MET 335

Module 7 – Orifice Plate Coefficents

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Purpose, Theory, and Procedure

1. **Experiment Title**
   a. Orifice Plate Coefficients
2. **Purpose**
   a. To apply Bernoulli's equation to orifice plates and while doing so, develop a learning on how to calculate the orifice plate coefficient. Learning said calculation will establish the orifice loss coefficients for difference sizes as a function of the Reynolds number.
3. **Theoretical Considerations**
   a. Bernoulli's equations between upstream location and the vena contracta:
      i. $\frac{P_1}{\gamma}+\frac{(V_1)^2}{2g}+\frac{P_2}{\gamma}+\frac{(V_2)^2}{2g}$
   b. Conversation of mass equation on the above equation allows to square both sides of the equation and divide by 2g:
      i. $\frac{V_1^{\ 2}}{2g}=\left(\frac{A_2}{A_1}\right)^2\frac{V_2^{\ 2}}{2g}$
   c. Substitute equation b. into equation a.
      i. $V_2=\sqrt{\frac{2g\frac{(P_1-P_2)}{\gamma}}{1-\left(\frac{A_2}{A_1}\right)^2}}$
   d. $A_2=C_C A_0$
   e. $Q=A_2V_2=C_CA_0V_2$
   f. $Q=C_CA_0\sqrt{\frac{2g\frac{\Delta P}{\gamma}}{1-C_C^{\ 2}(\frac{A_0}{A_1})^2}}$
   g. $\frac{C_0}{\sqrt{1-\left(\frac{A_0}{A_1}\right)^2}}=\frac{C_0C_C}{\sqrt{1-C_C^{\ 2}\left(\frac{A_0}{A_1}\right)^2}}$
   h. $Q=C_0A_0\sqrt{\frac{2gh_0\left(\frac{\gamma_m}{\gamma_{air}}-1\right)}{1-\left(\frac{A_0}{A_1}\right)^2}}$

i. $C_0 = \frac{Q}{A_0}\sqrt{\frac{1-\left(\frac{A_0}{A_1}\right)^2}{2gh_0\left(\frac{\gamma_m}{\gamma_{air}}\right)}}$

j. Where C_0 equals orifice coefficient

k. Where h_0 equals orifice manometer reading

l. Where γ_m equals specific weight of manometer fluid which is water in this case

m. Where γ_{air} equals specific weight of air at room pressure and temperature

n. $Q = C_V A_{throat}\sqrt{\frac{2gh_V\left(\frac{\gamma_m}{\gamma_{air}}\right)}{1-\left(\frac{A_{throat}}{A_{tube}}\right)^2}}$

o. Where C_V equals venturi coefficient

p. Where A_{throat} equals venturi throat area

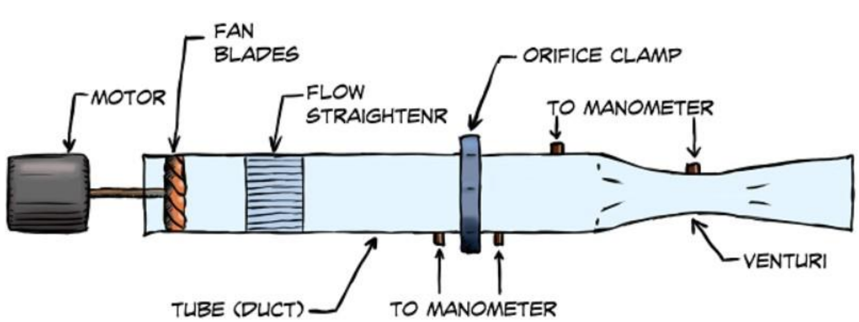
q. Where A_{tube} equals tube area

r. Where h_V equals venturi manometer reading

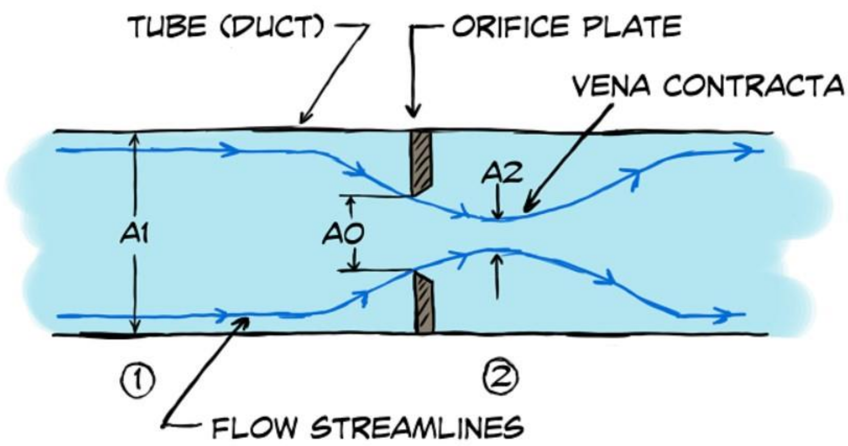
s. $N_R = \frac{4\rho Q}{\pi D_{tube}\mu}$

t. $C_V = 0.986 - \left(\frac{471.5}{N_{R,Max}^{\ 0.935}}\right)$

4. Drawing or Sketch



a. *Orifice plate apparatus*



b. *Orifice plate*

5. **Verbal Description**
    a. The apparatus above consists of a small, variable-speed turbofan with discharge ducting. This ducting contains a flow straightener and a location that can be used for the insertion of a variety of orifice plates that are locked in place in with a clamp. These orifice plates can also be used to measure flow rate, but during this lab, we are specifically determining the friction losses created by the orifice plates, so students will measure the flow rate with a venturi attached at the end of the apparatus (far right). Students will use a digital manometer for measuring the pressure drop across the orifice plate and venturi.
6. **Step-by-Step Procedure**
    a. Entered the lab room.
    b. Identified the six components used for the lab:
        i. Fan Motor
        ii. Orifice Plates
        iii. Venturi Throat Diameter
        iv. Digital Manometer
        v. Clamp
        vi. Duct Diameter
    c. Recorded room temperature (75 degrees Fahrenheit).
    d. Recorded barometric pressure reading (29.92in).
    e. Turned on the main power switch.
    f. Turned on the power switch for the dial.
    g. Turned on the power switch for the digital manometer.
    h. Verified tare button reset digital displays to zero.
    i. Recorded duct diameter (5.125in).
    j. Recorded venturi throat diameter (2.562in).

k. Chose smallest diameter orifice plate.
l. Recorded orifice plate diameter (1.03in).
m. Installed 1.03in diameter orifice plate into duct.
n. Turned motor control knob to 80%.
o. Recorded two manometer readings:
    i. Orifice head (3.00in)
    ii. Venturi head (0.027in)
p. Turned motor control knob to 75%.
q. Recorded two manometer readings:
    i. Orifice head (2.76in)
    ii. Venturi head (0.023in)
r. Turned motor control knob to 70%.
s. Recorded two manometer readings:
    i. Orifice head (2.48in)
    ii. Venturi head (0.020in)
t. Turned motor control knob to 65%.
u. Recorded two manometer readings:
    i. Orifice head (2.17in)
    ii. Venturi head (0.018in)
v. Turned motor control knob to 60%.
w. Recorded two manometer readings:
    i. Orifice head (1.91in)
    ii. Venturi head (0.013in)
x. Turned motor control knob to 55%.
y. Recorded two manometer readings:
    i. Orifice head (1.65in)
    ii. Venturi head (0.013in)
z. Turned motor control knob to 50%.
aa. Recorded two manometer readings:
    i. Orifice head (1.41in)
    ii. Venturi head (0.010in)
bb. Turned motor control knob to 45%.
cc. Recorded two manometer readings:
    i. Orifice head (1.21in)
    ii. Venturi head (0.008in)
dd. Turned motor control knob to 40%.
ee. Recorded two manometer readings:
    i. Orifice head (0.99in)
    ii. Venturi head (0.007in)
ff. Turned motor control knob to 0%.
gg. Removed 1.03in diameter orifice plate from duct.

hh. Recorded second orifice plate diameter (2.055in).
ii. Installed 2.055in diameter orifice plate into duct.
jj. Turned motor control knob to 80%.
kk. Recorded two manometer readings:
    i. Orifice head (2.24in)
    ii. Venturi head (0.335in)
ll. Turned motor control knob to 75%.
mm. Recorded two manometer readings:
    i. Orifice head (2.04in)
    ii. Venturi head (0.313in)
nn. Turned motor control knob to 70%.
oo. Recorded two manometer readings:
    i. Orifice head (1.79in)
    ii. Venturi head (0.279in)
pp. Turned motor control knob to 65%.
qq. Recorded two manometer readings:
    i. Orifice head (1.59in)
    ii. Venturi head (0.249in)
rr. Turned motor control knob to 60%.
ss. Recorded two manometer readings:
    i. Orifice head (1.40in)
    ii. Venturi head (0.215in)
tt. Turned motor control knob to 55%.
uu. Recorded two manometer readings:
    i. Orifice head (1.20in)
    ii. Venturi head (0.182in)
vv. Turned motor control knob to 50%.
ww. Recorded two manometer readings:
    i. Orifice head (1.04in)
    ii. Venturi head (0.157in)
xx. Turned motor control knob to 45%.
yy. Recorded two manometer readings:
    i. Orifice head (0.864in)
    ii. Venturi head (0.132in)
zz. Turned motor control knob to 40%.
aaa. Recorded two manometer readings:
    i. Orifice head (0.720in)
    ii. Venturi head (0.109in)
bbb. Turned motor control knob to 0%.
ccc. Removed 2.055in diameter orifice plate from duct.
ddd. Recorded last orifice plate diameter (4.10in).

eee. Installed 4.10in diameter orifice plate into duct.
fff. Turned motor control knob to 80%.
ggg. Recorded two manometer readings:
  i. Orifice head (0.515in)
  ii. Venturi head (2.500in)
hhh. Turned motor control knob to 75%.
iii. Recorded two manometer readings:
  i. Orifice head (0.462in)
  ii. Venturi head (2.230in)
jjj. Turned motor control knob to 70%.
kkk. Recorded two manometer readings:
  i. Orifice head (0.402in)
  ii. Venturi head (1.950in)
lll. Turned motor control knob to 65%.
mmm. Recorded two manometer readings:
  i. Orifice head (0.352in)
  ii. Venturi head (1.720in)
nnn. Turned motor control knob to 60%.
ooo. Recorded two manometer readings:
  i. Orifice head (0.310in)
  ii. Venturi head (1.500in)
ppp. Turned motor control knob to 55%.
qqq. Recorded two manometer readings:
  i. Orifice head (0.261in)
  ii. Venturi head (1.292in)
rrr. Turned motor control knob to 50%.
sss. Recorded two manometer readings:
  i. Orifice head (0.225in)
  ii. Venturi head (1.100in)
ttt. Turned motor control knob to 45%.
uuu. Recorded two manometer readings:
  i. Orifice head (0.192in)
  ii. Venturi head (0.932in)
vvv. Turned motor control knob to 40%.
www. Recorded two manometer readings:
  i. Orifice head (0.158in)
  ii. Venturi head (0.777in)
xxx. Turned motor control knob to 0%.
yyy. Removed 4.10in diameter orifice plate from duct.
zzz. Lab successfully completed.

7. Recorded Data Table(s)

Ambient Temperature:	75	Barometric Pressure:	29.92
Tube Diameter (D_T) (in):	5.125	Venturi Diameter (D_V) (in):	2.562

Orifice Diameter (in)	Motor Power (%)	Orifice Reading (h_0) (inches of water)	Venturi Reading (h_V) (inches of water)
1.03	80	3.00	0.027
	75	2.76	0.023
	70	2.48	0.020
	65	2.17	0.018
	60	1.91	0.013
	55	1.65	0.013
	50	1.41	0.010
	45	1.21	0.008
	40	0.99	0.007

Orifice Diameter (in)	Motor Power (%)	Orifice Reading (h_0) (inches of water)	Venturi Reading (h_V) (inches of water)
2.055	80	2.24	0.335
	75	2.04	0.313
	70	1.79	0.279
	65	1.59	0.249
	60	1.40	0.215
	55	1.20	0.182
	50	1.04	0.157
	45	0.864	0.132
	40	0.720	0.109

Orifice Diameter (in)	Motor Power (%)	Orifice Reading (h_0) (inches of water)	Venturi Reading (h_V) (inches of water)
4.10	80	0.515	2.500
	75	0.462	2.230
	70	0.402	1.950
	65	0.352	1.720
	60	0.310	1.500
	55	0.261	1.292
	50	0.225	1.100
	45	0.192	0.932
	40	0.158	0.777

Sample Calculations

$$A = \frac{\pi * (D/2)^2}{144} = \frac{\pi * (2.562/2)^2}{144} = \boxed{0.036\, ft^2}$$

$$Q = C_V A_{throat} \sqrt{\frac{2gh_V \left(\frac{\gamma_m}{\gamma_{air}} \right)}{1 - \left(\frac{A_{throat}}{A_{tube}} \right)^2}} = (1.0)(0.036) \sqrt{\frac{2 * 32.17 * \frac{0.027}{12} * \frac{62.26}{0.0764}}{1 - (\frac{0.036}{0.143})^2}} = \boxed{0.402 \frac{ft^3}{s}}$$

$$N_R = \frac{4 \rho Q}{\pi D_{tube} \mu} = \frac{4 * 1.9351 * 0.402}{\pi * \frac{5.125}{12} * 0.000019} = \boxed{121647}$$

$$C_V = 0.986 - \left(\frac{471.5}{N_{R,Max}^{\ 0.935}} \right) = 0.986 - (\frac{471.5}{121647^{0.935}}) = \boxed{0.9777}$$

$$C_0 = \frac{Q}{A_0} \sqrt{\frac{1 - \left(\frac{A_0}{A_1} \right)^2}{2gh_0 \left(\frac{\gamma_m}{\gamma_{air}} \right)}} = \frac{0.393}{0.0058} \sqrt{\frac{1 - (\frac{0.0058}{0.1433})^2}{2 * 32.17 * \frac{3.00}{12} * (\frac{62.26}{0.0764})}} = \boxed{0.5922}$$

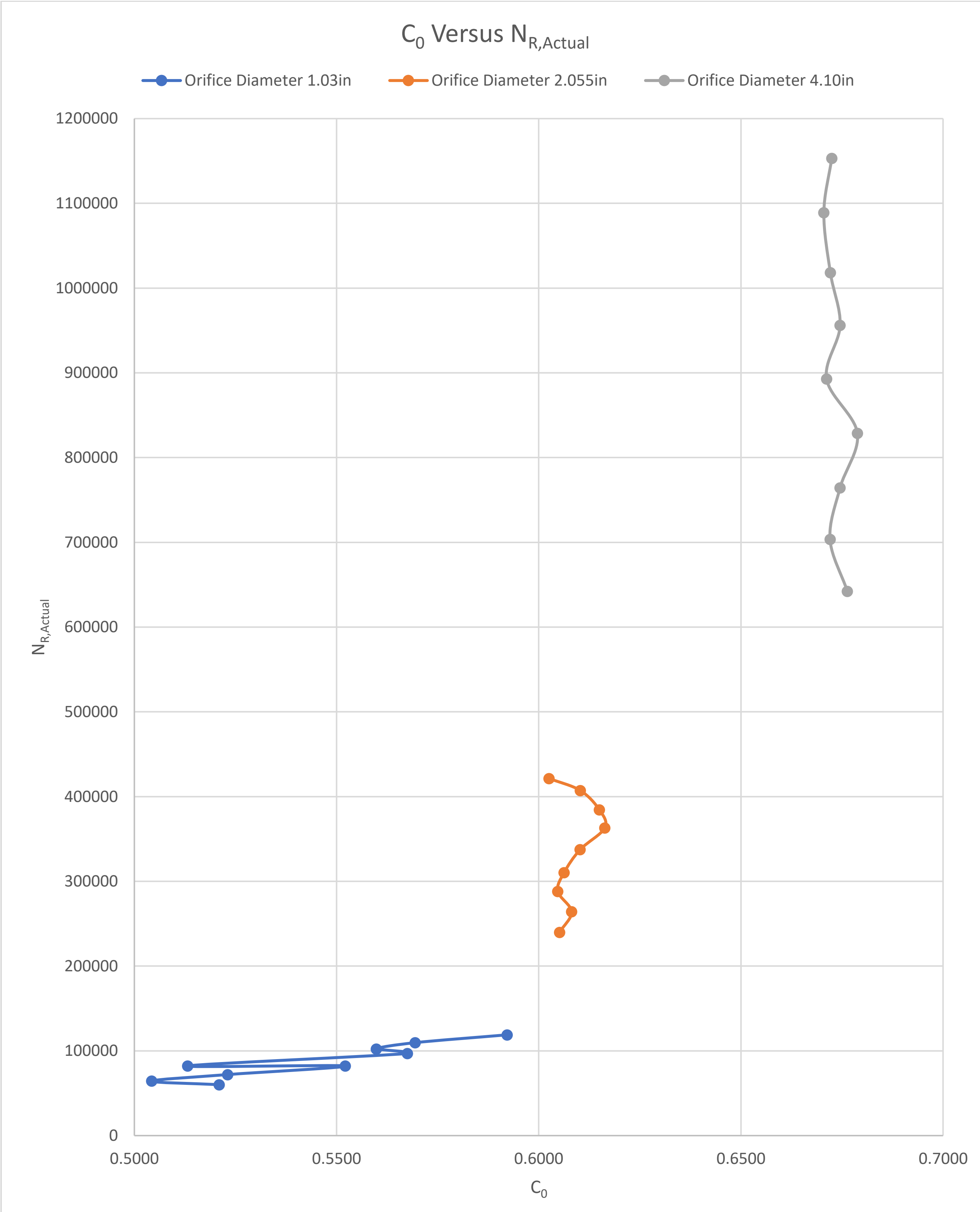
Calculated Data Table(s)

Orifice Diameter (in)	Q_{max} (ft^3/s) Flow Rate	$N_{R,Max}$ (Reynolds Number)	C_V (Venturi Coefficient)	Q_{actual} (ft^3/s) Flow Rate	$N_{R,Actual}$ (Reynolds Number)	C_0 (Orifice Plate Coefficient)
1.03	0.402	121647	0.9777	0.393	118935	0.5922
	0.371	112275	0.9771	0.362	109700	0.5695
	0.346	104697	0.9765	0.338	102232	0.5599
	0.328	99325	0.9760	0.320	96938	0.5675
	0.279	84410	0.9743	0.272	82242	0.5132
	0.279	84410	0.9743	0.272	82242	0.5522
	0.244	74032	0.9728	0.238	72019	0.5231
	0.219	66216	0.9713	0.212	64319	0.5043
	0.204	61940	0.9704	0.198	60107	0.5210

Orifice Diameter (in)	Q_{max} (ft^3/s) Flow Rate	$N_{R,Max}$ (Reynolds Number)	C_V (Venturi Coefficient)	Q_{actual} (ft^3/s) Flow Rate	$N_{R,Actual}$ (Reynolds Number)	C_0 (Orifice Plate Coefficient)
2.055	1.415	428493	0.9834	1.391	421398	0.6026
	1.367	414184	0.9834	1.345	407292	0.6103
	1.291	391042	0.9832	1.269	384478	0.6150
	1.220	369420	0.9831	1.199	363163	0.6164
	1.133	343273	0.9829	1.114	337388	0.6102
	1.043	315832	0.9826	1.025	310337	0.6063
	0.968	293340	0.9824	0.951	288164	0.6047
	0.888	268973	0.9820	0.872	264144	0.6082
	0.807	244419	0.9817	0.792	239941	0.6052

Orifice Diameter (in)	Q_{max} (ft^3/s) Flow Rate	$N_{R,Max}$ (Reynolds Number)	C_V (Venturi Coefficient)	Q_{actual} (ft^3/s) Flow Rate	$N_{R,Actual}$ (Reynolds Number)	C_0 (Orifice Plate Coefficient)
4.10	3.865	1170553	0.9850	3.807	1152996	0.6725
	3.650	1105537	0.9849	3.595	1088895	0.6705
	3.413	1033804	0.9849	3.361	1018171	0.6721
	3.205	970924	0.9848	3.157	956176	0.6745
	2.993	906706	0.9847	2.948	892862	0.6712
	2.778	841496	0.9846	2.735	828571	0.6788
	2.563	776457	0.9845	2.524	764448	0.6745
	2.360	714708	0.9844	2.323	703570	0.6721
	2.154	652577	0.9843	2.121	642315	0.6763

Graph(s)


C_0 Versus $N_{R,Actual}$
Orifice Diameter 1.03in
Orifice Diameter 2.055in
Orifice Diameter 4.10in
$N_{R,Actual}$
1200000
1100000
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
0.5000
0.5500
0.6000
0.6500
0.7000
C_0

Discussion of Results and Conclusions

First off, I'm hoping that my graphical curves are correct because at first glance, they seem a little "crazy". However, I double-checked my calculations to match against the theoretical consideration calculations and I have verified they match. I've also verified that I've aligned my units (in dividing the area by 144 and the tube diameters by 12.

It looks, from the graphical curves above, that the 1.03in orifice plate was a little "all over the place" but still mimics the other curves, while the 2.055in and the 4.1in orifice plate were more like each other. It also seems that the C_0 *likes to teeter back and forth as the* N_R *increases.*

Sources of error that could take place in this lab are quite a few. There are multiple constant values that could have easily been messed up. One being the acceleration of gravity constant. A lot of people like to use 32.2 feet per second squared, however the actual constant is 32.17405 feet per second squared. Another value is the specific weight of water. While one may think it's the constant of 62.4 pounds per foot cubed, instead the value is 62.26 because the water is at 75 degrees Fahrenheit. Another source of error could be students forgetting to align the units in their equations. I'll have to say, my first go around I forgot that the diameters were inches and not feet so I had to adjust the formulas for that.

I enjoyed this lab because setting up formulas/spreadsheets in Excel is fun to me (sort of in my line of career in the engineering field at E-Z-GO). It was fun to "play" with values and see the differences in the calculations for flow rate, Reynolds number, and the orifice plate coefficient.