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MODELING OF DISPERSION EFFECT FOR INTERMITTENT FLOW IN PREMISE PLUMBING SYSTEMS

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Outline

- Introduction
- Dispersion Modeling
- Literature Reviews
- Methods
- Results
- Conclusions

Introduction

- Water quality in premise plumbing system (PPS)
  - Raised public awareness of importance of safe drinking water in homes and buildings
  - Risk of exposure to contaminants from water in homes or buildings
- Quality of water at the end use is affected by numerous factors
  - plumbing materials, size, water chemistry, water use
- Concentrations of contaminants in a building can be changed due to hydraulic changes

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Waterborne disease outbreaks can be traced to plumbing systems in buildings

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November 9, 2017

Traditional water treatment efforts have focused on water leaving the treatment plant, but a large number of recent waterborne disease outbreaks in the U.S. can be traced to plumbing systems in buildings. Legionnaires disease outbreaks in New York City and toxic levels of lead in Flint, Michigan have raised questions about how to manage risks in aging water systems.

NEWS & POLITICS | MAY 19, 2018

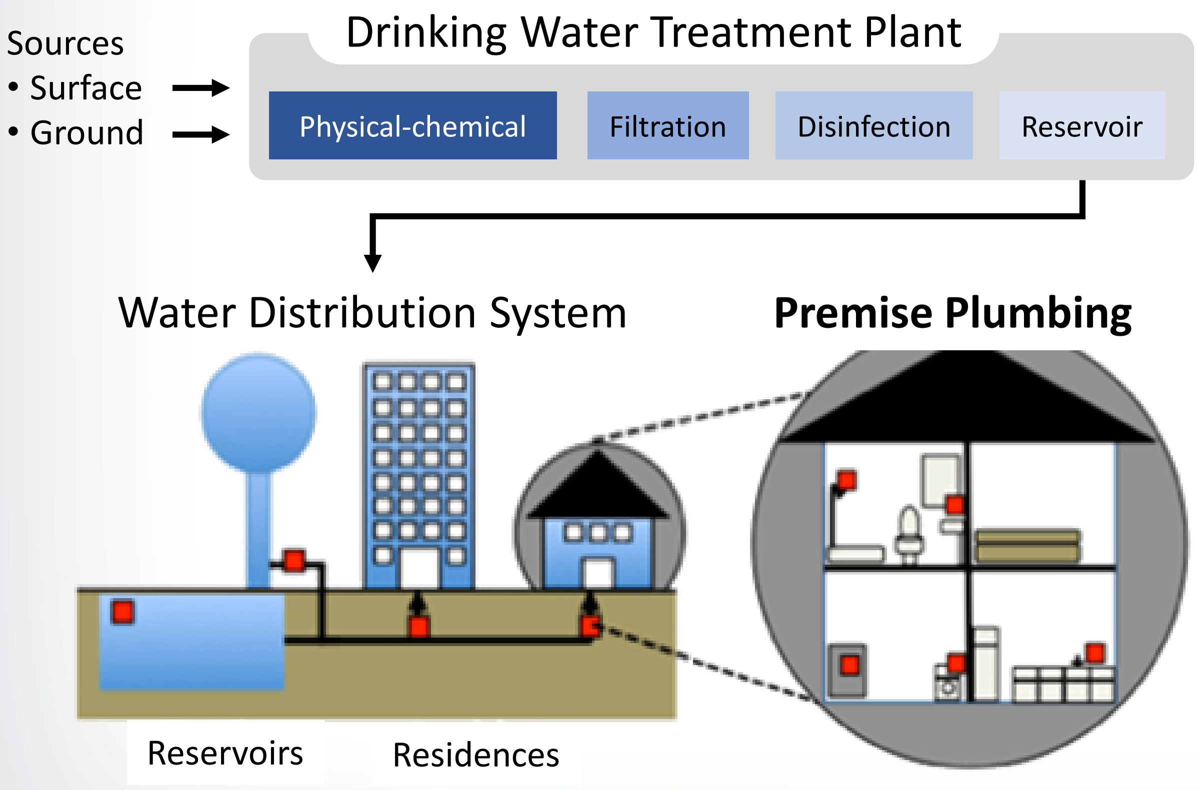
Flint Residents Still Don’t Trust The Water

Although the water is technically considered safe, Flint residents do not trust the water until all the pipes are replaced.

BY SAMANTHA JORGENS, CENTRAL MICHIGAN UNIVERSITY

Introduction

- Premise plumbing has several unique characteristics



Hydraulic Aspects → Intermittent Uses

- High Water Age
- **Variable Velocities**

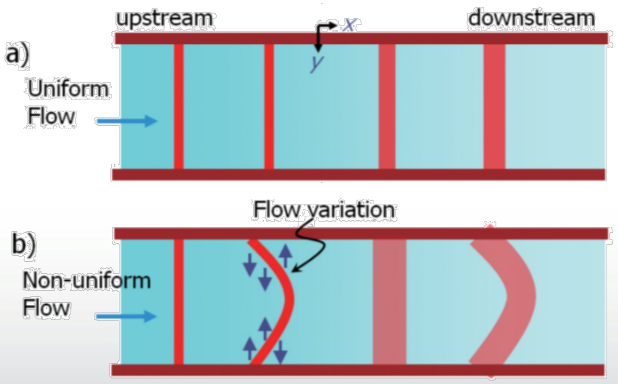
Water Quality Aspects

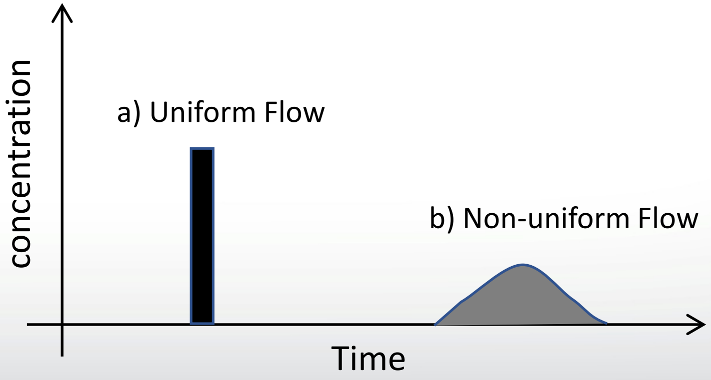
- High Surface Area to Volume Ratio
- Different Materials
- Extreme Temperatures
- Low Residual Disinfectant
- Shower Aerosols

https://www.nap.edu/read/11728/chapter/10

Dispersion Modeling

- EPANET does not accurately simulate PPS
  - EPANET solves advection and reaction equations.
  - EPANET assumes uniform flow in the pipe due to the dominant turbulent flow in advective transport.
- Dispersion plays an important role in the simulations
  - Dead end, laminar flow, transient flow, dispersion coefficient, chlorine decay
- Modeling of PPS also needs to consider dispersion due to the change of velocity in the pipe, specially in the laminar flow





Literature Reviews

1953 - 54 — Taylor, Aris
Dispersion equations for laminar and turbulent flow

1979 — Fischer et al.
A moment method to estimate the dispersion coefficient based on the concentration time profiles in the rivers

1996 — Axworthy and Karney
Low velocity/high dispersion flow - Dispersion plays an important role in laminar flow in the pipe flow

2001 — Tzatchkov et al.
Advection-dispersion transport is more close to actual water quality for intermittent flow in water distribution networks

2004 — Lee and Buchberger
Dispersion equations for unsteady laminar flows

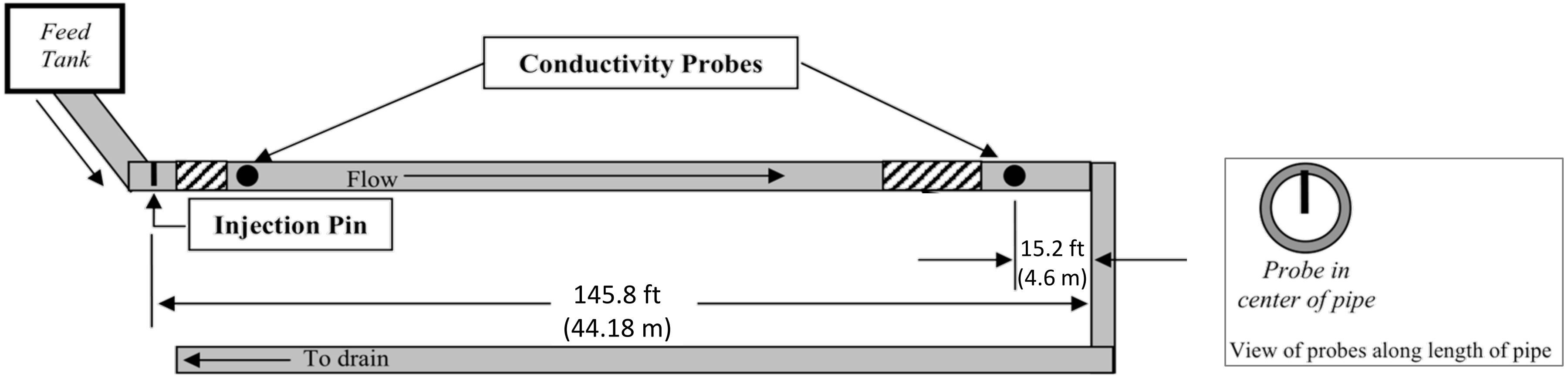
2006 — Li and Buchberger
An attempt to combine PRPmodel with 1D ADR together - ADRNET

2016 — Abokifa et al.
Extended ADRNET to consider spatial demand distribution - WUDESIM

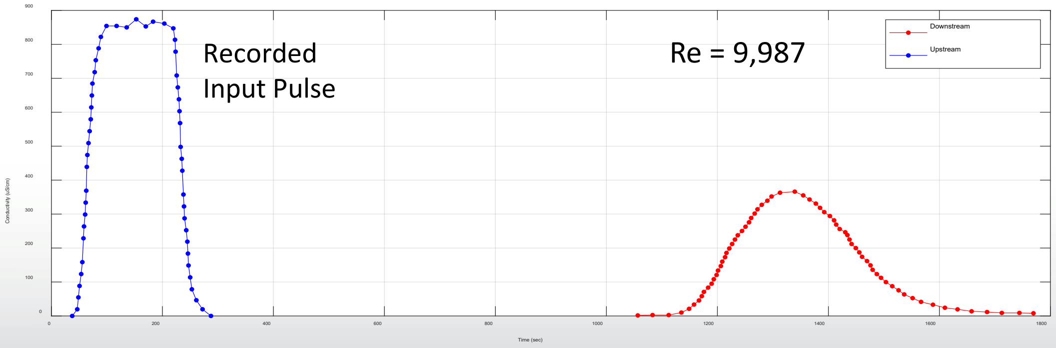
Most research was based upon Taylor's Dispersion Equation!

Tracer Study

- Experimental setup*
  - Tracer injection study at US EPA T&E



  - An example of measurements - conductivity versus time



*Ref. Cutter (2004)

Estimation of Dispersion Coefficients

- Dispersion coefficients are estimated using different methods
  - Taylor Equation

$$D = \begin{cases} \frac{a^2u^2}{48D_m} & Re < 2{,}300 \\ 10.1au_* & 4{,}000 < Re \end{cases}$$

Laminar dispersion

Turbulent dispersion

  - Method of Moments

$$D = \frac{1}{2}\frac{d\sigma^2}{dt} \approx \frac{1}{2}\frac{\Delta\sigma^2}{\Delta t}$$

  - Heuristic Method
    - Finding dispersion coefficient heuristically in the analytical equation
    - Parameters in the analytical equation (C_o, t_o, D)

$$C(x,t) = \begin{cases} C_oA(x,t) & 0 < t \leq t_o \\ C_o(A(x,t) - A(x, t - t_o)) & t > t_o \end{cases}$$

$$A(x,t) = \frac{1}{2}\mathrm{erfc}\left[\frac{\mathrm{x-ut}}{\sqrt{\mathrm{4Dt}}}\right] + \sqrt{\frac{\mathrm{u^2t}}{\pi\mathrm{D}}}\exp\left[-\frac{(\mathrm{x-ut})^2}{\mathrm{4Dt}}\right] - \frac{1}{2}\left(1 + \frac{\mathrm{ux}}{\mathrm{D}} + \frac{\mathrm{u^2t}}{\mathrm{D}}\right)\exp\left(\frac{\mathrm{ux}}{\mathrm{D}}\right)\mathrm{erfc}\left[\frac{\mathrm{x+ut}}{\sqrt{\mathrm{4Dt}}}\right]$$

Estimation of Dispersion Coefficients

- Parameters in the analytical equation (C_o, t_o, D)

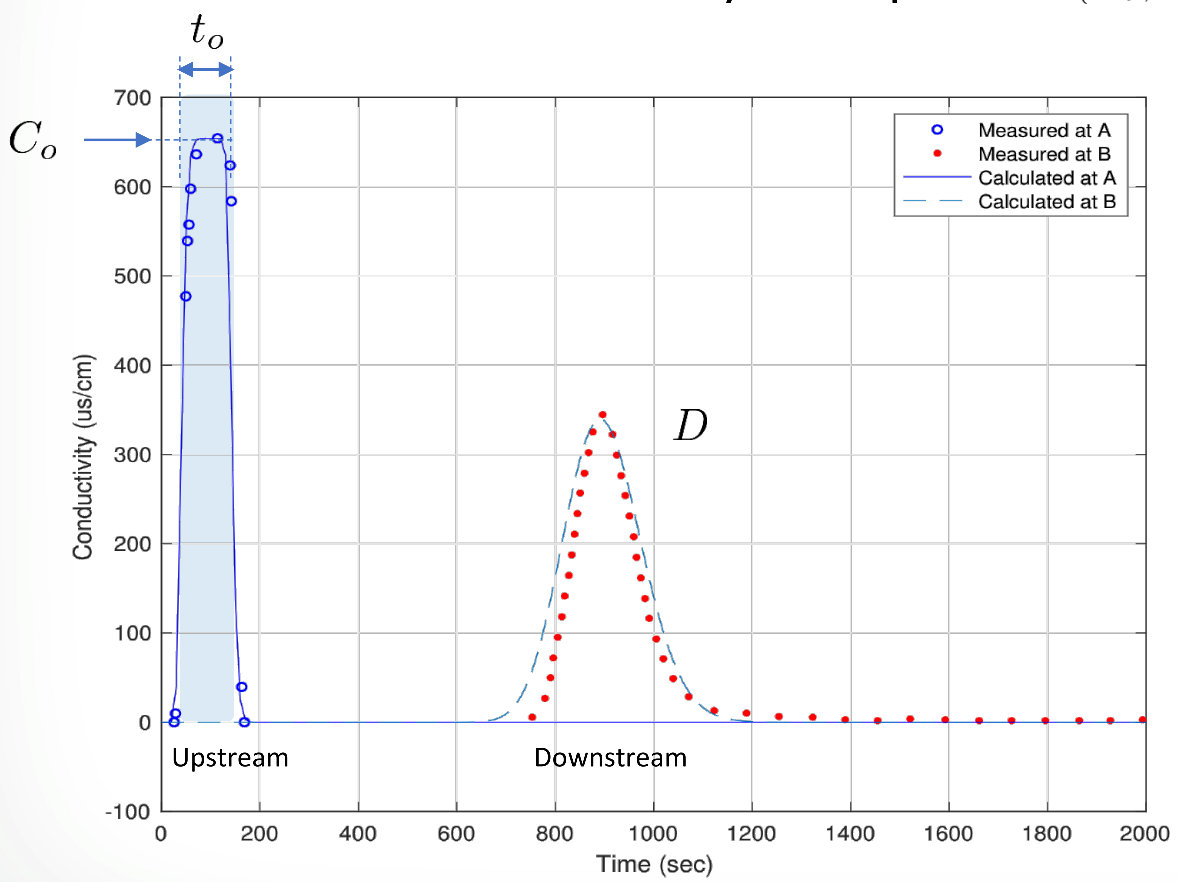


Figure 1. An example of tracer movement. The observed data was expressed with the dotted points and analytical solution was shown in continuous line (Re = 4,960)

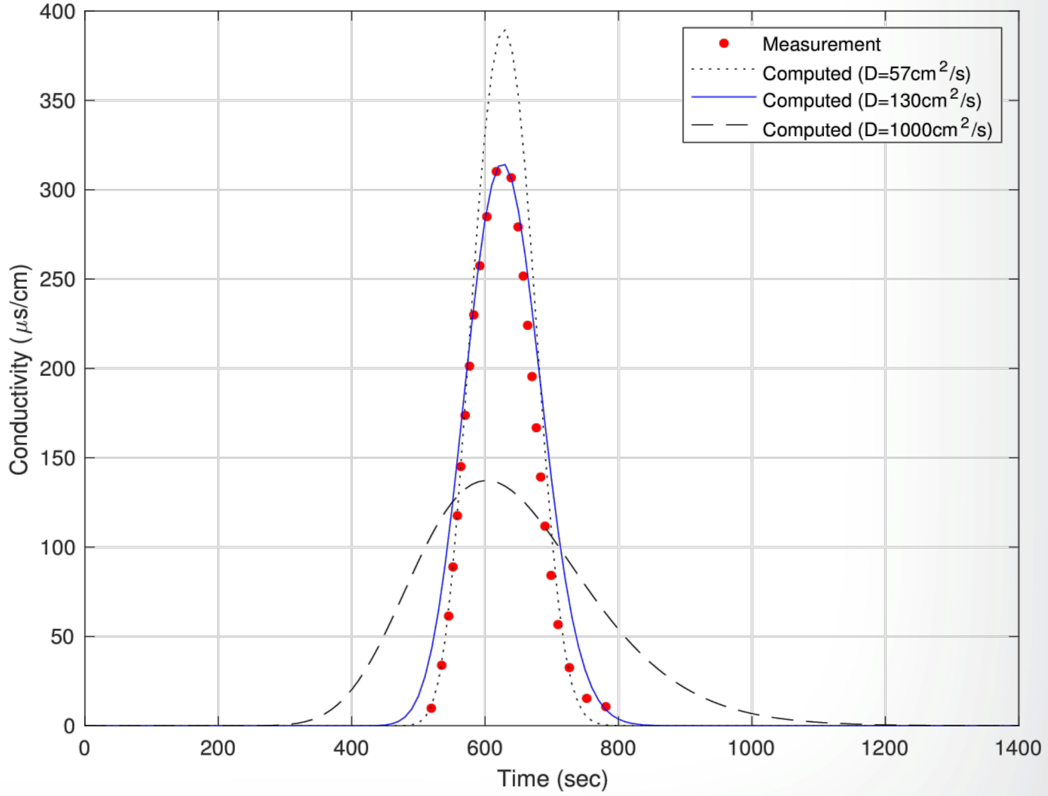
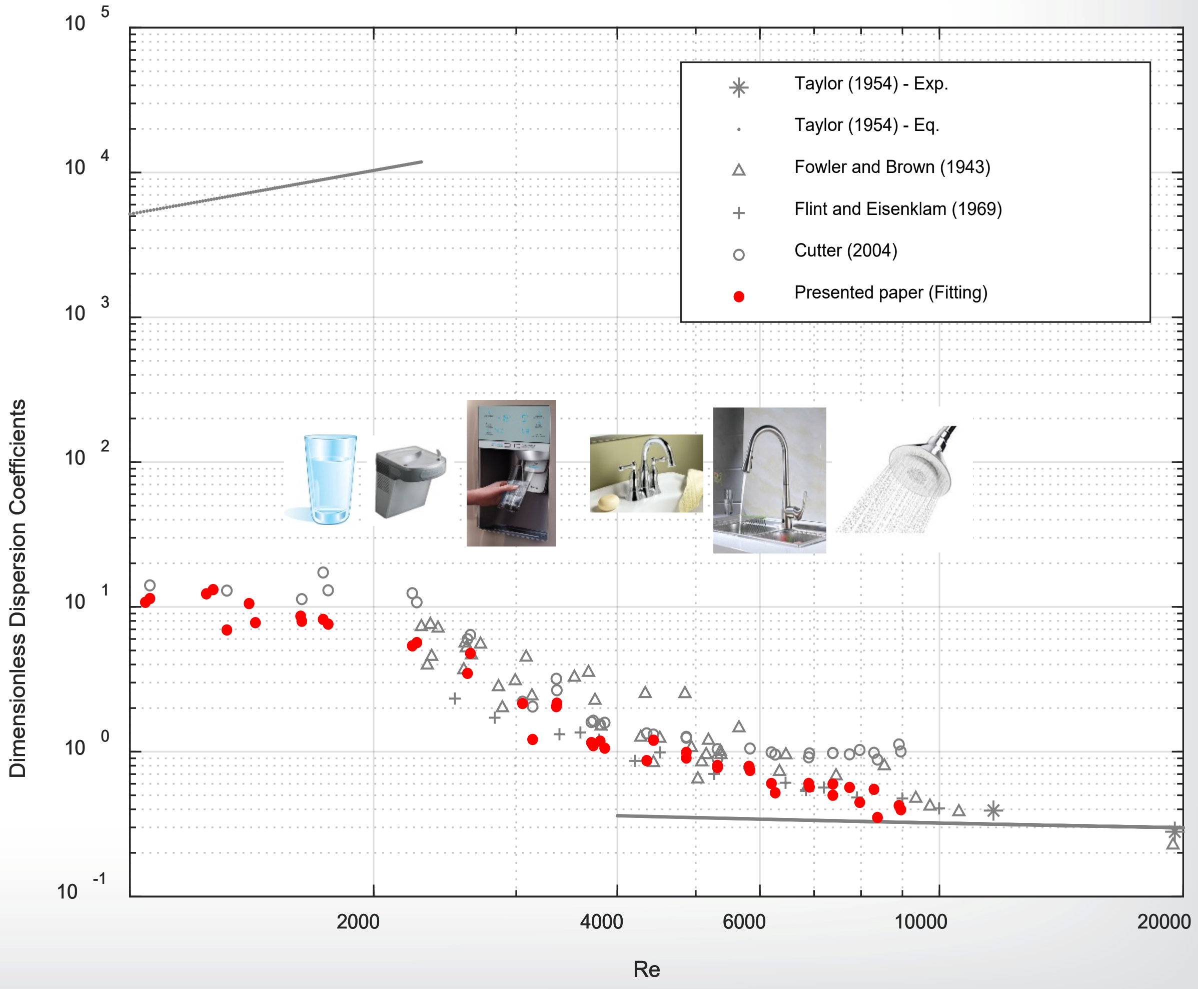


Figure 2. Concentration profiles with different dispersion coefficients and measurement data (plotted with red points)

Results

- Estimated dimensionless dispersion coefficients
  - Comparison with literatures
    - Taylor dispersion does not agree with experimental data for Re < 10,000
  - For a home plumbing system
    - Maximum water usages*
      - Faucet (kitchen): 2.2 GPM
      - Faucet (bathroom): 0.5 – 1.5 GPM
      - Toilet : 1.6 – 3.6 GPM
      - Shower: 2 – 2.5 GPM
    - Calculated Reynolds number for a pipe (internal diameter of 3/4 inches)
      - 2.21 GPM – Re = 10,000
      - 1.55 GPM – Re = 7,000

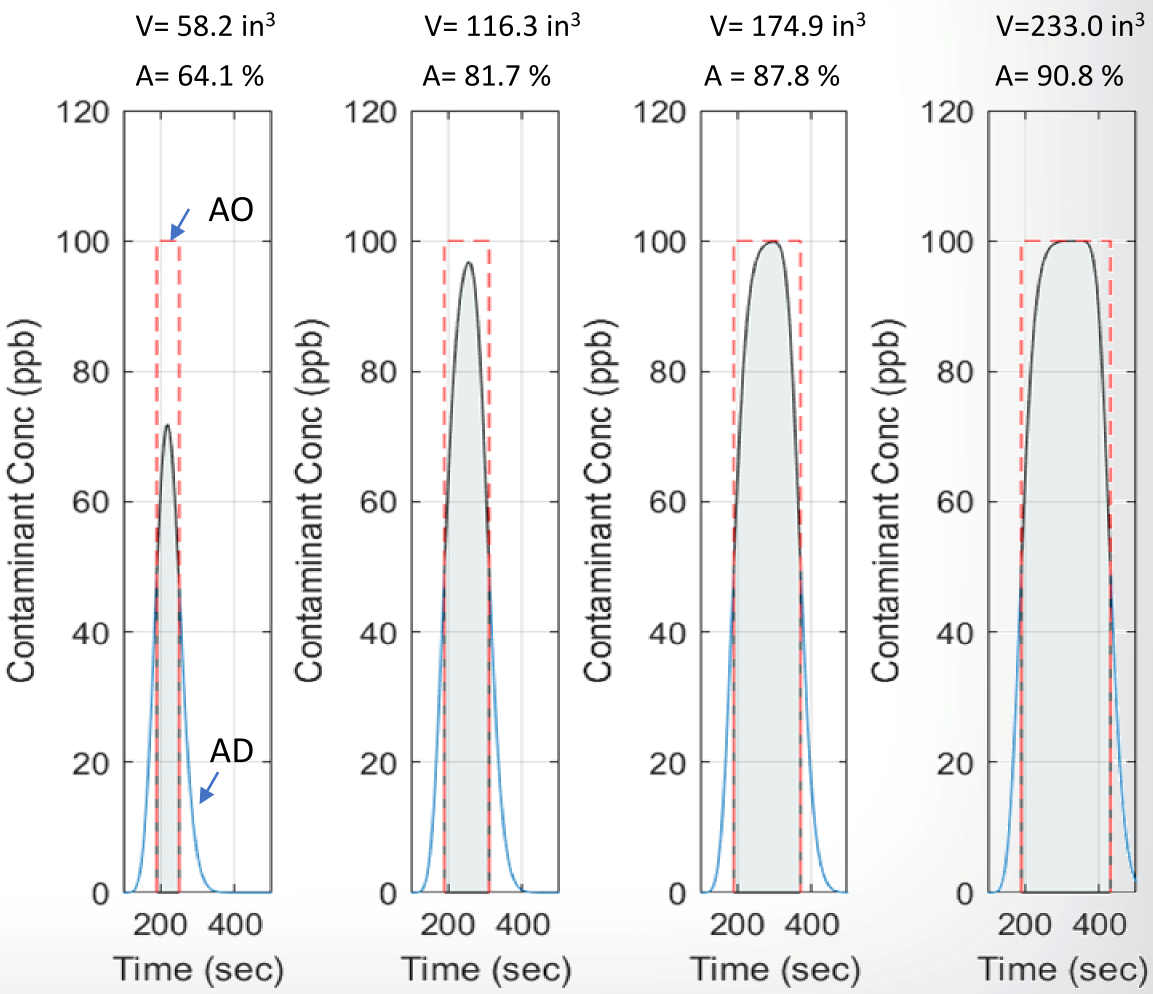


*https://www.home-water-works.org/

Results

- Dispersion effects to advective transport
  - Effects of various volumes of contaminant to advective transport
  - Comparison of percentage agreement between advection only (EPANET) and advection-dispersion equation
    - Compared the area under the curves between advection only and advection dispersion - converted to percentage
    - Advection only (AO) is shown as dashed lines and advection-dispersion (AD) is shown as solid lines

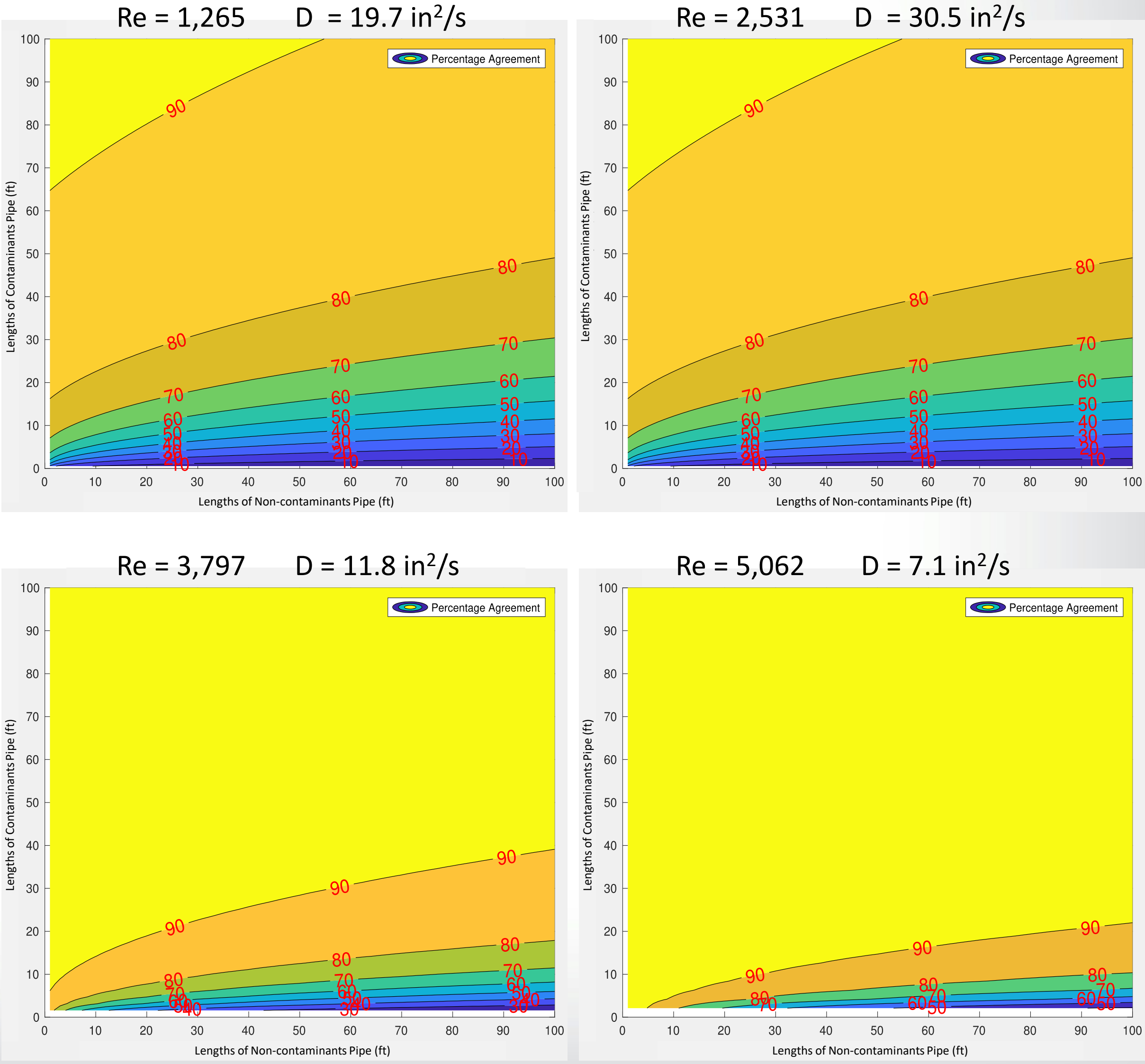
Re = 1,332, Diameter = 5/8 inches, D = 20.6 in^2/s



V: Contaminant volume, A: Area ratio under rectangular, D: Dispersion coefficient

Results

- Dispersion effects to advective transport
  - Changing velocity and various volumes of contaminant
    - Contour lines are the percentage agreement between AO and AD
    - Velocity increases, the higher numbers of percentage agreement are shown
    - When the volumes of contaminant increases, the percentage of agreement increases
  - Advection only equation
    - valid for the turbulent region
  - Small volume of contaminant
    - the advection only method may not be accurate due to the dispersion



Conclusion

- Hydraulic modeling of a PPS needs to consider dispersion effects
- Taylor dispersion is not applicable to practical application of premise plumbing system
  - Shower, kitchen, bathroom, refrigerator, drink a cup of water, and etc.
  - Only valid for fully developed turbulent region (Re > 10,000)
- Dimensionless dispersion coefficients:
  - For the pipe flow of transition and turbulent (2,000 < Re < 10,000)
    - Dimensionless dispersion coefficient varies between 0.3 and around 10.
  - For the pipe flow of laminar (1,000 < Re < 2,000)
    - Dimensionless dispersion coefficient seems to be around 10.
- Dispersion effects to advective transport in a PPS were investigated by changing velocity and various volumes of contaminant

Thank you !

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