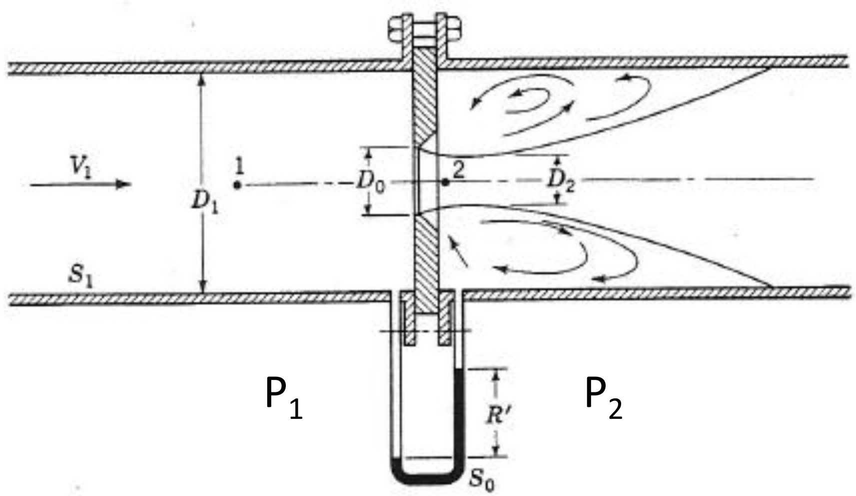
Lab X4 Free Jet Flow from an Orifice

(“Yikes! There is a hole in the keg and its leaking!

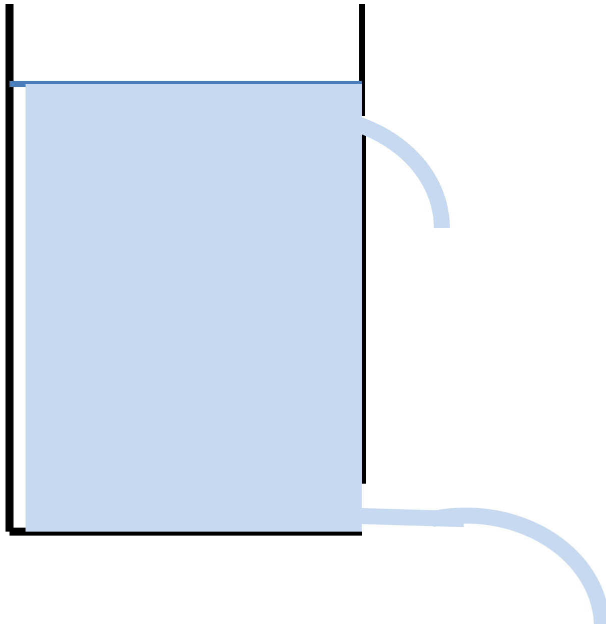
“Don’t just stand there, grab your mugs, quick.”)

From the X-2 Lab an ORIFICE is a restriction in the flow.
A simple one is shown; other types are common.



P_1 will be greater than P_2 because of <u>both</u> friction loss and the Bernoulli effect.

With calibration, this provides a means of flow measurement.



An opening in a tank is a type of orifice.

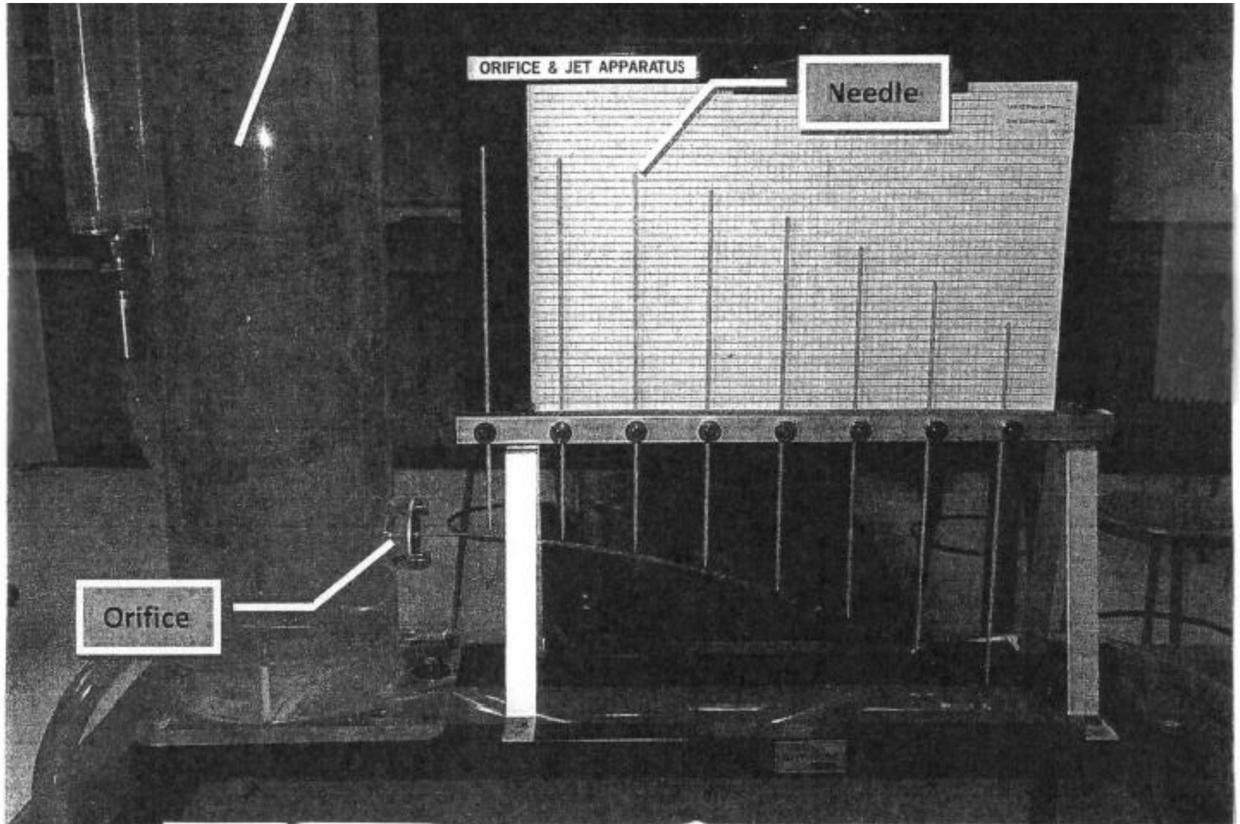
More often this could be a leak, not a measurement

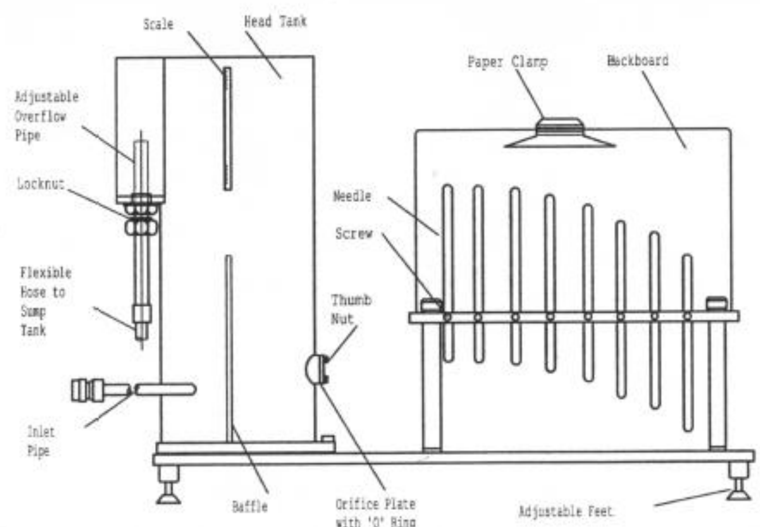
How fast it leaks depends on:

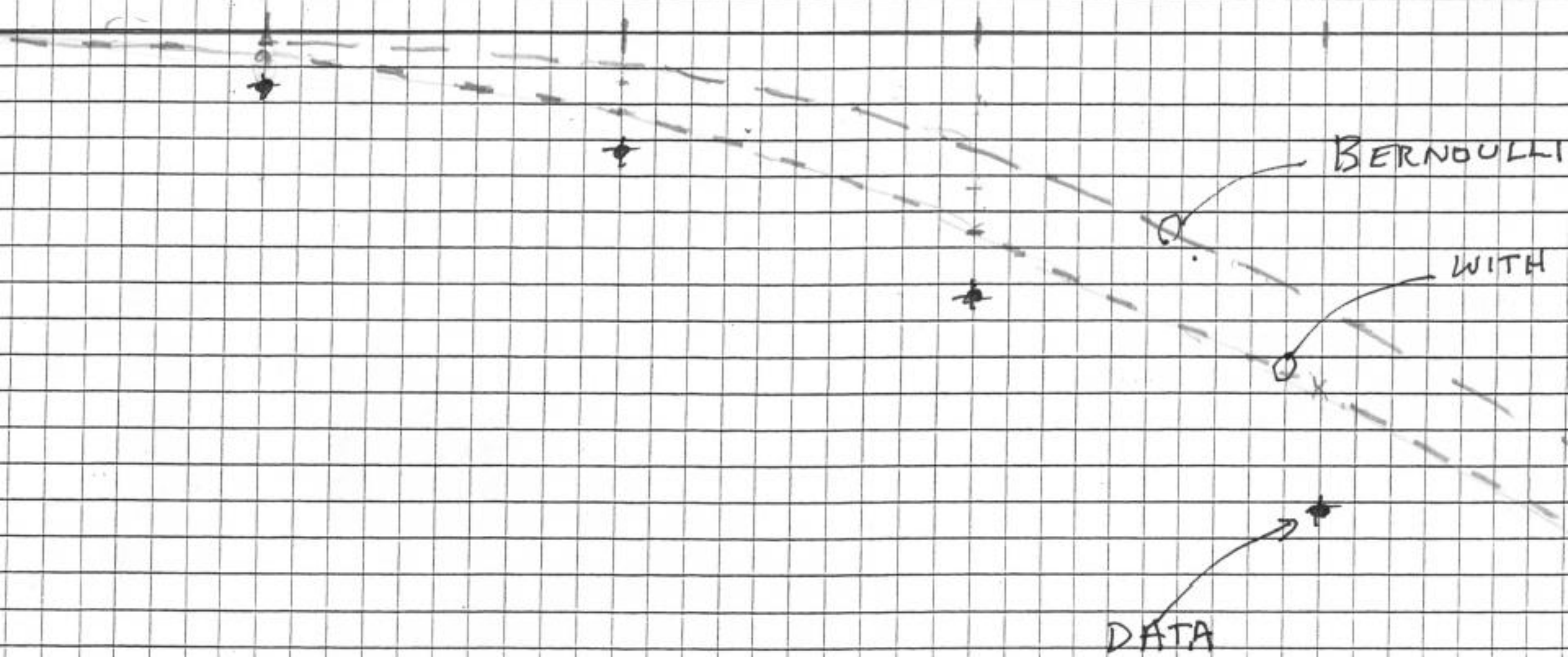
Height of fluid (ρgh)

Size of hole

And…

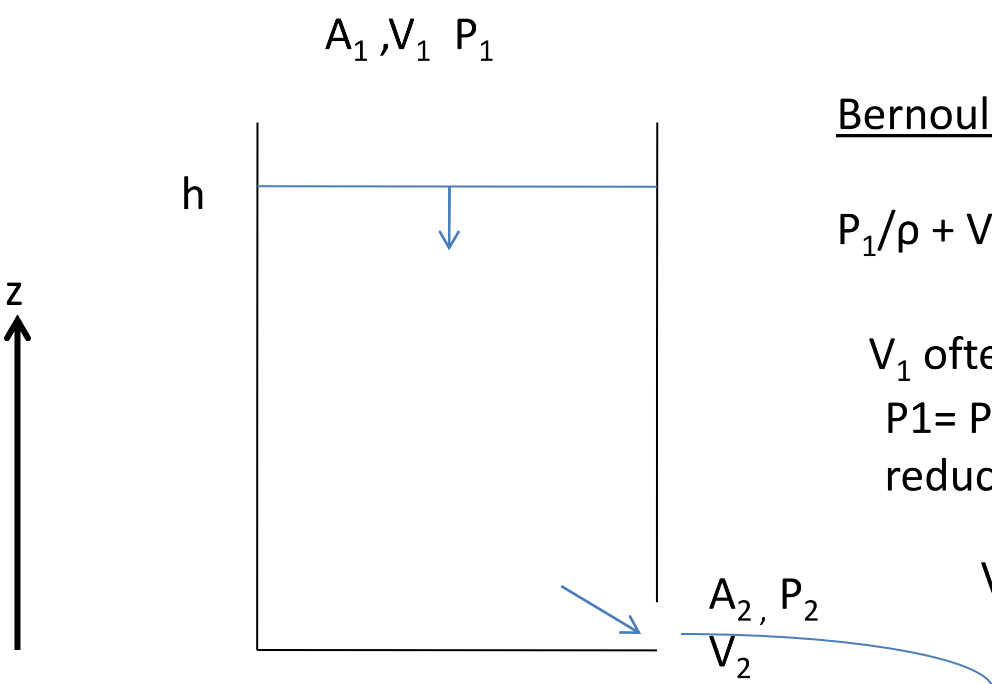

ORIFICE & JET APPARATUS
Needle
Orifice


Scale
Head Tank
Paper Clamp
Backboard
Adjustable
Overflow
Pipe
Locknut
Needle
Screw
Flexible
Hose to
Sump
Tank
Thumb
Nut
Inlet
Pipe
Baffle
Orifice Plate
with 'O' Ring
Adjustable Feet


BERNOULLI
WITH
DATA

A “free jet” is when the fluid jets from orifice into the atmosphere (or much larger vessel).

This is the case we will investigate. A very practical problem – tank draining, fluid transfer, accidental leaks, LOCA….



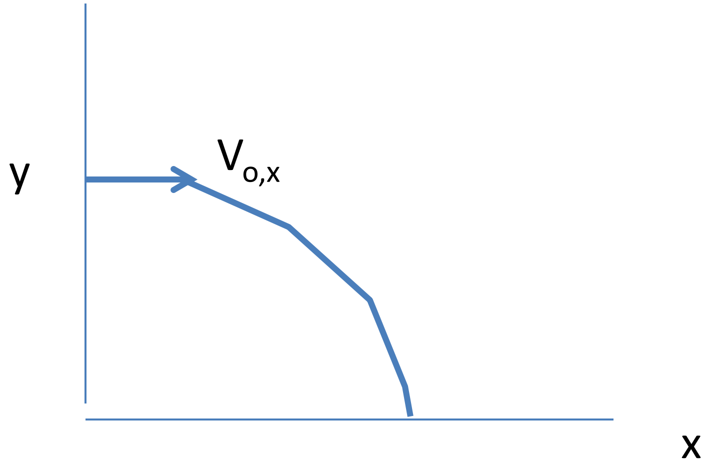
<u>Bernoulli’s equation</u> relates 1 and 2

$$P_1/\rho + V_1^2/2g + z_1 = P_2/\rho + V_2^2/2g + z_2$$

V_1 often is approximately zero
$P1 = P2 = P_{atm}$ so that eqn reduces to

$$V_2 = (2gh)^{1/2}$$

$$h = z_1 - z_2$$



The water stream behaves as a bunch of tossed particles

From dynamics (e.g., a tossed ball)

$$x = x_o + V_{o,x}\ t$$

$$y = y_o - (1/2)\ g\ t^2$$

Eliminate t and get y = -(1/2) g x^2 / $V_{o,x}$

It might follow that Flow $Q = A_2 * V_2$, but it does not because A_2 is not the exit area seen by the fluid!

The exit area and maximum velocity is at the vena contracta just downstream.

It is difficult to see or to directly measure.

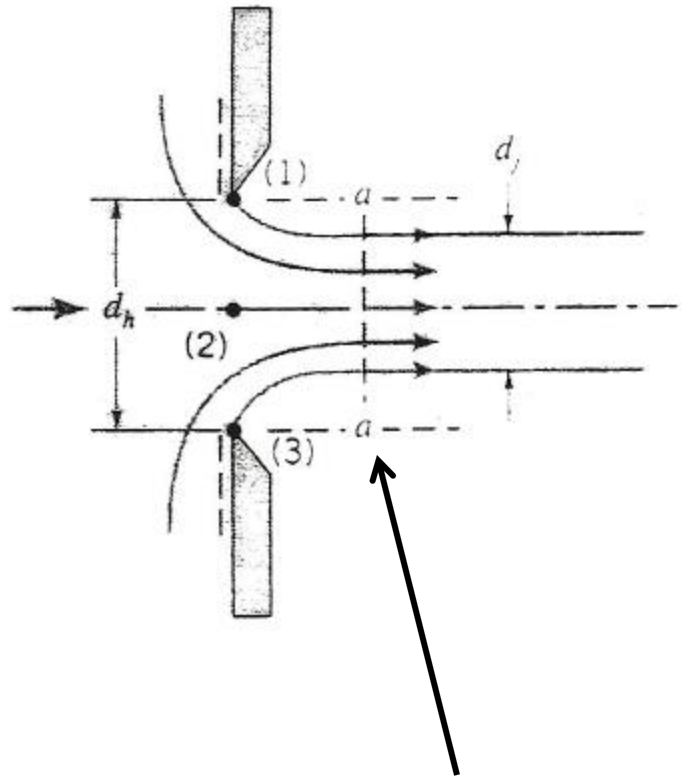
We apply a Velocity correction factor such that

$$V_2 = C_v \ (2gh)^{1/2}$$

$$A_c = C_v A_2$$

h = height of fluid above orifice

We can measure it indirectly with principles from dynamics.



Actual cross section area

Substituting for v and t, and including the correction factor, we get a better trajectory of the free jet:

$$x = 2C_v (yh)^{1/2}$$

The apparatus and data allow us to measure x and y, and obtain a value for C_v

A Data Reduction Technique, when phenomena is nonlinear:

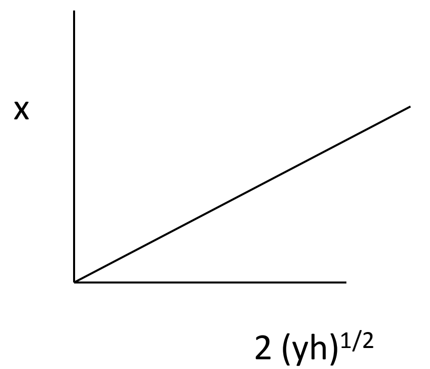
Given a function like $x = 2\ C_v\ (yh)^{1/2}$

And you have data for x, y, and h. Find C_v

Recall from algebra $y = m\ x$, a straight line with slope "m"?

Here, let ordinate values y be symbol x, and abscissa be quantity $2\ (yh)^{1/2}$

Then in a plot



The slope will be C_v

Using the velocity coefficient in Bernoulli's equation helps, but it still does not match reality.

Frictional effects are not considered.

We can come at it another way, by directly measuring the flow rate (bucket calibration) and obtaining data <u>combining both effects</u> into one coefficient C_d

$$Q = C_d A_2 (2gh)^{1/2}$$

We will measure what C_d is and use it.

- Compare to your data
- In the Design Objective problem

Finally, we will measure a **transient**, that is, the time it takes to drain this tank through the orifice jet.

We will compare the measured transient to a derived equation that incorporates the discharge coefficient just obtained.

$$- A_1 \, dh = Q \, dt$$

(Read: amount of fluid discharged = change in fluid volume in time dt)

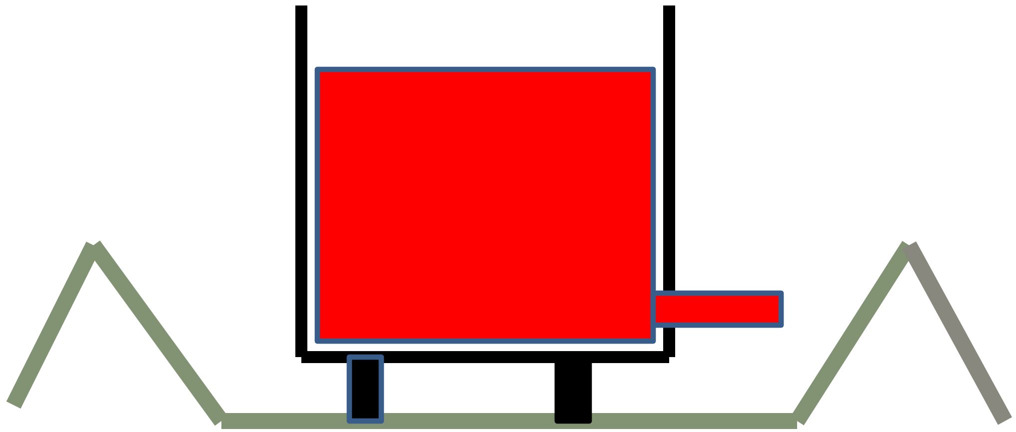
Separate the variables, integrate from h_1 to $h_{2,}$ tidy up, and

$$t = (1/C_d)(2/g)^{1/2}(d_1/d_2)^2 \, (h_1^{1/2} - h_2^{1/2}) \quad \text{seconds}$$

Here, h_2 = level of fluid at time t
h_1= initial level, at t=0

Design Objective

An interesting and realistic problem involving Leakage from a large tank.



What is the leak rate, assuming leak is orifice-like?
How long to fill the berm to overflow?


Hamburg Corner River Rd
9
© 2018 Google
Google Earth

Round Off of Calculations:

A result of 6.428571429 makes no sense if it comes from measurements good to no better than 1 decimal place.

(Not to mention if you report an Uncertainty of 0.05)

…ow observations. The table below displays the
…a pipe flow observation using equation [1]. The
…ive observations made during experimentation based on
…rried the dye.

		…(m^3)	Time (s)	Flow Rate, Q (m^3/s)	Velocity (m/s)	Reynolds Number
		0.00005	27.54	1.815E-06	0.023116186	255.7917625
		0.000058	28.44	2.039E-06	0.025966207	287.3286203
		0.000092	16.85	5.459E-06	0.069518124	769.2515998
	204	0.000204	2.78	7.338E-05	0.934319666	10338.69819
	208	0.000208	3.98	5.226E-05	0.665411621	7363.100849
	224	0.000224	3.61	6.204E-05	0.790043374	8742.211364
	236	0.000236	9.98	2.364E-05	0.301086706	3331.669765
…onal	122	0.000122	9.93	1.228E-05	0.156430236	1730.976087
Transitional	159	0.000159	7.02	2.264E-05	0.288383316	3191.100619
Transitional	189	0.000189	6.15	3.073E-05	0.39128825	4329.793403
Transitional	242	0.000242	19.2	1.260E-05	0.160481234	1775.802337
Transitional	249	0.000249	11.24	2.215E-05	0.282061074	3121.141957
Transitional	249	0.000249	11.53	2.159E-05	0.274966736	3042.639687

Using the experimental volume and time recorded of the fluid flow, the volumetric flow rate (m^3/s) could be calculated using Q = V/t. From there, the average velocity (m/s) of the fluid could be calculated using the relationship that V = Q/A. With the density, viscosity, and diameter of the pipe known, the Reynolds number was then calculated using equation [1]. As seen in Table 1, for the most part, the calculated Reynolds number for each fluid flow is in range of the expected, or theoretical, Reynolds numbers for laminar, turbulent, and transitional flow. The …xperimental laminar flows range from approximately 255 to 769. The experimental turbulent …s range from approximately 7363 to 10338.

…hange in pressure for pipe flow. The table below illustrates the pressure drop in the
…d travels through the vertical pipe. The Darcy friction factor, as seen in equation
… for each laminar and turbulent flow using the respective Reynolds number
…It was assumed that the pipe used in the experiment was a smooth pipe that
…nt roughness that would further influence the frictional factor.

…Rate, Q (…3/s)	Velocity (m/s)	Reynolds Number	(1/2)(ρ*V^2)(L/D)	Darcy Friction Factor	Change in Pressure (Pa)
…	0.023116186	255.7917625	18.64642492	0.250203522	4.665401196
	…0.025966207	287.3286203	23.52774166	0.222741473	5.240603824
	…9518124	769.2515998	168.6394916	0.083197747	14.03042576
	…9666	10338.69819	30461.70324	0.031337953	954.60741
	…1	7363.100849	15450.55078	0.034113156	527.0670431
		8742.211364	21780.36095	0.032679978	711.7817193

…sure, the change in pressure ultimately
…ther variables remain constant). With
… meaning that the pressure drop of the

Decimal places!

In practice you rarely know a Reynolds No. to nearest 100, and Certainly not to six decimal places.