Comparison of Pressure Measurements using Various Test Apparatus and Techniques

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A Bourdon gage, pressure transducer, differential gage, and micromanometer is used to measure static and dynamic pressure. Orifices of 4 diameters (0.031", 0.062", 0.128", and 0.240") are used to choke the air and cause for an unsteady thermodynamic environment. Using this information, the time constant is measured from the data of the pressure curves. Using this time constant, the discharge coefficients are found in the range of 0.56 to 0.83 for the 4 diameters. We also compare the change in temperature throughout the process to an ideal isothermal process and adiabatic process to see that the tank blowdown does not act as either.
The last part of the experiment used an H2O differential pressure transducer and a micromanometer with a battery operated ammeter to measure the pressure in a flow of a wind tunnel, which was used to calculate the velocity of the flow. Results of the experiment indicate the validity of these devices and the fact that a tank blowdown is neither an isothermal nor adiabatic process.

INTRODUCTION

There are many means to measure pressure with some being better methods to use than the others in certain situations. Here, we limit ourselves to the use of a dead weight tester, bourdon gage, diaphragm pressure diaphragm transducer, water differential pressure transducer, micromanometer, and a PC controlled Data Acquisition System (with a software called LabVIEW). These tools have been used by the industry for a long time to obtain accurate and quick measurements for a variety of engineering purposes. These tools make it more convenient to measure changes in pressure, which can be useful for calculating a variety of engineering values.

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Firstly, a dead weight tester (as shown in Figure 1) consists of a floating piston of known cross sectional area in an oil filled chamber and a moving plunger that rests on it. Set weights are placed on the plunger and the pressurized chamber is calibrated on the other hand by a connection where a bourdon gage is set. This equilibrium allows for static calibration of the gage. Hystersis effects are accounted for due to the fritional errors that may be present on the plunger and piston.

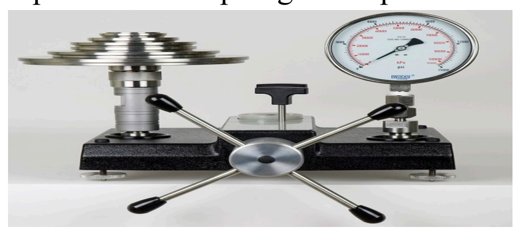

Figure 1. Dead Weight Tester

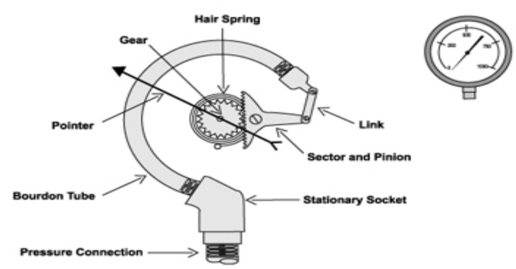

Figure 2. Bourdon Pressure Gage

Bourdon gages are used for static pressure measurements. In Figure 2, the inside of a gage is shown. The elastic curved tube is deformed when a pressure is applied at one end and a needle that is linked to the other end is rotated by the appropriate amount which can be read on the calibration scale of the gage. These gages are better for static rather than dynamic measurements because of the relatively large mass of the sensor tube.

Another type of pressure measurement device, called a diaphragm pressure transducer (Figure 3) translates a physical deformation of an elastic diaphragm due to the pressure difference on either side to an output voltage, which is measured on a Wheatstone bridge circuit. One sides of the diaphragm is exposed to atmospheric pressure, thus the device

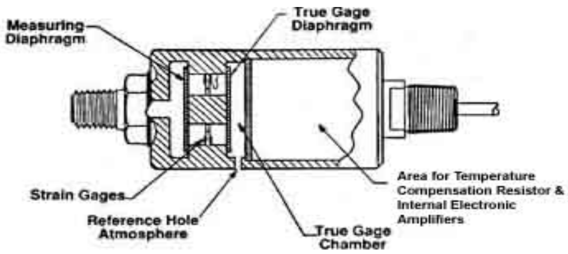

Figure 3. Diaphragm Pressure Transducer

measures gage pressure. Because the diaphragm is small in size and mass, it can accurately measure the change in strain due to dynamically changing pressures.

We use the pressure transducer for a tank blowdown, in which orifices of different diameters are inserted at the end of a pressurized air tank and air is released to see the change in pressure and temperature with time. The part of the blow- down that is above 30 psia is characterized by unsteady thermodynamics, in which Equation 1 gives the mass flow rate, where the pressure is atmospheric pressure.

$$\dot{m}[kg/s] = 0.0402 \times A_{valve} \frac{P_{\tan k}[Pa]}{\sqrt{T_{\tan k}[K]}} \quad [1]$$

There is known theory behind isothermal (steady temperature) systems and adiabatic (unsteady temperature) systems that help to derive formulas that relate the pressure and temperature in the tank with respect to time. Equation 2 is for isothermal systems and Equation 3 is for adiabatic systems, where C is the discharge coefficient, which is to be calculated from the measurements of τ**.** The specific heat value is of air, γ_{air}, which is 1.4.

$$P = P_0 \exp\left(-\frac{t}{\tau}\right) \text{ where } \tau = \frac{V}{0.0402R(CA_{valve})\sqrt{T_0}} \quad [2]$$

$$P = P_0\left(1+\frac{(\gamma-1)}{2}\frac{t}{\tau}\right)^{\frac{-2\gamma}{\gamma-1}} \text{ where } T = T_0\left(1+\frac{(\gamma-1)}{2}\frac{t}{\tau}\right)^{-2} \quad [3]$$

In the last part of the experiment, where we measure wind tunnel speed, a water differential pressure diaphragm transducer is used, which is a type of pressure transducer that is useful for measuring small pressure differences created by airflows in ducts. Equation 4 gives the relation between the measured voltage and the pressure differential in inches of water.

$$Voltage = 1 + 4*\Delta P \quad [4]$$

Another device we use to measure the speed of the flow is a micromanometer, which measures small changes in pressure using a U-tube manometer and microammeter alongside. The pressures obtained from these devices are used to obtain the velocity of the flow using Bernoulli's Equation (Equation 5).

$$P_{stag} - P_{stat} = \Delta P = \frac{1}{2}\rho V^2 \quad [5]$$

The velocities obtained from the differential pressure gage and from the micromanometer are then compared with the reading obtained from meter on the side of the "Wind Wright 100", the wind tunnel model that was used.

RESULTS AND DISCUSSION

The first part of the lab involved measurements of the dead weight tester using a Bourdon gage. The applied pressure using the known weights went from 10 to 80 psig and back down to account for hysteresis, which is shown in Figure 4.

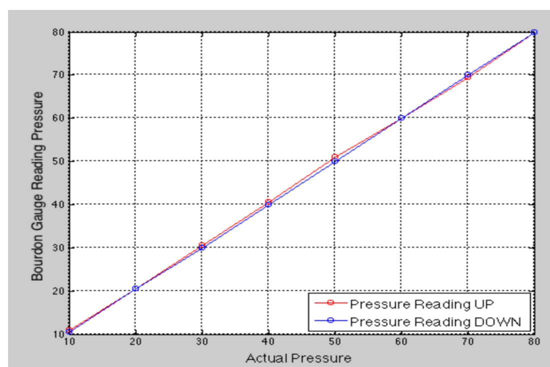

Figure 4. Calibration Curve of Bourdon Gage Pressure vs. Actual Pressure from Deadweight Tester (w/ hysteresis effects)

The calibration curve in Figure 4 of the Bourdon gage reading shows the strong agreement between the gage reading pressure and actual pressure known from the weight of the loads and the absence of significant hysteresis effects.

After calibrating the Bourdon gage, it is taken off of the dead weight tester setup and screwed into the pressured air tank, which is filled up with air to a pressure of 90 psig. Air is released from the tank in 5-psi intervals using the calibrated Bourdon gage as reference. A diaphragm pressure transducer is connected to a PC with LabVIEW software, which simultaneously records the corresponding pressure measurements. The calibration curve for these measurements shows a very linear curve, which verifies that, the Bourdon gage and transducer pressure measurements agree well (as shown in Figure 5).

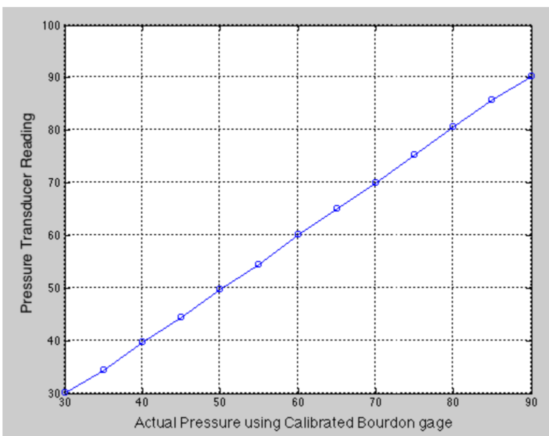

Figure 5. Calibration Curve for Pressure Transducer vs. Actual Pressure using Bourdon Gage Pressure & Deadweight Tester Calibrations.

Next, we use the same pressurized air tank and orifices of 4 different diameters, (namely 0.031", 0.062", 0.128", and 0.240") to observe the variation in pressure and temperature in the tank when the valve is completely opened with the orifice connected securely to the opening. Figure 6 shows the variation of pressure and temperature with time for tank blowdown with the 0.062" diameter orifice. Graphs for the other diameters are very similar to Figure 6.

As the graph of Figure 6 shows, temperature and pressure decrease in a nonlinear form with time. This part of the measurement is characterized by unsteady

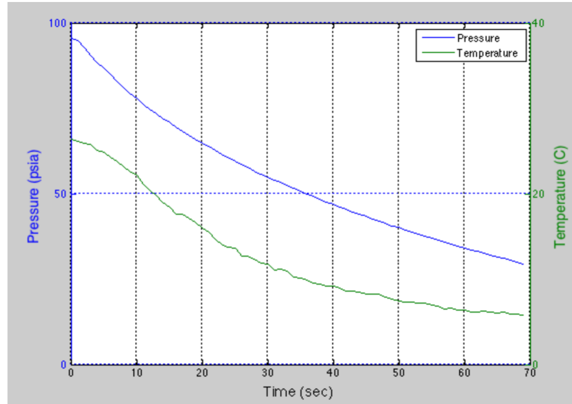

Figure 6. Pressure and Temperature Variation with Time using 0.062" diameter orifice.

thermodynamics, which allows us to use Equations 1, 2, & 3 and we use them to calculate 2 time constants, one based on the thermodynamic model and one based on the adiabatic model. For isothermal theory, we plot $\ln(P/P_0)$ vs. time, where the slope represents $-1/\tau$. For adiabatic theory, we plot $(P/P_0)^{-1/7}$ vs. Time, where the slope represents $0.2/\tau$. A graph for isothermal and adiabatic theory for orifice size of 0.031" is shown in Figures 7 and 8, respectively. Making a linear fit for each of the graphs and calculating for the time constants gives the values in Table 1 for the different orifice sizes.

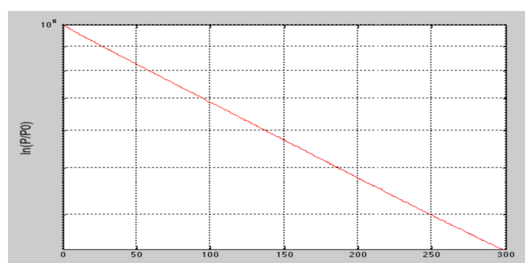

Figure 7. Isothermal Theory Plot: ln(P/P0) vs. Time for 0.031" orifice diameter.

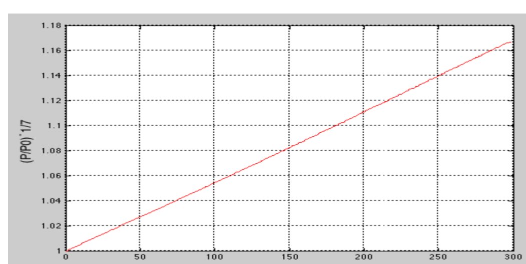

Figure 8. Adiabatic Theory Plot: $(P/P0)^{-1/7}$ vs. Time for 0.031" orifice diameter.

Table 1. Measured time constants for different orifice diameters.

Orifice Diameter (in)	τ (sec.) Isothermal theory	τ (sec.) Adiabatic theory
0.031	274.4682	355.0480
0.062	59.8945	76.8929
0.128	14.2306	18.2558
0.240	4.4486	5.5303

We use the time constant values obtained to find the discharge coefficient, C_0, using the right part of Equation 2; the results are displayed in Figure 9.

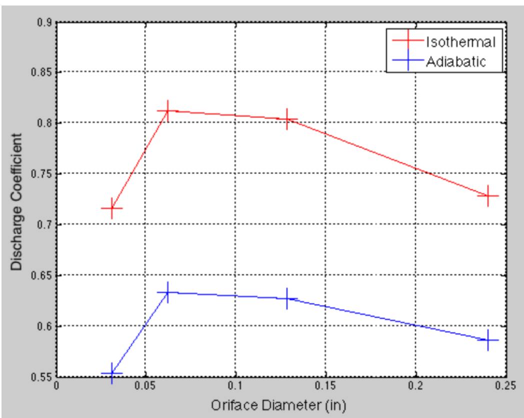

Figure 9. Discharge Coefficient vs. Orifice Diameter.

Lastly, for the tank blowdown, we analyze the change in temperature with time. Figure 10 shows T/T0 vs. Time/Tau for all the orifice diameters along with isothermal and adiabatic curves. Looking at the graph, it seems like the tank blowdown for all orifice sizes do not match with either curves, although they are closer to the isothermal curve. This tells us that the process was neither isothermal nor adiabatic, yet acted more closely to an isothermal process.

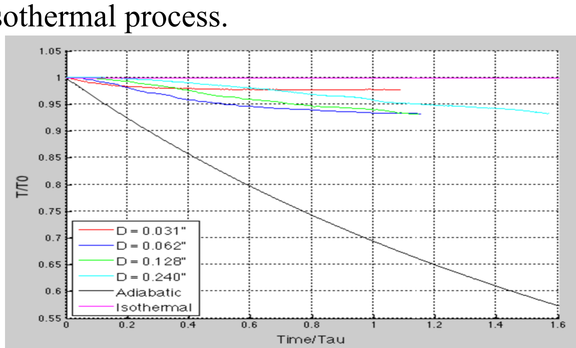

Figure 10. Temperature Variation vs. Time/Tau

The last part of the lab involved getting the velocity of a wind tunnel using pressure measurements. We used a differential pressure transducer and micromanometer to obtain local pressure differences. With the use of Equations 4 and 5, we arrived at the results shown in Table 2, which are compared to the reading on the wind tunnel meter. Although the results are not completely in sync, they agree to a high level of confidence.

Table 2. Wind Tunnel Speed Results

Wind Wright m/sec.	Differential Gage m/sec.	Micro-ameter m/sec.
4.5720	2.8912	3.6571
9.1440	6.3835	7.2568
13.7160	10.1191	10.7012
15.2400	11.2904	11.6367

CONCLUSIONS

In this lab, many pressure measurement systems were used. Bourdon gages were used to make static pressure measurements using dead-weight testers and a pressurized air tank. Orifices of different diameters were attached to the end of the air tank and the valve is opened to release air and we measure pressure and temperature using a transducer and LabVIEW. The data from these experiments helped to finalize that the system was neither isothermal nor adiabatic, which is what we could expect because the air tank is not insulated and the dynamic change in pressure would insinuate a change in temperature even from inspection of the ideal gas law. This was inferred through calculations of the time constant for the experiments and discharge coefficients. Comparing them to theory, we saw that it did not match either isothermal or adiabatic, although it was more on the side of isothermal than adiabatic.

For the last part of the experiment, a wind tunnel was used to compare the speed measurement given by the model with measurements using a differential gage and micro-ammeter to measure pressure and then use Bernoulli's equation to relate it to speed of the flow. These values agreed quite well.

REFERENCES

[1] Gere, J.M., *Mechanics of Materials,* 5th ed, Chapman and Hall, London, 2000.