MEMORANDUM

TO: Professor Weber
FROM: Mike Hennessy, Didi Ikenna, Jack Leon
DATE: October 18, 2021
SUBJECT: Venturi Meter

Introduction

The purpose of this assignment is to understand how a venturi meter works and learn to use Autodesk programs and graphing techniques in Excel. In addition, the objective is to create and test a venturi meter using Autodesk CFD, and use the results to determine the discharge coefficient.

The basic approach to the problem was to calculate the velocity head, pressure head, and total head from the entrance of the venturi to its throat. Then, graph the ideal flow rate (Q_{ideal}) versus change in piezometric head ($\triangle H$) in a log-log relationship. Next, create a CAD model of the venturi meter using Autodesk Fusion 360, transfer that model to a 2-D CAD drawing, run Autodesk CFD under given parameters to measure the flow rate, and finally compute the discharge coefficient (C_d).

Venturi Design

The equation for ideal flow rate (Q_{Ideal}) was derived from two equations under ideal conditions: the Continuity Equation and Bernoulli's Equation (figure 10). The ideal conditions included a head loss of zero and an elevation head of zero. The Q_{Ideal} formula was found to equal the Kappa value multiplied by the area and by the square root of the head loss.

Then, Excel was used to graph and calculate the velocity head, pressure head, and total head versus distance from the entrance of the venturi to its throat (figure 6); Q_{ideal} versus change in piezometric head ($\triangle H$) (figure 5); and Q_{ideal} versus change in piezometric head ($\triangle H$) utilizing a log-log relationship (figure 4).

To create the initial 3D CAD model, Autodesk Fusion 360 was used. The dimensions of the venturi meter were given (figure 7). The basis was a 241.31-millimeter length, with a 55 millimeter by 55-millimeter square base. The diameter of the circular meter started at 50 millimeters and got to as little as 39.59 millimeters, before increasing back to 50 millimeters. The 3D model created in Autodesk Fusion 360 was transformed into a 2D CAD drawing with isometric and orthographic views (figure 9). This drawing was transferred into Autodesk CFD 2021, where actual flow rates (Q_{Actual}) in cubic feet per second and dimensions were given and inputted into the program to find an exact pressure drop ($\triangle p$) in pounds per square inch. The exact pressure drop was found by having Autodesk CFD 2021 simulate 300 trials of water flowing through the modeled venturi meter to visualize the static pressure (figure 3). After the simulation was completed, a x-y chart was generated to show the correlation between static pressure and parametric distance (figure 1). Finally, we concluded the pressure drop by subtracting the maximum, 0.122019 pounds per square inch, and minimum, -0.34712 pounds per square inch, pressure values. The pressure drop was converted to a head loss by dividing by the specific weight of water, 62.4 pounds per cubic foot. The ideal flow rate (Q_{Ideal}) in cubic feet per second was calculated by multiplying the Kappa value in square root of feet per second by the area in square feet and by the square root of the head loss. Eight values for actual flow rates were given, with eight values of the pressure drop being found and converted to ideal flow rates. The actual flow rate was graphed against the ideal flow rate to perform a regression analysis.

Performance Results

Group 4's actual flow rate value was given to be 0.131, and the pressure drop was found to be about 0.469 pounds per square inch. The other seven values are included in Table 1 and were used to graph the actual flow rate vs. the ideal flow rate (figure 2). The discharge coefficient (C_d) is the actual flow rate divided by the ideal flow rate, so it is the slope of this graph. This theoretical value was found to be 0.9534.

Conclusion

The theoretical value of the discharge coefficient means that the actual flow rate is about 95.34% of the ideal flow rate. Almost 5% of flow rate was lost due to non-ideal conditions. These conditions could have been a head loss not equal to zero or an elevation head not equal to zero. The trials were run through an Autodesk CFD program, rather than a physical prototype. Since the program has better analysis and specifications than a physical form, the error is less than that of a prototype. All calculations were done through Excel, so no error occurred on that part. With average discharge coefficient ranging between 0.9 and 1, this venturi meter is effective.

Appendix

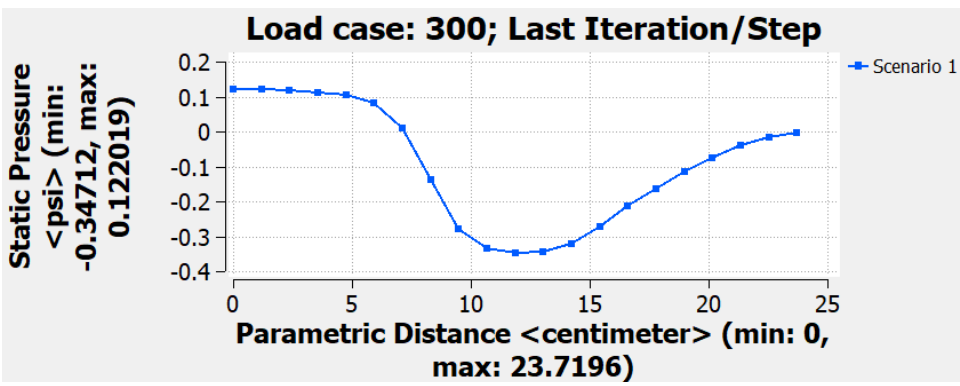


Figure 1 The correlation between static pressure and parametric distance

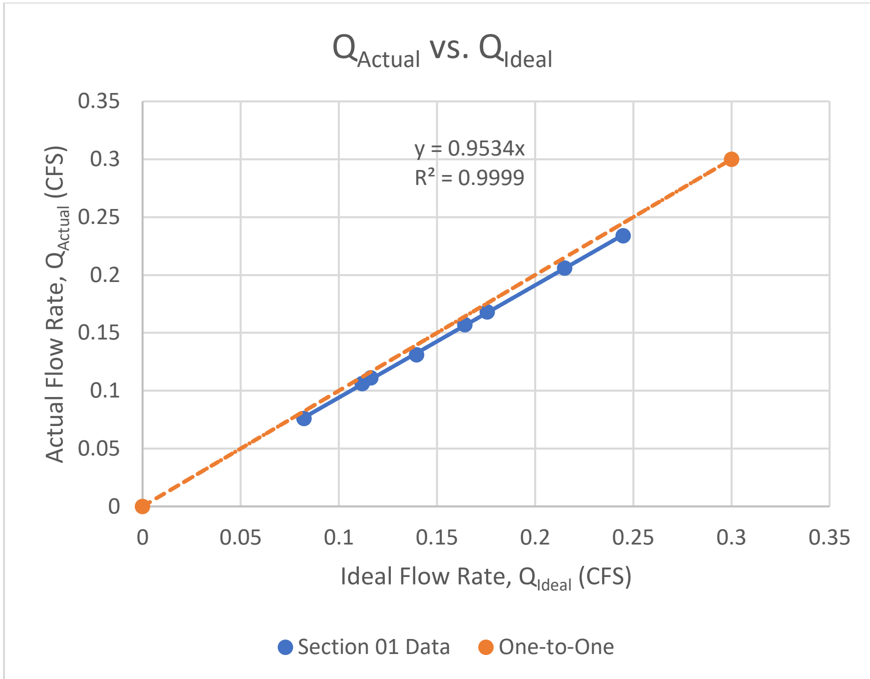


Figure 2 The correlation between actual flow rate and ideal flow rate

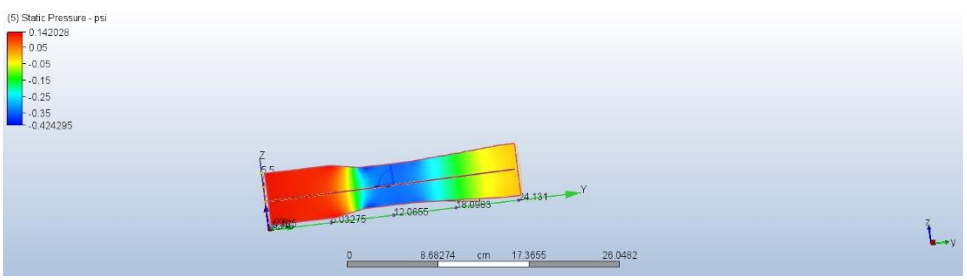


Figure 3 Visualization of static pressure in a venturi meter

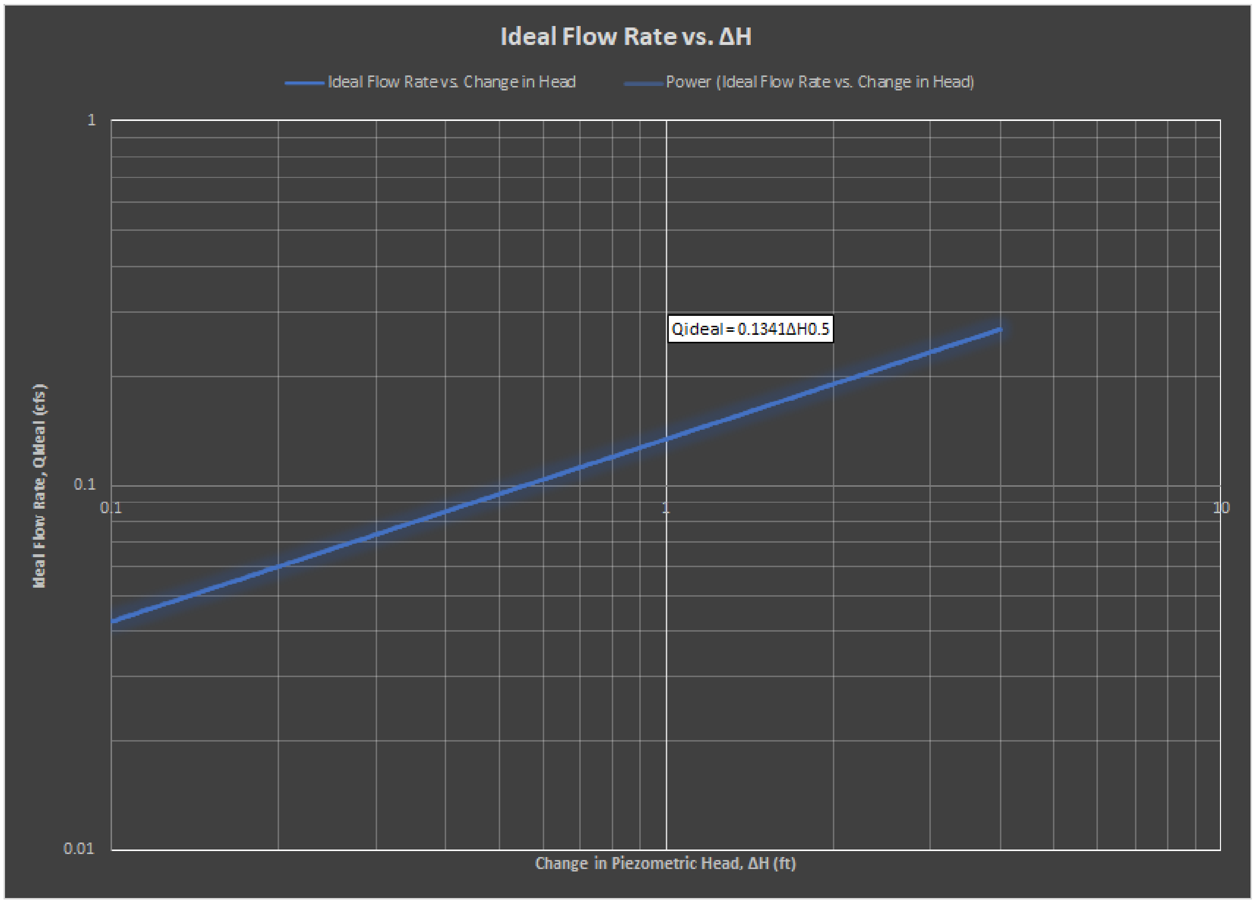


Figure 4 Correlation between logarithmic ideal flow rate and logarithmic change in piezometric head

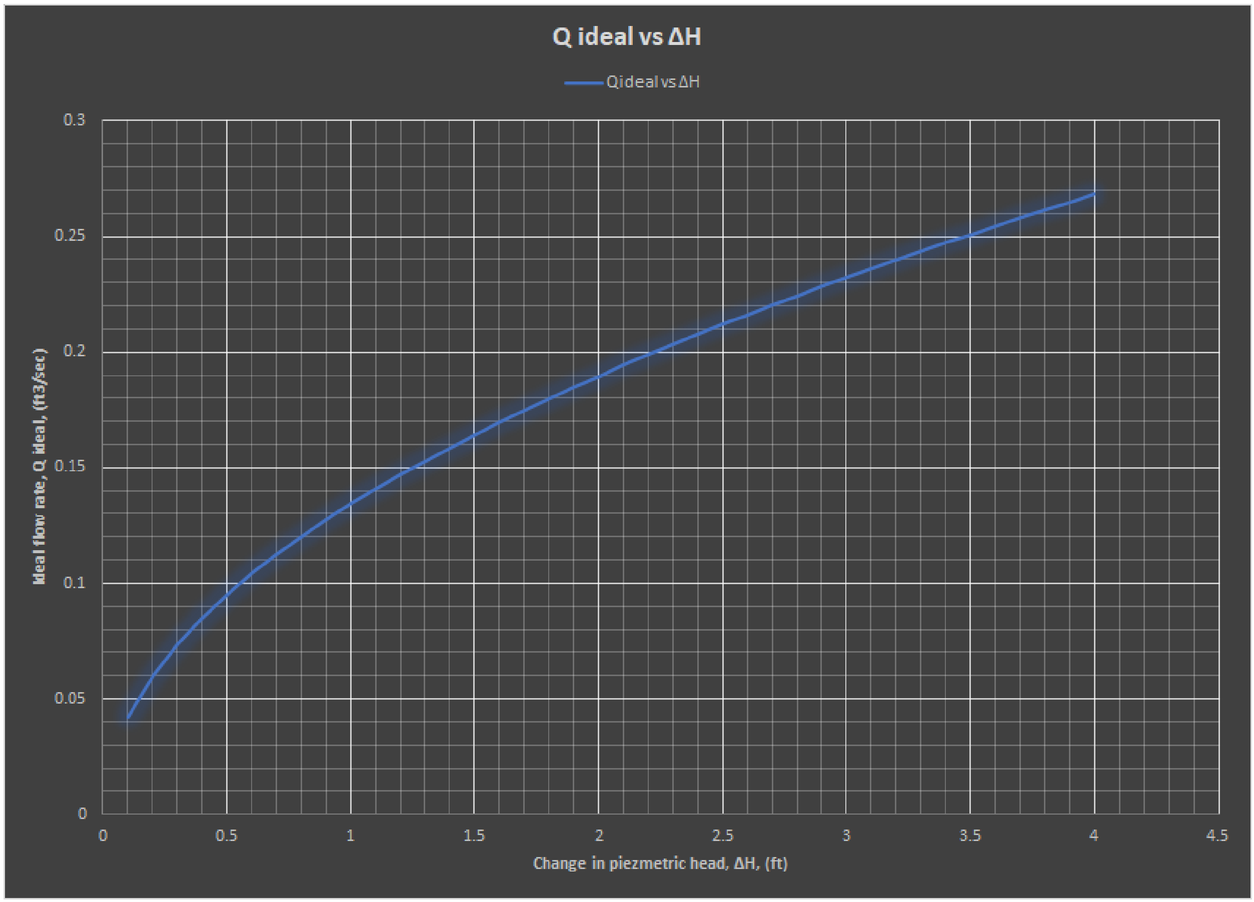


Figure 5 Correlation between ideal flow rate and change in piezometric head

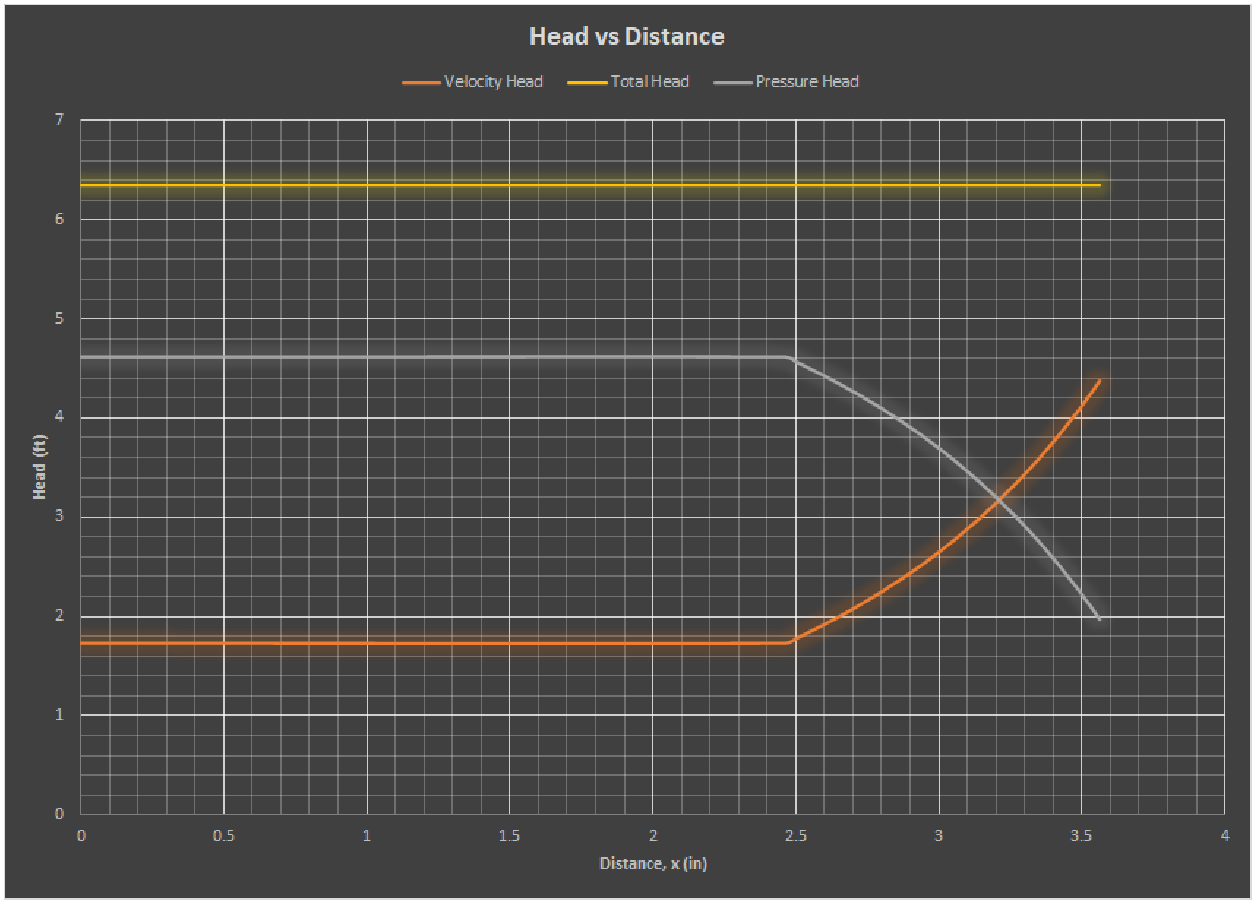


Figure 6 Correlation between head and distance

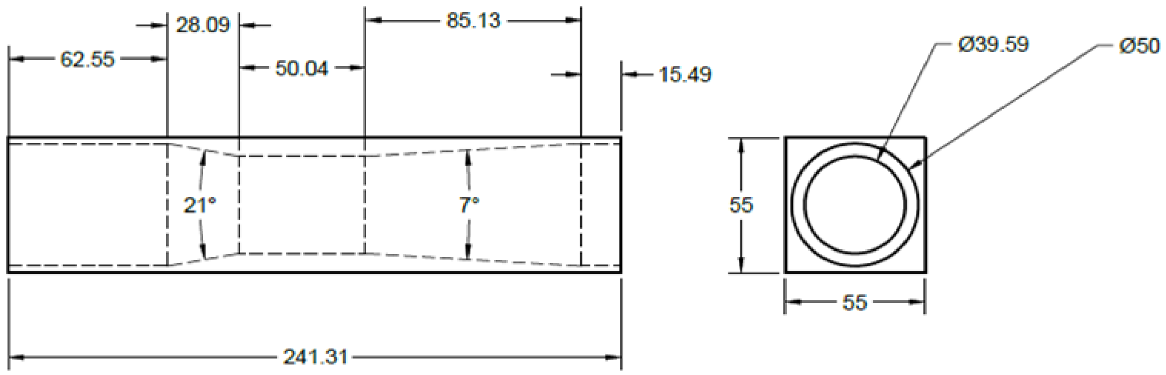


Figure 7 Isometric drawing of venturi meter

$$Q_{ideal} = \frac{\pi}{4} D_1^2 \left[\frac{(H_1 - H_2)2g}{\left(\frac{D_1}{D_2}\right)^4 - 1} \right]^{1/2} = \frac{\pi}{4} D_2^2 \left[\frac{(H_1 - H_2)2g}{1 - \left(\frac{D_2}{D_1}\right)^4} \right]^{1/2}$$

Figure 8 Ideal flow rate equation

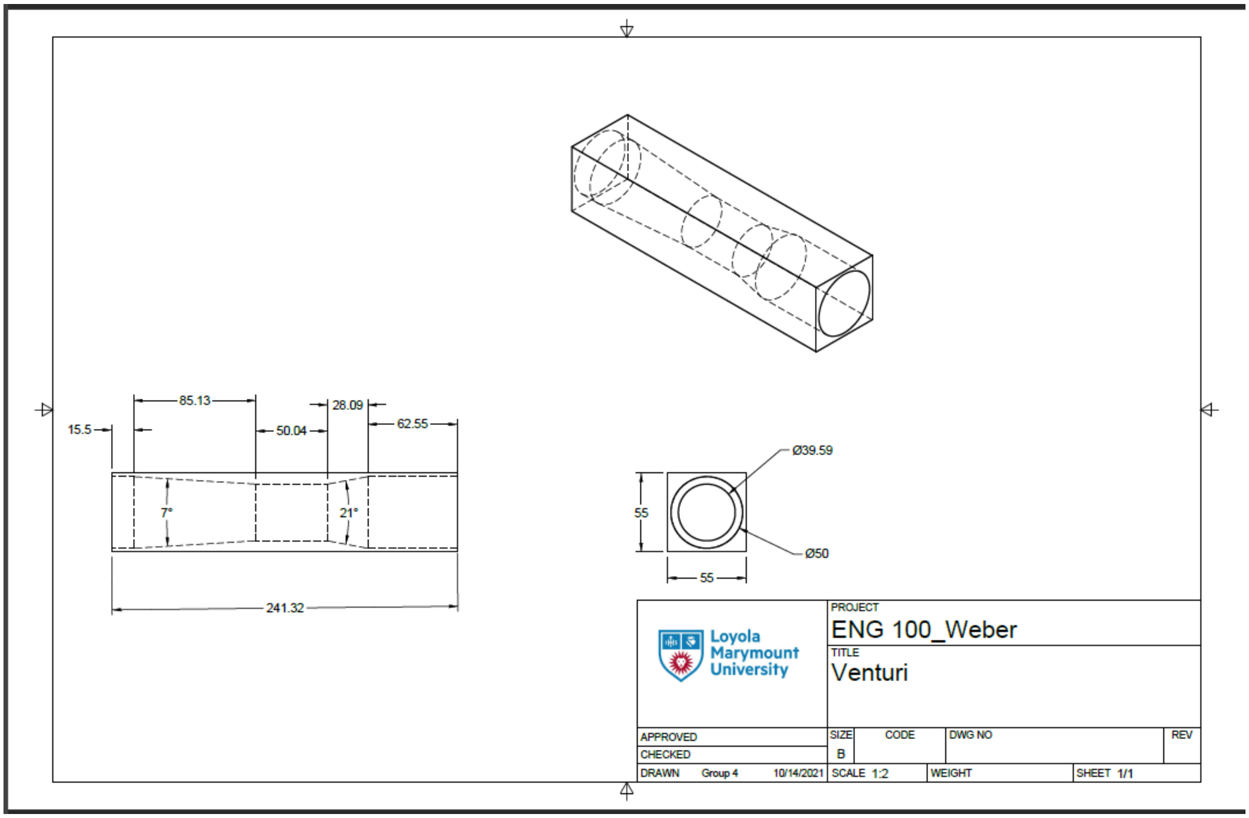


Figure 9 2D model of the venturi meter

ENG 100 - 02 Mike Hennessy, Jack Leon, Didi Ikenna

Part 1: Ideal Venturi Meter Derivation

Givens:

Continuity Equation: Q = Flow Rate, $Q_1 = Q_2$

Assume Ideal Conditions:
$H_L = 0$, $z_1 = 0$, $z_2 = 0$ $\quad Q = Av = A_1 v_1 = A_2 v_2$

Q = Flow Rate $\quad v$ = velocity $\quad A$ = area

Bernoulli's Equation:

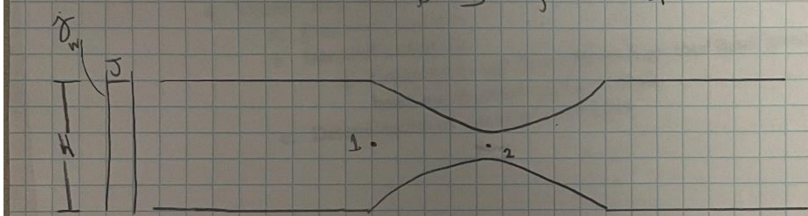
$$H_{Total} = \frac{p}{\gamma} + \frac{v^2}{2g} + z$$

H_{Total} = Total Head = Pressure Head + Velocity Head + Elevation (Potential) Head

Find: $Q_{Ideal} = KA_2(\Delta H)^{\frac{1}{2}}$

where $K = \left[\frac{2g}{1-\beta^4}\right]^{\frac{1}{2}}$; $\beta = \frac{D_2}{D_1}$

g = gravity = 32.2 ft/sec^2



Calculations:

$p = h\gamma \qquad h = \frac{p}{\gamma} \qquad H_{T,1} = H_{T,2} - h_{Losses}$

$$H_1 + \frac{v_1^2}{2g} + z_1 = H_2 + \frac{v_2^2}{2g} + z_2 + H_L$$

$$H_1 + \frac{v_1^2}{2g} = H_2 + \frac{v_2^2}{2g}$$

Δh = change in pressure head = $h_1 - h_2$

$$\Delta H = H_1 - H_2 = \frac{v_2^2}{2g} - \frac{v_1^2}{2g} = \frac{v_2^2 - v_1^2}{2g}$$

$$v_1 = \frac{A_2 v_2}{A_1} \qquad \Delta H = \frac{v_2^2 - \left(\frac{A_2 v_2}{A_1}\right)^2}{2g}$$

$$2g\Delta H = v_2^2\left(1 - \left(\frac{A_2}{A_1}\right)^2\right)$$

$$v_2 = \left(\frac{2g\,\Delta H}{1-\left(\frac{A_2}{A_1}\right)^2}\right)^{\frac{1}{2}}$$

$A_{circle} = \pi r^2 \qquad D = 2r$

$A_c = \pi\left(\frac{D}{2}\right)^2 = \frac{\pi D^2}{4}$

$$\frac{A_2}{A_1} = \frac{\frac{\pi D_2^2}{4}}{\frac{\pi D_1^2}{4}} = \frac{D_2^2}{D_1^2} = \left(\frac{D_2}{D_1}\right)^2$$

$$\beta = \frac{D_2}{D_1}$$

$$Q_{Ideal} = A_2 V_2 = A_2\left(\frac{2g\,\Delta h}{1-\left(\frac{A_2}{A_1}\right)^2}\right)^{\frac{1}{2}} = A_2(\Delta H)^{\frac{1}{2}}\left(\frac{2g}{1-\beta^4}\right)^{\frac{1}{2}}$$

$$Q_{Ideal} = KA(\Delta H)^{\frac{1}{2}}$$

Figure 10 Derivation of the ideal flow rate equation

Table 1 CFD modeling results of all groups

Group	Q_{act} (cfs)	CFD Modeling Results		Q_{ideal} (CFS)
		Δp (psi)	ΔH_cfd (ft)	
1	0.076	0.1628885	0.375896538	0.03697
2	0.106	0.3017771	0.696408692	0.043661
3	0.111	0.3261961	0.752760231	0.044679
4	0.131	0.469139	1.082628462	0.048538
5	0.157	0.649447	1.498723846	0.053137
6	0.168	0.742563	1.713606923	0.054967
7	0.206	1.114017	2.570808462	0.060866
8	0.234	1.444	3.332307692	0.064871