Measuring Pressure Losses in Plumbing Fittings at the NIST Plumbing Hydraulics Laboratory

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Pressure Loss in Plumbing Systems
- necessary to system design

Straight pipes:
\[ \Delta P_{\text{loss}} = f \frac{L \rho V^2}{D} \] (Darcy Equation)

- \( f \) - friction factor, determined by Moody chart or correlations

Fittings:
\[ \Delta P_{\text{loss}} = K \frac{\rho V^2}{2} \]

- \( K \) - loss coefficient, a function of \( D \), \( \text{Re} \), roughness, geometry

Problems:
- No standard test method for pressure loss in fittings
- Measured data not widely available for specific fittings and configurations
- Often estimated from literature values that may not be accurate
What about literature data?

- Reviewed literature since 1920, including handbooks and research papers
- A large portion of data are pre-1950, based on iron/steel fittings
- Very limited data for copper, PEX, and CPVC fittings, especially with $D \leq 1$ in.
- Large variation across data for the same type of fitting

![Graph showing data for various fittings](image)

Figure 1. Existing data for elbows (data source: Giesecke and Badgett (1932) [5]; Rahmeyer (1999) [6]; Rahmeyer (2002) [7]; Rahmeyer (2003) [8]).
Project Objectives

To develop the **measurement science** needed to establish **standardized** and **precise** means of characterizing pressure loss of modern plumbing fittings

Specifically ...

- Establish a new lab facility to measure pressure loss in fittings
- Provide benchmark data for common fittings
- Develop a test method to be submitted to an appropriate standards organization for consideration as an industry consensus
How Pressure Losses Occur

Pressure Loss: irreversible loss of mechanical energy (≠ Pressure Drop)

Root cause: Viscosity & Turbulence

**Straight pipes:**
Friction between fluid and pipe wall

**Fittings:**
Friction; Flow separation: Secondary flow
Pressure Loss Measurement: Traditional Method (two-tapping-location)

\[ \Delta P_{\text{loss}} = (P_1 - P_2) - \Delta P_{\text{friction,1}} - \Delta P_{\text{friction,2}} - \frac{1}{2} \rho (V_2^2 - V_1^2) \]

- Pressure taps 1 and 2 should be located where the flow is fully developed.
- Friction loss in straight pipes need to be measured in a separate experiment.

No established predictive method

Introducing additional uncertainties
Pressure Loss Measurement: Alternative Method (multi-tapping-location)

\[ \Delta P_{\text{loss}} = P_{t1} - P_{t2} - \frac{1}{2} \rho (V_2^2 - V_1^2) \]
Schematic of the test facility.
Pressure Measurement System

Pressure Tap Design
(piezometer ring)

Automated Pressure Distribution Measurement System
Calibration

Fit Equation: \( V = \beta_0 + \beta_1 P_s \)

<table>
<thead>
<tr>
<th>Date</th>
<th>( \beta_0 )</th>
<th>( u_{\beta_0} )</th>
<th>( \beta_1 )</th>
<th>( u_{\beta_1} )</th>
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</tbody>
</table>

Fit Equation: \( V = \beta P_s \)
\[ \beta = 1.9934 \]
\[ u_\beta = 0.0006 \]
Graphical User Interface: Monitor Mode
Pipe Fitting Pressure-Flow Test Facility

Measurement Control

- Tap # Sequence
- Calibration Time (s)
- Wait Time for Equilibrium (s)
- Volt. & Freq. Scan Time (s)
- Volt. Sampling Rate (Hz)
- Freq. Sampling Rate (Hz)
- RTD Scan Time (s)
- RTD Sampling Rate (Hz)

Pipe ID (in) [0.01905]
Pipe ID (in) [0.01605]

Working Directory

- DP_0: 0.0000
- DP_1a: 0.0000
- DP_1b: 0.0000
- DP_2a: 0.0000
- DP_2b: 0.0000
- DP_3a: 0.0000
- DP_3b: 0.0000
- DP_4: 0.0000

Pressure (psi)

- DP_0: 0.000
- DP_1a: 0.000
- DP_1b: 0.000
- DP_2a: 0.000
- DP_2b: 0.000
- DP_3a: 0.000
- DP_3b: 0.000
- DP_4: 0.000

Flow Rate (kg/s)

- DP_0: 0.000
- DP_1a: 0.000
- DP_1b: 0.000
- DP_2a: 0.000
- DP_2b: 0.000
- DP_3a: 0.000
- DP_3b: 0.000
- DP_4: 0.000

Density (kg/m³)

- D0: 800
- D1: 850
- D2: 900
- D3: 950

Graphical User Interface: Monitor Mode

- Auto-Measure
- Shutdown
- State: Initialize

Pipe ID [0.01905]
Pipe ID [0.01605]

Revisions:
1. The amplitude increases with the pump speed (flow rate).
2. The frequency (time scale) doesn't change with the pump speed. The frequency is ~2 Hz, and the time scale is ~0.5 s.
3. There is smaller noise with ~60 Hz. This is noticeable in small RPM and no flow. Probably from the electronics.
4. The sampling rate should be >> 2 Hz to capture the variance in a single wave, an.
5. The window for collecting samples should be much longer than 0.5 s to capture the variance.
Data Collection and Post-processing

Figure 15. Schematic of a single scan for a piezometer.

1. Switch Piezometer
2. Wait Time
3. Measure DP (Rough)
4. Switch DP Sensor
5. Wait Time
6. Measure RTD
7. Measure Flowrate
8. Measure DP (Fine)

TAP 7

- Pressure (psi) vs. Sample #
- Density (kg/m³) vs. Sample #
- Flow Rate (kg/s) vs. Sample #
- Temperature (°C) vs. Sample #
Average Values for All Taps

\( V_{\text{avg}} = 6.0 \text{ ft/s} \)

Pressure Loss Coeff. = \( \Delta P / \left( \frac{1}{2} \rho V^2 \right) \)

Friction Factor = \( \frac{\text{Slope} \times D}{\frac{1}{2} \rho V^2} \)
Sample Data – Straight Pipe

Copper Pipe, NPS ¾, Type L

Inside Diameter = 20.11 mm

Mean Absolute Deviation = 6%

Error of Colebrook Eq. = ~ 15%
Sample Data – Elbow

Pressure Loss Coeff. $= \Delta P \left( \frac{1}{2} \rho V^2 \right)$

$\text{Re} = \rho V D / \mu$
Sample Data – Coupling

\[ Re = \frac{\rho V D}{\mu} \]
Conclusions

Measuring pressure drop is challenging, particularly at low flows, and for straight sections.

Preliminary findings show the methodology is promising to repeatably establish pressure drop for both straight couplings and elbows.

Data is consistent with established relationships for straight pipe, and provides measured results for modern fittings.
Future Plans

Current Plans:

• Measure pressure loss in elbows of various materials (e.g., copper, PVC, PEX, and other plastics) from different manufacturers

• Collaborate with industry & academia

• Draft test method for consideration by a standards development organization
TECHNICAL APPROACH

- Establish test bed to simulate building hot water systems (from water heaters to plumbing fixtures)
- Create novel methods for real-time physical and chemical water quality parameters measurements
- Improve measurement science for quantifying microbial concentrations in plumbing systems

EXPERIMENTAL OBJECTIVE

- Investigate the impact of water use pattern, setpoint temperature, and incoming water quality parameters on the occurrence of OPPPs at the top and bottom of electric storage WHs

METHODOLOGY

- Bench scale measurements: chlorine residual, pH, turbidity, conductivity, and hardness
- Culture methods: Heterotrophic Plate Counts (HPCs)
- Molecular methods using Droplet Digital PCR (ddPCR): *Legionella pneumophila, Mycobacterium avium, Pseudomonas aeruginosa* and *Naegleria fowleri*
Preliminary Results

Top of WHs:
• Draw volume per day and setpoint temp have an inverse relation with concentrations of both *Legionella* and *Mycobacterium* spp.

Bottom of WHs:
• Stagnation time (time between draws) and setpoint temp have effect of *Legionella* spp.
• Only stagnation time has effect of *Mycobacterium* spp.
Other NIST research results

TECHNICAL APPROACH

- Designed plumbing systems according to 2018 International Plumbing Code
- Produced Revit files for all models (architectural and plumbing)
- 3 residential & 4 commercial buildings

Table 1. Description of reference buildings (from NIST TN-2266)

<table>
<thead>
<tr>
<th>BUILDING SOURCE</th>
<th>NAME</th>
<th>FLOOR AREA (m²)</th>
<th>FLOORS</th>
<th>BATHROOMS</th>
<th>KITCHEN</th>
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<tbody>
<tr>
<td>NIST suite of homes</td>
<td>Single family, detached home (DH-A(7))</td>
<td>107</td>
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<td>Single family, detached home (DH-F(4))</td>
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<td>Mid-rise Apartment (APT-2A(7))</td>
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<td>DOE prototype building models</td>
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<td>Primary School</td>
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<td>Full-Service Restaurant</td>
<td>511</td>
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</table>
CHALLENGES

Building types best representative models
  • Cost effective

Different codes and standards governing plumbing system design
  • International Plumbing Code (IPC), Uniform Plumbing Code (UPC), states use their own codes based on IPC or UPC, ADA


Create a product that can be used by a wide audience
  • Revit files that can be translated by researchers to fit their study
Acknowledgment

NIST Staff:
- Luis Luyo (Mechanical Technician)
- Tyler Gervasio (Mechanical Technician)
- Tania Ullah
- Stephen Zimmerman
- *John Wright (Flow Calibration Lab, PML)
- *Marylia Duarte Batista

*Former NIST Staff

Collaborators
- Gary Klein
- Lance MacNevin

Thank you! Questions?