Pressure Loss in Plumbing Systems

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PDH: 4

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Course Author: Roman Titov

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1. Introduction

Premise plumbing systems provide reliable access to clean water and sanitation, which is an essential building service. Modern plumbing designs aim to optimize water usage through technology and water management while considering functional requirements, system capacity, system and material limitations, applicable plumbing codes, and industry standards. However, incorrect pipe sizing in hot- and cold-water distribution systems can impede achieving design flows, increase operating and installed cost, reduce energy efficiency, and increase the building's carbon footprint. Incorrect pipe sizing can also result in reduced flow rates that can contribute to water stagnation, decay of disinfectants, potential growth of biofilms and opportunistic pathogens, and reduced water quality. Therefore, the pressure losses within piping systems are of primary importance to the sizing of pipes, fittings, and pumps.

Since the original plumbing codes of the 1920s (i.e., the Hoover Codes [1]), there have been significant technological advances in product design, including advances that promote water efficiency and water quality and a significant shift in the materials of construction and joining methods used for both pipes and fittings. However, some original data and calculations in the Hoover Codes are still being used today for plumbing design. This is problematic as the data are not representative of modern fittings and flow conditions. The current water use in buildings, on a per-fixture basis, is much lower than that in the 20th century due to control advances such as improved aeration and automatic shut-off, and the peak water use is much lower than what building codes require. Also, there has been a fundamental shift in materials and design concepts that are implemented in modern buildings, including the predominant use of copper and plastics as the material of construction, and the use of innovative water distribution designs to reduce dead ends and unnecessarily long runs. The National Institute of Building Sciences (NIBS)'s Consultative Council recently published a report [2] that highlights the link between plumbing design and decarbonization, noting "right-sizing of plumbing systems in residential occupancies and an overall reduction of pipe sizes in the built environment… not only leads to improved water efficiency, but also an overall reduction in carbon footprint in the built environment of plumbing systems."

For modern premise plumbing systems to meet the performance goals of protecting occupant health, increasing efficiency, and reducing environmental impacts, an entirely new technical knowledge base must be developed. In its 2016 annual report [3], the NIBS Consultative Council identified several measurement science needs related to premise plumbing, specifically calling on NIST to resume premise plumbing research to modernize water pipe-sizing calculations.

Regardless of whether designers use the equivalent length method or the excess head method, the pressure loss in plumbing systems is fundamental to sizing water distribution pipes. One of the current shortcomings of these methods is that the pressure loss is often estimated. Lin et al. [4] reviewed the existing data, published from 1926 to 2021, on pressure loss of fluid flow through pipe fittings. The literature review confirmed that most of the existing data are not representative of modern pipe fittings. A large portion of data are pre-1950s and based on malleable iron and wrought steel fittings. There is also very limited data for copper, PVC, CPVC and PEX fittings, particularly for diameters at or less than 1 inch (25.4 mm). Figure 1 shows the digitized data for pressure loss in elbows. It is evident that pressure loss data for elbows show a large variation across the data.

Other identified gaps include [5]: 1) no standard test method for pressure loss in fittings, 2) measured data not widely available for specific fittings and configurations, and 3) reported pressure loss of fittings often estimated from literature values that may not be accurate. In 2021, NIST began to design and build a test facility to measure the pressure loss in plumbing fittings and facilitate the development of standard test methods.

This report documents the measurement principles to accurately quantify pressure losses in pipes and fittings, provides a description of the NIST Plumbing Hydraulics Laboratory, and discusses the instrumentation and measurement techniques employed along with the reasoning for their selection. It is intended that this unique test facility provide updated technical data on the pressure loss in pipe fittings to support the modernization of design and operation.

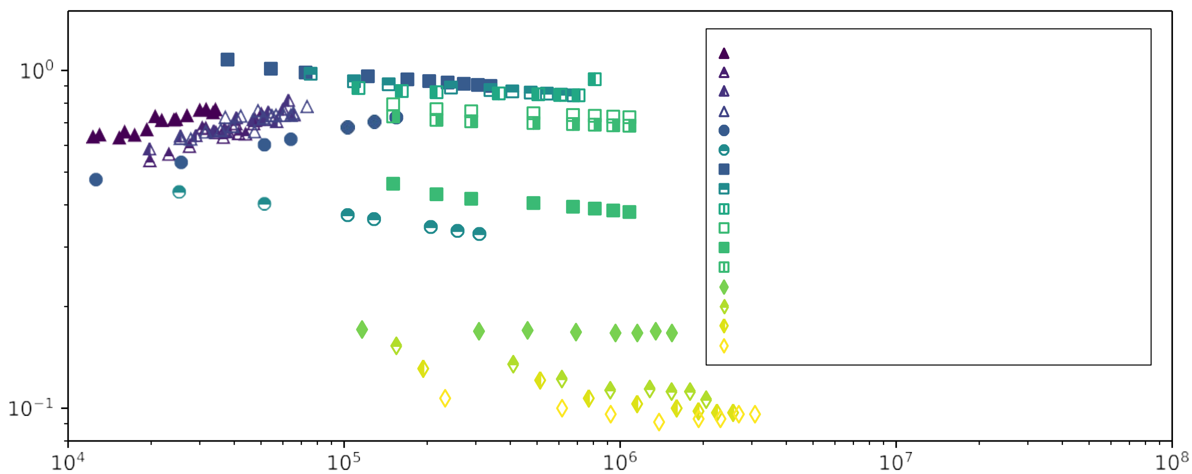

Figure 1. Existing data for elbows (data source: Giesecke and Badgett (1932) [6]; Rahmeyer (1999) [7]; Rahmeyer (2002) [8]; Rahmeyer (2003) [9]).

2. Measurement Principles

Pressure loss is an irreversible loss of mechanical energy of a flowing fluid. Pressure losses caused by pipes and fittings are referred to as “major loss” and “minor loss”, respectively, in most textbooks and engineering handbooks. While pressure losses in pipes are caused by the fluid friction, pressure losses in fittings are primarily due to the flow separation and mixing effects induced by a change of flow direction or cross section [4]. The term “pressure drop” is sometimes used alternatively or interchangeably with “pressure loss” in industry and other communications. However, they are not equivalent. A “pressure drop” is simply the reduction of the static pressure. It includes not only friction and other irreversibilities, but also acceleration (e.g., flow through a reducer) or elevation. In plumbing design, the pressure change due to the change of pipe size and/or elevation is generally calculated separately, and hence it should not be included again when evaluating fittings. Therefore, the term “pressure loss” is recommended and used in this report as well as by the NIST Plumbing Hydraulics Lab.

Pressure losses in pipes and fittings can be accurately determined by establishing the pressure distribution, or the “hydraulic grade line”, which can be obtained by measuring the static pressure at several different locations along the pipe. Figure 2 illustrates a hydraulic grade line of a fluid flowing through straight pipes connected by a fitting.

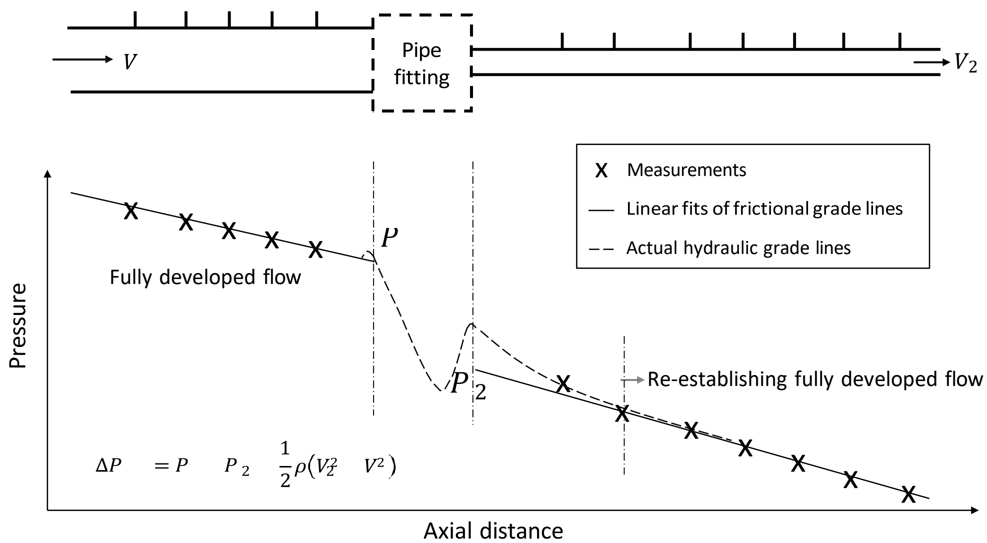

Figure 2. Illustration of a hydraulic grade line.

The pressure loss of a fully-developed flow in straight pipes is linear and can be described by the Darcy–Weisbach equation:

$$\Delta P_{L,\mathrm{fr}} = f \frac{\Delta L}{D} \frac{\rho V^2}{2} \tag{1}$$

wherein,

ΔP	-	Pressure difference
f	-	Friction factor
ΔL	-	Length
D	-	Pipe diameter
ρ	-	Density
V	-	Average velocity

The presence of a fitting causes a pressure loss and a diversion in the hydraulic grade line, which occurs not only within the fitting, but also slightly upstream and significantly downstream. The impact wanes as the flow fully redevelops and the linear relationship is again established.

The pressure loss due to the fitting ($\Delta P_{L,}$) can be calculated by:

$$\Delta P_{L,} = P_t \quad P_{t2} \tag{2}$$

where P_t is the value of the hydraulic grade line extended from the upstream fully-developed region to the fitting inlet, P_{t2} is the value of the hydraulic grade line extended from the downstream fully-developed region to the fitting outlet.

In cases of reducer and expansion fittings, the effect of acceleration or deceleration due to the change of diameter must be considered, and Eq. (2) becomes:

$$\Delta P_{L,} = P_t \quad P_{t2} + \frac{1}{2}\rho\left(V^2 \quad V_2^2\right) \tag{3}$$

Eq. (3) also applies to branching fittings such as tees and crosses. In this case, the hydraulic grade line is, with respect to the flow, to or from a specific branch, as is the computed pressure loss of the fitting.

The measured pressure loss may be reduced to loss coefficient, K_L, to characterize a given pipe fitting:

$$K_L = \frac{\Delta P_{L,}}{\rho V^2/2} \tag{4}$$

3. Test Facility

The test facility is designed to measure the pressure loss for various fittings (i.e., various types, materials, and diameters) over a range of flow velocity from 0.3 m/s to 4.6 m/s (1.0 ft/s to 15 ft/s). Figure 3 shows the schematic of the test facility. It is a recirculation system of water driven by a centrifugal pump. The pump draws water from the bottom of a 190 L (50 gal.) tank to the test section, where the pressure loss of a fitting sample is measured, and then the water is returned to the tank. The water level in the tank is maintained at approximately 3.7 m above the pump to provide sufficient net positive suction head (NPSH) and prevent cavitation. The entire facility is approximately 4.6 m long, 2.4 m wide, and 2.1 m high. The facility size is limited by the lab space, and this limits the length of the test section and thereby the diameter of test pipes and fittings (up to 2.54 cm or 1 in.).

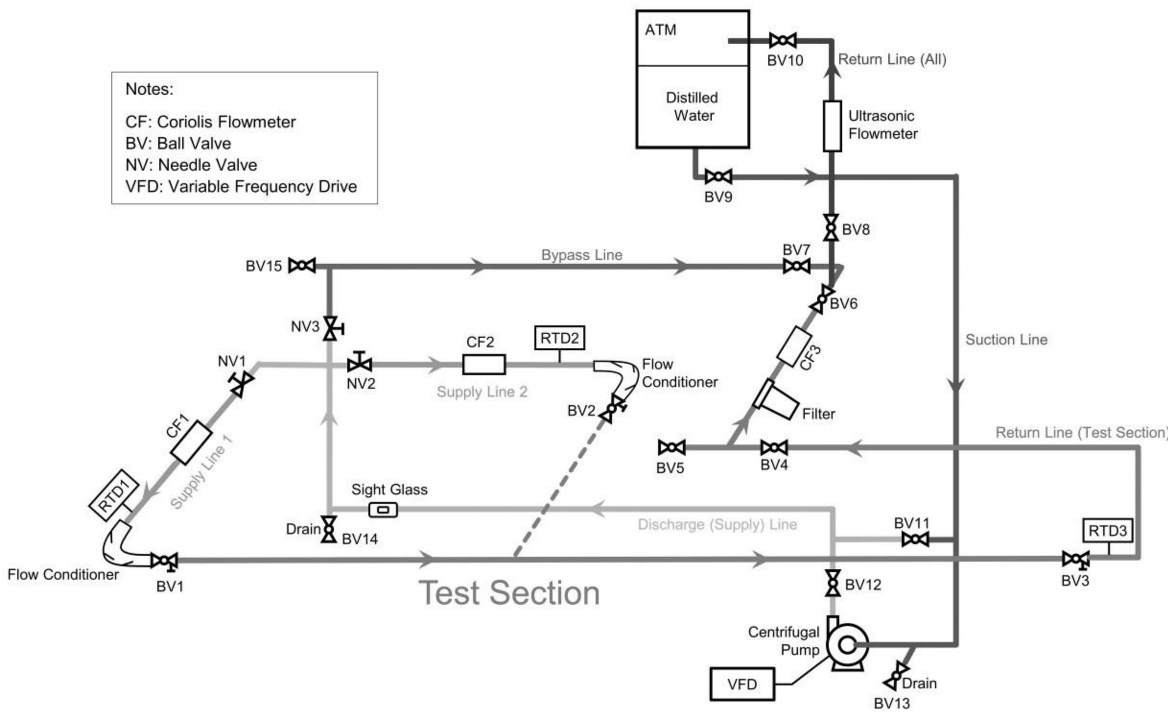

Figure 3. Schematic of the test facility.

The test section is approximately 3.7 m (12 ft.) long, constructed on a horizontal plane 1.8 m (6.0 ft.) above the ground. There are two supply lines branched from the pump discharge line to the inlet(s) of the test section. The two supply lines are identical in length and instrumentation, and they are connected at a 90° angle, which allows different piping configurations of the test section for different types of fittings, as shown in Figure 4. The test section consists of a test fitting and two to four straight pipes connected by the fitting, depending on the type of the fitting. For two-way fittings (i.e., flow-through fittings), the lengths of upstream and downstream pipes are 1.5 m (5.0 ft.) and 2.1 m (7.0 ft.), respectively. The same upstream pipe can be used for testing straight fittings (e.g., straight coupler or reducer/expander) and elbows. The switch can be done by disconnecting the upstream pipe from Supply Line 1 and connecting it to Supply Line 2. For three-way fittings (i.e., tees), an additional upstream pipe is used, and

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