CM3215
Fundamentals of Chemical Engineering Laboratory

Typing Equations in MS Word 2010

https://www.youtube.com/watch?v=ceNp9meHTmY

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Calibrate Rotameter and Orifice Meter and Explore Reynolds #

Extra features!

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What is an Orifice Flow Meter?

- Obstruct flow
- Build upstream pressure
- $\Delta p$ is a function of $Q$

Pressure drop across the orifice is correlated with flow rate (mechanical energy balance)

$$\frac{\Delta p}{\rho} + \frac{\Delta (v^2)}{2} + g\Delta z + F = \frac{W_{S,om}}{m}$$

(SI-SO, steady, $\rho$ const., no rxn, no phase chg, $T$ const, no heat xfer)
Orifice Flow Meters

MEB: Apply MEB between upstream point (1) and a point in the vena contracta (2):

\[
\frac{\Delta p}{\rho} + \frac{\Delta (v^2)}{2} + g\Delta z + F = \frac{W_{son}}{m}
\]

\[
\frac{p_2 - p_1}{\rho} + \frac{(v_2)^2 - (v_1)^2}{2} = 0
\]

Macroscopic mass balance:

\[
\frac{(v_1)pD^2}{4} = \frac{(v_2)pD_0^2}{4}
\]

Combine and eliminate \((v_2)\)


Q: What should you plot versus what to get a straight-line correlation?

(answer in prelab)
What is a Rotameter Flow Meter?

Reading on the rotameter (0-100%) is linearly correlated with flow rate.

www.alicatscientific.com/images/rotometer_big.gif
Rotameter Flow Meters

Think of the float cap as a pointer

Reading on the rotameter (0-100%) is linearly correlated with flow rate

Reynolds Number

\[ Re \equiv \frac{\rho (v_z) D}{\mu} \]

This combination of experimentally measureable variables is the key number that correlates with the flow regime that is observed. In a pipe:

- Laminar (Re < 2100)
- Transitional
- Turbulent (Re > 4000)
**O. Reynolds’ Dye Experiment, 1883**

Re laminar flow

\[ \text{Re} \equiv \frac{\rho \langle v_x \rangle D}{\mu} \]

Transitional flow

Turbulent flow


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**Flow Regimes in a Pipe**

- **Laminar**
  - Re < 2100
  - smooth
  - one direction only
  - predictable

- **Transitional**
  - 2100 < Re < 4000

- **Turbulent**
  - Re > 4000
  - chaotic - fluctuations within fluid
  - transverse motions
  - unpredictable - deal with average motion
  - most common

\[ \text{Re} \equiv \frac{\rho \langle v_x \rangle D}{\mu} \]

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Data may be organized in terms of two dimensionless parameters:

**Reynolds Number**

\[ \text{Re} \equiv \frac{\rho \langle v_z \rangle D}{\mu} \]

\( \rho \) = density  
\( \langle v_z \rangle \) = average velocity  
\( D \) = true pipe inner diameter  
\( \mu \) = viscosity  
\( (p_t - p_u) \) = pressure drop  
\( L \) = pipe length

(This is a definition)

**Fanning Friction Factor**

\[ f = \frac{1}{4} \frac{\Delta p_{\text{pipe}}}{L} \left( \frac{1}{2} \frac{1}{\rho \langle v_z \rangle^2} \right) \]

\( \rho \) = density  
\( \langle v_z \rangle \) = average velocity  
\( D \) = true pipe inner diameter  
\( \mu \) = viscosity  
\( (p_t - p_u) \) = pressure drop  
\( L \) = pipe length

(This comes from applying the definition of friction factor \( f \) to pipe flow)

For now, we measure this.
Data may be organized in terms of two dimensionless parameters:

**Reynolds Number**

\[
\text{Re} \equiv \frac{\rho \langle v_z \rangle D}{\mu}
\]

For now, we measure this

**Fanning Friction Factor**

\[
f = \frac{1}{4} \frac{\Delta p_{\text{pipe}}}{\frac{L}{D} \left( \frac{1}{2} \rho \langle v_z \rangle^2 \right)}
\]

In a few weeks, we measure this as well

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**Experimental Notes**

- Measure orifice pressure drop with DP meter (low pressure drops) or Bourdon gauges (high pressure drops)
- Determine **uncertainty** for both measurements (reading error, calibration error, error propagation)
- DP meter has valid output only from 4-20mA – above 20mA it is **over range**
- What is lowest **accurate** \( \Delta p \) that you can measure with the Honeywell DP meter? With the Bourdon gauges? Consider your uncertainties. (At what point will the error be 100% of your signal? What’s your tolerance for %error?)
- True triplicates must include all sources of random error (All steps that it takes to move the system to the operating condition must be taken for each replicate. Thus, setting the flow rate with the needle valve and the rotameter must be done for each replicate.)
- Watch level of Tank-01 (there is no **overflow** protection)
Report Notes

- Design your graphs to communicate a point clearly (chart design)
- The axes of your graphs must reflect the correct number of significant figures for your data
- Calculate averages of triplicates (needed for replicate error)
- Do not use the averages in calibration-curve fitting (use unaveraged data and LINEST).
- Use LINEST to determine confidence intervals on slope and intercept
- True inner diameter of type L copper tubing may be found in the Copper Tube Handbook (see lab website). The sizes \( \frac{1}{4} \), \( \frac{1}{2} \), and \( \frac{3}{8} \) are called nominal pipe sizes.

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Lab: Calibrate Rotameter and Explore Reynolds Number

- Pump water through pipes of various diameters
- Measure flow rate with pail-and-scale method
- Calibrate the rotameter
- Calibrate the orifice meter (measure \( \Delta P_{\text{Orifice}}(Q) \))
- Calculate Re for each run
- Determine if flow is laminar, turbulent, transitional
- Use appropriate error analysis, sig figs

Calibrate Flowmeters and Explore Reynolds Number

Pre-laboratory Assignment
Familiarize yourself with Reynolds number, rotameters, and orifice meters. Find an accurate calibration curve for the Honeywell DP meter at your lab station (your own calibration curve or one from the machine) and have it plotted in your lab notebook. Prepare a safety section in your laboratory notebook detailing all safety issues associated with this laboratory. Prepare the data tables in your notebook; you will need for data acquisition. All sheets of paper must be affixed to all data tables with clear tape before the start of lab.

Answer these questions as part of your problem sets (write answers in the notebook):

- Objectives as discussed in Data Analysis below

Experimental Procedures
Overall procedure:
1. Prepare the work station for isothermal water flow (see Procedure A in the appendix).
2. Turn on the electronic scale (Model CD-13 W-999) that is attached to the balance under Task 1 by plugging in the AC/DC power converter (120VAC or 9VDC 500 mA) into the AC outlet. When the electronic scale is on it will show the following on its screen: “Weight 4.100 kg (for example),” Press “Zero” key. It will show “0.000 kg.”
3. Read the Honeywell DP meter (see

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PreLab Assignment

- Familiarize yourself with Reynolds number, rotameters, and orifice meters.
- Find a good estimate of the calibration curve for the DP meter at your lab station (cycle 2) and have the equation in your lab notebook.
- Prepare a safety section
- Prepare data acquisition tables
- Answer these questions in your lab notebook:
  1. What should you plot (what versus what) to get a straight line correlation out of the orifice meter calibration data?
  2. In this experiment we calibrate the rotameter for flow directed through ¼", 3/8", and ¼" pipes (nominal sizes); will the calibration curve be the same for these three cases, or different?
  3. What is “dead heading” the pump?
First, look carefully at the data.

We are permitted to correct or omit “blunders.”

-歷史平均值

- 偏差

- 坡度

- 截距

- 标准误差

- 自由度
\[ n \text{ large guarantees that the means } \bar{m}, \bar{b} \text{ are good estimates of the true values (assuming only random errors are present)} \]

**Historical, 95% CI:**

\[ \bar{m} = 0.2308 \pm 0.0022 \text{ psi/mA} \]
\[ \bar{b} = -0.98 \pm 0.05 \text{ psi} \]

We are 95% confident that the true values of the slope and intercept are within these intervals.

(if only random error is present)
Note that the historical average almost goes through the point $(I, \Delta p) = (4,0)$.

Can you comment on that?

Station 1 Archive

Historical, 95% CI:
\[ \bar{m} = 0.2308 \pm 0.0022 \text{ psi/mA} \]
\[ \bar{b} = -0.98 \pm 0.05 \text{ psi} \]

Station 1 Archive

(identify a systematic error; correct the calibration curve)

\[ \Delta p \text{ (psi)} = \bar{m} I \text{ (mA)} + \bar{b} \]

If we know this point is on our correlation line, we can solve for a value of \( \bar{b} \), independent of the systematic offset in the data.
Another Error-Related question:

What's the **lowest** accurate \( \Delta p \)?

Can we measure \( \Delta p = 10 \text{psi} \)?
- 1 psi?
- 0.1 psi?
- 0.01 psi?
- 0.001 psi?
- 0.0001 psi?

When will the **value** be indistinguishable from the **noise** (error)?

Ordinary, **Least Squares**, Linear Regression

What are the error limits on a value of \( y \) obtained from the equation \( y = \hat{m}x + b \)?

**Answer:**

at \( x_p \), \( y_p = (\hat{m}x_p + \hat{b}) \pm 2s_{yp} \)

\[
s_{yp}^2 = s_{yx}^2 \left( \frac{1}{n} + \frac{(x_p - \bar{x})^2}{SS_{xx}} \right)
\]

for \( n - 2 \leq 6 \), replace "2" with \( t_{0.025,n-2} \)

Use this for error limits on the fit.

\( \Delta p = \Delta p \text{ predicted from calibration curve} \pm 2s_{yp} \)

From Error Analysis Lecture 5 on LINDEX:

In Excel:
- \( s_{yx} = \text{STEYX}([y\text{-range}],[x\text{-range}]) \)
- \( SS_{xx} = \text{DTVSQ}([x\text{-range}]) \)
- \( \hat{b} = \text{AVERAGE}([y\text{-range}]) \)
Another Error-Related question:

What’s the **lowest** accurate \( \Delta p \)?

\[
(\Delta p; \text{psi}) = (\bar{m})(I; \text{mA}) + b
\]

\[
\Delta p = \Delta p_{\text{predicted}} \pm 2s_y_p
\]

\( s_y_p \) is the standard deviation of the calibration curve.

Another Error-Related question:

What’s the **lowest** accurate \( \Delta p \)?

\[
(\Delta p; \text{psi}) = (\bar{m})(I; \text{mA}) + b
\]

\[
2s_y_p = y_p \Rightarrow 100\% \text{ error}
\]

\[
\Delta p = \Delta p_{\text{predicted}} \pm 2s_y_p
\]

\( s_y_p \) is the standard deviation of the calibration curve.
Another Error-Related question:

What's the lowest accurate $\Delta p$?

$\Delta p = \Delta p_{\text{predicted}} \pm 2s_{y_p}$

- $8s_{y_p} = y_p \Rightarrow 25\%$ error
- $4s_{y_p} = y_p \Rightarrow 50\%$ error
- $2s_{y_p} = y_p \Rightarrow 100\%$ error

Another Error-Related question:

$\Delta p = \Delta p_{\text{predicted}} \pm 2s_{y_p}$
Another Error-Related question:

What's the lowest accurate $\Delta p$?

$\Delta p = \Delta p_{predicted} \pm 2s_{yp}$

from calibration curve

$\Delta p = \Delta p_{psi}(\bar{m}; I; mA) + b$

$8s_{yp} = y_p \Rightarrow 25\%$ error

$4s_{yp} = y_p \Rightarrow 50\%$ error

$2s_{yp} = y_p \Rightarrow 100\%$ error

The choice is up to you.

Summary

- We can omit “blunders” from data sets
- We are always looking for possible sources of systematic error
- When a systematic error is identified (leftover water in unequal amounts on the two sides of the DP meter), we are justified in making adjustments to our correlations
- Note that the units of $\Delta p$ are $psi$ not $psig$. You’ve subtracted two numbers:

  $\Delta p = p_1 - p_2$

  For example:

  $p_1 = 5psi = 6psia$
  $p_2 = 0psi = 1psia$

  $\Delta p = 5psi = 5psi$

- The lowest number you can accurately report depends on your tolerance for uncertainty (25% max relative error is a good rule of thumb $\Rightarrow \Delta p_{min} \approx 8s_{yp}$)
Summary

• We can omit “blunders” from data sets
• We are always looking for possible sources of systematic error
• When a systematic error is identified (e.g., unequal amounts of water on the two sides of the DP meter), we are justified in making adjustments to our correlations
• Note that the units of $\Delta$ are not $\text{cm}^3$.
• The lowest number you can accurately report depends on your tolerance for uncertainty (25% max relative error is a good rule of thumb $\Rightarrow \Delta p_{\text{min}} \approx 8\sigma_p$)

Pay attention to pressures, and $\Delta p$’s: we measure many different pressures and $\Delta p$’s and often there is confusion

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