Date: March 30, 2006
To: Engineering World Health
From: BME 201 Design Team, UW-Madison
Subject: Flow Meter Design Proposal

This proposal is in response to your offer to provide funding for the production of a flow meter prototype. Our members include:

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We are all sophomores in the BME department at the University of Wisconsin - Madison. We have based our design specifications on a substantial amount of preliminary work and now need to build and test it in order to provide proof-of-concept. We request $74.32 to fund parts for this project. The check should be made out and sent to:

Biomedical Engineering Department
Attention: Corrine Bahr
1550 Engineering Drive
Madison, WI 53706-1609

Theory

Our flow meter design idea is based on the pressure drop across a Venturi-type constriction. The design, as depicted in the figures 1 and 2 below, consists of a main body tube, an obstruction to create a resistance partway through the tube, connectors on either side with ridges to secure the tubing and a loop of thinner tubing with ends on either side of the obstruction. This loop will be transparent, calibrated, and contain water in order to act as a manometer. The theory behind this design is fairly simple; it relates the pressure difference across the resistance to the gas flow rate through the tube.

Figure 1: Side View

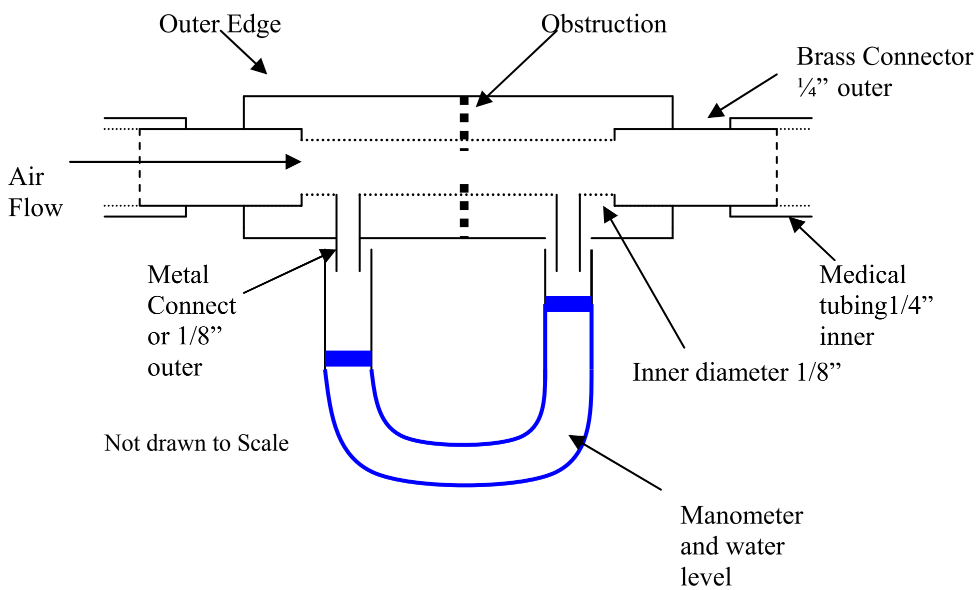
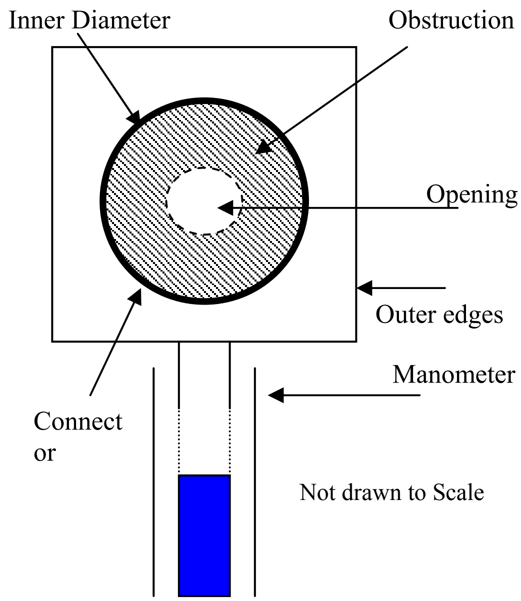


Figure 2: Front View



The flow rate through the tube using can be calculated from the pressure drop across the constriction via the Venturi equation:

$$Q = C\, \varepsilon\, \pi\, D_1^2\, (2\, \Delta P/\rho_g)^{1/2} / (4(1-\beta^2))^{1/2} \text{ (Webster, 1999)}$$

With the following parameters:

Symbol	Description
D_1	Inner Tube Diameter
D_2	Obstruction Diameter
C	Discharge Coefficient (based on machining of tube)
ΔP	Pressure Drop across obstruction
ε	Expansibility Factor, $[1/(1-(D_2/D_1)^4)]^{1/2}$
β	D_1 / D_2
ρ_g	Density of the Gas (1.275 kg/m^3 for air)

(The equation for ε can be found on the Flowmeter Directory website, and *β* can be found in Measurement, Instrumentation, and Sensors Handbook by Webster.)

This equation applies to viscous flow through a tube, where the simpler Bernoulli's equation applies to invicid flow only. The differences in pressure ΔP can be found from the difference in the heights of the fluid in the manometer with the equation $\Delta P = \rho_f g\, (\Delta h)$ where ΔP is the pressure difference, ρ_f is the density of the water (998 kg/m^3 at room temperature), Δh is the difference in height of the fluid, and g is the acceleration of gravity (Gerhardt, 1985). After the manometer is calibrated it can be used to find the flow rate of the gas through the tube based on the levels of the water. The Δh could be seen on the manometer by lines etched into the tubing.

We believe that our flowmeter design has several advantages. The Venturi-related design does not incorporate any moving parts, which could lead to measurement errors if the parts become lodged inside the main device. This also makes the device easier to maintain over a long period of time. Another important advantage when considering the locations and situations of potential use is that the design is simple to use and does not require any special training. We also believe that it will be accurate within ten percent. The device could be put to use immediately.

Specifications

The Venturi tube will be constructed from a 1" by 1" by 1" block of acrylic. The block will be machined to create a Venturi tube 1" long with an inner diameter of $^1/_8$" and ¼" connections on either end to attach to an external gas source. The inner diameter of the tube will be set by drilling a $^1/_8$" hole through the tube. Then additional ¼" diameter holes will be drilled $^1/_8$" in to both sides of the tube. These holes will be concentric with the original $^1/_8$" hole drilled through the entire tube. Brass tubing with an inner diameter of .22" and an outer diameter of ¼" will then be glued into these holes to use as connections.

The obstruction in the tube will be cut from another rectangular piece of acrylic. The main body of the meter will be cut in half and the obstruction would be glued in between both sides. This piece can then be accurately aligned with the outer tube so that the obstruction will be accurately centered inside the main tube. It will be placed ½” into the tube, and a smaller diameter will be machined separately than the overall tube diameter. We plan on testing several different diameters for the obstruction and then using the one that produces the best results. The manometer will attach to the main tube with one end removable to allow water refilling. The connections for the manometer will be made by drilling two $^1/_8$” hole upwards to connect with the main $^1/_8$” hole running through the entire tube. These holes will be drilled ¼” from the edge of the tube on either side. Brass tubes with an outer diameter of 1/8” will then be glued in and used to fit on the manometer tubing which will extend up to 3” below the main tube. The manometer will be filled with colored water, which will serve as the indicator. The manometer tube will be calibrated for a single readout design with a proper range indicated on the tube. Therefore, when the flow rate is in the desired range the water inside the manometer will be between two markings indicated on the manometer tube.

Budget

Below is a spreadsheet of the necessary materials and cost of tubing and acrylic blocks in order to make flow meters in quantities of 3 and 500, as well as our requested amount. Our calculated amount is based off of the fact that one of the companies we are purchasing from, United States Plastics Corp., only sells the acrylic blocks in lengths of 6 ft, the manometer tubing in 50 ft increments and the medical tubing in 10 ft increments. The brass tubes, from McMaster-Carr, come in a pack of 8 or 1, each 12” long, for the ¼” outer diameter and a pack of 15, each 12” long, for the 1/8” outer diameter. The epoxy is for connecting the brass tubing to the flow meter as well as securing the obstruction in the middle. We are requesting money to buy the medical tubing in order to perform the tests to accurately calibrate our device. With these materials we will be able to make several flow meters, some with different obstruction diameters, to test as well as have extra in case of manufacturing mistakes. We do not believe that the person hours required to put this device together will be over our budget after the process is perfected. There is also the possibility for a mold to be made for the main body of the flow meter that would greatly reduce the manufacturing time to make a single meter.

The requested materials include:

- Acrylic rods – 1” x 1” x 6’ (item number 44141 from http://www.usplastic.com)
- Medical tubing – ¼” inner diameter, ⅜” outer diameter, length of 10’ (item number 54003 from http://www.usplastic.com)
- Manometer tubing – ⅛” inner diameter, ¼” outer diameter, length of 50’ (item number 59002 from http://www.usplastic.com)
- Epoxy – 115 in^2 (item number 506/19 from http://www.mcmaster.com)
- Brass Tube – ¼” outer diameter (item number 8859K24 or 7782T111 from http://www.mcmaster.com)
- Brass Tube – 1/8” outer diameter (item number 8859K19 from http://www.mcmaster.com)

Amount of items needed	Tubing (ft)	Acrylic Block (ft)	Medical Tubing(ft)	Epoxy (bottles)	Brass Tubing 1/4” (ft)	Brass Tubing 1/8” (ft)
For 3 flow meters	50	6	0	1	1	15
For 500 flow meters	500	84	0	10	48	45
Our requested amount	50	6	10	1	1	15

Cost($)	Tubing	Acrylic Block	Medical Tubing	Epoxy	Brass Tubing ¼”	Brass Tubing 1/8”	Shipping	Total
For 3 flow meters	4.00	27.12	0.00	11.70	4.38	13.33	20.00	80.03
For 500 flow meters	40.00	379.68	0.00	117.00	65.56	39.99	50.00	692.23
Our requested amount	4.00	27.12	11.50	11.70	4.38	13.33	20.00	92.03

Resources

1) Flowmeter Directory. “Medical Flowmeter.” 29 Jan. 2006 <http://www.flowmeterdirectory.com/flowmeter_medical.html>

2) Gerhart, M. and Gross, J. Fundamentals of Fluid Mechanics. Addison-Wesley: 1985.

3) Webster, J.G., Editor. Measurement, Instrumentation, and Sensors Handbook. CRC Press: 1999.