ENGR 83 Final Project:
Affordable Flowmeter for Measurement of Low-Flowrate Suspended-Particulate Flow

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Presentation Outline

- Introduction
- Design Process
- Testing & Results
- Conclusion

Introduction

- Problem: build a flow meter to measure volumetric flow through a hookah

http://www.languageofflowers.org/wp-content/uploads/2009/11/hookah_setup_diagram.gif

Introduction

- Goals
  - Measure flow rate to within ± 10%
    - Instantaneous output
  - Total cost ≤ $100
  - Long-term reliability of system.

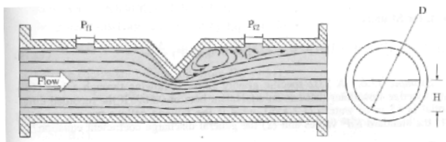
- Constraints
  - Low flow velocity/flow rate
  - Gas with suspended particulate matter
    - "Sticky"/corrosive particulate
  - Can't impede flow

Design Process

- Step 1: Problem Identification
  - Flow Characteristics
    - Dirty flow with "sticky" particulate
    - Low flow rate – mean flow of 12.9 lpm = 2.15 x 10^{-4} m^3/s (Shihadeh)
    - Low Reynolds numbers – between 1000 and 3000
  - Meter Characteristics
    - VERY low allowable pressure differential – under .1 kPa (.014 PSI) or use will be interfered with (Shihadeh)
    - Meter must be clog-resistant, easily cleaned, no moving parts
    - Meter must be corrosion-resistant

Design Process

- Step 1 Results
  - Type of Flowmeter: Wedge-type Meter



$$\beta_{Wedge} = \frac{d}{D} = \left(\frac{1}{\pi}\left\{\arccos\left(1-\frac{2H}{D}\right) - 2\left(1-\frac{2H}{D}\right)\left[\frac{H}{D}-\left(\frac{H}{D}\right)^2\right]^{1/2}\right\}\right)^{1/2}$$

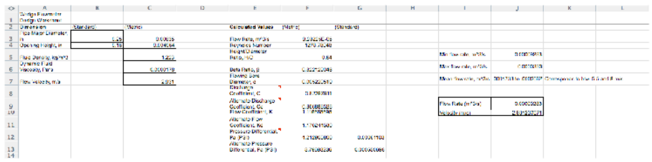
Figure 11.25 Wedge Flowmeter. *(Courtesy ABB-Kent Taylor.)*

Flow Measurement Engineering Handbook 11.35

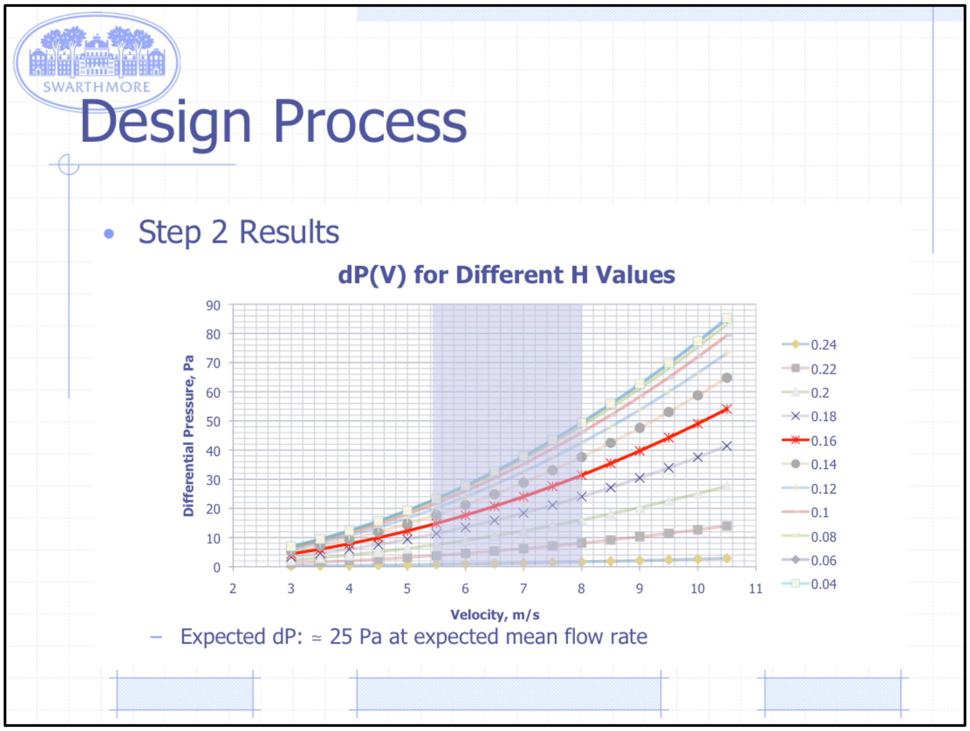
- Differential pressure meter
- Simple construction
- Resistant to clogging, low pressure loss, functional with low Reynolds number

Design Process

- Step 2: Analytic Design



  - Inputs: pipe diameter, opening height, fluid density, dynamic viscosity, flow velocity
    - Assumptions: Discharge coefficient is for .5” to 1” pipe
  - Outputs: Flow rate, Reynolds number, beta ratio, expected differential pressure



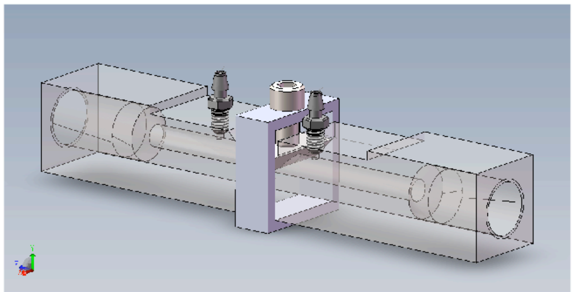
Mean expected flow region – between 5.5 and 8 m/s

Design Process

- Step 2 Results
  - Flow sensor: Sensirion SDP 1000-L025 Differential Pressure Sensor
    - Bidirectional differential pressure sensor
    - Analog output, logic level
    - Range: ± 62 Pa (.0089 PSI)
    - Resolution: .1 Pa (1.45×10^{-5} PSI)
    - Accuracy: .31 Pa (4.49×10^{-5} PSI)
  - For desired flow range, optimal H is .16”

Design Process

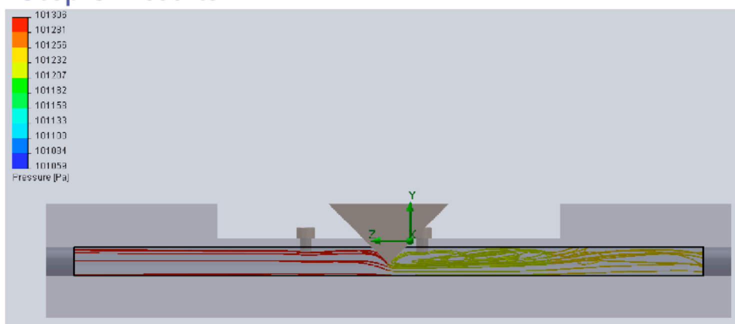
- Step 3: Computer Simulation
  - Meter modeled in SolidWorks



  - Simulated in Solidworks Flow Simulation

Design Process

- Step 3 Results



  - Much higher dP: ≃ 100 Pa at expected mean flow rate

However, not accurate simulation. Assumes atmospheric pressure at inlet and expected flow rate at output → does not account for pressure losses elsewhere in hookah, so assumes that they occur only in flowmeter. Consequently, simulation overestimates dP

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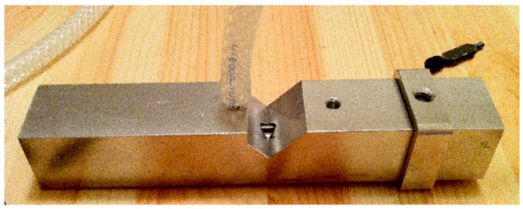
Design Process

- Step 4: Construction

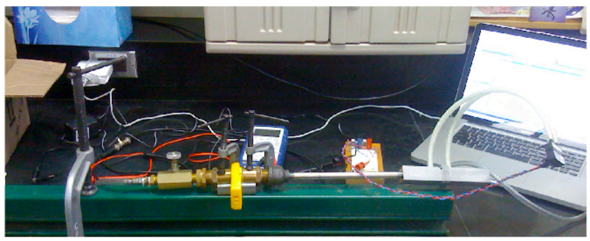


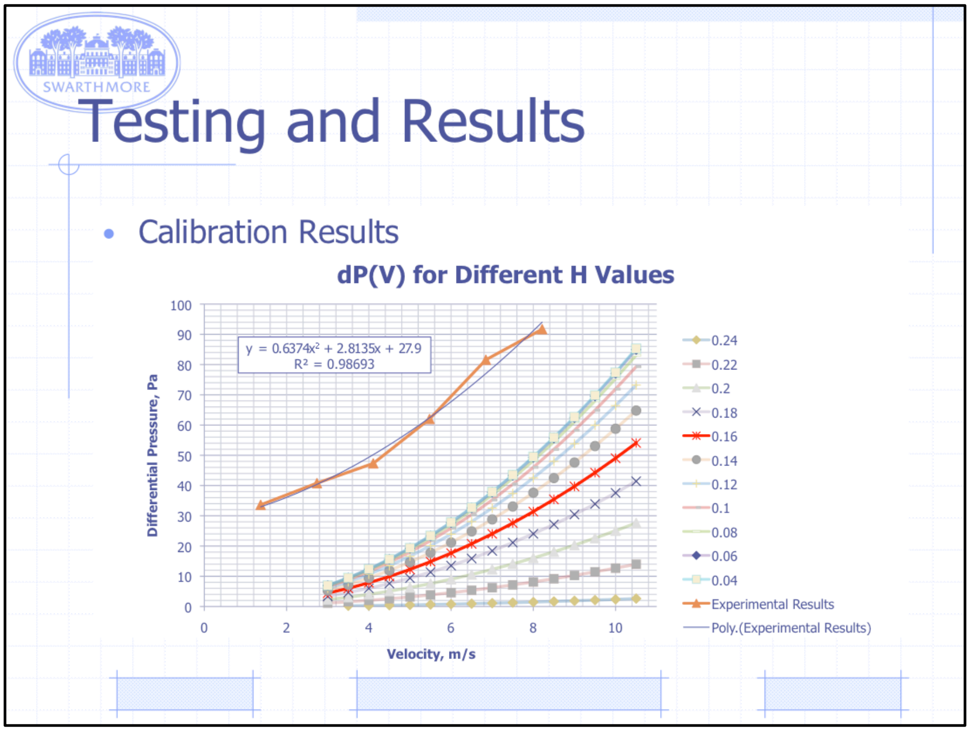
Meter Body

Wedge Element

Testing and Results

- Calibration
  - Meter calibrated by placing meter in series with anemometer in known-diameter pipe
  - Calibration possible between 4.33×10^{-5} and 2.60×10^{-4} m^3/s – above, exceeds limits of sensor
  - Test setup:





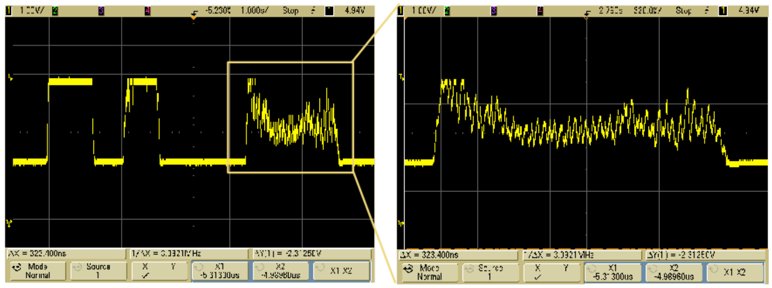
Exponential fit used because dP is function of velocity^2

Significantly higher pressure differentials than expected – simulation results are much closer to accurate

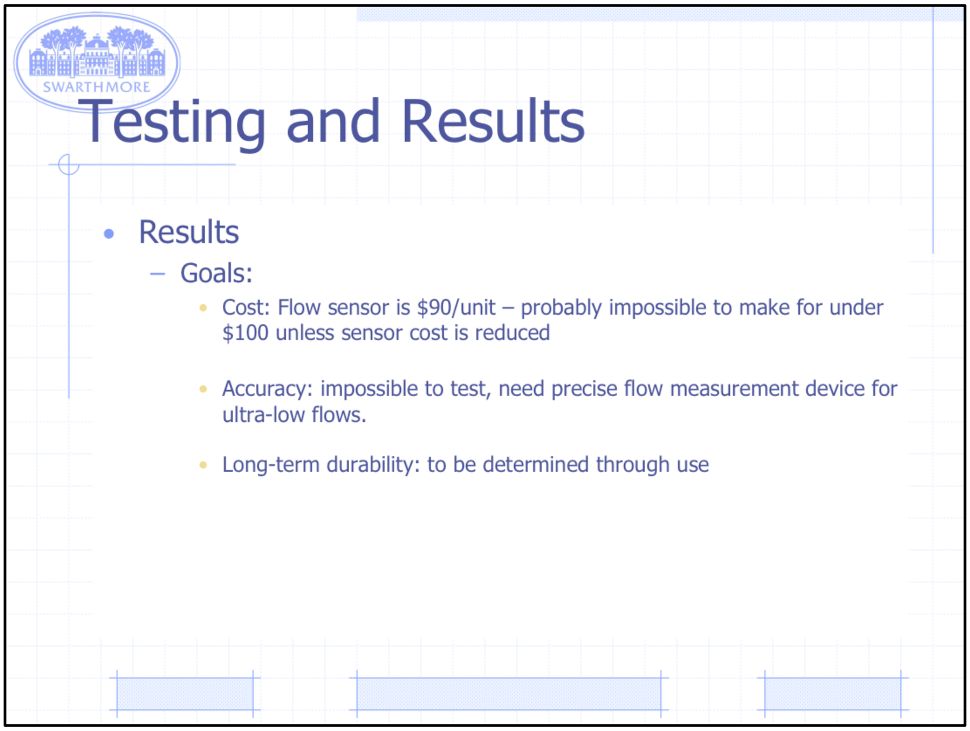
Needed new flow sensor – appears to work better, but still possible to "max out". Need to reanalyze what maximum flow rate is

Testing and Results

- Other Tests
  - "Bubbling" signal noise – 11 Hz noise



  - Does not interfere with signal - eliminated in software using LPF



Initial results indicate that contamination of the sensor itself is unlikely to be a problem, but flooding of the pressure lines with hookah fluid may be.

Testing and Results

- Future Work
  - Calibrate new sensor: ensure that sensor has not been damaged by handling
  - Implement contaminant traps for hookah fluid
    - Also reduce "bubbling" by providing vibration damper
  - Determine whether additional filtration is required
  - Implement more advanced "bubbling" filter in software

Conclusion

Questions?

References

- Miller, Richard W. *Flow Measurement Engineering Handbook*, 3rd Ed. McGraw Hill, 1996.
- Shihadeh, Alan. *A portable, low-resistance puff topography instrument for pulsating, high flow smoking devices.* http://webfea.fea.aub.edu.lb/aerosol/downloads/MS-03-63_revised.pdf
- ———. *Towards a topographical model of narghile water-pipe café smoking: a pilot study in a high socioeconomic status neighborhood of Beirut, Lebanon.* http://webfea.fea.aub.edu.lb/aerosol/downloads/topography.pdf