the sense that each percentage on the right represents a ratio of lengths, not a ratio of areas.

More interesting than the ratio $\Delta z/D$ would instead be the cross-sectional area represented by Δz, i.e. the air gap at the end of the pipe divided by the total cross-sectional area $\pi D^2/4$. Leaving the details aside, it's possible to show the ratio R of areas to be:

$$\begin{aligned} R(17\%) &\approx 11\% \\ R(25\%) &\approx 20\% \\ R(33\%) &\approx 29\% \\ R(69\%) &\approx 74\% \end{aligned}$$

We can make the most informed conclusion from the right side of the above results. At the vent connection, we conclude that a 1.25 in pipe needs about 10% of its cross-sectional area open for venting. Going up in diameter, the two-inch pipe needs 20% open area, the three-inch pipe needs 30% open area.

For the four-inch pipe, we see nearly three quarters of the pipe is reserved for venting, presumably because such pipes tend to carry large volumes of solids.

8.3 Vent Through Roof (VTR)

Vent terminals extending through the roof shall comply with 248 CMR 10.07.12.a, 10.16.3, and related material standards in 10.06. These provisions ensure that each vent through roof (VTR) is watertight, properly sized, frost-protected, and located to prevent contamination of air openings.

- **Undiminished size.** Each vent pipe or stack vent shall extend undiminished in size through the roof to open air; no reduction in diameter is permitted above the highest fixture served (10.16.3.a).
- **Termination height.** Each vent terminal shall extend not less than 18 to 24 inches above the roof surface. Where the roof is used for observation, parking, or recreation, the vent shall extend at least eight feet above the surface (10.16.3.a-b).
- **Frost protection.** In cold climates, the vent terminal shall be increased in size to not less than four inches in diameter beginning one foot below the roof surface to prevent frost closure (10.16.3.c).
- **Clearance to openings.** Each vent terminal shall terminate at least ten feet horizontally from, or two feet above, any window, door, air intake, or vent shaft. No vent shall terminate beneath an overhang unless the opening is at least twelve inches below the soffit and no soffit vent is located above it (10.16.3.d-f).
- **Roof usage.** Where the roof is accessible or occupied, vent terminations shall be extended or relocated to prevent odor or frost problems and shall be protected from mechanical damage (10.16.3.a-b).
- **Grouped vents.** Multiple vent stacks may connect to a vent header before passing through the roof, provided the header is properly sized for the combined load and terminates through a single opening (10.16.2.e, 10.16.3).
- **Material.** Vent pipes exposed above the roof shall be of approved material, resistant to corrosion and suitable for outdoor exposure. Metallic vents shall be corrosion-protected, and plastic vents shall be UV-rated (10.06.2.a.4, 10.06.Table.1, 10.16.3).
- **Weather protection.** Vent openings shall not be covered with strainers or screens that may collect debris or frost. Where protection is necessary, a product-accepted vent cap or hood may be used (10.16.3).
- **Roof flashing.** VTR assemblies shall be made watertight by approved flashing or roof boots compatible with the roofing material and properly sealed to prevent leakage (10.07.12.a, 10.06.Table.1).

Roof Flashing

Roof flashing shall be installed to provide a durable, watertight seal at the point where the vent passes through the roof. Flashing prevents moisture penetration and allows for thermal expansion and contraction (10.07.12.a, 10.16.3, 10.6.Table.1).

- **Approved materials.** Flashing shall be made of lead, copper, stainless steel, or other corrosion-resistant materials suitable for the roofing system per 10.06.2.a.4. Lead flashing shall weigh not less than 2.5 pounds per square foot and extend at least four inches up the vent pipe and four inches onto the roof surface (10.06.2.a.4, 10.06.Table.1).
- **Flexible boots.** Elastomeric or flexible roof boots may be used where Product-accepted and installed per manufacturer instructions. The boot shall form a watertight seal without restricting vent movement (10.07.12.a).
- **Integration.** Flashing shall be lapped and sealed into the roofing membrane or shingles in accordance with standard roofing practice and the Building Code (780 CMR) (10.07.12.a, 10.06.Example.1).
- **Roof drains.** Where roof drains are installed, flashing around the drain body shall be watertight and integrated with the roof membrane in accordance with 10.17.11.b. Roof drains and vent flashings shall meet the same waterproofing standard (10.17.11.b).
- **Maintenance.** Flashing and vent boots shall be inspected periodically for watertightness and replaced when showing deterioration or corrosion (10.07.12.a, 10.16.3).

8.4 Future Vent

A *future vent* is a pipe installed to permit the future connection of an additional fixture vent or branch vent. It is connected to the vent system so that it remains available for later use without reopening finished construction (10.16.11).

Each future vent shall terminate not less than six inches above the flood level rim of the highest fixture served or at another approved location accessible for future connection. The open end shall be securely capped or plugged with an approved threaded, soldered, or solvent-welded cap to prevent leakage or the escape of sewer gas.

All materials and fittings used for future vents shall conform to 10.06 and be compatible with the vent system to which they will connect. Installation shall meet all applicable venting provisions of 10.16.11(a).

Identification and Marking

Each future vent shall be permanently marked or otherwise clearly identifiable as a vent connection point for future use (10.16.11.a). Marking shall be durable, legible, and visible after construction. Labels, color coding, or stamped fittings may be used, provided they remain accessible and conform to the intent of 10.16.11(a). The marking shall indicate that the capped pipe is a vent connection and not a waste or water line.

9 Pipe and Support Geometry

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10 Water Distribution

10.1 General Knowledge

10.2 Water Pipe Sizing

According to CMR 10.14, the water supply fixture unit (WSFU) does not apply or exist. Instead, CMR 10.14.2(a) introduces three terms, namely ‘factor value’, ‘demand factor’, and ‘capacity value’, none of which are defined in CMR 10.03. Regardless, these together do the equivalent job of the water supply fixture unit.

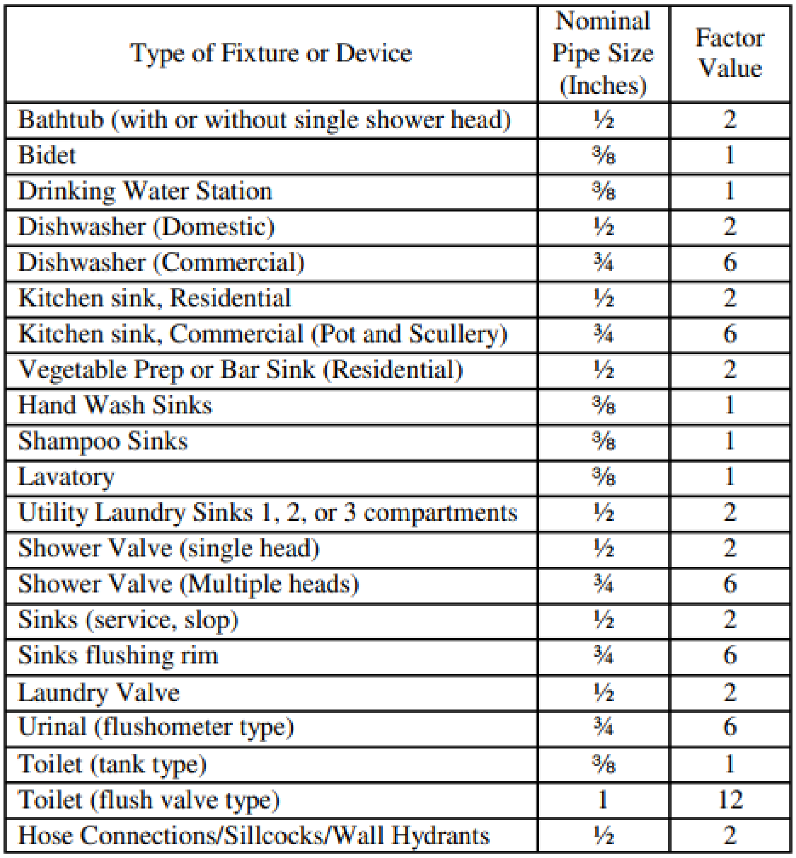
Figures 1.9, 1.10, 1.11 occur in succession in CMR 10.14 as Table 1, Table 2, Table 3, respectively. These essentially tell the story of sizing water supply pipe.

CMR 10.14 Table 1 lists common plumbing fixtures with the associated factor value. Between these is the nominal pipe size for the fixture. For multiple fixtures on the same branch, we’re still adding factor values as if they’re water supply fixture units. The total factor value for a branch or building is the sum of the individual factor values.

Next, CMR 10.14 Table 2 implies how ‘demand factor’ figures in. In particular, one must consider the type of ‘occupancy use’, and then multiply the total factor value by the demand factor, and this yields the capacity value:

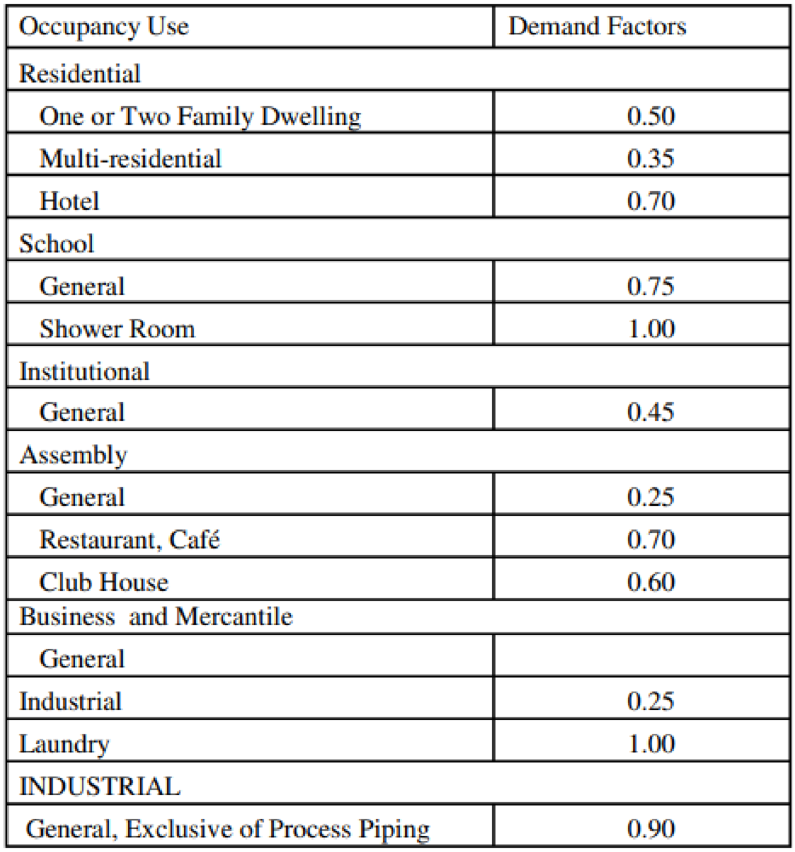
$$(\text{Factor value}) \times (\text{Demand factor}) = \text{Capacity value}$$

One may think of capacity value as a context-adjusted water supply fixture unit. With the capacity value in hand, one turns to CMR 10.14 Table 3 to select the appropriate pipe diameter.



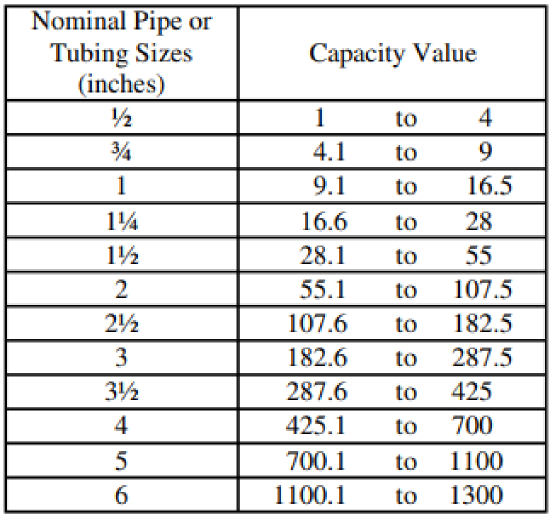
Type of Fixture or Device	Nominal Pipe Size (Inches)	Factor Value
Bathtub (with or without single shower head)	½	2
Bidet	⅜	1
Drinking Water Station	⅜	1
Dishwasher (Domestic)	½	2
Dishwasher (Commercial)	¾	6
Kitchen sink, Residential	½	2
Kitchen sink, Commercial (Pot and Scullery)	¾	6
Vegetable Prep or Bar Sink (Residential)	½	2
Hand Wash Sinks	⅜	1
Shampoo Sinks	⅜	1
Lavatory	⅜	1
Utility Laundry Sinks 1, 2, or 3 compartments	½	2
Shower Valve (single head)	½	2
Shower Valve (Multiple heads)	¾	6
Sinks (service, slop)	½	2
Sinks flushing rim	¾	6
Laundry Valve	½	2
Urinal (flushometer type)	¾	6
Toilet (tank type)	⅜	1
Toilet (flush valve type)	1	12
Hose Connections/Sillcocks/Wall Hydrants	½	2

Figure 1.8. CMR 10.14 Table 1: Minimum Sizes of Individual Fixture Branches and Factor Values.



Occupancy Use	Demand Factors
Residential	
One or Two Family Dwelling	0.50
Multi-residential	0.35
Hotel	0.70
School	
General	0.75
Shower Room	1.00
Institutional	
General	0.45
Assembly	
General	0.25
Restaurant, Café	0.70
Club House	0.60
Business and Mercantile	
General	
Industrial	0.25
Laundry	1.00
INDUSTRIAL	
General, Exclusive of Process Piping	0.90

Figure 1.9. CMR 10.14 Table 2: Occupancy and Demand Factor.



Nominal Pipe or Tubing Sizes (inches)	Capacity Value		
½	1	to	4
¾	4.1	to	9
1	9.1	to	16.5
1¼	16.6	to	28
1½	28.1	to	55
2	55.1	to	107.5
2½	107.6	to	182.5
3	182.6	to	287.5
3½	287.6	to	425
4	425.1	to	700
5	700.1	to	1100
6	1100.1	to	1300

Figure 1.10. CMR 10.14 Table 3: Capacity Values for Service, Mains, Risers and/or Branches.

Capacity Value v.s. Diameter

The exact relationship between the pipe diameter and the capacity value is a bit elusive when looking at numbers alone. Since cross-sectional area grows as the square of the diameter, one could roughly assume that the capacity value versus pipe diameter follows a similar law. Trying this out, one could let x represent the diameter in inches and y represent the capacity value. Then, for some unknown coefficient A, we have

$$y = Ax^2 .$$

Trying out a few values, one finds:

$$A = \frac{(16.5 + 9.1)/2}{1^2} = 12.8$$
$$A = \frac{(107.5 + 55.1)/2}{2^2} = 20.33$$
$$A = \frac{(287.5 + 182.6)/2}{3^2} = 26.12$$
$$A = \frac{(700 + 425.1)/2}{4^2} = 35.16$$

These values for A are all over the place. The model $y = Ax^2$ doesn't work.

Going instead for a power law model, we write

$$y = Ax^B ,$$

where A and B are unknown coefficients. The y-variable still represents capacity value, and the x-variable still represents pipe diameter in inches. Continue by writing

$$\ln(y) = \ln(A) + B \ln(x) ,$$

and the problem is now fit for linear regression analysis. Sparing the details, one finds

$$A \approx 13.858$$
$$B \approx 2.5686$$

such that:

$$y = (13.858)\, x^{2.5686} \tag{1.1}$$

Up to a small error, Equation (1.1) completely encodes CMR 10.14 Table 3 and can be used in place of it.

Diameter v.s. Capacity Value

We can also derive a formula for the pipe diameter as a function of capacity value, which amounts to solving Equation (1.1) for x:

$$x = \left(\frac{y}{13.858}\right)^{1/2.5686} = (0.35935)\, y^{0.38932}$$

Of course, the result will come out to an exotic decimal. Treat any outputs as approximate and use CMR 10.14 Table 3 to inform any final decisions.

Volume Flow v.s. Diameter

Conspicuously absent from the water pipe sizing heuristic for plumbing in Massachusetts is any mention of the volume passing through any pipe of a given size.

Luckily, this problem has been studied thoroughly and charts and tables are freely available. Choosing one from *WCP Online*, we see in Figure 1.12 the relation between volume flow in gallons per minute versus pipe diameter at a 15 psi pressure drop across the pipe.

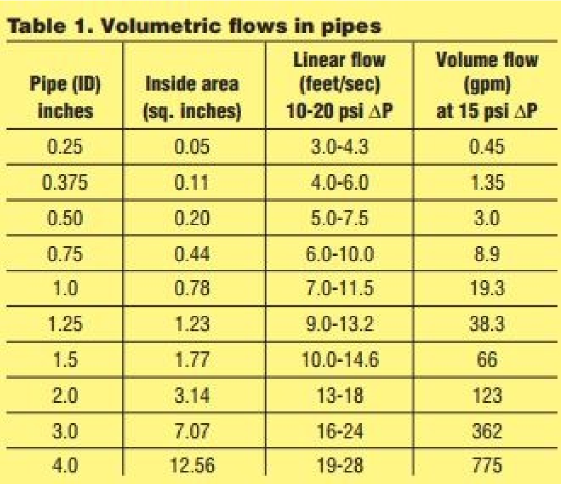


Table 1. Volumetric flows in pipes

Pipe (ID) inches	Inside area (sq. inches)	Linear flow (feet/sec) 10-20 psi ΔP	Volume flow (gpm) at 15 psi ΔP
0.25	0.05	3.0-4.3	0.45
0.375	0.11	4.0-6.0	1.35
0.50	0.20	5.0-7.5	3.0
0.75	0.44	6.0-10.0	8.9
1.0	0.78	7.0-11.5	19.3
1.25	1.23	9.0-13.2	38.3
1.5	1.77	10.0-14.6	66
2.0	3.14	13-18	123
3.0	7.07	16-24	362
4.0	12.56	19-28	775

Figure 1.11. Hydrodynamic design, part 2: Flows, pipe. (2013, February 3). WCP Online. https://wcponline.com/2013/02/03/hydrodynamic-design-part-2-flows-pipe/

Supposing that the capacity value in Figure 1.11 is related to the volume flow column in Figure 1.12, we can do a similar power law fit

$$y = Ax^B$$

on the first and last columns to learn

$$A \approx 19.495$$
$$B \approx 2.6963$$

such that:

$$y = (19.495)\, x^{2.6963} \tag{1.2}$$

Capacity Value v.s. Volume Flow

Paying attention to the exponents we're found, we see 2.5686 from Equation (1.1) is comparable to the the value 2.6963 from Equation (1.2). In parciular, consider the ratio of the two equations

$$R = \frac{(13.858)\, x^{2.5686}}{(19.495)\, x^{2.6963}} \approx (0.71085)\, x^{-0.1277}$$

The exponent on x is close enough to zero to ignore the whole x-term, leaving the ratio $R \approx 0.71085$. Interpreting this, we see that for a given pipe diameter, the capacity value (CMR 10.14 Table 3) is roughly equal to 0.71085 times the volume flow (Figure 1.12). Said another way, the volume flow in gallons per minute through a pipe is roughly (the reciprocal of 0.71085, thus) 1.4068 times the capacity value:

$$\text{Capacity value} \approx 0.71085 \times (\text{Volume flow})$$
$$\text{Volume flow} \approx 1.4068 \times (\text{Capacity value})$$

Example: Three-Story Residence

Consider two variations on a three-story residential dwelling shown in Figures 1.13, 1.14. Each single dwelling requires a kitchen sink, a bathroom lavatory, a toilet, and a bathtub. Each basement contains a utility sink, three washing machines, and two external wall hydrants as depicted.

Despite the configuration of the water heating beeing different between variations, the total water demand is the same in each case. Thus many calculations involving factor values, demand vactor, and capacity value are identical for each, and are containied in the Tables that follow. The Table data is then used to size each system.

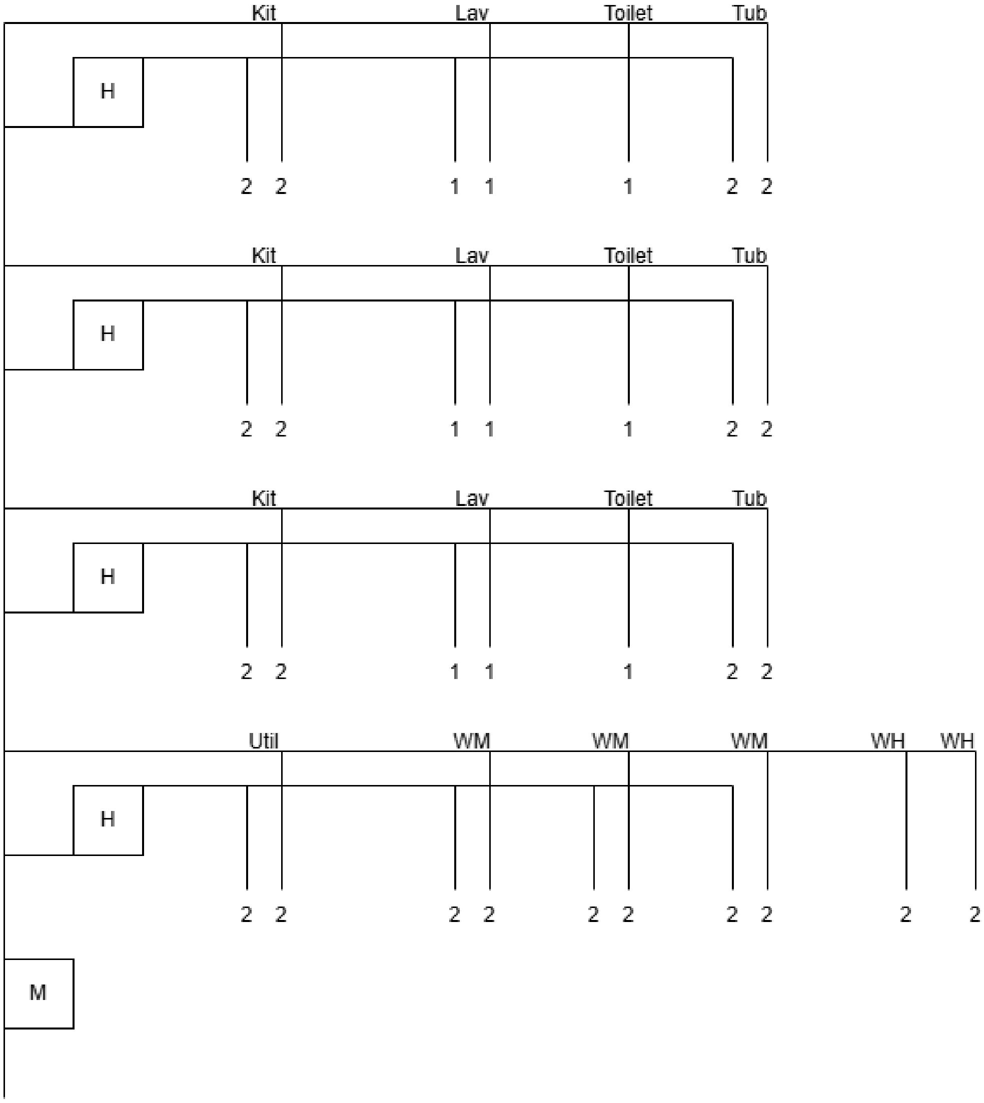


Figure 1.12. Three-story dwelling (wth basement) with a water heater serving each story.

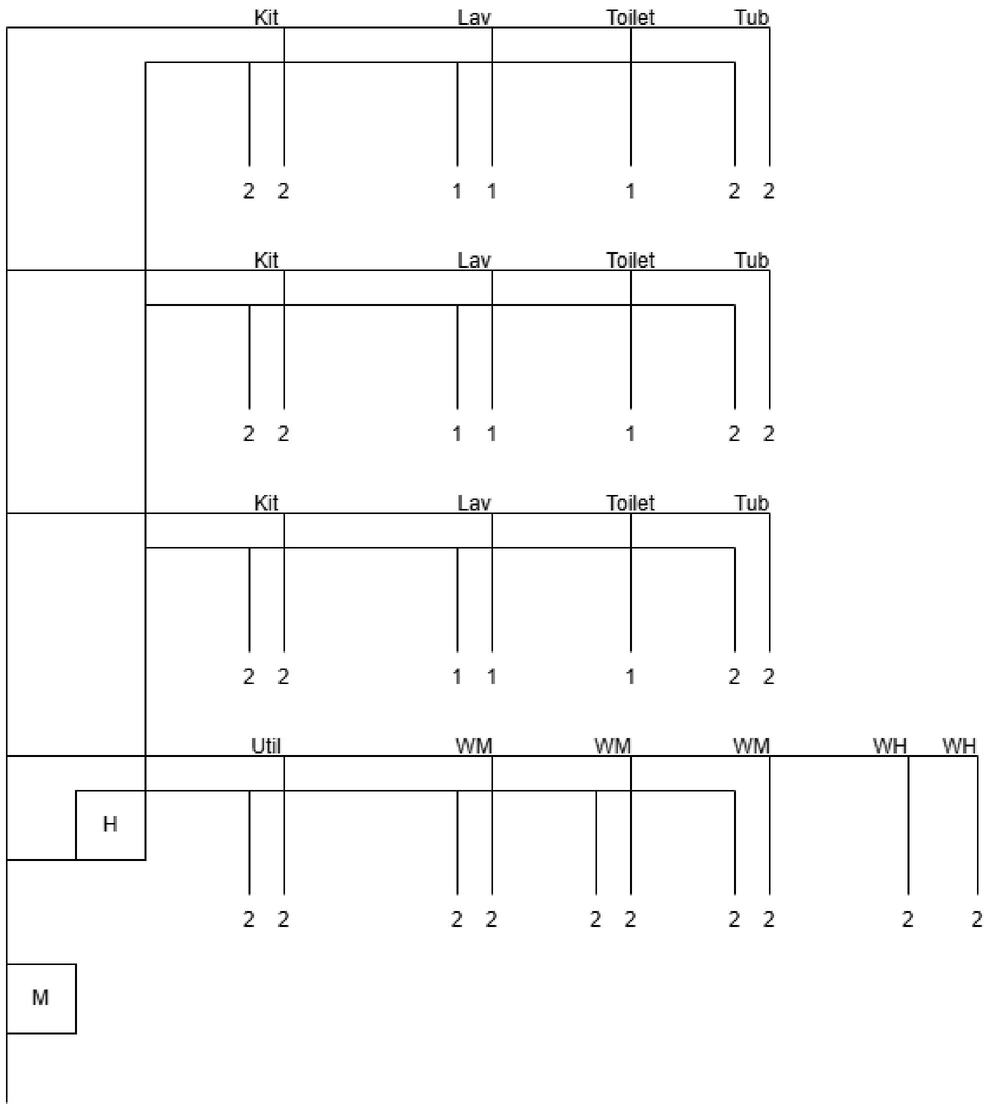


Figure 1.13. Three-story dwelling with a common basement water heater.

Single Dwelling					
Fixture	Nom. D. (in.)	Count	Hot FV	Cold FV	
Kit. Sink	0.5	1	2	2	
Lav	0.5	1	1	1	
Toilet	0.5	1	0	1	
Tub	0.5	1	2	2	
Subtotal FV			5	6	11
Capacity Value (×0.35)			1.75	2.1	3.85
Iterations (×3)					
Total FV			15	18	33
Capacity Value (×0.35)			5.25	6.3	11.55

Basement					
Fixture	Nom. D. (in.)	Count	Hot FV	Cold FV	
Util. Sink	0.5	1	2	2	
Wash. Mach.	0.5	3	6	6	
Wall Hyd.	0.5	2	0	4	
Total FV			20	28	48
Capacity Value (×0.35)			7.0	9.8	16.8

Building Demand			
Zone	Hot FV	Cold FV	
Single Dwelling ×3	15	18	
Basement	20	28	
Total FV	35	46	81
Capacity Value (×0.35)	12.25	16.1	28.35

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11 Valves and Devices

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12 Plumbing Fixtures

12.1 Domestic Dishwashers

Domestic dishwashing machines are considered plumbing fixtures and are regulated under 248 CMR 10.14.7, 10.10.5.g, 10.08, and 10.15.10. Each dishwasher must be supplied with approved hot water, connected indirectly to the drainage system, and installed in accordance with the manufacturer's instructions.

- **Water supply.** Each dishwasher shall receive hot water from the potable supply at not less than 120 degrees F and not more than 140 degrees F unless limited by the manufacturer (10.14.7.a-b).
- **Shutoff valve.** The supply shall be controlled by an accessible shutoff valve and connected with an approved flexible connector or listed fitting (10.14.7.b).
- **Dedicated branch.** The dishwasher supply shall not be taken from a branch serving other fixtures except downstream of an individual fixture shutoff (10.14.7.b).
- **Approved materials.** Supply piping shall conform to 10.06.Table.2 and be suitable for hot potable water (10.06.1.a-e).
- **Drain connection.** The waste discharge shall be made through an approved indirect waste method such as an air gap fitting above the flood level rim or a high-loop connection under the countertop where permitted (10.14.7.c, 10.10.5.g).
- **Prohibited direct connection.** The dishwasher shall not connect directly to the building drain. All discharges must pass through an air gap or equivalent device to prevent backflow or cross-connection (10.14.7.c, 10.15.10).
- **Trap requirements.** The dishwasher shall not be separately trapped when connected to a kitchen sink or disposer. It discharges into the sink tailpiece or the manufactured inlet of the disposer, both protected by the sink trap. The connection shall occur on the fixture side of that trap (10.08.2.a.1, 10.14.7.c).
- **Indirect waste receptor.** Where a commercial-style or multi-compartment sink is used, a separate trapped and vented receptor may be required (10.10.5.g, 10.16).
- **Venting.** The trap serving the dishwasher connection shall be vented in accordance with 10.16.10.Table.1 (10.16).
- **Backflow protection.** Air gaps or backflow preventers shall be installed where required by 248 CMR 10.15.10 or the manufacturer. Check valves or mechanical seals shall not substitute for an air gap or vent (10.15.10).

12.2 Toilets

Toilets, also known as water closets, are regulated under 248 CMR 10.10.3 and associated provisions. All water closets shall be of approved design, properly vented, and installed to ensure sanitary operation and accessibility.

- **Approved types.** Only product-accepted fixtures shall be installed. Each toilet shall be designed for the type of flush control and trapway intended (10.10.3.a).
- **Trap seal.** Every toilet shall have an integral trap with a minimum 2-inch water seal (10.08, 10.10.3).
- **Flush volume.** Maximum flush volume shall not exceed 1.6 gallons per flush for standard water closets unless specifically approved for a higher rate (10.10.3.b).
- **Outlet type.** Water closets may be floor-mounted (outlet through the floor) or wall-hung (outlet through the wall) and shall be installed using fittings listed in 10.07 (10.10.3.b).
- **Vertical drop.** The vertical distance from the finished floor of a floor-mounted toilet to the centerline of the horizontal drain shall not exceed 20 inches; if greater, the fixture must be individually vented (10.16.10.c.1-2).
- **Waste connection.** Each toilet shall discharge through a 3-inch minimum diameter trap arm connected to a soil stack or branch. Closet bends and fittings shall provide smooth, self-scouring flow (10.10.3).
- **Floor flange.** The closet flange shall be securely fastened to the finished floor and set flush with it. The flange opening shall match the fixture outlet (10.10.3).
- **Vent protection.** Each toilet shall be vented in accordance with 10.16 to prevent trap seal loss and maintain proper drainage (10.16.10).
- **Accessibility.** At least one toilet in each accessible restroom shall be installed in compliance with 521 CMR and ADA requirements, with proper clearances and grab bars (10.10.3.e).

- **Prohibited practices.** No toilet shall discharge to a grease interceptor, sump, or unvented line (10.10.3, 10.09).

12.3 Urinals

Urinals are regulated under 248 CMR 10.10.3.g-i. Each urinal shall be of approved type and connected to an approved trap and vent system.

- **Approved types.** Urinals shall be of the wall-hung, pedestal, or stall type and shall be product-accepted for use under 248 CMR 3.04 (10.10.3.g).
- **Trap requirement.** Each urinal shall have an integral trap or one located immediately beneath the fixture, providing a minimum 2-inch seal (10.08, 10.10.3.g).
- **Waterless urinals.** Waterless urinals shall have a liquid-barrier trap seal, be installed downstream of at least one water-supplied fixture, and include a roughed-in water line for future use (10.10.3.g.1-3).
- **Flush control.** Flush valves or flush tanks shall be of approved type and adjusted to deliver the manufacturer's rated volume, not exceeding 1.0 gallon per flush for standard urinals (10.10.3.h).
- **Vent protection.** Each urinal shall be vented per 10.16 to prevent trap siphonage and backpressure (10.16.10).
- **Accessibility.** At least one urinal in an accessible restroom shall be installed at accessible height and clearance per 521 CMR (10.10.3.i).
- **Prohibited installations.** Urinals shall not discharge into a trap serving another fixture or into unvented lines (10.08, 10.10.3.g).

13 Water Heaters

14 Tools and Techniques

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15 Water Column

Water Column

In plumbing theory, a *water column* is exactly what it sounds like–a vertical column filled with water, presumably weighted by the effect of gravity. For our purposes, we will consider two essential cases: (i) circular cross section (Figure 1.15), (ii) rectangular cross section (Figure 1.16).

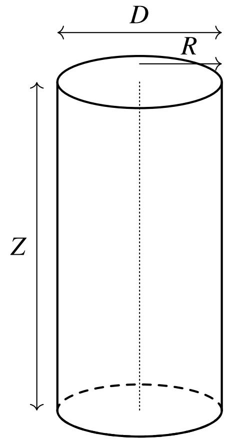

Figure 1.14. Cylindrical column.

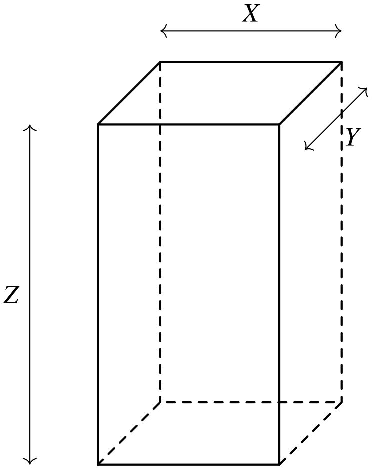

Figure 1.15. Rectangular column.

15.1 Cross Section

The *cross section* of a solid is a two-dimensional profile that would be exposed if the solid were sliced with a plane. We understand a cross section to be "sliced" perpendicular to the primary direction of length along the solid.

Circular Cross Section

When dealing with circles, it's worth memorizing some digits of "pi", written π, as:

$$\pi = 3.14159\ldots$$

The digits go on forever. Just remember $\pi \approx 3.14$ for short. The reason we have π at all is to relate the diameter D of a circle to its *circumference*, written C, which is the length around the circle:

$$C = \pi \times D$$

The *radius* of a circle, written R, is half the diameter of the circle:

$$R = \frac{D}{2}$$

In terms of the radius, the area of a circle, i.e. the area A of the circular cross section of a water column, is given by

$$A = \pi R^2 .$$

Since plumbers usually deal with the diameter rather than the radius, we substitute $R = D/2$ to arrive at an equivalent area formula:

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

Note that either formula for A respects the *units* expected for area. We know area is square-*something*, hence the presence of R^2 or D^2 on the right. If the radius or diameter is measured in inches, the area comes out in inches-squared.

Rectangular Cross Section

If instead we consider a water column that is more box-like, the cross section is a rectangle. For any rectangle, we may represent the sides as X and Y. (The height of the column is denoted Z.) In these variables, the *perimeter* of the column (a trip around the rectangle) is $X + Y + X + Y$. For perimeter calculations, use $C = 2X + 2Y$.

Using the same variables, the cross-sectional area is

$$A = X \times Y .$$

As expected, the units of A come out to the *square* of the units carried by X and Y. For clean calculations, these units should be matching (in × in or ft × ft). Be careful when mixing units. (You can avoid a lot of memorization by working in inches rather than feet.)

15.2 Column Capacity

The *volume* of a water column, synonymous with *capacity*, indicates how much water the column can hold. The overall shape of a water column, and therefore its volume/capacity is determined by two factors: (i) the length (or height) of the column, and (ii) the cross-sectional area of the column. The product of these equals the volume of water contained:

$$\text{Volume} = \text{Height} \times \text{Area}$$

We represent the volume as V, the height as Z, and the area as A. Thus the above is compactly written as

$$V = Z \times A .$$

Pay attention to the *units* carried by each factor in the above. Height Z is measured in inches or feet, however area A is measured in inches *squared* or feet *squared* (in^2 or ft^2). Multiplying height with area must always result in a volumetric unit such as inches cubed, feet cubed, or gallons (in^3, ft^3, gal). If someone tells you the volume of a container is 6 or 6 inches, they're *wrong*.

Volume Calculation

Going from our definition, the capacity or volume V of *any* water column is given by $V = Z \times A$, where Z is the height and A is the cross-sectional area. For circular pipes use $A = \pi R^2$ or $A = \pi D^2/4$. For rectangular pipes use $A = X \times Y$. Explicitly, this means:

$$\begin{aligned} \text{Circular:} \quad & V = Z \times \left(\pi D^2/4\right) \\ \text{Rectangular:} \quad & V = Z \times (X \times Y) \end{aligned}$$

Supposing all calculations have been done in *inches*, then the result of the volume calculation will be in cubic inches.

Conversion to Gallons

For any volume in cubic inches, the conversion to gallons can be done exactly without decimal approximation. We can take as a matter of definition that:

$$1 \text{ gallon} = 231 \text{ in}^3$$

That is, one gallon is 231 cubic inches.

In practice, the result of a volume calculation will look like

$$V = N \text{ in}^3 ,$$

where N is a unitless number because the in^3 factor is written explicitly. In order to convert to gallons, we must 'cancel out' cubic inches using the conversion factor above:

$$V = N \cancel{\text{in}^3} \left(\frac{1 \text{ gal}}{231 \cancel{\text{in}^3}} \right) = \frac{N}{231} \text{ gal}$$

This can be boiled down to "divide cubic inches by 231 and you've got gallons."

As a pure volume conversion, this analysis is not limited to water - it applies to any substance (including vacuum) occupying space.

<u>Problem 1</u>

One cubic inch is equal to how many gallons?

$$\begin{aligned} 1 \text{ in}^3 &= 1 \cancel{\text{in}^3} \left(\frac{1 \text{ gal}}{231 \cancel{\text{in}^3}} \right) = \frac{1}{231} \text{ gal} \\ &= 0.0043290 \text{ gal} \end{aligned}$$

<u>Problem 2</u>

One gallon is equal to how many cubic feet?

Answer:

$$\begin{aligned} 1 \text{ gal} &= 1 \cancel{\text{gal}} \left(\frac{231 \cancel{\text{in}^3}}{\cancel{\text{gal}}} \right) \left(\frac{1 \text{ ft}}{12 \cancel{\text{in}}} \right)^3 = \frac{231}{12^3} \text{ ft}^3 \\ &= 0.13368 \text{ ft}^3 \end{aligned}$$

<u>Problem 3</u>

One cubic foot is equal to how many gallons?

Answer:

$$\begin{aligned} 1 \text{ ft}^3 &= 1 \cancel{\text{ft}^3} \left(\frac{12 \cancel{\text{in}}}{1 \cancel{\text{ft}}} \right)^3 \left(\frac{1 \text{ gal}}{231 \cancel{\text{in}^3}} \right) = \frac{12^3}{231} \text{ gal} \\ &= 7.4805 \text{ gal} \end{aligned}$$

<u>Problem 4</u>

If 3 inches of rain was trapped on a 62 ft long × 40 ft wide roof, how many gallons would that equal?

Answer:

$$\begin{aligned} V &= 3 \text{ in} \times 62 \cancel{\text{ft}} \left(\frac{12 \text{ in}}{1 \cancel{\text{ft}}} \right) \times 40 \cancel{\text{ft}} \left(\frac{12 \text{ in}}{1 \cancel{\text{ft}}} \right) \\ &= 3 \times 62 \times 40 \times 12^2 \cancel{\text{in}^3} \left(\frac{1 \text{ gal}}{231 \cancel{\text{in}^3}} \right) = 4637.9 \text{ gal} \end{aligned}$$

<u>Problem 5</u>

A fifty-gallon drum (cylindrical) is 3 feet tall. Calculate the diameter in inches.

Answer:

$$50 \cancel{\text{gal}} \left(\frac{231 \text{ in}^3}{1 \cancel{\text{gal}}} \right) = 3 \cancel{\text{ft}} \left(\frac{12 \text{ in}}{1 \cancel{\text{ft}}} \right) \times \left(\pi D^2/4 \right)$$

$$D = \sqrt{\frac{50 \times 231 \times 4}{3 \times 12 \times \pi}} \text{ in} = 20.21 \text{ in}$$

Remark on Formula Quality

A plumbing license study guide *PHCC of MA* (Slide 25) poses the question: *What is the capacity in gallons of a 3-inch diameter pipe which is 27 inches long?* The solution is claimed to come from

$$\texttt{Capacity} = \texttt{Diameter}^2 \times \texttt{Length} \times 0.0034\,.$$

While 0.0034 is calculator-ready, the suggested formula is deeply flawed, and so is every cheat sheet equation written this way. The formula obscures the geometry and unit conversions into decimal data, and offers no hint that capacity comes out in gallons and all lengths are in inches. The student has to memorize chunks of setup information in order to deploy one fragile formula - and this must be done with nearly *every* formula.

It is *much* better for plumbers to attain a basic understanding of geometry and unit conversion so such formulas can be derived rather than memorized. There is no sane reason for memorizing hundreds of special cases, decimal numbers, or limiting circumstances. Let geometry rule each situation, not battalions of little rules.

For the example on hand, it just happens - and you're encouraged to prove this from what we said above - that the numerical factor comes from

$$\frac{\pi}{4 \times 231} \approx 0.003399992\,.$$

Problem 6

The cylindrical gallon capacity formula

$$\texttt{Capacity} = \texttt{Diameter}^2 \times \texttt{Length} \times X$$

with $X \approx 0.0034$ only applies when the diameter and length are in inches. Derive similar factors Y, Z that apply for (i) diameter in inches and length in feet, (ii) diameter in feet and length in feet.

Answer:

$$\begin{aligned} Y &= \frac{12\pi}{4 \times 231} \approx 0.04079990 \\ Z &= \frac{12^3\pi}{4 \times 231} \approx 5.875186 \end{aligned}$$

15.3 Column Surface Area

In the context of water columns, the surface area s (lowercase) of a column, not including the endcaps, is the product of the height and the cross-sectional perimeter. For a circle of diameter D, the perimeter is the same as the circumference, so $C = \pi D$. For a rectangle of sides X, Y, the perimeter is $C = 2X + 2Y$. For each case, we then have:

$$\begin{aligned} \text{Circular:} \quad & s = Z \times (\pi D) \\ \text{Rectangular:} \quad & s = Z \times 2\,(X + Y) \end{aligned}$$

Note that the *total* surface area S (uppercase) of a column must account for s and also the area of the two endcaps, A. Recall $A = \pi D^2/4$ for circles and $A = XY$ for rectangles:

$$\text{Total Surface Area} = s + 2A$$

Problem 7

How many square feet of insulation is required to wrap the outside of a (cylindrical) storage tank which is 18 inches in diameter and 5 feet long?

Answer:

$$\begin{aligned} \text{S} &= Z \times (\pi D) + 2\left(\pi D^2/4\right) \\ &= 5\text{ ft} \times \left(\pi\ 18\,\cancel{\text{in}}\right)\left(\frac{1\text{ ft}}{12\,\cancel{\text{in}}}\right) + 2\left(\pi \frac{18^2}{4}\right)\cancel{\text{in}^2}\left(\frac{1\text{ ft}}{12\,\cancel{\text{in}}}\right)^2 \\ &= \frac{5 \times \pi \times 18}{12}\text{ ft}^2 + \frac{2 \times \pi \times 18^2}{4 \times 12^2}\text{ ft}^2 \\ &= 27.096\text{ ft}^2 \end{aligned}$$

Problem 8

A cube (box with $X = Y = Z$) is covered with three gallons of paint. The thickness of the paint is 0.005 inches. Calculate the height of the box in feet.

Answer:

$$\begin{aligned} 3\text{ gal} &= 0.005\text{ in} \times 6Z^2 \\ 3\,\cancel{\text{gal}}\left(\frac{231\text{ in}^2\,\cancel{\text{in}}}{1\,\cancel{\text{gal}}}\right) &= 0.005\,\cancel{\text{in}} \times 6Z^2 \end{aligned}$$

$$\begin{aligned} Z &= \sqrt{\frac{3 \times 231}{0.005 \times 6}}\,\cancel{\text{in}}\left(\frac{1\text{ ft}}{12\,\cancel{\text{in}}}\right) \\ &= 12.67\text{ ft} \end{aligned}$$

15.4 Column Water Weight

The weight of water in a column is understood on a few assumptions. First, we assume all plumbing takes place close enough to sea level such that the conversion from kilograms to pounds is not thrown off by elevation. Second, we assume the temperature of the water is in a range such that the density can be approximated as 1000 kilograms per cubic meter. While conditions certainly vary, these assumptions lead to a conversion factor:

$$\rho_{\text{water}} = 8.344\,\frac{\text{lb}}{\text{gal}}$$

Don't worry about the greek character ρ ("rho"). Use d for "density" instead if you like. Either way, we gather that one gallon of water weighs about 8.344 pounds.

Conversion from gallons to pounds certainly involves the volume V and the number 8.344, but do we multiply or divide? The way to solve this question is to *cancel the units you don't want*.

Suppose the volume V is exactly N cubic inches. Converting to gallons (this is review), write

$$V = \frac{N}{231}\text{ gal}\,,$$

and get in the habit of writing gal, even if you already know you're working in gallons. Looking at the numerator and denominator of the density ρ, we see the unit for pounds in the numerator, and gallons in the denominator. Watch what happens when we multiply the density with the volume:

$$W = \rho \times V = 8.344\,\frac{\text{lb}}{\cancel{\text{gal}}} \times \frac{N}{231}\,\cancel{\text{gal}}$$

The only unit surviving cancellation is pounds, as we should expect for a weight calculation, hence why we call the product W. Cleaning up a bit, we have, for the weight of water in a column:

$$W = \frac{8.344}{231} \times N\text{ lb}\,,$$

where N is the number of cubic inches in the volume. Said another way, $8.344/231$ is the weight in pounds of one cubic inch of water.

Problem 9

Calculate the weight of one cubic foot of water.

Answer:

$$\begin{aligned} W &= \rho \times \left(1\ \text{ft}^3\right) = 8.344\ \frac{\text{lb}}{\cancel{\text{gal}}}\left(12^3\ \cancel{\text{in}^3}\right)\left(\frac{1\ \cancel{\text{gal}}}{231\ \cancel{\text{in}^3}}\right) \\ &= \frac{8.344\times 12^3}{231}\ \text{lb} = 62.42\ \text{lb} \end{aligned}$$

Problem 10

How many cubic inches are in one pound of water?

Answer:

$$\begin{aligned} V &= \frac{W}{\rho} = 1\ \cancel{\text{lb}} \times \frac{1\ \cancel{\text{gal}}}{8.344\ \cancel{\text{lb}}}\left(\frac{231\ \text{in}^3}{1\ \cancel{\text{gal}}}\right) = \frac{231}{8.344}\ \text{in}^3 \\ &= 27.68\ \text{in}^3 \end{aligned}$$

Problem 11

Calculate the weight of a water column with $H = 10$ ft and a circular cross section with $D = 4$ in.

Answer:

$$\begin{aligned} W_{\text{circ}} &= \rho \times V_{\text{circ}} = \frac{8.344\ \text{lb}}{1\ \text{gal}}\ H \times \left(\frac{\pi D^2}{4}\right) \\ &= \frac{8.344\ \text{lb}}{1\ \cancel{\text{gal}}}\ 120\ \cancel{\text{in}} \times \left(\frac{\pi 4^2\ \cancel{\text{in}^2}}{4}\right)\left(\frac{1\ \cancel{\text{gal}}}{231\ \cancel{\text{in}^3}}\right) \\ &= \frac{8.344\times 120\times 4\pi}{231}\ \text{lb} = 54.47\ \text{lb} \end{aligned}$$

Problem 12

Calculate the weight of a water column with $H = 10$ ft and a rectangular cross section with $X = Y = 4$ in.

Answer:

$$\begin{aligned} W_{\text{rect}} &= \rho \times V_{\text{rect}} = \frac{8.344\ \text{lb}}{1\ \text{gal}}\ H \times (X \times Y) \\ &= \frac{8.344\ \text{lb}}{1\ \cancel{\text{gal}}}\ 120\ \cancel{\text{in}} \times \left(4^2\ \cancel{\text{in}^2}\right)\left(\frac{1\ \cancel{\text{gal}}}{231\ \cancel{\text{in}^3}}\right) \\ &= \frac{8.344\times 120\times 16}{231}\ \text{lb} = 69.35\ \text{lb} \end{aligned}$$

Problem 13

A cylindrical water column of height L and diameter D has the same weight as a rectangular water column with height Z and equal sides of length D. How much longer is L than Z?

Answer:

$$\begin{aligned} W = \rho \times V_{\text{cyl.}} &= \rho \times V_{\text{box}} \\ V_{\text{cyl.}} &= V_{\text{box}} \\ L \times \left(\pi D^2/4\right) &= Z \times (D \times D) \end{aligned}$$

$$L = \frac{4Z}{\pi} \quad \longrightarrow \quad L - Z = Z\left(\frac{4}{\pi} - 1\right)$$

Problem 14

A ten-foot length of cast iron drain pipe has four-inch inner diameter and an outer diameter of 4.38 inches. Determine the volume of cast iron in cubic inches required to manufacture the pipe. (That is, how many one-inch cubes do you get by melting the pipe down?)

Answer:

$$\begin{aligned} V &= 10\ \cancel{\text{ft}}\left(\frac{12\ \text{in}}{1\ \cancel{\text{ft}}}\right) \times \frac{\pi}{4}\left(4.38^2 - 4.00^2\right)\ \text{in}^2 \\ &= \frac{120\pi}{4}\left(4.38^2 - 4.00^2\right)\ \text{in}^2 \\ &= 300.1\ \text{in}^3 \end{aligned}$$

Problem 15

The density of cast iron is known to be $0.260\ \text{lb}/\text{in}^3$. Convert this to pounds per gallon. How many times heavier is cast iron than water?

Answer:

$$\rho_{\text{C.I.}} = 0.260\ \frac{\text{lb}}{\cancel{\text{in}^3}}\left(\frac{231\ \cancel{\text{in}^3}}{1\ \text{gal}}\right) = 60.1\ \frac{\text{lb}}{\text{gal}}$$

$$\frac{\rho_{\text{C.I.}}}{\rho_{\text{water}}} = \frac{60.1}{8.344} = 7.20$$

15.5 Pressure in a Column

By definition, *pressure* is equal to force divided by area. In the context of water columns, we can ask about the ‘weight of water’ felt under the surface at any height, including the bottom.

At the bottom of a water column, the weight of the water pressing down is represented by W, which qualifies as a force. Dividing this by the cross-sectional area A, and using the definition of pressure, we write

$$P_{\text{bottom}} = \frac{W}{A}$$

for the pressure at the bottom.

Since the volume is given by $V = ZA$, eliminate A from the above to get

$$P_{\text{bottom}} = \frac{W}{V} Z\ .$$

The quantity W/V is the total weight per total volume of water. This, of course, reduces to 8.344 pounds per 231 cubic inches of water. Thus if Z is measured in inches, we get the pressure at the bottom measured in pounds per square inch:

$$P_{\text{bottom}} = \frac{8.344}{231} \times Z\ \texttt{psi}$$

A popular formula for the above calculation involves providing Z in feet rather than inches. In this case - and we'll leave the details of unit cancelation to the reader - we multiply the numerical factor by 12. Using H (in feet) in place of Z, we have

$$P = \frac{12 \times 8.344}{231} \times H \,\texttt{psi}\ .$$

The numerical prefactor works out to roughly 0.4335, in agreement with plumbing cheat sheets.

<u>Problem 16</u>

Suppose the pressure at the base of a water column is one pound per square inch. Calculate the height of the column in inches.

Answer:

$$\begin{aligned} 1\,\texttt{psi} &= \frac{8.344}{231} \times Z \,\texttt{psi} \\ Z &= 1 \times \frac{231}{8.344} \text{ in} = 27.68 \text{ in} \end{aligned}$$

15.6 Atmospheric Pressure

The air around us has weight, and this weight exerts pressure on everything it touches. This pressure, called *atmospheric pressure*, is what supports the mercury in a barometer and the water in a straw. At sea level, atmospheric pressure is about 14.7 `psi`, meaning each square inch of surface is pressed upon by 14.7 pounds of air.

<u>Problem 17</u>

Convert 14.7 `psi` to pounds per square foot.

Answer:

$$\begin{aligned} 14.7 \, \frac{\text{lb}}{\text{in}^2} &= 14.7 \, \frac{\text{lb}}{\text{in}^2} \left(\frac{12 \, \cancel{\text{in}}}{1 \text{ ft}} \right)^2 \\ &= 14.7 \times 12^2 \, \frac{\text{lb}}{\text{ft}^2} = 2116.8 \, \frac{\text{lb}}{\text{ft}^2} \end{aligned}$$

<u>Problem 18</u>

When a straw is lifted from water while sealed at the top (perhaps using your thumb), atmospheric pressure on the open surface below supports a water column. The water rises only until its weight balances with the surrounding air pressure; any additional height produces a vacuum space under the seal, just as in a barometer. Calculate the maximum height L of the water column above the water surface (presuming the straw is at least as tall as L).

Answer:

$$\begin{aligned} \frac{8.344}{231} \times L \text{ in} \, \cancel{\texttt{psi}} &= 14.7 \, \cancel{\texttt{psi}} \\ L &= \frac{231 \times 14.7}{8.344} \, \cancel{\text{in}} \left(\frac{1 \text{ ft}}{12 \, \cancel{\text{in}}} \right) \\ L &= 33.91 \text{ ft} \end{aligned}$$

<u>Problem 19</u>

Explain why no vacuum-lift system operating in the atmosphere can raise a column of water higher than about 34 ft at sea level.

Answer: A vacuum system does not pull water upward; it merely removes the opposing air pressure above the column. The rise of water depends entirely on the surrounding atmospheric pressure pushing on the reservoir below. At sea level, the atmosphere can only support a column of water about 34 ft tall—beyond this height, the weight of the water exactly balances the air pressure, leaving a vacuum space above and no further rise possible.

<u>Problem 20</u>

In standard conditions, mercury has a density of

$$\rho_{\text{mercury}} = 113.5 \, \frac{\text{lb}}{\text{gal}}\ .$$

Being much heavier than water, mercury allows for more compact construction of fluid columns, barometers, etc. If the pressure at the base of a mercury column is 1 `psi`, calculate the column height in inches.

Answer:

$$\begin{aligned} 1\,\texttt{psi} &= \frac{113.5}{231} \times Z \,\texttt{psi} \\ Z &= 1 \times \frac{231}{113.5} \text{ in} = 2.0352 \text{ in} \end{aligned}$$

<u>Problem 21</u>

If the atmosphere displaces about 34 feet vertically in a top-sealed water column, what is the vertical displacement in a similar mercury column?

Answer:

$$\begin{aligned} 14.7\,\texttt{psi} &= \frac{113.5}{231} \times Z \,\texttt{psi} \\ Z &= 14.7 \times \frac{231}{113.5} \text{ in} = 29.918 \text{ in} \end{aligned}$$

<u>Problem 22</u>

One inch is approximately 2.54 centimeters (cm), and there are 10 millimeters (mm) in one centimeter. Convert 29.918 inches to millimeters.

Answer:

$$\begin{aligned} 29.918 \text{ in} &= 29.918 \, \cancel{\text{in}} \left(\frac{2.54 \, \cancel{\text{cm}}}{1 \, \cancel{\text{in}}} \right) \left(\frac{10 \text{ mm}}{1 \, \cancel{\text{cm}}} \right) \\ &= 29.918 \times 25.4 \text{ mm} = 759.9 \text{ mm} \end{aligned}$$

15.7 Horizontal Column

Consider a cylindrical tank of volume $V = \pi R^2 L$, where $R = D/2$ is the radius and L is the length. The tank is resting on its side and is filled partially with water to a depth h above the lowest point in the tank. For a given ratio h/R, what fraction of the tank's volume is filled with water? See Figure 1.17.

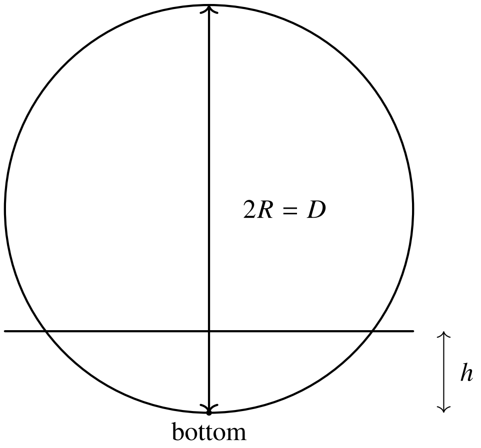

Figure 1.16. Cylindrical tank cross section showing vertical diameter $D = 2R$ and liquid level at height h above the bottom.

For convenience, redefine 'down' as pointing along the positive x-axis so the empty tank fills horizontally from the right. Placing the origin at the center of the circular cross section, the line defining the water's surface has length

$$2y = 2R\sin(\theta) \ ,$$

where θ is placed conventionally. In this frame, we can forget about the length of the tank entirely.

Letting x represent the distance from the center of the tank to the water's surface, presuming $h < R$, then the x-coordinate obeys

$$x = R\cos(\theta) \ ,$$

along with

$$x + h = R \ .$$

We'll need a formula for h/R, which we take from the above:

$$\frac{h}{R} = 1 - \frac{x}{R} = 1 - \cos(\theta)$$

Per our setup, the ratio h/R picks out a unique value for θ_*, so long as $0 \leq \theta_* \leq \pi/2$.

Setting up the area integral for the cross section of water occupying the tank, we begin with

$$A = -2\int_R^{x_*} y\,dx \ ,$$

which after using the trigonometric substitutions above becomes

$$A = -2R^2 \int_0^{\theta_*} \sin^2(\theta)\,d\theta \ ,$$

simplifying further to

$$A = R^2\left(\theta_* - \frac{1}{2}\sin(2\theta_*)\right) \ .$$

Keep in mind that θ_* is nontrivially related to the ratio h/R. Using a machine equipped to run Newton's method in one dimension, we generate the following results:

Ratio h/D	**Angle** θ_*	**Vol. Rat.**
0	0	0
0.05	0.45103	0.018693
0.1	0.64350	0.052044
0.15	0.79540	0.094060
0.2	0.92730	0.14238
0.25	1.0472	0.19550
0.3	1.1593	0.25232
0.35	1.2661	0.31192
0.4	1.3694	0.37353
0.45	1.4706	0.43644
0.5	$\pi/2$	0.5

The handle the case $\pi/2 \leq \theta_* \leq \pi$, write

$$\frac{h}{R} = 1 + \cos(\theta)$$

and regenerate the list of θ_*-values to find:

Ratio h/D	**Angle** θ_*	**Vol. Rat.**
0.55	1.6710	0.56356
0.6	1.7722	0.62647
0.65	1.8755	0.68808
0.7	1.9823	0.74768
0.75	2.0944	0.80450
0.8	2.2144	0.85762
0.85	2.3462	0.90594
0.9	2.4981	0.94796
0.95	2.6906	0.98131
1	π	1

Problem 23

A pipe laying on its side is partially filled with water such that $h/D = 25\%$. Use the information above to estimate the fraction of the pipe's volume that is occupied.

Answer:

$$h/D = 0.25 \quad \rightarrow \quad 19.55\% \text{ filled}$$

Problem 24

A pipe laying on its side is partially filled with water such that $h/D = 75\%$. Use the information above to estimate the fraction of the pipe's volume that is occupied.

Answer:

$$h/D = 0.75 \quad \rightarrow \quad 80.45\% \text{ filled}$$

16 Fixture Units

16.1 Review of Definitions

A term used heavily throughout the plumbing code is the *fixture unit*, which has a definition tailored for plumbers appearing in *Section 10.03: Definitions*:

Fixture Unit. *One cubic foot of water drained in a* 1.25 *in pipe over a period of one minute. One cubic foot of water is equal to* 7.5 *gal.*

The definition provided is alarmingly vague. Whether (or not) one cubic foot of water really drains through a 1.25 inch diameter pipe in exactly one minute is questionable. Needless to mention, one cubic foot is closer to 7.4805 gallons of liquid. As 7.5 carries only two digits of precision, the author may as well be saying the pipe is 1.3 inches in diameter.

Dimensionality

Given the definition in CMR 10.03, one may expect that a fixture unit is a flow rate, perhaps measured in gallons per minute, and then perhaps multiplied (or divided?) by 1.25 somewhere, because surely the pipe diameter factors in. It turns out none of this is correct.

Browsing CMR 10 or comparable resources, one instead finds that fixture units are *not* measured in physical units, but are instead always dimensionless scale factors like 3, π, or 1000. This is also troublesome for the definition, because we lack three numbers to balance the units of gallons, minutes, and inches.

16.2 Alternate Definitions

Massachusetts Plumbing Code (CMR 10.03)

Also found in *Section 10.03: Definitions* is the definition of *load factor*, which reads:

Load Factor. *The percentage of the total connected fixture unit flow which is likely to occur at any point in the drainage system. It varies with the type of occupancy, the total flow unit above this point being considered, and with the probability factor of simultaneous use.*

This definition is a slight improvement over the previous one by alluding to likelihood of occurrence and type of occupancy.

Sadly, the terms ‘probability’ and ‘load factor’ appear nowhere else in CMR 10. There is, of course, the suspiciously-related term ‘demand factor’ used in CMR 10.14, but this term is not defined in 10.03. A similar comment applies to the term ‘factor value’. That is, ‘factor value’ seems to be related, is used, but is never defined in CMR 10.03.

Uniform Plumbing Code (UPC)

Reaching for the *Uniform Plumbing Code*, *IAPMO/ANSI 1 - 2021*, one finds a dignified but unhelpful word salad explaining the fixture unit:

Fixture Unit. *A quantity in terms of which the load-producing effects on the plumbing system of different kinds of plumbing fixtures are expressed on some arbitrarily chosen scale.*

International Plumbing Code (IPC)

We finally encounter a sensible definition of the fixture unit in the *International Plumbing Code (IPC)* (e.g., 2021 edition), which reads:

Drainage Fixture Unit. *A measure of the probable discharge into the drainage system by various types of plumbing fixtures. The drainage fixture-unit value for a particular fixture depends on its volume rate of drainage discharge, on the time duration of a single drainage operation and on the average time between successive operations.*

Mometrix Media

A set of flash cards produced by Mometrix Media offers the following comment on fixture units:

A fixture unit is a unit used to measure the rate of water flow, equal to one cubic foot of water (roughly 7.48 *gallons) per minute.*

Claiming that the fixture unit is *equal* to one (physical) cubic foot of water per (real-time) minute is almost as bad as what we find in CMR 10.

One can speculate as to why the definition of the fixture unit varies so vividly per authority. Regardless of this, any literal understanding of the matter will remain elusive if plumbing codes are the only resource.

The Plan

We’ve racked up plenty of bad karma by slaughtering the definition of the fixture unit, and the intent here is not to solve the problems with the definition stated in CMR 10 or other publications. Instead, the plan is to take a first-principles approach using probability theory in the same way as done by the inventor of the fixture unit, Roy B. Hunter, in the years leading to 1940.

We start with a homemade exercise called the **Valve and Tank Problem**, which is informed by a mixture of real data and more-or-less made up numbers corresponding to likelihood of occurrence, type of occupancy, etc., of certain plumbing fixtures.

Next, we pursue **Hunter’s Calculation** to once-and-for-all force an understanding of the fixture unit. Such an effort also yields the so-called *Hunter's curve*, which is the source of the various 'gallons per minute versus fixture unit' tables occurring in the myriad of plumbing resources, including CMR 10. **You can skip the gritty calculations if math isn't your thing.**

Fixture unit values tend to change over time and location, however the work that follows will readily generalize to suit any fixture parameters. Data contemporary to the 1940s is used to ensure we're on track with the original work of R. B. Hunter.

16.3 Valve and Tank Problem

Two devices, or *fixtures* in American plumbing systems are the (i) *flush valve*, and (ii) the *flush tank*. The flush valve conveys 4 gallons of water over a period of 9 seconds.[1] The flush tank conveys 4 gallons in 60 seconds. Assume that all flush valves and flush tanks are used six times per hour on average.

If a certain building has $V = 20$ flush valves and $T = 30$ flush tanks, use only the information provided to (i) estimate the combined number of devices j being used simultaneously. (ii) Calculate the probability $P(j)$ of any j occurring and check that the estimate for j is correct. (iii) Calculate the probability that zero devices are in use at a given moment. (iv) Determine the number k at which $P(k) \approx 1\%$. (v) Calculate the final water demand using k.

Per hour (3600 seconds), a flush valve is operating for an average of 54 seconds. Similarly, a flush tank operates for 360 seconds. At a given moment, there is a

$$p_v = \frac{54}{3600} = 0.015$$

probability that a given flush valve is operating, and a

$$p_t = \frac{360}{3600} = 0.1$$

probability that a flush tank is operating.

Modal Analysis

Let x_v denote the number of flush valves in use simultaneously, and let x_t be the number of flush tanks being used such that

$$j = x_v + x_t$$

at a given moment.

Modeling each fixture as a weighted coin, we know from the binomial distribution that the most probable values for x_v, x_t are approximately the respective modes

$$\begin{aligned} x_v^* &= Vp_v - (1 - p_v) \approx Vp_v \\ x_t^* &= Tp_t - (1 - p_t) \approx Tp_t \ , \end{aligned}$$

or

$$\begin{aligned} x_v^* &= (20)\,(0.015) = 0.3 \\ x_t^* &= (30)\,(0.1) = 3 \ . \end{aligned}$$

The convoluted mode j^* ought to be the sum of the individual modes

$$j^* \approx x_v^* + x_t^* \ ,$$

and using the numbers on hand, one finds

$$j^* \approx 3.3 \ .$$

That is, we expect about three devices to be conveying water at a given moment. The total mode is essentially dominated by x_t^*.

In terms of x_v, x_t, the water demand rate $D(x_v, x_t)$ is given by

$$D(x_v, x_t) = x_v \left(\frac{4\text{ gal}}{9\text{ s}}\right) + x_t \left(\frac{4\text{ gal}}{60\text{ s}}\right) \ .$$

Using $j = 3$, it follows that x_v can take on any value 0, 1, 2, 3. Thus:

$$\begin{aligned} &D(0,3) = 0.2\text{ gal/s} \\ &D(1,2) = \left(0.44\overline{4} + 0.13\overline{3}\right)\text{gal/s} = 0.57\overline{7}\text{ gal/s} \\ &D(2,1) = \left(0.88\overline{8} + 0.066\overline{6}\right)\text{gal/s} = 0.95\overline{5}\text{ gal/s} \\ &D(3,0) = 1.3\overline{3}\text{ gal/s} \end{aligned}$$

To make use of the above information, recall from the values of x_v^*, x_t^* that $(0,3)$ (zero flush valves in use, three flush tanks in use) is the most likely configuration at a given moment, and the typical water demand is estimated at 0.2 gal/s, or 12 gallons per minute.

Of course, we don't want to design based on typical use. It's much better to anticipate the worst-probable case, which is not the worst *possible* case. (To design based on the worst possible case scenario is inefficient, costly, or worse.)

Probabilistic Analysis

The probability that there are x_v flush valves in use is given by the binomial distribution:

$$P_v(x_v) = \binom{V}{x_v} (1 - p_v)^{V - x_v}\, p_v^{x_v}$$

Also in terms of x_v, we write for the flush tank:

$$P_t(j - x_v) = \binom{T}{j - x_v} (1 - p_t)^{T - (j - x_v)}\, p_t^{j - x_v}$$

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[1] Figures gathered from PDH Course M126, *Sizing Plumbing Water System.* A. Bhatia. 2020. *www.PDHonline.prg*

The total probability is the sum of convolutions of the two above distributions:

$$P(j) = \sum_{x_v=\max(0,j-T)}^{\min(j,V)} P_v(x_v) \cdot P_t(j - x_v)$$

Using $j = 3$, the above probability is

$$P(3) = \sum_{x_v=0}^{3} P_v(x_v) \cdot P_t(j - x_v) \ ,$$

where:

$$\begin{aligned} P_v(x_v) &= \binom{20}{x_v} (1 - 0.015)^{20-x_v} (0.015)^{x_v} \\ P_t(j - x_v) &= \binom{30}{3 - x_v} (1 - 0.1)^{30-(3-x_v)} (0.1)^{3-x_v} \end{aligned}$$

Evaluating $P(3)$ is quite a chore. For $x_v = 0$, we have:

$$\begin{aligned} P_v(0) &= \binom{20}{0} (1 - 0.015)^{20} (0.015)^0 \approx 0.7391 \\ P_t(3) &= \binom{30}{3} (1 - 0.1)^{27} (0.1)^3 \approx 0.2361 \\ P_v(0) \cdot P_t(3) &\approx 0.1745 \end{aligned}$$

Continuing for $x_v = 1$:

$$\begin{aligned} P_v(1) &= \binom{20}{1} (1 - 0.015)^{19} (0.015)^1 \approx 0.2251 \\ P_t(2) &= \binom{30}{2} (1 - 0.1)^{28} (0.1)^2 \approx 0.2277 \\ P_v(1) \cdot P_t(2) &\approx 0.05126 \end{aligned}$$

Continuing for $x_v = 2$:

$$\begin{aligned} P_v(2) &= \binom{20}{2} (1 - 0.015)^{18} (0.015)^2 \approx 0.03257 \\ P_t(1) &= \binom{30}{1} (1 - 0.1)^{29} (0.1)^1 \approx 0.1413 \\ P_v(2) \cdot P_t(1) &\approx 0.004602 \end{aligned}$$

Continuing for $x_v = 3$:

$$\begin{aligned} P_v(3) &= \binom{20}{3} (1 - 0.015)^{17} (0.015)^3 \approx 0.002976 \\ P_t(0) &= \binom{30}{0} (1 - 0.1)^{30} (0.1)^0 \approx 0.04239 \\ P_v(3) \cdot P_t(0) &\approx 0.0001262 \end{aligned}$$

The total probability that any three of the 20 + 30 flush valves and flush tanks are in simultaneous use is the sum of the above convolutions:

$$P(3) \approx 0.2394 \approx 23.94\%$$

Returning briefly to the issue of water demand, compare each convolution $P_v(x_v) \cdot P_t(j - x_v)$ to see the figure 0.1745 dominating its siblings, thus $(0, 3)$ is the most likely configuration in accordance with our estimate of $j^* = 3$.

We still need to establish that $P(3)$ is greater than all other $P(j)$. To study the $j = 2$ case, we need

$$P(2) = \sum_{x_v=0}^{2} P_v(x_v) \cdot P_t(j - x_v) \ ,$$

or:

$$\begin{aligned} P(2) = {} & P_v(0) \cdot P_t(2) + P_v(1) \cdot P_t(1) \\ & + P_v(2) \cdot P_t(0) \end{aligned}$$

Using the figures calculated above, we learn

$$\begin{aligned} P(2) &\approx 0.1683 + 0.03181 + 0.001381 \\ &\approx 0.2015 = 20.15\% \ . \end{aligned}$$

The $j = 1$ case is also done easily, as

$$P(1) = P_v(0) \cdot P_t(1) + P_v(1) \cdot P_t(0)$$

readily computes to

$$\begin{aligned} P(1) &\approx 0.1044 + 0.009542 \\ &\approx 0.1139 \approx 11.39\% \ . \end{aligned}$$

The $j = 0$ case is trivial from the information on hand, coming out to

$$P(0) \approx (0.7391)(0.04239) \approx 0.03133 \approx 3.133\% \ .$$

Reading this result backward, we see there is a 96.87% chance that at least one device is operating at a given moment.

Technically, we need to also check all additional $P(j)$ up to $j = 50$. This is best left to a machine, so we'll do one more case by hand, namely $j = 4$. For this, we need

$$\begin{aligned} P(4) = {} & P_v(0) \cdot P_t(4) + P_v(1) \cdot P_t(3) \\ & + P_v(2) \cdot P_t(2) + P_v(3) \cdot P_t(1) \\ & + P_v(4) \cdot P_t(0) \ . \end{aligned}$$

Most of these figures were calculated above, with the new members being:

$$\begin{aligned} P_v(4) &= \binom{20}{4} (1 - 0.015)^{16} (0.015)^4 \approx 0.0001926 \\ P_t(4) &= \binom{30}{4} (1 - 0.1)^{26} (0.1)^4 \approx 0.1771 \end{aligned}$$

Turning the crank, one finds

$$\begin{aligned} P(4) = {} & 0.1309 + 0.05315 \\ & + 0.007416 + 0.0004205 \\ & + .000008164 \ , \end{aligned}$$

or

$$P\left(4\right) \approx 0.1919 \approx 19.19\% \, .$$

To summarize, we found

$$\begin{aligned} P\left(0\right) &= 3.133\% \\ P\left(1\right) &= 11.39\% \\ P\left(2\right) &= 20.15\% \\ P\left(3\right) &= 23.94\% \\ P\left(4\right) &= 19.19\% \, , \end{aligned}$$

which is maximal at $j = 3$. Given that $P\left(4\right)$ begins a downward trend, we can be sure that all subsequent $P\left(j > 4\right)$ are all less than $P\left(3\right)$.

Summing each percentage above, we conclude that there is a 77.80% chance that any number from zero to four devices are in use simultaneously. This means there is a 22.20% chance that any number $5 \leq j \leq 50$ devices are in use simultaneously.

Reading the trend in the $P\left(j\right)$, we estimate that the probability should be less than 1% by say, $j = 10$, thus we define a variable

$$k = 10 \approx 3j^{*} \approx 1 + 9 \, ,$$

which corresponds to one flush valve and nine flush tanks.

For a final flow rate we find

$$D\left(1, 9\right) = 1.04\overline{4} \, \frac{\text{gal}}{\text{s}} \, ,$$

which is about 63 gallons per minute.

Design Factor

To reiterate the last step, one reasons that $P\left(k\right) = 1\%$ corresponds to the worst probable use case. The special value k is also called a *design factor*. For this problem, there is about a 1% chance that more than 10 of the 50 fixtures are operating simultaneously.

16.4 Hunter's Calculation

While adequate, the above calculation is admittedly too detailed for application in the field, especially when there are multiple types of plumbing devices in the system.

To work toward something simpler, separately consider a (i) flush valve, (ii) flush tank, (iii) bathtub having the following characteristics[2]:

- The flush valve conveys 4 gallons over an interval of 9 seconds per use, and is used once every 5 minutes (300 s, twelve uses per hour).
- The flush tank conveys 4 gallons over an interval of 60 seconds per use, and is used once every 5 minutes (300 s, twelve uses per hour).
- A bathtub requires 16 gallons over an interval of 120 seconds, and is used once every 30 minutes (1800 s).

From these, we find that the flush valve operates a total of 108 seconds for every 3600. Thus the probability of any given flush valve being in use is

$$p_v = \frac{108}{3600} = 0.03 \, .$$

Similarly, the flush tank has

$$p_f = \frac{720}{3600} = 0.2 \, ,$$

and finally for the bathtub:

$$p_b = \frac{120}{1800} = 0.06667$$

Then, one can immediately write the probability that x_v flush valves are in use out of V total valves:

$$P_v\left(x_v, V\right) = \binom{V}{x_v} \left(1 - p_v\right)^{V - x_v} p_v^{x_v}$$

From each value V we can derive a most-likely number of valves x_v^{*} in simultaneous use, along with a design factor k_v such that $P\left(k_v, V\right) = 1\%$. The very same can be said for flush tanks by switching indices $v \longrightarrow t$, $V \longrightarrow T$, leading to

$$P_t\left(x_t, T\right) = \binom{T}{x_t} \left(1 - p_t\right)^{V - x_t} p_t^{x_t} \, ,$$

and then switching indices to b, B for bathtubs, we have

$$P_b\left(x_b, B\right) = \binom{B}{x_b} \left(1 - p_b\right)^{V - x_b} p_b^{x_b} \, .$$

Now we must find a design factor for each probability considered. To proceed, choose $V = T = B = 25$ and use a computer to find:

- $P_v\left(x_v, 25\right)$ equals 1% at $k_v = 3.671$
- $P_t\left(x_t, 25\right)$ equals 1% at $k_t = 0.4622$
- $P_b\left(x_b, 25\right)$ equals 1% at $k_b = 5.412$

Using each k-value, calculate the total water demand for each case of 25 fixtures:

$$\begin{aligned} D_v\left(k_v\right) &= 3.671 \left(\frac{4 \text{ gal}}{9 \text{ s}}\right) = 97.89 \, \frac{\text{gal}}{\text{min}} \\ D_t\left(k_v\right) &= 10.16 \left(\frac{4 \text{ gal}}{60 \text{ s}}\right) = 40.64 \, \frac{\text{gal}}{\text{min}} \\ D_b\left(k_b\right) &= 5.412 \left(\frac{8 \text{ gal}}{60 \text{ s}}\right) = 43.30 \, \frac{\text{gal}}{\text{min}} \end{aligned}$$

Repeating for $V = T = B = 50$, find:

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[2] National Bureau of Standards Report: BMS 65 by Late Dr. R. B. Hunter (1940)

- $P_v\left(x_v, 50\right)$ equals 1% at $k_v = 5.194$
- $P_t\left(x_t, 50\right)$ equals 1% at $k_t = 16.72$
- $P_b\left(x_b, 50\right)$ equals 1% at $k_b = 8.139$

Then, for 50 fixtures:

$$D_v\left(k_v\right) = 5.194\left(\frac{4\text{ gal}}{9\text{ s}}\right) = 138.5\,\frac{\text{gal}}{\text{min}}$$

$$D_t\left(k_v\right) = 16.72\left(\frac{4\text{ gal}}{60\text{ s}}\right) = 66.88\,\frac{\text{gal}}{\text{min}}$$

$$D_b\left(k_b\right) = 8.139\left(\frac{8\text{ gal}}{60\text{ s}}\right) = 65.11\,\frac{\text{gal}}{\text{min}}$$

Repeating again for $V = T = B = 75$, find:

- $P_v\left(x_v, 75\right)$ equals 1% at $k_v = 6.509$
- $P_v\left(x_t, 75\right)$ equals 1% at $k_t = 22.84$
- $P_b\left(x_b, 75\right)$ equals 1% at $k_b = 10.58$

Then, for 75 fixtures:

$$D_v\left(k_v\right) = 6.509\left(\frac{4\text{ gal}}{9\text{ s}}\right) = 173.6\,\frac{\text{gal}}{\text{min}}$$

$$D_t\left(k_v\right) = 22.84\left(\frac{4\text{ gal}}{60\text{ s}}\right) = 91.36\,\frac{\text{gal}}{\text{min}}$$

$$D_b\left(k_b\right) = 10.58\left(\frac{8\text{ gal}}{60\text{ s}}\right) = 84.64\,\frac{\text{gal}}{\text{min}}$$

Repeating once more for $V = T = B = 100$, find:

- $P_v\left(x_v, 100\right)$ equals 1% at $k_v = 7.720$
- $P_v\left(x_t, 100\right)$ equals 1% at $k_t = 28.74$
- $P_b\left(x_b, 100\right)$ equals 1% at $k_b = 12.87$

Then, for 100 fixtures:

$$D_v\left(k_v\right) = 7.720\left(\frac{4\text{ gal}}{9\text{ s}}\right) = 205.9\,\frac{\text{gal}}{\text{min}}$$

$$D_t\left(k_v\right) = 28.74\left(\frac{4\text{ gal}}{60\text{ s}}\right) = 115.0\,\frac{\text{gal}}{\text{min}}$$

$$D_b\left(k_b\right) = 12.87\left(\frac{8\text{ gal}}{60\text{ s}}\right) = 103.0\,\frac{\text{gal}}{\text{min}}$$

16.5 Fixture Unit Defined

After suffering (or skipping) the above analysis, it would be efficient to restate all results in table form with assistance from a computer or programmable calculator to crunch the numbers.

Fixture Count v.s. GPM

In the following table, the first column holds a number of fixtures, and the remaining three columns hold the gallons-per-minute (gpm) flow rates through the respective fixtures. This is an extended summary of Hunter's calculation:

Fixture (count)	**Valve** (gpm)	**Tank** (gpm)	**Bath** (gpm)
5	51.65	15.25	20.15
10	66.29	22.58	27.20
15	78.06	29.00	33.08
20	88.41	34.97	38.37
25	97.89	40.64	43.30
50	138.5	68.88	65.11
75	173.6	91.36	84.64
100	205.9	114.9	103.0
125	236.4	138.0	120.5
150	265.8	160.6	137.6
175	294.2	183.0	154.4
200	322.0	205.1	170.8
250	375.8	248.8	202.9
300	428.0	292.1	234.4
350	489.0	334.9	265.4

GPM v.s. Fixture Count

One can derive a similar table with a fixed gpm rate and a variable number of fixtures. Aiming for 50 gal/m, we find (i) $V = 5$ yields $D_v = 51.65$ gal/m, (ii) $T = 34$ yields $D_t = 50.42$ gal/m, (iii) $B = 33$ yields $D_v = 50.68$ gal/m. Together, we jot the ratio 5 : 34 : 33 for flush valves, flush tanks, and bathtubs, respectively. Repeating this for incrementing gpm rates yields the following:

Demand (gpm)	**Valve** (count)	**Tank** (count)	**Bath** (count)
50	5	34	33
100	27	85	96
150	58	139	169
200	96	195	246
250	137	252	326
300	181	310	407

The relationship between the flow rate in gallons per minute and total fixture count is more-or-less linear for each fixture type in the domain 150 gpm to 300 gpm, thus we will toss out any data outside this window.

GPM v.s. Flush Valve Ratio

The next move is to express all fixtures in terms of the flush valve as Hunter did. Going across each row, divide the respective numbers of flush tanks and bathtubs by the number of flush valves. Also divide the number of flush valves by itself to attain 1. Doing so yields:

Demand (gpm)	Valve (ratio)	Tank (ratio)	Bath (ratio)
150	1	2.397	2.914
200	1	2.031	2.563
250	1	1.839	2.380
300	1	1.713	2.249
(Average:)	(1)	(1.995)	(2.523)

Interpreting the bottom row, we reason that it would require 10 flush valves to meet the same gpm demand as about 5 flush tanks (because $1.995 \times 5 \approx 10$). Similarly, the same 10 flush valves are equivalent to 4 bathtubs (because $2.523 \times 4 \approx 10$).

The numbers 10, 5, 4 are the respective *fixture units*, abbreviated FU, for the flush valve, flush tank, and bathtub, respectively.

Better Definition

We have proven that **any plumbing fixture is characterized by one or more fixture units, a dimensionless number informed by the fixture's volume through-rate and probability/duration of use. The total gpm demand of multiple fixtures is not the sum gpm demand of each fixture. Rather, count the total fixture units and use Hunter's curve (or equivalent chart) to determine total gpm demand.**

Corollary

The fixture unit does *not* differentiate between water supply versus waste drainage. This is because in a typical building, the average water supply is equal to the average waste drainage (minus whatever passes through things like roof drains.)

To accomodate exceptions to the above, it's prudent to differentiate between water supply fixture units (WSFU) versus waste drainage fixture units (DFU). Fixture unit values tend to vary in each regime, as the conditions and contents of a given pipe may factor into that pipe's ability to pass volume through the system.

Plumbers have derived or inherited various prejudices against the universality of 'fixture unit' and have adopted their own terms. CMR 10.14 offers the term 'factor value' for water supply, however this term is not defined in CMR 10.03. Meanwhile, 'fixture unit' is seemingly reserved for waste and drainage.

Forensics

Reviewing the definitions that brought us here, it appears that *International Plumbing Code*, *ICC A117.1-2017* contains no inaccuracies, but also skimps elaboration on what 'kind' of measure to which the definition alludes.

Meanwhile, in *IAMPO/ANSI 1 - 2021*, *Uniform Plumbing Code*, the allusion to 'some arbitrarily chosen scale' in should be clear at this point. They mean Hunter's curve (See Figure 1.19).

What are we to do with the definition listed in CMR 10? Back to flush valves... The modern flush valve, according to CMR 10.15, is classified as *Toilet, Valve Operated*, assigned to have 6 fixture units. Accordingly, such a modern valve conveys $\approx$ 1.5 gallons over 6 seconds. Thus we deduce that one fixture unit corresponds to 0.25 gallons conveyed over one second, or 15 gallons per minute. Up to a factor of ≈ 2, this reproduces CMR 10.03's definition.

Note, of course, that the 1.25 inch diameter pipe mentioned in CMR 10 never entered the analysis, and is nothing more than a distraction.

16.6 Hunter's Curve

Fixture unit calculations were originally carried out by Roy B. Hunter in the years leading to 1940 and published by the *National Bureau of Standards Report: BMS 65*.

Using 10, 5, 4 as scale factors, recast the 'gpm vs. count' table by multiplying all V by 10, all T by 5, and all B by 4. This produces an equivalent table with fixture counts replaced by fixture units:

Demand (gpm)	Valve (FU)	Tank (FU)	Bath (FU)
150	580	695	676
200	960	975	984
250	1370	1260	1304
300	1810	1550	1628

Extending the table above and plotting the information on a graph, much as Hunter did, leads to Figure 1.18. Using the Figure, Hunter reasoned:

'...the error made by using curve 2 for both flush tanks and bathtubs for any number of either up to 300 would be small. Also, the demand load relative to the number of fixture units may be approximately represented in this range by a smoother curve drawn above the two probability curves and merged with curve 1 as shown by the broken line in [the] Figure...'

That is, curve 2 and curve 3 are essentially interchangeable before the broken line, and then the broken line takes over for curves 2 and 3 until joining curve 1, giving rise to Figure 1.19. The result is called called *Hunter's Curve*.

Demand vs Fixture Units

Finally, we summarize the information in Hunter's curve using the tables that follow.

Demand (Load) (FU)	**Valve** (gpm)	**Tank** (gpm)
10	32.82	9.63
20	39.09	13.56
30	43.92	18.49*
40	48.02	27.20
50	51.65	30.24
60	54.97	33.08
70	58.04	35.78
80	60.93	38.37
90	63.67	40.87

Before the asterisk we derive values from curve 2. At the asterisk we use the average of curves 2 and 3. After the asterisk we use curve 3 and throughout the next table.

Demand (Load) (FU)	**Valve** (gpm)	**Tank** (gpm)
100	66.29	43.30
140	75.84	52.45
180	84.40	61.00
200	88.41	65.11
250	97.89	75.05
300	106.8	84.60
400	123.2	102.9
500	138.5	120.5
750	173.6	162.6

After ≈ 1000 fixture units, all values are represented by curve 1.

Demand (Load) (FU)	**Valve** (gpm)	**Tank** (gpm)
1000	205.9	205.1
1250	236.4	236.4
1500	265.8	265.8
1750	294.2	294.2
2000	322.0	322.0
2500	375.8	375.8
3000	428.0	428.0
4000	529.0	529.0
5000	626.8	626.8

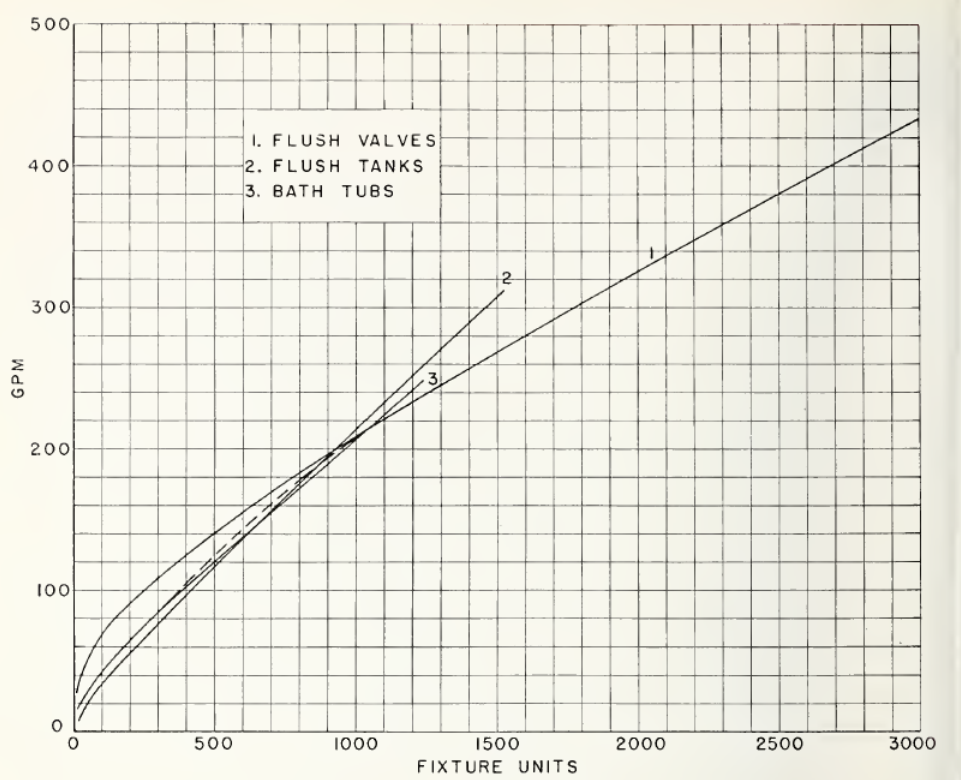

Figure 1.17. Gallons per minute versus fixture unit count for flush valves, flush tanks, and bathtubs. (*National Bureau of Standards Report: BMS 65*, 1940)

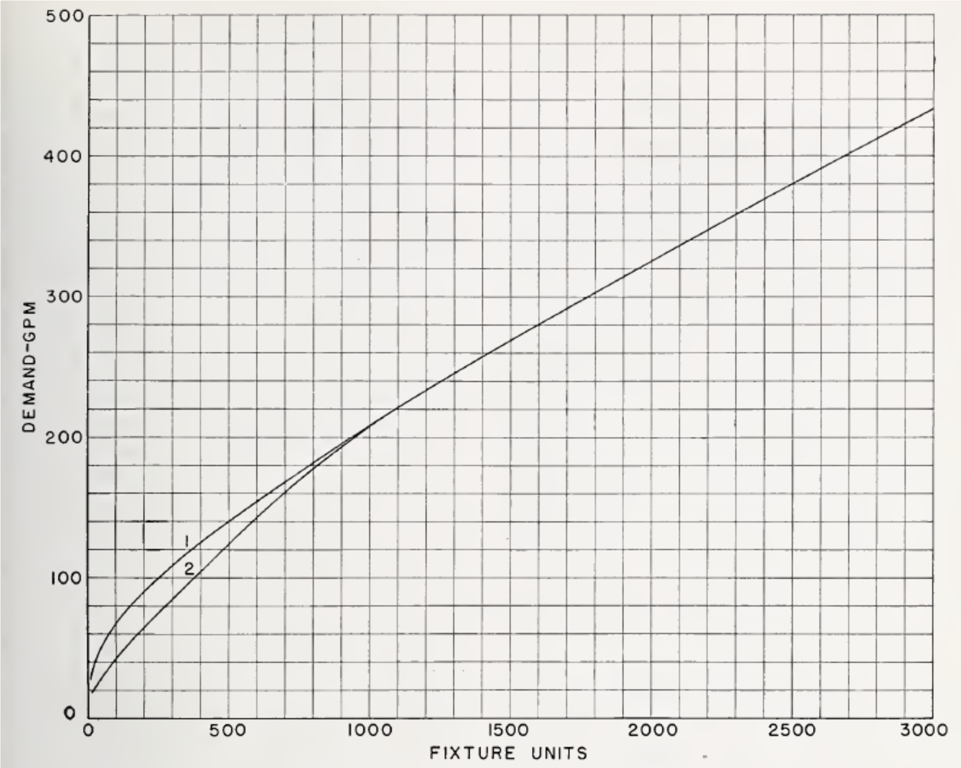

Figure 1.18. Hunter's Curve. (*National Bureau of Standards Report: BMS 65*, 1940)

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17 Gas Pipe Sizing

17.1 Pipe Sizing Equations

In Revision 12/8/23 of CMR 10, the term ‘gas’ occurs 165 times. The term ‘pipe’ occurs 327 times. The combination ‘gas pipe’ occurs 0 times. Instead, one’s first impression of gas pipe sizing must come from elsewhere, such as *NFPA ANSI Z223.1*, Chapter 6.

In this, the reader is alerted that *where the pipe size is to be determined using any of the three methods in 6.1.1 through 6.1.3, the diameter of each pipe segment shall be obtained from the pipe sizing tables in Section 6.2 or Section 6.3 or from the sizing equations in Section 6.4.*

The so-called three methods are the (i) longest length method, (ii) branch length method, (iii) and hybrid pressure method. Each heuristic varies slightly from the others and each may return different answer for the same input.

There do exist other methods of gas pipe sizing, including the less-often used ‘pressure drop per 100 feet’ method. Things also get wooly when adding new fixtures to existing systems. The going advice is when one calculation method gives an undesirable answer, try a different method.

Low Pressure Gas Formula

Appearing as item `6.4.1` is the *low pressure gas formula*, which describes gases below a pressure of 1.5 psi, or 10.3 kPa:

$$D = \frac{Q^{0.381}}{19.17\left(\Delta H/(Cr \cdot L)\right)^{0.206}} \tag{1.3}$$

In the above: (i) D is the inner diameter of the pipe measured in inches. (ii) Q is the volumetric flow rate through a pipe measured in cubic feet per hour in standard conditions. (iii) ΔH is a pressure drop measured in inches of water column. (This is a confusing unit that we’ll have to take on below.) (iv) L is the length of pipe measured in feet.

The terms Cr, and as we’ll also see, Y are uncolorfully called *formula factors*. Natural gas has $Cr = 0.6094$ and $Y = 0.9992$. Undiluted propane has $Cr = 1.2462$ and $Y = 0.9910$.

High Pressure Gas Formula

A variation on the low pressure gas formula is the *high pressure gas formula*, valid for pressures higher than pressure of 1.5 psi, or 10.3 kPa:

$$D = \frac{Q^{0.381}}{18.93\left(\left(P_1^2 - P_2^2\right)Y/(Cr \cdot L)\right)^{0.206}} \tag{1.4}$$

The terms P_1, P_2 are the respective upstream and downstream pressures, measured in psia.

One should feel suspicious when an equation contains any baked-in decimals, especially in exponents. It’s irresistible, then, to figure out where the low- and high pressure gas equations come from.

17.2 Derivation of Formulas

The equations for gas pipe sizing originate from undergraduate-level thermodynamics. Particularly, we work within the *incompressible fluid* regime, in where the mass per unit volume is constant. Going for a minimalist derivation, we lay out only the important terms in what follows.

Hydraulic Diameter

Consider the motion of incompressible fluid through a straight pipe with cross sectional area A. For a notion of pipe diameter, define the *hydraulic diameter* D_H as

$$D_H = \frac{4A}{P} \,,$$

where P is the perimeter of the pipe. For the case of cylindrical pipes, we have

$$D_H = \frac{4\pi D^2}{4\pi D} = D \,,$$

which is just the circular diameter.

Volumetric Flow

Define the *wetted area* A_W as the portion of the cross-sectional area that is in contact with the moving fluid, i.e. the water flowing on the bottom of a pipe. The *volumetric flow*, denoted Q, is defined as

$$Q = A_W \left\langle v \right\rangle \,,$$

where $\langle v \rangle = v$ is the mean velocity of the fluid. Since gas occupies its entire container, we take A_W as the pipe’s inner surface area, namely $\pi D L$, where L is the length.

Frictional Resistance

A model for the force of friction imposed on a moving fluid is attributed to Froude, providing the formula

$$F_R = f' \times A_W \times v^2 \,.$$

The coefficient f' is the frictional force per unit area with units to balance the v^2-term.

Bernoulli's Principle

A handy notion that we understand in terms of Newtonian laws and energy conservation is the famed *Bernoulli's principle*, stating that *for an incompressible fluid, the sum of its potential energy, pressure, and velocity remains constant.*

In the context of fluid moving through a pipe, one can expect that the effect of friction causes a loss of pressure ΔP between two given points in the pipe. Generally, one may write

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = \Delta P + P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \,,$$

which accounts for the kinetic, gravitational potential, and pressure terms responsible for the motion of the fluid from point '1' to point '2'.

Head Loss

A quantity

$$H_f = \frac{\Delta P}{\rho g} \,,$$

called the *head loss* is used to characterize the drop in pressure along a length of pipe. Dimensionally, we have

$$\left[H_f\right] = \frac{\text{kg m}}{\text{s}^2\,\text{m}^2}\frac{\text{m}^3\,\text{s}^2}{\text{kg m}} = \text{m} \,,$$

i.e. pressure is interpreted as length (of water displaced in a column, for instance).

Darcy-Weisbach Equation

The effect of friction on a fluid moving in a pipe is characterized by the dimensionless *Darcy friction factor*, denoted f. To motivate this, consider the uniform motion of fluid at velocity v through a circular pipe of cross-sectional area A. With zero net acceleration, we use Newton's second law to establish

$$A\Delta P - F_R = 0 \,,$$

or after simplifying,

$$H_f = \frac{f'}{\rho g}\frac{4}{D}Lv^2 \,.$$

The combination f'/ρ is dimensionless, which we take as proportional to the coefficient of friction for fluid moving through the pipe. To keep consistent with common literature on the topic, define

$$f = \frac{8f'}{\rho}$$

so the above is finally written

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

known as the Darcy-Weisbach equation.

In terms of volumetric flow, the same equation is written

$$H_f = f\frac{8L}{\pi^2 g}\frac{Q^2}{D^5} \,.$$

If solving for the diameter of pipe involved, one has:

$$D = \left(\frac{f}{H_f}\frac{8L}{\pi^2 g}\right)^{1/5} Q^{2/5} \qquad (1.5)$$

From analysis alone, equation (1.5) is the closest we will get to the low- and high pressure gas Equations (1.3), (1.4).

Laminar Flow (Optional)

For the case of laminar flow, it can be shown that the friction factor f is exactly

$$f = \frac{64}{\text{Re}} \,,$$

where Re is the *Reynold's number*, defined as

$$\text{Re} = \frac{\rho D}{\mu}\left\langle v\right\rangle \,,$$

where μ is the viscosity of the fluid.

Engineering Fudge Factors

In terms of Q, H_f, L, the diameter of the pipe, according to Darcy-Weisbach via Euation (1.5), can be written

$$D = A \times Q^{0.4} H_f^{-0.2} L^{0.2} \,,$$

where A is a factor not depending on Q, H_f, L.

Taking, for instance, the low pressure gas forumla and comparing coefficients, we see that the term 0.4 has been tweaked to 0.381, whereas 0.2 became 0.206, and so on. The high pressure gas formula, particularly the dependence on P^{-2} rather than P^{-1}, is the product of playing similar games with the equations of physics.

17.3 Fixture Demand

The reason we concern about gas pipe sizing is to supply enough fuel to each consuming fixture while not oversizing all supply lines to the point of hazard or waste.

A gas fixture's 'demand' is characterized by the average energy spent over time, measured in British thermal units per hour. Note that energy over time is formally equivalent to 'power'.

In the following we list several natural gas-consuming fixtures with the respective energy consumption rate. Numeric values are hashed together from a variety of teaching and real-world sources. All are subject to change. (The term 'domestic' is abbreviated as 'dom.')

- Dryer (clothing, dom.) (30-35 kBtu/hr)
- Fireplace (direct vent.) (30-40 kBtu/hr)
- Furnace (100 kBtu/hr)
- Hydronic boiler (dom.) (100-120 kBtu/hr)
- Pool Heater (4 gal./min.) (285 kBtu/hr)
- Stove (freestanding range, dom.) (65 kBtu/hr)
- Water Heater (40 gal. dom.) (35-40 kBtu/hr)
- Water Heater (50 gal. dom.) (50 kBtu/hr)

Calorific Value

Gas-consuming fixtures are usually characterized by energy consumption rate in British thermal units per hour. However this information is often reported as the volume of gas consumed in cubic feet per hour (`cfh`). To convert between the amount of energy (Btu) in a gas and the cubic-foot volume (ft^3) of the gas, one needs to know the *calorific value* of the gas.

By a conspiracy between engineers and God, it just happens that the calorific value of natural gas is about one thousand British thermal units per cubic foot:

$$\text{C.V. of natural gas} \approx 1000\ \text{Btu}/\text{ft}^3$$

For this reason, we can usually fudge the unit kBtu/hr as being effectively equal to ft^3/hr. Of course, the calorific value depends on a few variables that, for our purposes, are held standard and are baked into the number 1000.

Such a shortcut doesn't work for other gases such as propane, or even natural gas under different conditions. Some texts and manuals use the calorific value of $1100\ \text{Btu}/\text{ft}^3$. Using this, we may convert some number X Btu/hr into Y cubic feet per hour by writing:

$$Y = \frac{X\,\cancel{\text{Btu}}/\text{hr}}{1100\,\cancel{\text{Btu}}/\text{ft}^3} = \frac{X}{1100}\,\frac{\text{ft}^3}{\text{hr}}$$

17.4 Schematics

Any gas distribution system can be represented in a diagram, usually two-dimensional, much like a schematic for an electric circuit. The so-called pipe sizing schematic contains at least one point of delivery for gas service, along with all gas-consuming fixtures represented as locations.

Connecting the point(s) of service to all fixtures is a network of pipes represented as lines as shown in Figure 1.20.

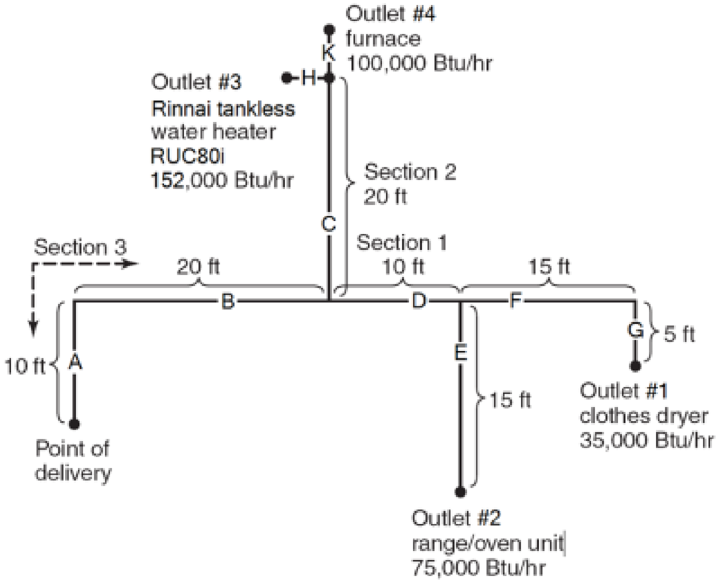

Figure 1.19. Sample gas distribution schematic. (*Rinnai Technical Bulletin 111-1/2". Gas Line Piping Information.* [a])

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[a] All Information was obtained from National Fuel Gas Code, NFPA54, ANSI Z223.1.

It's not clear whether the Rinnai company originated the diagram published. The *2010 Oregon Mechanical Specialty Code*, in Appendix C-A, offers a suspisciously similar schematic shown in Figure 1.21.

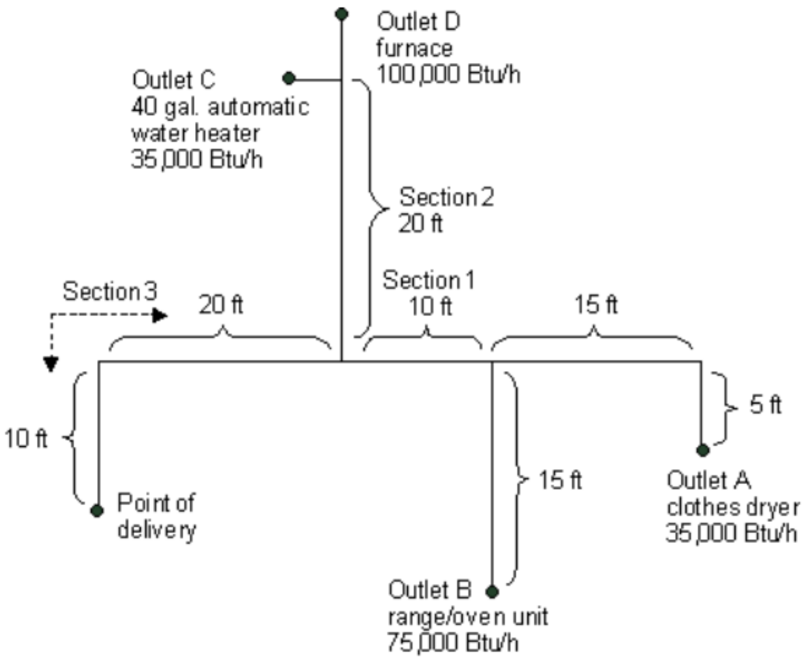


Figure 1.20. Sample gas distribution schematic. (*2010 Oregon Mechanical Specialty Code. Figure C-A.7.1. Piping Plan Showing a Steel Piping System*)

A very similar diagram appears in the literature of El Dorado County, California as shown in Figure 1.22. The engineers responsible for these diagrams must have cheated off the same guy.

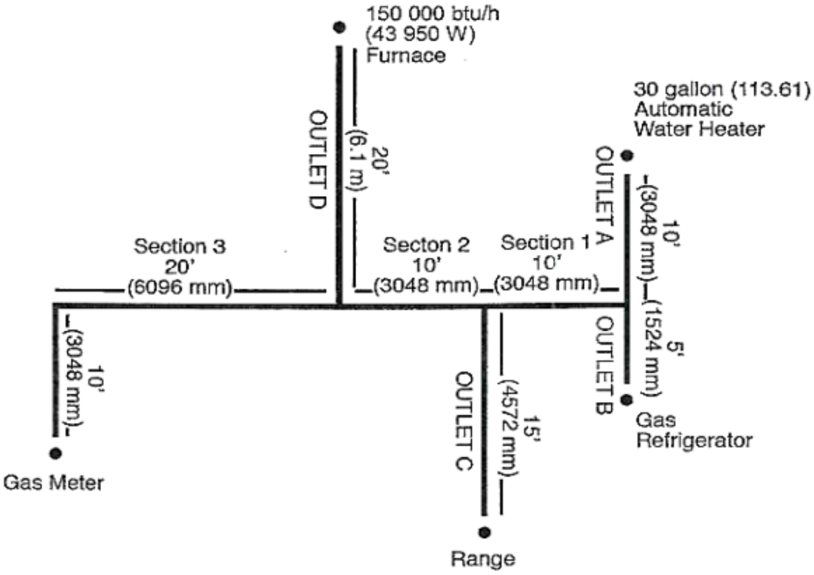


Figure 1.21. Sample gas distribution schematic. (*El Dorado County, CA. GAS PIPE LINE CALCULATION SIZING. Figure A*)

Some new symbols for the gas meter, distribution manifold, shut-off valve, and pressure regulator are shown in Figures 1.23-1.24. In each Figure, the fixture demands are listed in cubic feet per hour rather than British thermal units per hour. (Beware this difference!)

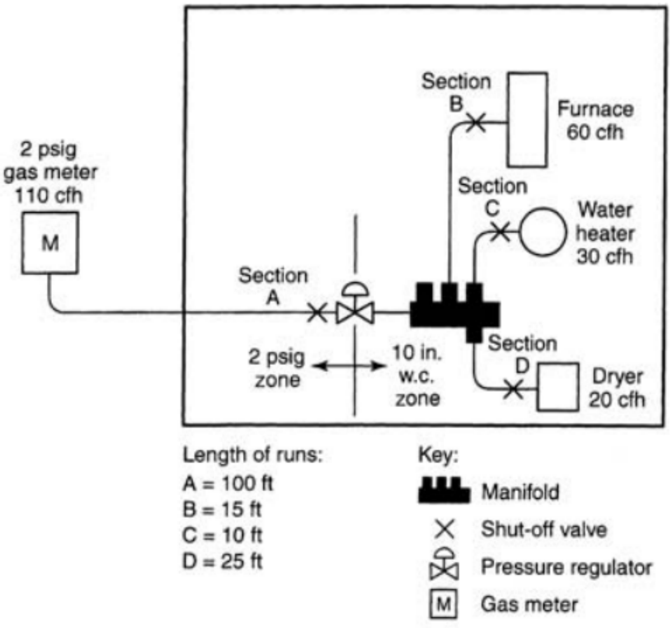


Figure 1.22. Sample gas distribution schematic. (*2010 Oregon Mechanical Specialty Code. Figure C-A.7.2. Piping Plan Showing a CSST System*)

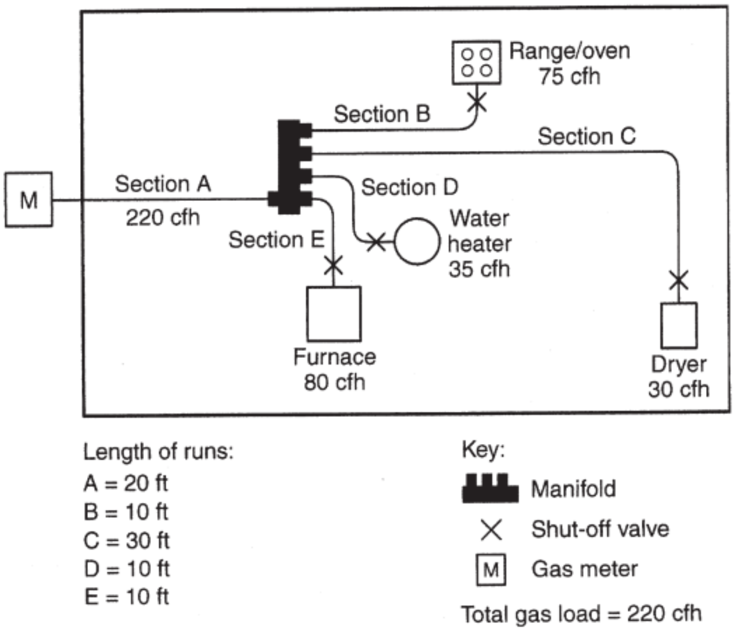


Figure 1.23. Sample gas distribution schematic. (*2010 Oregon Mechanical Specialty Code. Figure C-A.7.3. Piping Plan Showing a Copper Tubing System*)

17.5 Preparing a Schematic

When confronted with a gas pipe sizing problem, the diagram is everything. However, these may be handed to you with too much or too little information on the page. To make a clean preparation, let us do some edits on Figure 1.21 (example alpha) and Figure 1.22 (example beta).

For starters, ignore any extraneous information such as 'section' number. The point of delivery is denoted `M` (for meter) with an arrow indicating direction of flow as shown in Figures 1.25, 1.26.

Label all Fixtures (A, B, C, ...)

If not present in the schematic, write the resource demand in ft^3/hr or kBtu/hr of each fixture. Each fixture, or 'outlet', should take a unique label such as A, B, C, etc.

Label all Tees (X, Y, Z, ...)

It also helps to label each tee connection in the system with a different grouping of letters than those reseved for fixtures. For these, it suffices to use the labels X, Y, Z, etc.

Label the Meter (M)

Apart from 'M' standing for 'meter', it's convenient that 'M' stands in the middle of the alphabet, dividing fixtures (A, B, ...) from tees (X, Y, ...).

Turns and Couplings

For our purposes, there is no need to label any ninety-degree connections or similar. The pipe diameter is assumed constant across such fittings.

However, when there are a large number of accessories involved, i.e. elbows, valves, etc., there is reason to account for the friction introduced at each. In a sentence, the effect of a given accessory is characterized by the some length of pipe that would impose the same effect as the accessory.

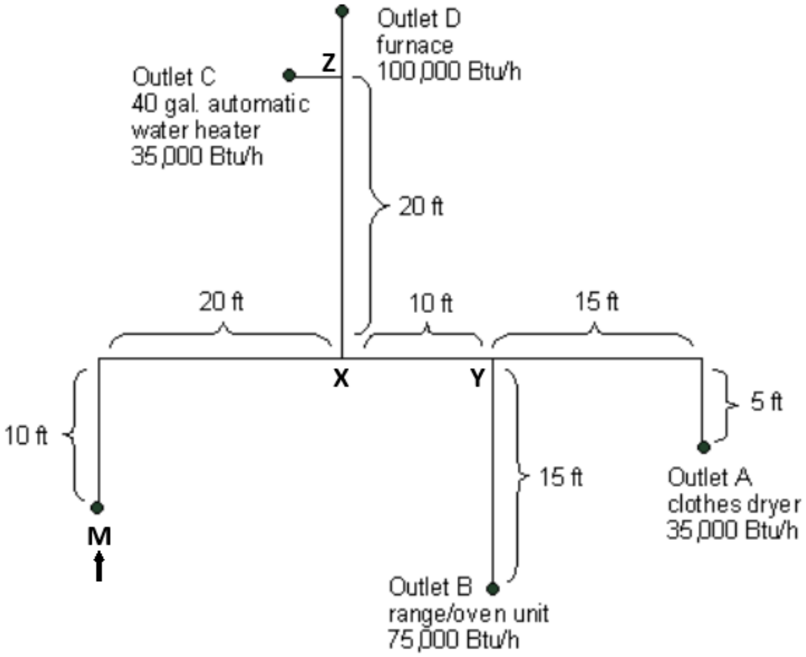


Figure 1.24. Example alpha: Sample schematic (Figure 1.21) prepared for pipe sizing.

Worksheet alpha				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	60	35 from Y using ?	-	-
B	55	75 from Y using ?	-	-
C	50	35 from Z using ?	-	-
D	50	100 from Z using ?	-	-
M	0	-	245 to X	-
X	30	245 from M using ?	110 to Y	135 to Z
Y	40	110 from X using ?	35 to A	75 to B
Z	50	135 from X using ?	35 to C	100 to D

Table 1.1. Example alpha worksheet: Representation of Figure 1.25.

Prepare Worksheet

Before choosing any sizing method, it's helpful to determine all pertinent lengths and flow rates throughout the system. This can be done on the schematic itself, however we'll develop the habit of capturing schematics like Figure 1.25 in worksheet form as shown. (Note fixtures C and D are each directly connected to Z. That is, each is located 20 ft from X.)

Reading the worksheet, one observes:

- The worksheet encodes the essential information on the schamatic.
- The objective is to turn question marks (?) into pipe diameters in inches.
- The 'Input', 'Out 1', and 'Out 2' columns are reported in ft^3/hr, i.e. cfh.
- The sum of all fixture inputs equals the meter output.
- For a given tee connection, the input equals the sum of the outputs.
- The words 'to' and 'from' occur in equal numbers.
- The input to the meter and the output from each fixture is ignored.

Performing a similar task on the second example (beta) gives rise to Figure 1.26 and the corresponding worksheet:

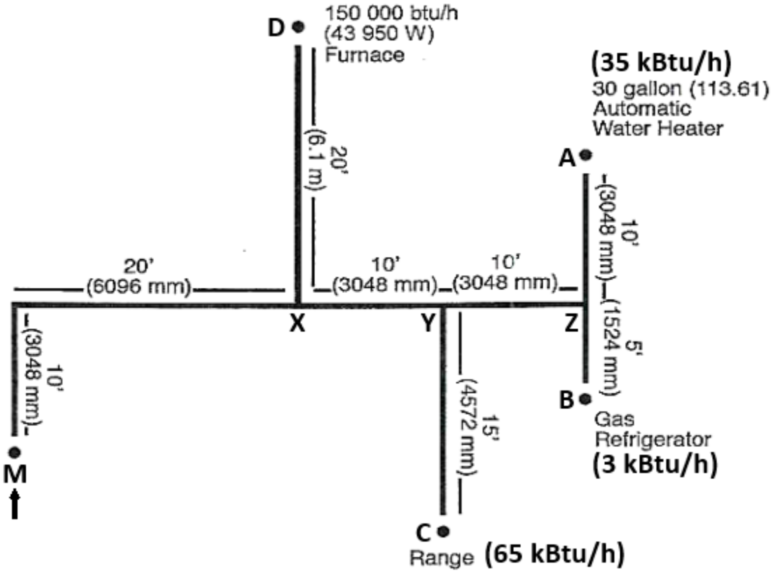


Figure 1.25. Example beta: Sample schematic (Figure 1.22) prepared for pipe sizing.

Worksheet beta				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	60	35 from Z using ?	-	-
B	55	3 from Z using ?	-	-
C	55	65 from Y using ?	-	-
D	50	150 from X using ?	-	-
M	0	-	253 to X	-
X	30	253 from M using ?	150 to D	103 to Y
Y	40	103 from X using ?	65 to C	38 to Z
Z	50	38 from Y using ?	35 to A	3 to B

Table 1.2. Example beta worksheet: Representation of Figure 1.26.

To prepare another schematic (example gamma), we turn to the *Plumbing-Heating-Cooling Contractors of Massachusetts*, or *PHCC*, for a study guide called *Introduction: PSI Exams*. Figure 1.27 contains a gas pipe sizing problem adapted from Slide 291. All fixtures, tees, and pipe lengths are labeled.

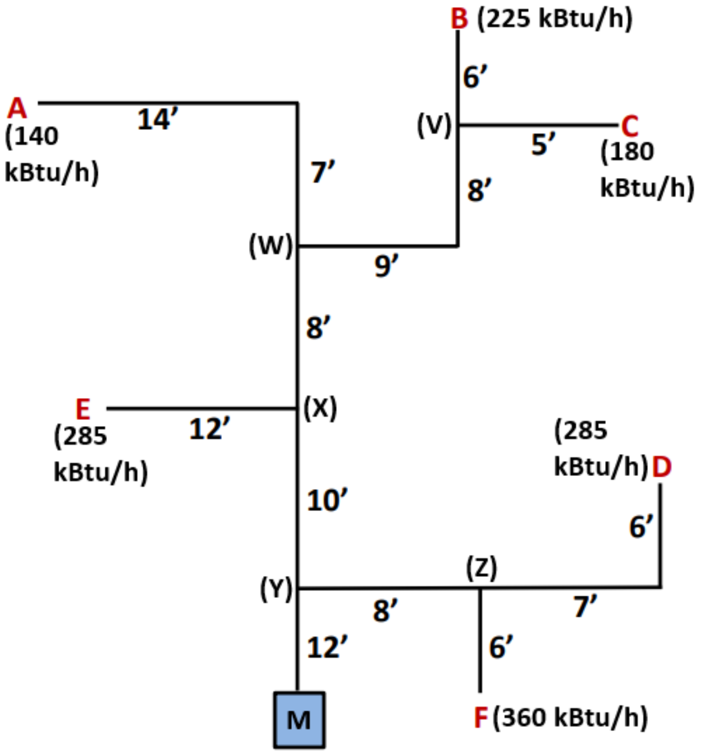


Figure 1.26. Example gamma: Sample schematic perpared for pipe sizing. Adapted from *PHCC. Introduction: PSI Exams. Slide 291*.

Worksheet gamma				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	51	140 from W using ?	-	-
B	53	225 from V using ?	-	-
C	52	180 from V using ?	-	-
D	33	285 from Z using ?	-	-
E	34	285 from X using ?	-	-
F	26	360 from Z using ?	-	-
M	0	-	1475 to Y	-
V	47	405 from W using ?	225 to B	180 to C
W	30	545 from X using ?	140 to A	405 to V
X	22	830 from Y using ?	285 to E	545 to W
Y	12	1475 from M using ?	830 to X	645 to Z
Z	20	645 from Y using ?	285 to D	360 to F

Table 1.3. Example gamma worksheet: Representation of Figure 1.27.

In each example above (alpha, beta, gamma), assume all pipes carry natural gas under conditions consistent with *ANSI Z223.1*, Table 6.2(b). Schedule 40 Metallic Pipe. (See Figure 1.28.)

17.6 Pipe Sizing Charts

Throughout *ANSI Z223.1* are various pipe sizing charts for natural gas in various conditions. The reason for having charts is to save the plumber from directly applying Equations (1.3) and (1.4) in the field.

Header

Shown in Figures 1.28, 1.29 are samples from *ANSI Z223.1*, indicitave of all Tables. Every bit of information on a Table is relevant, especially the header.

Before considering the body of the chart, the header contains six bits of information (reading from Table 6.2(b) in Figure 1.28):

- Title, Table 6.2(b).
- Material to be used: sch. 40 metallic
- Type of gas: natural
- Inlet pressure: less than 2 psi
- Pressure drop: 0.5 in. w. c. (This is the head loss H_f.)
- Specific gravity: 0.60 (Specific gravity is the ratio of the density of gas to the density of atmosphere.)

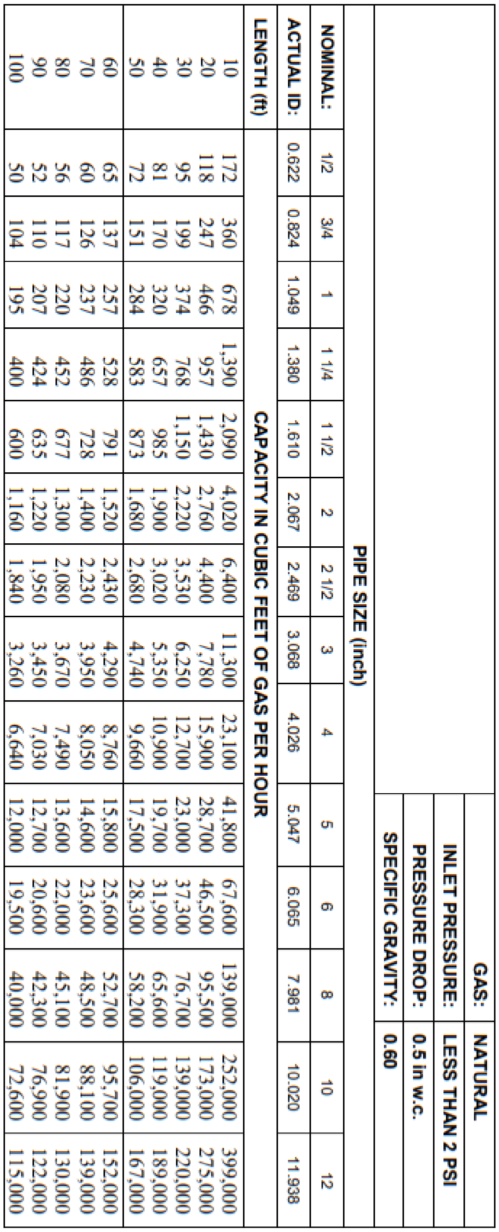
Note the inlet pressure is below 2 psi, thus we assume the low pressure gas formula will be behind the numbers.

Axes

The axes of all Tables have pipe length charted vertically and pipe diameter charted horizontally. As for pipe diameter, we tend to ignore the 'Actual ID' row, reading instead from the 'nominal' row.

Body

Any cell in the body of the Table is some number measured in $\mathrm{ft}^3/\mathrm{hr}$, which, for natural gas, is sometimes interchangeable with kBtu/hr. For a given demand, read to the left axis for the pipe length, and read to the top axis for the pipe diameter.



GAS: NATURAL
INLET PRESSURE: LESS THAN 2 PSI
PRESSURE DROP: 0.5 in w.c.
SPECIFIC GRAVITY: 0.60

	PIPE SIZE (inch)												
NOMINAL:	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4	5	6	8	10	12
ACTUAL ID:	0.622	0.824	1.049	1.380	1.610	2.067	2.469	3.068	4.026	5.047	6.065	7.981	10.020	11.938
LENGTH (ft)	CAPACITY IN CUBIC FEET OF GAS PER HOUR													
10	172	360	678	1,390	2,090	4,020	6,400	11,300	23,100	41,800	67,600	139,000	252,000	399,000
20	118	247	466	957	1,430	2,760	4,400	7,780	15,900	28,700	46,500	95,500	173,000	275,000
30	95	199	374	768	1,150	2,220	3,530	6,250	12,700	23,000	37,300	76,700	139,000	220,000
40	81	170	320	657	985	1,900	3,020	5,350	10,900	19,700	31,900	65,600	119,000	189,000
50	72	151	284	583	873	1,680	2,680	4,740	9,660	17,500	28,300	58,200	106,000	167,000
60	65	137	257	528	791	1,520	2,430	4,290	8,760	15,800	25,600	52,700	95,700	152,000
70	60	126	237	486	728	1,400	2,230	3,950	8,050	14,600	23,600	48,500	88,100	139,000
80	56	117	220	452	677	1,300	2,080	3,670	7,490	13,600	22,000	45,100	81,900	130,000
90	52	110	207	424	635	1,220	1,950	3,450	7,030	12,700	20,600	42,300	76,900	122,000
100	50	104	195	400	600	1,160	1,840	3,260	6,640	12,000	19,500	40,000	72,600	115,000

Figure 1.27. Sample from *ANSI Z223.1*, Chapter 6. Table 6.2(b). Schedule 40 Metallic Pipe.

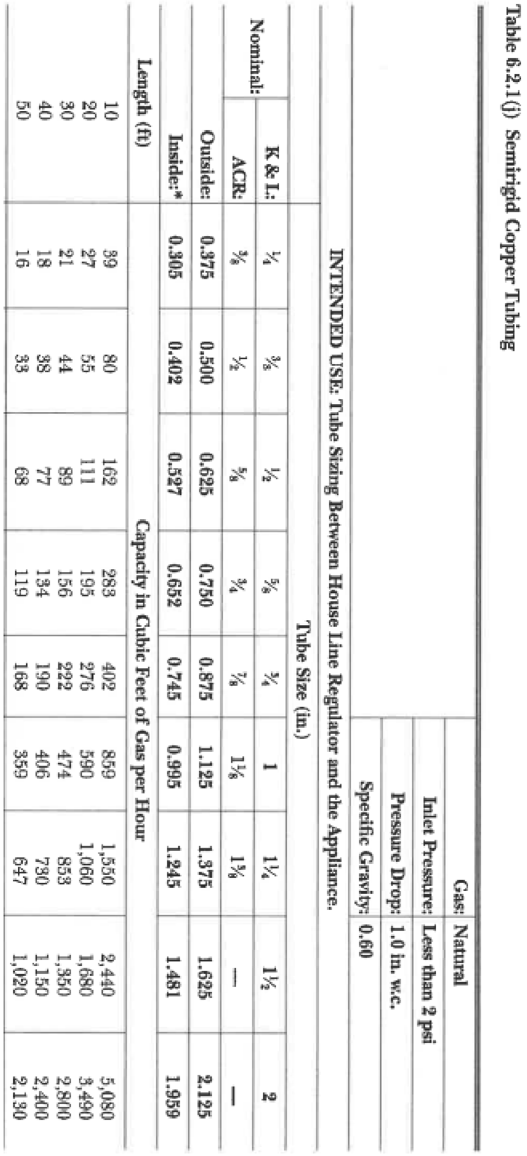


Table 6.2.1(j) Semirigid Copper Tubing

Gas:	Natural
Inlet Pressure:	Less than 2 psi
Pressure Drop:	1.0 in. w.c.
Specific Gravity:	0.60

INTENDED USE: Tube Sizing Between House Line Regulator and the Appliance.

		Tube Size (in.)								
Nominal:	K & L:	1/4	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	2
	ACR:	3/8	1/2	5/8	3/4	7/8	1 1/8	1 3/8	—	—
	Outside:	0.375	0.500	0.625	0.750	0.875	1.125	1.375	1.625	2.125
	Inside:*	0.305	0.402	0.527	0.652	0.745	0.995	1.245	1.481	1.959
Length (ft)		Capacity in Cubic Feet of Gas per Hour								
10		39	80	162	283	402	859	1,550	2,440	5,080
20		27	55	111	195	276	590	1,060	1,680	3,490
30		21	44	89	156	222	474	853	1,350	2,800
40		18	38	77	134	190	406	730	1,150	2,400
50		16	33	68	119	168	359	647	1,020	2,130

Figure 1.28. Sample from *ANSI Z223.1*, Chapter 6. Table 6.2.1(j). Semirigid Copper Tubing.

17.7 Longest Length Method

Quoting directly from *ANSI Z223.1*, Chapter 6, the longest length method is stated as:

> The pipe size of each section of gas piping shall be determined using the longest length of piping from the point of delivery to the most remote outlet and the load of the section.

Implementing the longest length method goes as follows:

1. Determine which fixture is furthest distance from the meter in developed length. This is the so-called longest length. (This is also the last time you count distances to fixtures in this method.)
2. Determine the total ft^3/hr demand of each fixture and of the whole system. (Convert from kBtu/hr if necessary.)
3. In the appropriate Table such as 6.2(b), read down the left column until finding the longest length from Step 1. Round your search to the next row if necessary, but never round down in pipe size.
4. Staying in the longest length row, read across the Table until finding the total ft^3/hr demand from Step 2. Round your total up to the next column if necessary.
5. At this step you're pointing at one cell in the body of the Table. The header of the column indicates the diameter of the gas pipe leaving the meter.
6. All other pipe sizes are derived from the *same* row in the Table. To size any given pipe segment, determine the total demand at the end of that segment and read the Table as done in Steps 3-5.
7. Tip: Deal with all fixtures first. Then treat tee fittings as if they're fixtures.

Worked Example: Alpha

Apply the longest length method to example alpha represented in Figure 1.25. The two pipes leaving Z are assumed to have negligible length.

Referencing the Figure (namely the worksheet beneath it), the longest length corresponds to outlet A at 60 ft from meter. The total demand of the system is 245 ft^3/hr. (Steps 1 and 2.)

Looking in the Table 6.2(b) for a length of 60 ft and a demand of 245 ft^3/hr leads to the cell labeled 257 ft^3/hr. The header of this column indicates 1 inch. The pipe diameter leaving the meter is 1 inch. (Steps 3, 4, and 5.)

In ft^3/hr, the fixtures A, B, C, D receive 35, 75, 35, 100 respectively. Staying in the 60 ft row of the Table, we straightforwardly read off the diameters going to each fixture. In inches, the results are 1/2, 3/4, 1/2, 3/4.

The tee labeled X receives 245 ft^3/hr. Looking in the Table for a length of 60 ft and a demand of 245 ft^3/hr leads to the cell labeled 257 ft^3/hr. The header of this column indicates 1 inch. The pipe diameter entering X from M is 1 inch.

The tee labeled Y receives 110 ft^3/hr. Looking in the Table for a length of 60 ft and a demand of 110 ft^3/hr leads to the cell labeled 137 ft^3/hr. The header of this column indicates 3/4 inch. The pipe diameter entering Y from X is 3/4 inch.

The tee labeled Z receives 135 ft^3/hr. Looking in the Table for a length of 60 ft and a demand of 135 ft^3/hr leads to the cell labeled 137 ft^3/hr. The header of this column indicates 3/4 inch. The pipe diameter entering Z from X is 3/4 inch.

All pipes are now sized and the problem is solved. The updated worksheet is as follows:

Worksheet alpha: Longest length method (using Table 6.2(b))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	60	35 from Y using 1/2 in	-	-
B	55	75 from Y using 3/4 in	-	-
C	50	35 from Z using 1/2 in	-	-
D	50	100 from Z using 3/4 in	-	-
M	0	-	245 to X	-
X	30	245 from M using 1 in	110 to Y	135 to Z
Y	40	110 from X using 3/4 in	35 to A	75 to B
Z	50	135 from X using 3/4 in	35 to C	100 to D

Worked Example: Beta

Apply the longest length method to example beta represented in Figure 1.26.

Referencing the Figure (namely the worksheet beneath it), the longest length corresponds to outlet A at 60 ft from meter. The total demand of the system is 253 ft^3/hr. (Steps 1 and 2.)

Looking in the Table 6.2(b) for a length of 60 ft and a demand of 253 ft^3/hr leads to the cell labeled 257 ft^3/hr. The header of this column indicates 1 inch. (Steps 3, 4, and 5.) The pipe diameter leaving the meter is 1 inch.

In ft^3/hr, the fixtures A, B, C, D receive 35, 3, 65, 150 respectively. Staying in the 60 ft row of the Table, we straightforwardly read off the diameters going to each fixture. In inches, the results are 1/2, 1/2, 1/2, 1.

The tee labeled X receives 253 ft^3/hr. Looking in the Table for a length of 60 ft and a demand of 253 ft^3/hr leads to the cell labeled 257 ft^3/hr. The header of this column indicates 1 inch. The pipe diameter entering X from M is 1 inch.

The tee labeled Y receives 103 ft^3/hr. Looking in the Table for a length of 60 ft and a demand of 103 ft^3/hr leads to the cell labeled 137 ft^3/hr. The header of this column indicates 3/4 inch. The pipe diameter entering Y from X is 3/4 inch.

The tee labeled Z receives 38 ft^3/hr. Looking in the Table for a length of 60 ft and a demand of 38 ft^3/hr leads to the cell labeled 65 ft^3/hr. The header of this column indicates 1/2 inch. The pipe diameter entering Z from Y is 1/2 inch.

From this point we get to cheat the rest. All pipe diameters downstream of Y are 1/2 inch.

Worksheet beta: Longest length method (using Table 6.2(b))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	60	35 from Z using 1/2 in	-	-
B	55	3 from Z using 1/2 in	-	-
C	55	65 from Y using 1/2 in	-	-
D	50	150 from X using 1 in	-	-
M	0	-	253 to X	-
X	30	253 from M using 1 in	150 to D	103 to Y
Y	40	103 from X using 3/4 in	65 to C	38 to Z
Z	50	38 from Y using 1/2 in	35 to A	3 to B

Worked Example: Gamma

Apply the longest length method to example gamma represented in Figure 1.27.

Referencing the Figure (namely the worksheet beneath it), the longest length corresponds to outlet B at 53 ft from meter. The total demand of the system is 1475 ft^3/hr. (Steps 1 and 2.)

Looking in the Table 6.2(b) for a length of 60 ft and a demand of 1475 ft^3/hr leads to the cell labeled 1520 ft^3/hr. The header of this column indicates 2 inch. (Steps 3, 4, and 5.) The pipe diameter leaving the meter is 2 inch. Therefore segment MY is 2 inch.

In ft^3/hr, the fixtures A, B, C, D, E, F receive 140, 225, 180, 285, 285, 360, respectively. Staying in the 60 ft row of the Table, we straightforwardly read off the diameters going to each fixture. In inches, the results are 1, 1, 1, 1.25, 1.25, 1.25.

The tee labeled V receives 405 ft^3/hr. Looking in the Table for a length of 60 ft and a demand of 405 ft^3/hr leads to the cell labeled 528 ft^3/hr. The header of this column indicates 1.25 inch. The pipe diameter entering V from W is 1.25 inch.

The tee labeled W receives 545 ft^3/hr. Looking in the Table for a length of 60 ft and a demand of 545 ft^3/hr leads to the cell labeled 791 ft^3/hr. The header of this column indicates 1.5 inch. The pipe diameter entering W from X is 1.5 inch.

The tee labeled X receives 830 ft^3/hr. Looking in the Table for a length of 60 ft and a demand of 830 ft^3/hr leads to the cell labeled 1520 ft^3/hr. The header of this column indicates 2 inch. The pipe diameter entering X from Y is 2 inch.

The tee labeled Z receives 645 ft^3/hr. Looking in the Table for a length of 60 ft and a demand of 645 ft^3/hr leads to the cell labeled 791 ft^3/hr. The header of this column indicates 1.5 inch. The pipe diameter entering Z from Y is 1.5 inch.

All pipes are now sized and the problem is solved. The updated worksheet is as follows:

Worksheet gamma: Longest length method (using Table 6.2(b))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	51	140 from W using 1 in	-	-
B	53	225 from V using 1 in	-	-
C	52	180 from V using 1 in	-	-
D	33	285 from Z using 1.25 in	-	-
E	34	285 from X using 1.25 in	-	-
F	26	360 from Z using 1.25 in	-	-
M	0	-	1475 to Y	-
V	47	405 from W using 1.25 in	225 to B	180 to C
W	30	545 from X using 1.5 in	140 to A	405 to V
X	22	830 from Y using 2 in	285 to E	545 to W
Y	12	1475 from M using 2 in	830 to X	645 to Z
Z	20	645 from Y using 1.5 in	285 to D	360 to F

Problems

Problem 25

Let A, B, C, D represent gas-consuming fixtures that operate under conditions consistent with Table 6.2(b). In particular:

- A = Furnace (100 kBtu/hr)
- B = Water heater (40 kBtu/hr)
- C = Dryer (30 kBtu/hr)
- D = Fireplace (30 kBtu/hr)

Assume the calorific value of natural gas is 1000 Btu/ft^3. If the system is arranged according to the following worksheet, calculate all pipe diameters using the longest length method.

Answer: Longest length 62 ft, round up to 70 ft.

- A: 100 from X using 3/4 in
- X: 200 from M using 1 in
- Y: 100 from X using 3/4 in
- All other diameters 1/2 in.

Longest length method (using Table 6.2(b))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	22	100 from X using ?	-	-
B	21	40 from Y using ?	-	-
C	28	30 from Z using ?	-	-
D	62	30 from Z using ?	-	-
M	0	-	200 to X	-
X	14	200 from M using ?	100 to A	100 to Y
Y	16	100 from X using ?	40 to B	60 to Z
Z	22	60 from Y using ?	30 to C	30 to D

Problem 26

For systems that tolerate a pressure drop of 0.3 in. w.c. instead of 0.5, the Table we've been using must be replaced with Table 6.2(a), shown in Figure 1.30.

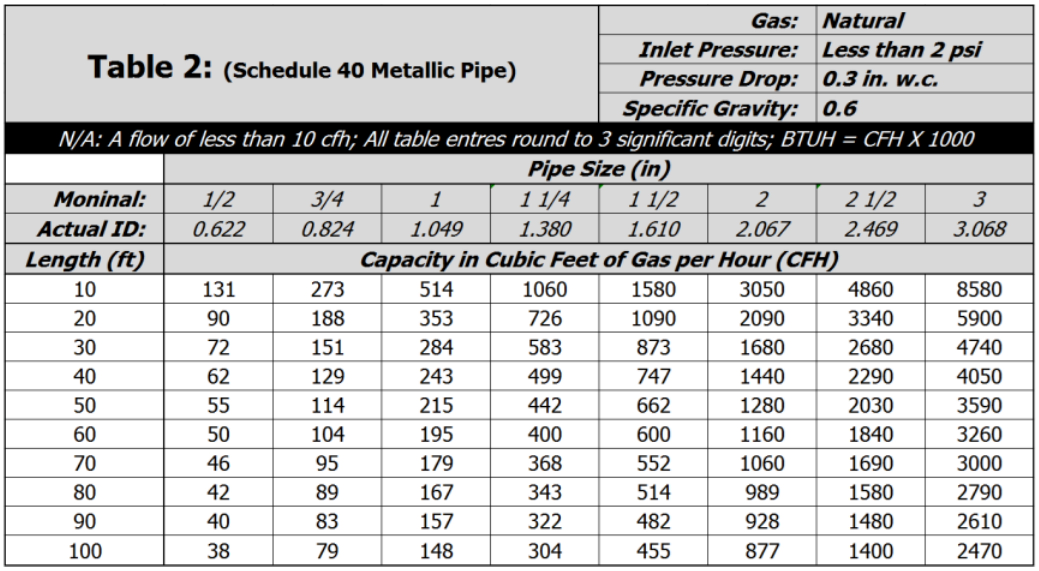


Table 2: (Schedule 40 Metallic Pipe)

Gas: *Natural*
Inlet Pressure: *Less than 2 psi*
Pressure Drop: *0.3 in. w.c.*
Specific Gravity: *0.6*

N/A: A flow of less than 10 cfh; All table entres round to 3 significant digits; BTUH = CFH X 1000

	Pipe Size (in)							
Moninal:	*1/2*	*3/4*	*1*	*1 1/4*	*1 1/2*	*2*	*2 1/2*	*3*
Actual ID:	*0.622*	*0.824*	*1.049*	*1.380*	*1.610*	*2.067*	*2.469*	*3.068*
Length (ft)	***Capacity in Cubic Feet of Gas per Hour (CFH)***							
10	131	273	514	1060	1580	3050	4860	8580
20	90	188	353	726	1090	2090	3340	5900
30	72	151	284	583	873	1680	2680	4740
40	62	129	243	499	747	1440	2290	4050
50	55	114	215	442	662	1280	2030	3590
60	50	104	195	400	600	1160	1840	3260
70	46	95	179	368	552	1060	1690	3000
80	42	89	167	343	514	989	1580	2790
90	40	83	157	322	482	928	1480	2610
100	38	79	148	304	455	877	1400	2470

Figure 1.29. Sample from *ANSI Z223.1*, Chapter 6. Table 6.2(a). Schedule 40 Metallic Pipe.

Let A, B, C, D, E represent gas-consuming fixtures that operate under conditions consistent with Table 6.2(b). In particular:

- A = Furnace (100 kBtu/hr)
- B = Water heater (40 kBtu/hr)
- C = Dryer (30 kBtu/hr)
- D = Fireplace (30 kBtu/hr)
- E = Stove (65 kBtu/hr)

Assume the calorific value of natural gas is 1000 Btu/ft^3. If the system is arranged according to the following worksheet, calculate all pipe diameters using the longest length method.

Answer: Longest length 40 ft.

- A: 100 from X using 3/4 in
- B: 40 from Y using 1/2 in
- C: 30 from Z using 1/2 in
- D: 30 from Z using 1/2 in
- E: 65 from Z using 3/4 in
- W: 140 from X using 1 in
- X: 265 from M using 1.25 in

Longest length method (using Table 6.2(a))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	32	100 from X using ?	-	-
B	30	40 from Y using ?	-	-
C	28	30 from Z using ?	-	-
D	40	30 from Z using ?	-	-
E	37	65 from Z using ?	-	-
M	0	-	265 to X	-
W	26	140 from X using ?	100 to A	40 to B
X	16	265 from M using ?	140 to W	125 to Y
Y	23	125 from X using ?	30 to C	95 to Z
Z	28	95 from Y using ?	30 to D	65 to E

- Y: 125 from X using 3/4 in
- Z: 95 from Y using 3/4 in

17.8 Branch Length Method

Quoting directly from *ANSI Z223.1*, Chapter 6, the branch length method is stated as:

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1. Pipe size of each section of the longest pipe run from the point of delivery to the most remote outlet shall be determined using the longest run of piping and the load of the section.
2. The pipe size of each section of branch piping not previously sized shall be determined using the length of piping from the point of delivery to the most remote outlet in each branch and the load of the section.

Implementing the branch length method goes as follows:

1. Choose a fixture and determine its distance from the meter in developed length. (This number changes per fixture.)
2. Determine that fixture's demand in ft^3/hr. (Convert from kBtu/hr if necessary.)
3. In the appropriate Table such as 6.2(b), read down the left column until finding the length from Step 1. Round your search to the next row if necessary, but never round down in pipe size.
4. Staying in the length row, read across the Table until finding the total ft^3/hr demand from Step 2. Round your total up to the next column if necessary.
5. At this step you're pointing at one cell in the body of the Table. The header of the column indicates the diameter of the gas pipe serving the fixture.
6. Repeat for all fixtures.
7. Treat tee fittings as if they're fixtures with the following extra rule: the effective distance from the meter to a tee fitting includes the length of pipe from the fitting to the most remote outlet after the fitting.

The branch length method involves more fiddling with pipe lengths in the schematic. This process can get wooly, thus it's strongly recommended to generate a worksheet or mark the schematic with all pertinent information. In particular (reiterating Step 7), **the effective distance from any tee fitting to the meter must include the distance to the most remote outlet downstream of the fitting**.

Reworked Examples

Let us rework Examples alpha, beta, gamma using the branch length method. Starting with the same worksheets under Figures 1.25, 1.26, 1.27, use Steps 1-7 to reason:

In Example alpha, the results attained by the branch length method are the same as those attained with the longest length method.

In Example beta, all results agree with the longest length method with one exception, and that is the pipe size leading to outlet D. To double check, we have that outlet D is 50 ft from the meter while demanding 150 ft^3/hr, which, according to the branch length method, requires 3/4 inch pipe as calculated. This number came out to 1 inch using the longest length method, namely because we were trapped in the 60 ft row.

Worksheet alpha: Branch length method (using Table 6.2(b))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	60	35 from Y using 1/2 in	-	-
B	55	75 from Y using 3/4 in	-	-
C	50	35 from Z using 1/2 in	-	-
D	50	100 from Z using 3/4 in	-	-
M	0	-	245 to X	-
X	30 (+30)	245 from M using 1 in	110 to Y	135 to Z
Y	40 (+20)	110 from X using 3/4 in	35 to A	75 to B
Z	50 (+0)	135 from X using 3/4 in	35 to C	100 to D

Worksheet beta: Branch length method (using Table 6.2(b))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	60	35 from Z using 1/2 in	-	-
B	55	3 from Z using 1/2 in	-	-
C	55	65 from Y using 1/2 in	-	-
D	50	150 from X using 3/4 in	-	-
M	0	-	253 to X	-
X	30 (+30)	253 from M using 1 in	150 to D	103 to Y
Y	40 (+20)	103 from X using 3/4 in	65 to C	38 to Z
Z	50 (+10)	38 from Y using 1/2 in	35 to A	3 to B

Problems

Problem 27

Let A, B, C, D, E represent gas-consuming fixtures that operate under conditions consistent with Table 6.2(b). In particular:

- A = Pool heater (250 kBtu/hr)
- B = Boiler (100 kBtu/hr)
- C = Fireplace (30 kBtu/hr)
- D = Stove (365 kBtu/hr)
- E = Water heater (40 kBtu/hr)

Assume the calorific value of natural gas is 1000 Btu/ft^3. If the system is arranged according to the following worksheet, calculate all pipe diameters using the branch length method.

Answer:

- A: 250 from W using 1.25 inch
- B: 100 from X using 3/4 inch
- C: 30 from Y using 1/2 inch
- D: 65 from Z using 1/2 inch
- E: 40 from Z using 1/2 inch
- W: 485 from M using 2 inch
- X: 235 from W using 1 inch
- Y: 135 from X using 3/4 inch
- Z: 105 from Y using 3/4 inch

Worksheet gamma: Branch length method (using Table 6.2(b))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	51	140 from W using 1 in	-	-
B	53	225 from V using 1 in	-	-
C	52	180 from V using 1 in	-	-
D	33	285 from Z using 1 in	-	-
E	34	285 from X using 1 in	-	-
F	26	360 from Z using 1 in	-	-
M	0	-	1475 to Y	-
V	47 (+6)	405 from W using 1.25 in	225 to B	180 to C
W	30 (+23)	545 from X using 1.5 in	140 to A	405 to V
X	22 (+31)	830 from Y using 2 in	285 to E	545 to W
Y	12 (+41)	1475 from M using 2 in	830 to X	645 to Z
Z	20 (+13)	645 from Y using 1.25 in	285 to D	360 to F

Branch length method (using Table 6.2(b))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	163	250 from W using ?	-	-
B	28	100 from X using ?	-	-
C	38	30 from Y using ?	-	-
D	44	65 from Z using ?	-	-
E	54	40 from Z using ?	-	-
M	0	-	485 to W	-
W	13 (+150)	485 from M using ?	250 to A	235 to X
X	18 (+37)	235 from W using ?	100 to B	135 to Y
Y	28 (+27)	135 from X using ?	30 to C	105 to Z
Z	34 (+20)	105 from Y using ?	65 to D	40 to E

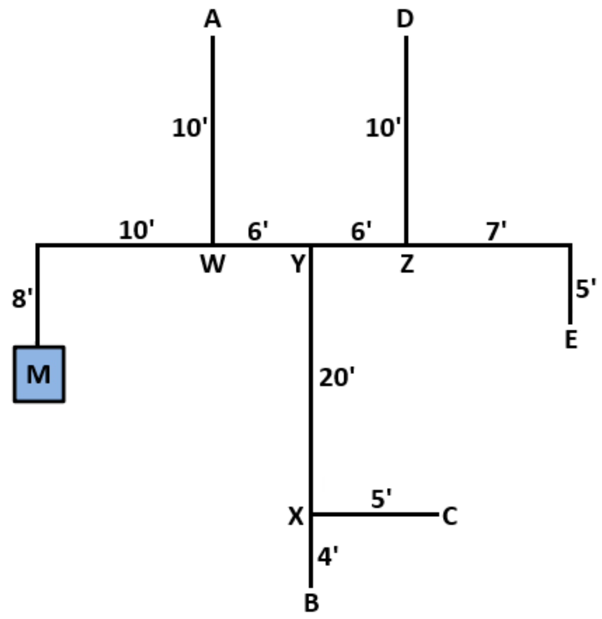
Problem 28

Let A, B, C, D, E represent gas-consuming fixtures that operate under conditions consistent with Table 6.2(b). In particular:

- A = Stove (65 kBtu/hr)
- B = Furnace (100 kBtu/hr)
- C = Water heater (40 kBtu/hr)
- D = Dryer (30 kBtu/hr)
- E = Fireplace (30 kBtu/hr)

Assume the calorific value of natural gas is 1000 Btu/ft^3.

The system is depicted in the accompanying Figure. Distances not to scale. For the longest length method and the branch length method, generate worksheets representing the schematic and size the system.



Longest length or Branch length method (using Table 6.2(b))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
A	28	65 from W using 1/2 in	-	-
B	48	100 from X using 3/4 in	-	-
C	49	40 from X using 1/2 in	-	-
D	40	30 from Z using 1/2 in	-	-
E	42	30 from Z using 1/2 in	-	-
M	0	-	265 to W	-
W	18 (+31)	265 from M using 1 in	65 to A	200 to Y
X	44 (+5)	140 from Y using 3/4 in	100 to B	40 to C
Y	24 (+25)	200 from W using 1 in	140 to X	60 to Z
Z	30 (+12)	60 from Y using 1/2 in	30 to D	30 to E

Problem 29

Consider the system depicted in Figure 1.24. Ignoring the effect of any shut-off valves, the central player in the schematic is a manifold, denoted X, which is essentially a tee with many branches.

The system is to be piped with semirigid copper tubing sustaining a pressure drop at 1 in. w. c. The gas has a specific gravity of 0.60 and the calorific valus of the gas is 1000 Btu/hr.

Given the material and conditions, it is warranted to size the system using Table 6.2.1(j) as depicted in Figure 1.29. Create an appropriate worksheet and size the system using the branch length method.

Answer: For the effective distance to X, use 20 ft plus the distance to the furthest outlet, i.e. 30 ft.

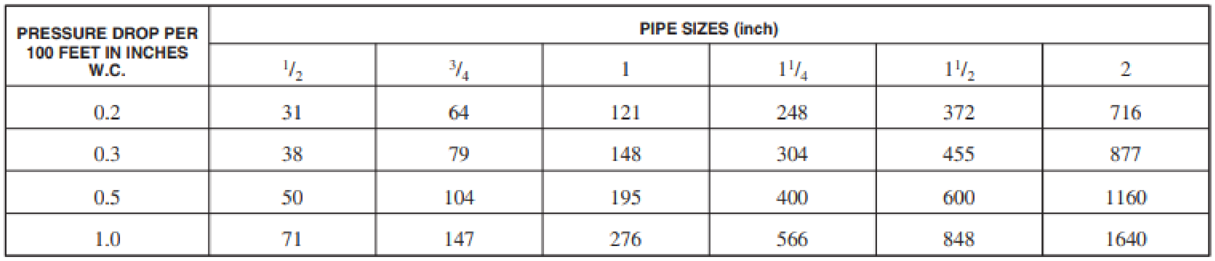
Branch length method (using Table 6.2.1(j))				
Symbol	**From Meter** (ft)	**Input** (cfh)	**Out 1** (cfh)	**Out 2** (cfh)
B	30	75 from X using 1/2 in	-	-
C	50	30 from X using 3/8 in	-	-
D	30	35 from X using 3/8 in	-	-
E	30	80 from X using 1/2 in	-	-
M	0	-	220 to X	-
X	20 (~~+10~~)	220 from M using 1 in	75 to B	-
X	20 (+30)	-	30 to C	-
X	20 (~~+10~~)	-	35 to D	-
X	20 (~~+10~~)	-	80 to E	-

17.9 Other Sizing Methods

There are several ways to solve the gas pipe sizing problem, but arguably the longest length method and branch lengthod are the most practical in the field.

When there is a pressure regular in the system, as sketched in Figure 1.23, then the **Hybrid pressure method** must be used. In such a case, the system is divided into (at least) one high-pressure section and one-low pressure section, each following its own sizing procedure.

There also exists the **Pressure drop per 100 feet method**. This method considers the loss in pressure due to lengths of pipe in the system, rather than loss in volume through fixtures. Per one hundred feet, there is a fractional decrease in pressure, ΔH, via inches in water column. Figure 1.31 displays a Table for indicating pipe diameter as a function of pressure loss.



PRESSURE DROP PER 100 FEET IN INCHES W.C.	PIPE SIZES (inch)					
	$^1/_2$	$^3/_4$	1	$1^1/_4$	$1^1/_2$	2
0.2	31	64	121	248	372	716
0.3	38	79	148	304	455	877
0.5	50	104	195	400	600	1160
1.0	71	147	276	566	848	1640

Figure 1.30. Sample gas distribution schematic. (*2010 Oregon Mechanical Specialty Code. Table C-A.3.4. Thousands of Btu/h (MBTU) of Natural Gas per 100 Feet of Pipe at Various Pressure Drops and Pipe Diameters*)

Finally, one can use the **direct application of Equations** (1.3), (1.4) for low- or high-pressure gas. After all, these are responsible for all other sizing methods and the associated charts and tables.

In many situations, natural gas may be treated as *ideal gas*, which could be useful in the following scenario: If a closed piping system is installed on a warm afternoon but tested on a chilled morning, the pressure will have decreased according to the ideal gas law:

$$PV = NKT$$

With V, N, K constant, it follows that the pressure-temperature relationship can be written

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} .$$

18 Testing

Testing requirements ensure that all plumbing and gas systems are installed watertight, gas-tight, and capable of maintaining their designed pressure and function before being placed in service. The following subsections outline the procedures for testing drainage, water supply, and gas systems in accordance with 248 CMR 10.00 and 3.00.

18.1 Drainage and Vent Systems

All drainage and vent systems shall be tested upon completion of rough piping and before concealment, connection to fixtures, or backfilling. The system shall prove free of leaks and defects and demonstrate that all vents are continuous and unobstructed. Tests shall be performed in the presence of the Inspector unless otherwise approved (10.13.1).

- **Timing of test.** Drainage and vent piping shall be tested either in sections or as a complete system prior to concealment or connection to any fixture. The Inspector may require retesting if piping is altered after the initial approval (10.13.1.a).
- **Methods permitted.** Tests shall be conducted using one of the following: a water (hydrostatic) test, an air (pressure) test, or a special test approved by the Inspector such as a smoke or peppermint test. Only approved materials and fittings may be used during testing (10.13.1.b, 10.06.1.a).
- **Water test.** All openings shall be tightly plugged except the highest, through which the system shall be filled with water. The head of water shall be not less than ten feet measured above the highest fitting being tested, and shall be maintained for at least fifteen minutes. The system shall show no evidence of leakage (10.13.2.a).
- **Air test.** Where air testing is used, all openings shall be tightly plugged except the highest, through which air shall be introduced to maintain a pressure of five pounds per square inch. The pressure shall be held for at least fifteen minutes with no measurable loss indicated on a calibrated gauge (10.13.2.b).
- **Smoke test.** A smoke-producing machine shall be connected to the system, and smoke shall be forced through the piping under slight pressure. Any escape of smoke indicates leakage or defective joints. The test shall continue until the entire system has been filled with dense smoke (10.13.3.a).
- **Peppermint test.** A small quantity of oil of peppermint (approximately two ounces per 100 feet of pipe) shall be introduced at the top of the system, followed by one gallon of warm water. Detection of odor at any point outside the test zone indicates leakage (10.13.3.b).
- **Test preparation.** Cleanouts, traps, and fittings shall be accessible and watertight. Caps or plugs shall be properly braced to resist test pressure, and vertical stacks shall be securely supported during the test (10.13.1.c).
- **Repair of defects.** Any leakage, odor emission, or loss of pressure shall be corrected, and the system retested until it meets the approval of the Inspector (10.13.1.d).
- **Inspection.** No portion of the drainage or vent system shall be covered or concealed until it has been successfully tested and approved by the Inspector. Approval shall be noted before continuation of the work (10.13.4).

18.2 Water Supply Systems

All water supply piping shall be tested under working pressure before being placed in service.

- Hydrostatic pressure: test pressure shall be not less than the normal operating pressure of the system, but not less than 125 psi for standard installations.
- Duration: maintain pressure for a minimum period as prescribed in 10.13.
- Inspection: test must be witnessed and accepted by the Inspector prior to connection with fixtures or appliances.

18.3 Gas Piping Systems

Gas piping shall be tested and proved tight before use or connection to any appliance, in accordance with 248 CMR 3.00 and applicable NFPA 54 provisions.

- Test medium: air, nitrogen, or other inert gas; combustible gas shall not be used for testing.
- Pressure and duration: follow the minimum pressure and test time requirements for the length and diameter of the piping.
- Certification: the test shall be performed by a licensed gas fitter and verified by the Inspector.