TEXAS TECH UNIVERSITY

DEPARTMENT OF CIVIL, ENVIRONMENTAL AND CONSTRUCTION ENGINEERING

Lab Report Number: 03

Flow Measurement Apparatus

CE 3105-Fluid Laboratory [redacted]

Section: [redacted]

Instructor: [redacted]

Group Number [redacted]

Members:

[redacted]

Date of Experiment: [redacted]

Date: July [redacted]

Table of Contents

List of Figures

List of Tables

Theory

The objective of this experiment is for the participants to understand the typical methods of measuring the discharge of a theoretically incompressible fluid. Then the participants need to apply the Continuity equation and Bernoulli's equation in order to determine the flowrates. In this lab, flowrate is measured by using multiple meters including a Venturi meter, wide angle diffuser, orifice meter and a rotameter. These meters were used to measure the continuity equation, the Bernoulli's equation, mass flow rate and head losses.

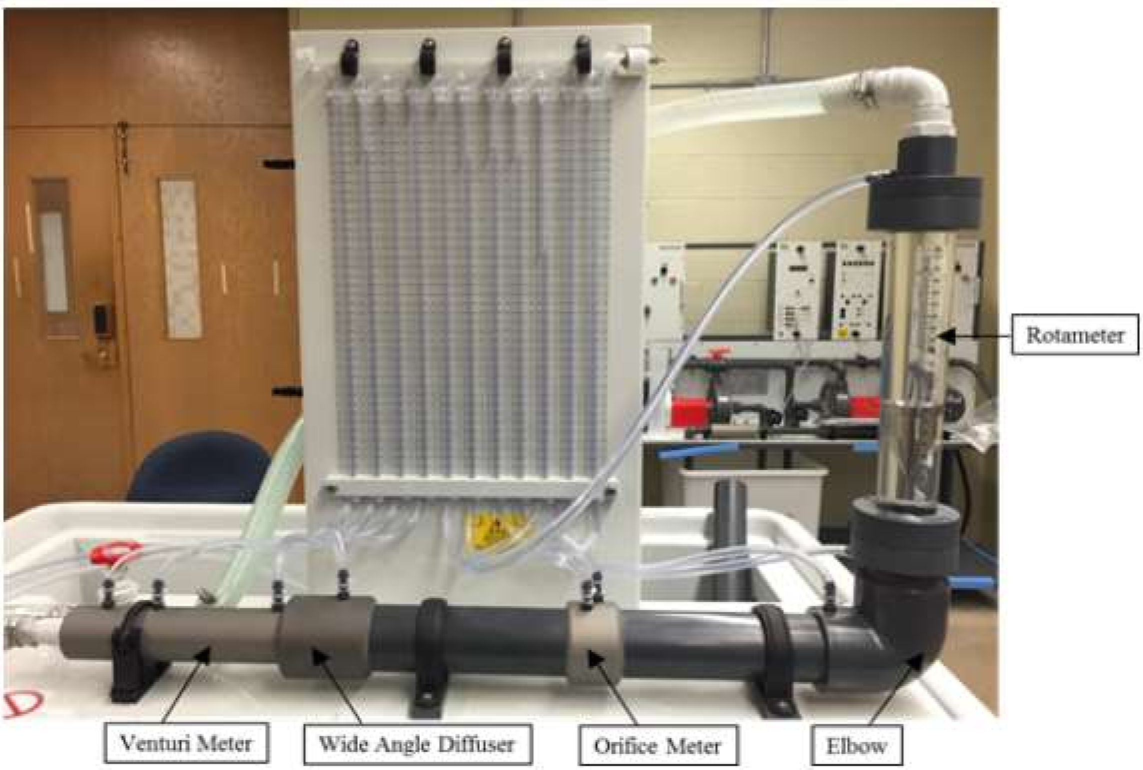


Figure 1: Flow Measurement Apparatus

Figure 1 shows us the machine that we will be using in this experiment. This apparatus utilizes 6 main elements which is the venturi, diffuser, orifice, elbow, rotameter, and the manometers which all gives us insight into the purpose of this laboratory experiment which was previously mentioned. Figure 2 below shows the cross-sectional area of the piping and components of the apparatus. We will now go into a little more detail about specific items which are listed in this apparatus.

The venturi meter is the combination of a diverging tube, a throat and a converging tube. The fluid discharge is found by measuring the pressure differential between the throat and inlet. This discharge of fluid is caused by the differences in diameters, which then changes the pressure using the concept of continuity ("Experiment 3: Flow...").

From continuity:

$$\rho V_A A_A = \rho V_B A_B$$

The discharge:

$$Q = A_B V_B$$

Where:

$$Q = A_B \left[\frac{2g}{1 - \left(\frac{A_B}{A_A}\right)^2} \left(\frac{P_A}{\rho g} - \frac{P_B}{\rho g} \right) \right]^{\frac{1}{2}}$$

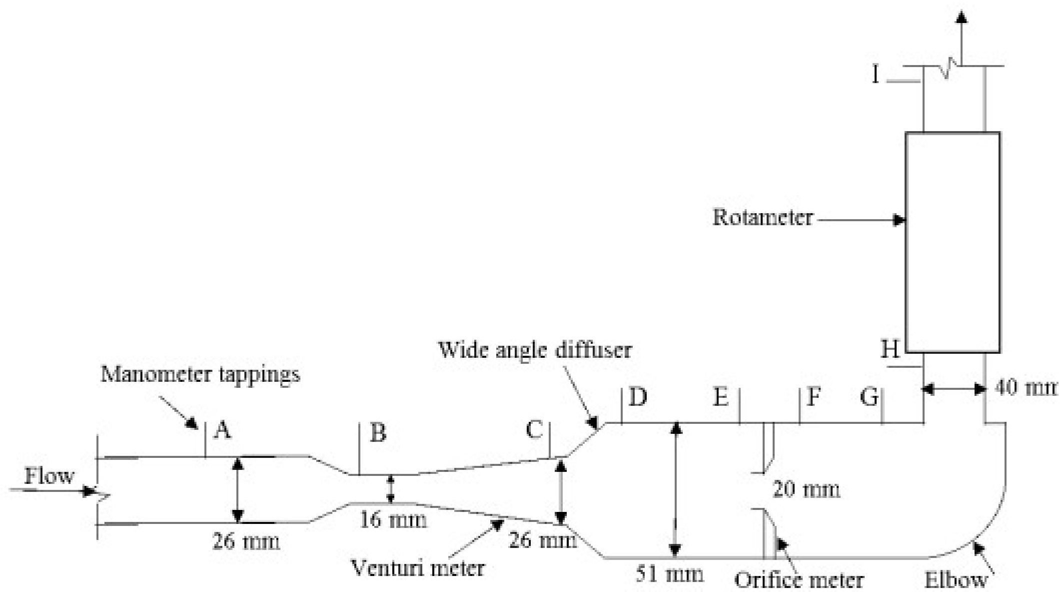


Figure 2: Cross-Sectional Area of Flow Measuring Apparatus

The orifice meter is a metal plate with a round opening in the plate. This device is placed perpendicular to the direction of flow inside of a pipe. This is a meter with measurements of both the outer and inner diameters. Measuring head loss between the downstream and upstream is required to find the discharge. Head loss can be written in terms of a coefficient of K. The K value can vary based on the type of the orifice meter chosen.

$$\frac{V_F^2}{2g} - \frac{V_E^2}{2g} = K^2 \left(\frac{P_E}{\rho g} - \frac{P_F}{\rho g} \right)$$

Then:

$$Q = A_F V_F$$

Where:

$$Q = KA_F\left[\frac{2g}{1-\left(\frac{A_F}{A_E}\right)^2}\left(\frac{P_E}{\rho g}-\frac{P_F}{\rho g}\right)\right]^{\frac{1}{2}}$$

The rotameter measures flowrate by re-aligning the position of the float. The device is a vertical tube shape that has a float inside. Since it has greater flow area at the top of the device, velocity is lower there than the bottom. The fluid that is flowing lifts the float up using a drag force created by the fluid, while the fluid's weight acts downward. The equilibrium position of the fluid greatly depends on the flow rate.

$$\pi\left(R_t^2 - R_f^2\right) = 2R_f^2\delta$$

= Cross sectional area or Discharge/Constant peripheral velocity

Mass flow rate is presented as:

$$\mathfrak{m} = \rho Q$$

Apparatus

Figure 1: Laboratory Machinery

This figure shows water flowing through the Flow Measuring Apparatus in order to quantify discharge by measuring the change in head loss between the upstream and downstream of the device.

Figure 3: Laboratory Machinery

Figure 2: Machinery Pipe Cross Section

This figure shows the various unique pieces and parts within the flow measuring apparatus. It shows the pipe including the narrow and wide angle, orifice meter, elbow, and rotameter. The image can be seen on the following page.

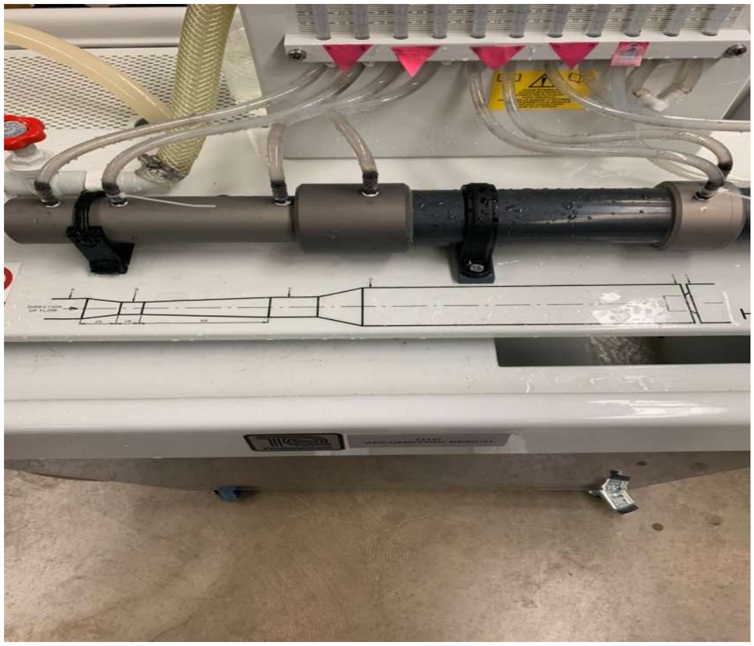


Figure 4: Machinery Pipe Cross Section

<u>Figure 3: Machinery Manometer Levels</u>

This figure shows the system of how the manometers levels are read based upon the discharge and flow rate being produced from the provided pipe system.

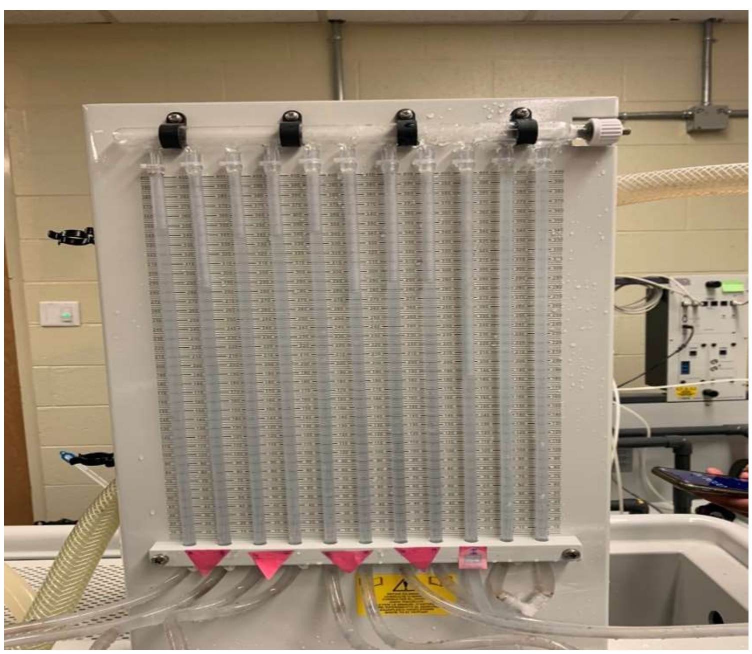


Figure 5: Machinery Manometer Levels

Variables:

- Liquid Density (lb/ft^3)
- Velocity (ft/s)
- Flow Area (ft^2)
- Flow Rate (ft^3/s)
- Gravity (ft/s^2)
- Pressure Head (ft)
- Velocity Head (ft)
- Coefficient of discharge (=.601)
- Float Radius (ft)
- Local Bore of the Rotameter (ft)
- Mass Flow Rate (lb/s)
- Head Loss (ft)

Materials:

- Water
- Large Graduated Cylinder
- Stopwatch/Video
- Thermometer
- Flow Measuring Apparatus
    - Venturi Meter
    - Wide Angle Diffuser
    - Orifice Meter
    - Elbow
    - Rotameter
- Machinery shown in figures 1, 2, and 3

Results

Table 1 shows the acquired results after conducting our experiment. We were able to easily calculate the flow rate by simply dividing the water volume by our time to give us a final flow rate in ml/s.

Table 1: Lab Data Results

		Test Numbers				
		Team 1	**Team 2**	**Team 3**	**Team 4**	**Team 5**
Manometer Levels (mm)	**A**	390	386	378	364	344
	B	388	374	354	326	282
	C	390	382	372	358	332
	D	390	384	374	360	336
	E	392	384	376	362	340
	F	388	374	352	320	276
	G	390	376	358	330	286
	H	392	376	358	330	286
	I	286	274	256	224	184
Rotameter Level (mm)		10	30	50	70	90
Water Volume (mL)		600	600	800	1200	1200
Time (seconds)		11.50	5.97	5.49	5.65	4.86
Flow Rate (mL/s)		52.17	100.50	145.72	212.39	246.91

Table 2 simply shows our results for the discharge rate through the orifice and Venturi. The calculations for this table can be seen in the "Sample Calculations" section that will go more in depth of how we were able to acquire these numbers.

Table 2: Discharge through Orifice and Venturi

Flow Rate Resuts (ft^3/s)					
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**
Orifice	0.001887	0.002984	0.004622	0.006115	0.007548
Venturi	0.001516	0.003714	0.005253	0.00661	0.008443

sample only

Table 3 shows our summarized values of the mass flow rate, head loss, and our inlet kinetic head for the Venturi, Orifice, Rotameter, Weight Tank, and even the elbow of the machine. All necessary calculations can be seen in "Sample Calculations." One important thing to note about the inlet Kinect head, all of the values are the same despite the different values which is interesting to think about.

Table 3: Calculated Measurements

		Test Numbers				
		Team 1	**Team 2**	**Team 3**	**Team 4**	**Team 5**
Mass Flow Rate (lb/s)	**Venturi**	0.0946	0.2318	0.3278	0.4125	0.5268
	Orifice	0.1177	0.1862	0.2884	0.3815	0.4710
	Rotameter	0.0946	0.2318	0.3278	0.4125	0.5268
	Weight Tank	0.1150	0.2215	0.3211	0.4680	0.5441
Head Loss (ft)	**Venturi**	0.0066	0.0394	0.0787	0.1247	0.2034
	Orifice	0.0109	0.0272	0.0654	0.1144	0.1743
	Rotameter	0.3478	0.3346	0.3346	0.3478	0.3346
	Diffuser	0	0	0	0.0164	0.0164
	Elbow	0	0	0.0164	0	0.0164
ΔH	**Venturi**	0.0014	0.0082	0.0164	0.026	0.0424
	Orifice	0.0023	0.0057	0.0136	0.0238	0.0363
	Rotameter	0.0725	0.0697	0.0697	0.0725	0.0697
	Diffuser	0	0	0	0.0034	0.0034
	Elbow	0	0	0.0034	0	0.0088

Using data from Table 1, we were able to create a rotameter calibration curve based off of the height of the rotameter and the calculated flow rate. From this curve we will be able to predict any flow rate based off of the height of the rotameter and in return calculate the mass flow rate. If we take the remaining values from that same table, we can see it will fit perfectly along our calibration curve.

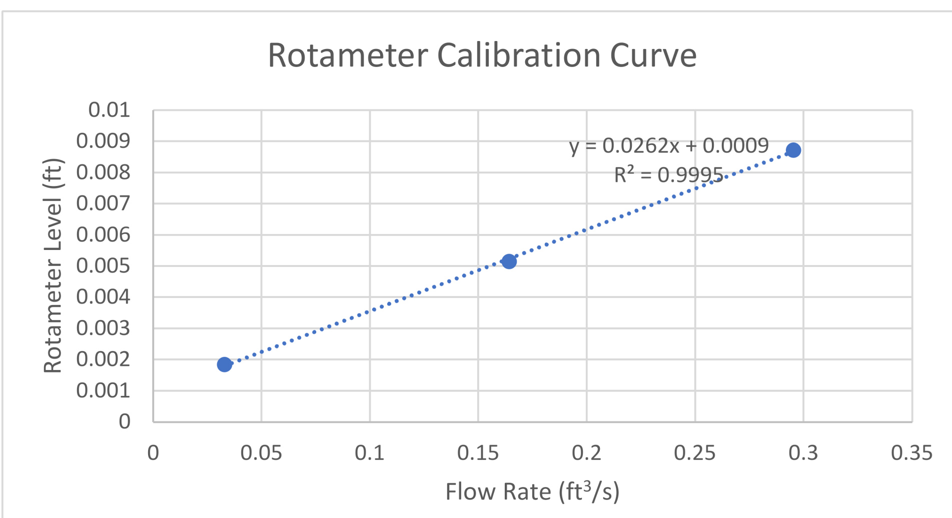


Figure 6: Rotameter Calibration Curve

Discussion

1. How did the different flow rate measurements compare?

The flow rate measurements increased at every trial. The formula used to find flow rate is the Water Volume over Time.

2. How did the different mass flow measurements compare?

The mass flow rate measurements increased at each trial. The formula used to find mass flow rate is the Density of water multiplied by the flow rate of that trial. Since density is constant and the flow rate varies at each trial, the mass flow rate would then increase at each trial.

3. How different were the measured head losses across the pipe?

The rotameter had the most head loss in each trial. While the other parts of the device head loss values slowly increased at each trial.

4. How can someone reduce the head losses associated with the wide-angle diffuser and the right-angled bend?

In order to reduce the overall head loss, the friction in the pipe needs to be reduced. It is possible to reduce it by making the length of the pipe smaller. Bends in the pipe increase the value for head losses. Removing the right-angle bend would greatly reduce the head losses. The wide-angled diffuser head loss could be reduced by making the pipe diameter greater.

5. Was the purpose of the experiment met?

Yes, the purpose of the experiment was met. The participants were able to understand the different ways to measure the discharge on incompressible fluids. Then able to apply the Bernoulli's equation and continuity to determine the flowrates.

6. Were there any sources of error in this lab?

There are a few sources of error that could occur. The first potential human error would be having the rotameter level at the wrong level. This would lead to wrong values found in the manometer. Another human error would be the use of a timer to find the time it takes to achieve the desired volume of fluid. Since human reaction time is not perfect this would lead to a less accurate time frame.

7. What is a real life application?

The design of a dam. When designing the dam, pressure and flowrate are important values. The dam has to have the correct flow rate in order to have the desired flow rate out. Also pressure is important because too much pressure could lead to the bursting of pipes. Using manometers and rotameters, water design engineers can closely observe the condition of the dam.

Data Appendix

CE3105 Mechanics of Fluids Laboratory Date[redacted]
Department of Civil Engineering
Texas Tech University

Experiment #3: Flow Measurement Apparatus - Data Sheet Date of Experiment:

TEAM NAME: 3 Team Member[redacted]

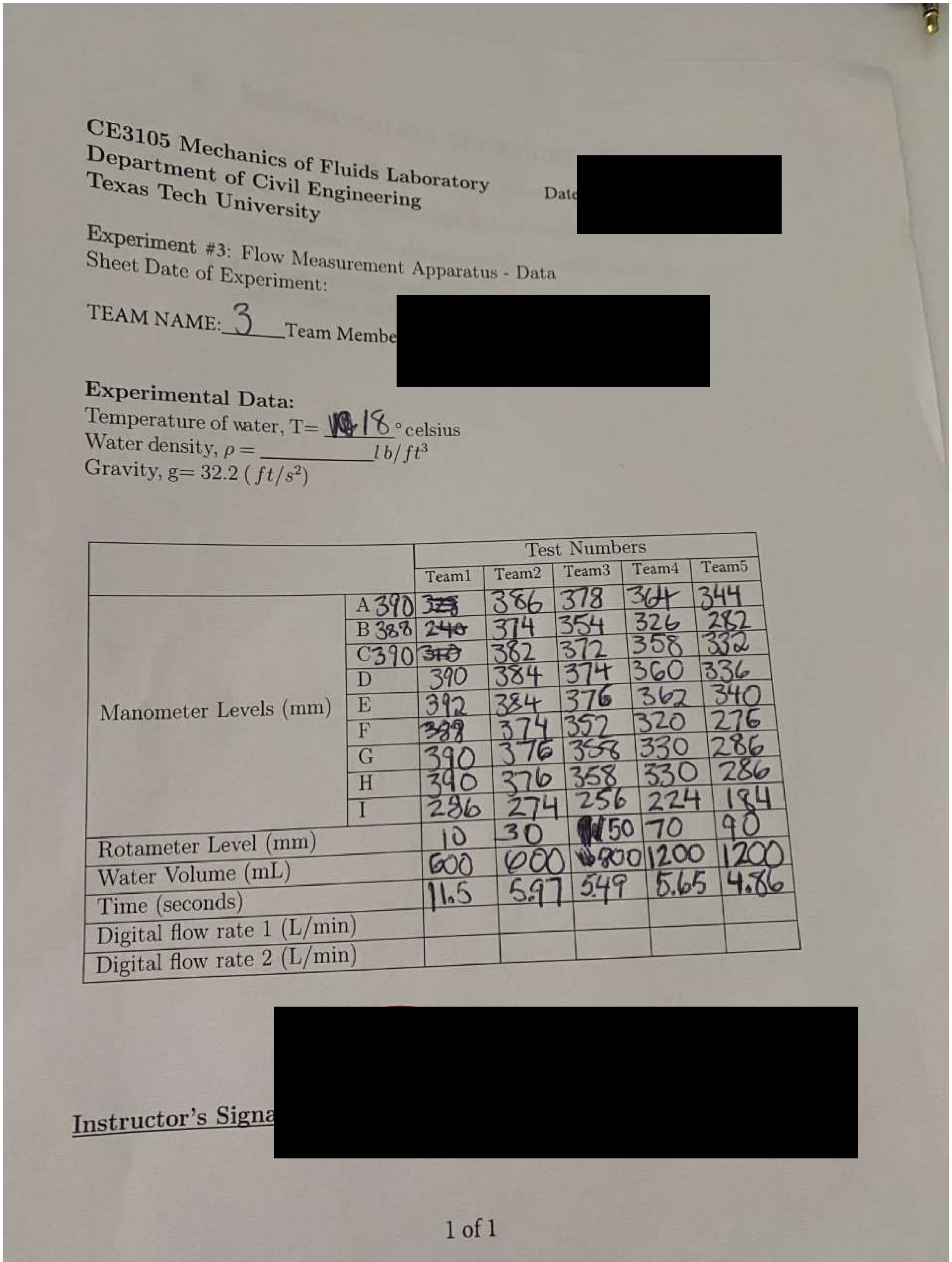
Experimental Data:
Temperature of water, T= 18 °celsius
Water density, ρ = ________ lb/ft^3
Gravity, g= 32.2 (ft/s^2)

		Test Numbers				
		Team1	Team2	Team3	Team4	Team5
Manometer Levels (mm)	A	390	386	376	364	344
	B	388	374	354	326	282
	C	390	382	372	368	332
	D	390	384	374	360	336
	E	392	384	376	362	340
	F	388	374	352	320	276
	G	390	376	358	330	286
	H	390	376	368	330	286
	I	286	274	286	204	154
Rotameter Level (mm)		10	30	50	70	90
Water Volume (mL)		600	600	800	1200	1200
Time (seconds)		11.6	5.97	6.49	9.68	4.86
Digital flow rate 1 (L/min)						
Digital flow rate 2 (L/min)						

Instructor's Signat[redacted]

1 of 1

Figure 7: [redacted]



CE3105 Mechanics of Fluids Laboratory
Department of Civil Engineering
Texas Tech University

Date [redacted]

Experiment #3: Flow Measurement Apparatus - Data Sheet Date of Experiment:

TEAM NAME: 3 Team Membe[redacted]

Experimental Data:

Temperature of water, T= ~~[illegible]~~ 18 ° celsius

Water density, $\rho =$ ________ lb/ft^3

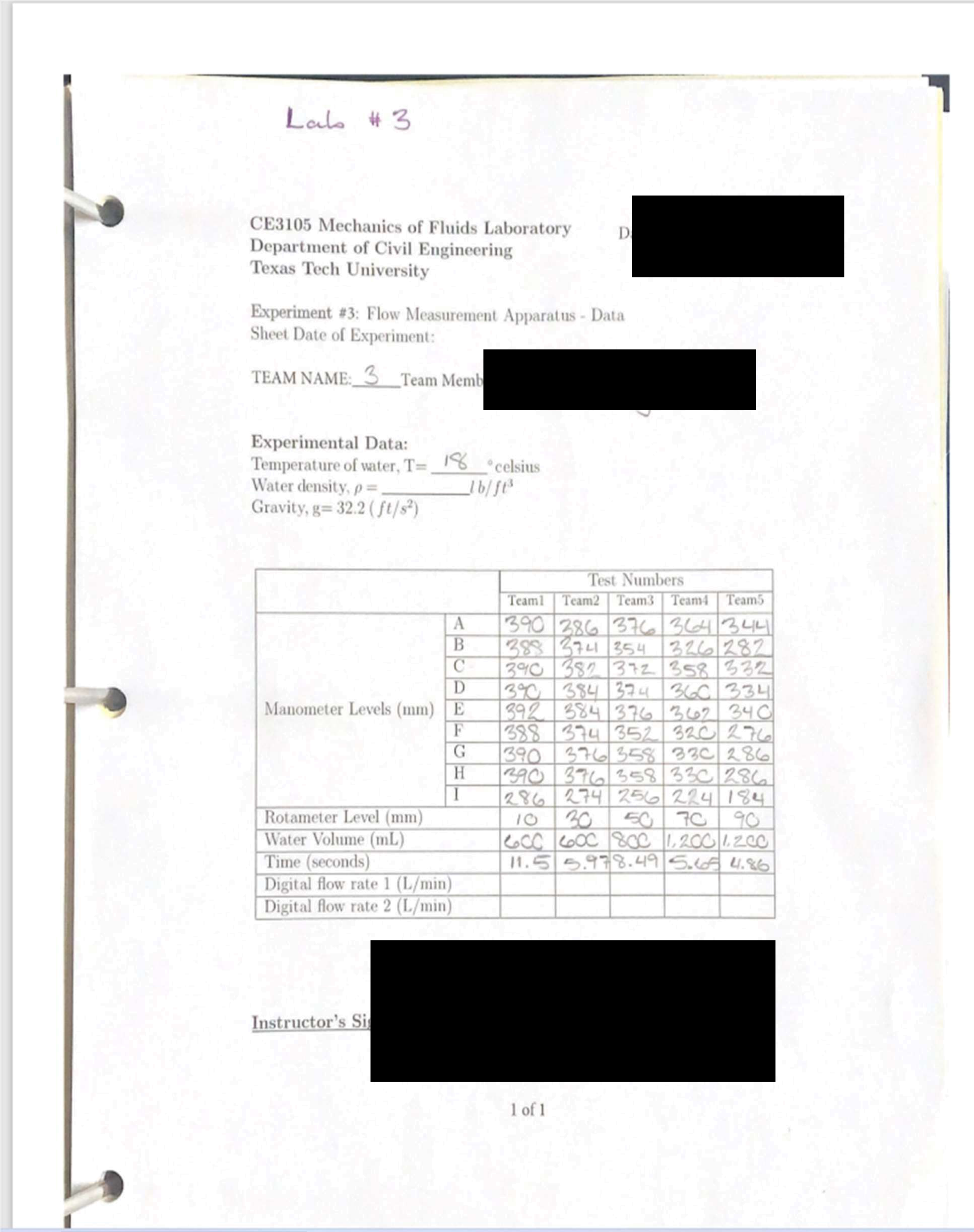
Gravity, g= 32.2 (ft/s^2)

		Test Numbers				
		Team1	Team2	Team3	Team4	Team5
Manometer Levels (mm)	A	390 ~~[illegible]~~	386	378	364	344
	B	388 ~~240~~	374	354	326	282
	C	390 ~~310~~	382	372	358	332
	D	390	384	374	360	336
	E	392	384	376	362	340
	F	388	374	352	320	276
	G	390	376	358	330	286
	H	390	376	358	330	286
	I	286	274	256	224	184
Rotameter Level (mm)		10	30	50	70	90
Water Volume (mL)		600	600	800	1200	1200
Time (seconds)		11.5	5.97	5.49	5.65	4.86
Digital flow rate 1 (L/min)						
Digital flow rate 2 (L/min)						

Instructor's Signa[redacted]

1 of 1

Figure 8 [redacted]


Lab #3

CE3105 Mechanics of Fluids Laboratory
Department of Civil Engineering
Texas Tech University

D[redacted]

Experiment #3: Flow Measurement Apparatus - Data Sheet Date of Experiment:

TEAM NAME: 3 Team Memb[redacted]

Experimental Data:

Temperature of water, T= 18 ° celsius
Water density, $\rho =$ ________ lb/ft^3
Gravity, g= 32.2 (ft/s^2)

		Test Numbers				
		Team1	Team2	Team3	Team4	Team5
Manometer Levels (mm)	A	390	386	376	364	344
	B	388	374	354	326	282
	C	390	382	372	358	332
	D	390	384	374	360	334
	E	392	384	376	362	340
	F	388	374	352	320	276
	G	390	376	358	330	286
	H	390	376	358	330	286
	I	286	274	256	224	184
Rotameter Level (mm)		10	30	50	70	90
Water Volume (mL)		600	600	800	1,200	1,200
Time (seconds)		11.5	5.97	8.49	5.65	4.86
Digital flow rate 1 (L/min)						
Digital flow rate 2 (L/min)						

Instructor's Si[redacted]

1 of 1

Figure 9[redacted]

Error Analysis

Sample Error Analysis Calculation:

The "actual value" that we used came from the weigh tank which had the actual mass flow rate. The calculated value that we are using came from the Venturi meter all of which came from "Team 1" column in table 1.

$$\% \text{ Error} = \left|\frac{Actual\ Value - Calculated\ Value}{Actual\ Value}\right| = \left|\frac{.1150 - .0946}{.1150}\right| = 17.74\%$$

Table 4: Error Analysis Summary

Error Analysis					
Venturi	17.69312	4.656589	2.077135	11.87487	3.172398
Orifice	2.42183	15.93459	10.18066	18.47816	13.43652
Rotameter	17.69312	4.656589	2.077135	11.87487	3.172398

Sample Calculations

Constants:

$K = 0.6$

$\rho = 62.4$ lb/ft^3

$G = 32.2$ ft/s^2

Knowns:

Orifice Meter Radius = 10mm = 0.328 ft

Point A Radius = 13mm = .0427 ft

Point B Radius = 8mm = .0262 ft

Point E Radius = 25.5mm = .0836 ft

Point F Radius = 10 mm = .0328 ft

$P/(\rho g)$ = Height of manometer

NOTE: All of the following calculations can be repeated for all data points that are listed in the "Results" section of the report. I have listed samples of our calculations to avoid too much repetitive information.

Calculations:

1) Venturi Meter

$A_A = \pi r^2 = \pi(.0427)^2 = .00573$ ft^2

$A_B = \pi r^2 = \pi(.0262)^2 = .00216$ ft^2

$Q = (A_B)(\frac{2g}{1-\left(\frac{A_B}{A_A}\right)^2}\left(\frac{P_A}{rg} - \frac{P_B}{rg}\right)^{.5} = (.00216)(\frac{2(32.2)}{1-\left(\frac{.00216}{.00573}\right)^2}(1.28 - 1.27)^{.5} = .001516$ ft^3/s

Mass flow rate = m = Qp = .001516*62.4 = .0946 lb/s

2) Orifice Meter

$A_F = \pi r^2 = \pi(.0328)^2 = .00338$ ft^2

$A_E = \pi r^2 = \pi(.0836)^2 = .0219$ ft^2

$Q = K(A_F)(\frac{2g}{1-\left(\frac{A_F}{A_E}\right)^2}\left(\frac{P_E}{rg} - \frac{P_F}{rg}\right)^{.5} = 0.6(.00338)(\frac{2(32.2)}{1-\left(\frac{.00338}{.0219}\right)^2}(1.28 - 1.27)^{.5} = .00187$ ft^3/s

Mass flow rate = m = $Q\rho$ = .00187*62.4 = .117 lb/s

3) Rotameter

NOTE: This follows the same calculation method as the Venturi Meter

4) Weigh Tank
   $Q = V/T = 600/11.5 = 52.17$ mL/s = .001842 ft^3/s
   Mass flow rate = m = Qρ = .001842*62.4 = .11494 lb/s

5) Head Loss
   Venturi head loss = Manometer A – Manometer B = 1.2795-1.2729 = .066 ft
   Rotameter = Manometer H – Manometer I = 1.2861 - .9383 = .0109 ft

6) ΔH/Inlet Kinetic Head
   Inlet Kinetic Head = 4.8
   - Orifice = Head Loss/4.8 = .0109/4.8 = .00227
   - Rotameter = Head Loss/4.8 = .3478/4.8 = .0725

Sources

Experiment 3: Flow Measurement Apparatus