University of Jordan

Faculty of Engineering

Department of Chemical Engineering

Fluids Lab.

(0905363)

Contents

Experiment Number -1-

Losses in Piping System

Objective:

- To find the pressure losses across valves, along pipes and across fittings for a range of flow rates.
- To find K values for fittings and valves from actual experiment.
- To compare theoretical friction factor from the Blasius equation with that found from actual results.

Equipment:

The following equipment is required to perform the Losses in Pipes experiment:

- The H16 Losses in Piping System device.
- H1F Digital Hydraulic Bench.
- H16p Optional Rough Pipe Assembly.

Figure 1: H16 Losses in piping system

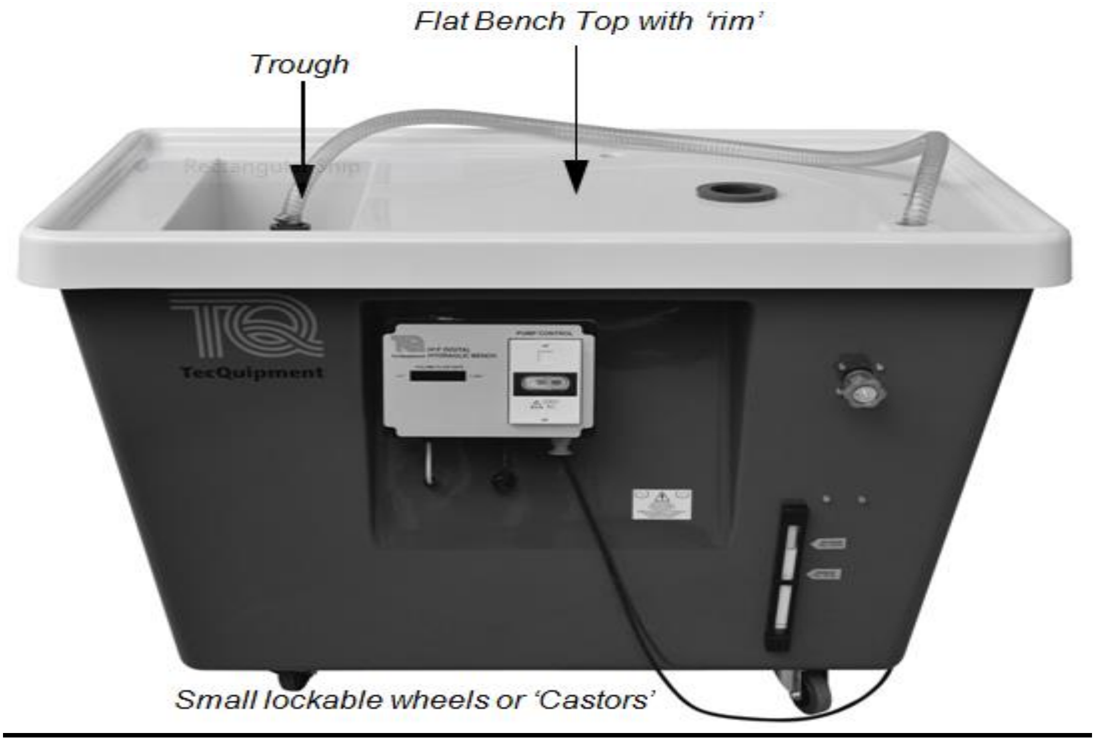


Figure 2: Digital Hydraulic Bench.

Equipment Description:

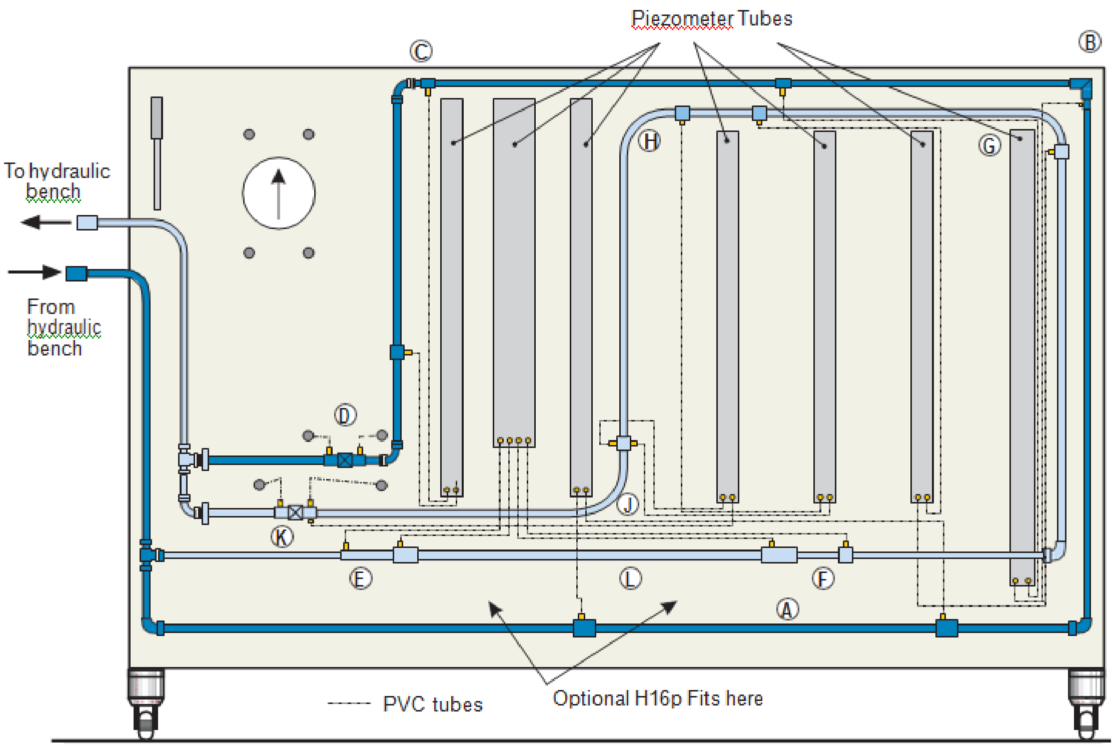


Figure 3: Main parts.

Figure 3 shows a diagram of the main parts. The parts include two separate circuits; one painted dark blue, one painted light blue. Each circuit has a number of pipe system components. Both circuits are supplied with water from the same hydraulic bench. A gate valve controls the flow in the dark blue circuit. A globe valve controls the flow in the light blue circuit. The valves are both downstream of the pipe work to reduce the chance of turbulence from the valves affecting the pipe work readings.

The piezometer tubes measure pressure change across the pipe work components. A differential pressure gauge measures the pressure change across the valves.

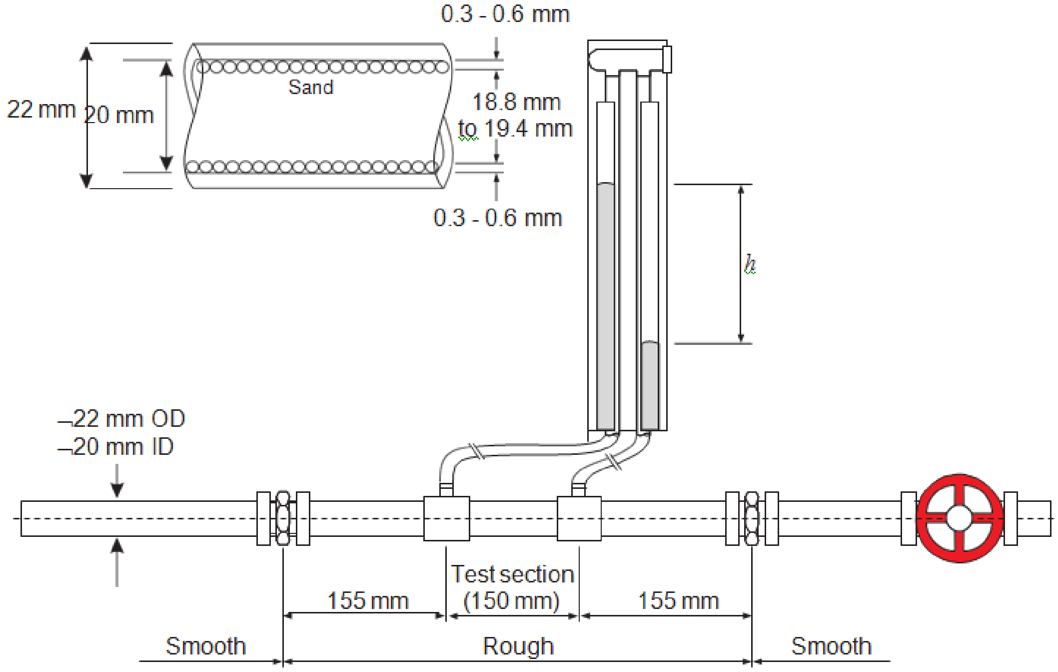


Figure 4: H16p details

The optional H16p fitted to the main unit of the H16. It works as a stand-alone unit because it has its own piezometer. It only needs connection to a hydraulic bench for water supply and flow measurement.

The main part of this optional assembly is a length of pipe that includes a short section of roughened pipe, two pressure tappings and a downstream flow control valve. The roughened section of pipe has an artificially roughened internal surface. The pressure tapping's measure the pressure drop along a test section of the roughened pipe, to avoid any minor disturbance at the entrance and exit to the roughened section. The flow control valve is downstream so that it cannot introduce turbulence to the flow, affecting results.

Technical Details:

Pipes: Standard-bore straight pipe (nominally 13.6 mm bore copper)
Larger-bore straight pipe (nominally 26.2 mm bore copper)

Bends: 90-degree miter bend (no radius) R/d= 0
Elbow (13.6 mm radius) R/d= 1
Small radius, smooth 90º bend (50 mm radius) R/d= 3.7
Medium radius, smooth 90º bend (100 mm radius) R/d= 7.35
Large radius, smooth 90º bend (150 mm radius) R/d= 11.03

Tapping Distance: Distance L between pressure tapping for pipe and bends =0.914m

Theory:

For an incompressible fluid (for example water) flowing through a pipe, the following equations apply:

$$Q = V_1 A_1 = V_2 A_2 \ (Continuity\ equation)$$

$$Z_1 + \frac{P_1}{\rho g} + \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + h_L \ \ (Bernoulli's\ equation)$$

The continuity equation shows that the volume flow at one part of the pipe is the same as the volume flow at any other part (assuming no leaks or flow diversions)

Bernoulli's equation shows that when calculating relative properties of flow along a pipe, you must allow for the change in head (or head loss).

Total head loss is the relative pressure drop (measured in meters of water) caused by the flow resistance of a pipe system. There are two main causes of total head loss (h_L) in a pipe system:

1. Head loss (h_F) due to pipe friction throughout the circuit (**Major losses).**
2. Head loss due to localized effects such as valves, sudden changes in area and bends. These are often termed the **minor head losses**, as they are usually small compared to the frictional head losses of the pipe work.

So generally, around any fitting: $h_L = h_F$ + minor losses

Mutual interference between parts that are near each other in a complex circuit means that total head loss may not be simply the sum of the individual losses of each part.

To help predict the relative head loss in fittings and valves caused by changes in dimensions, engineers use a term called the **K** value. This is a **loss coefficient** or **loss factor** based on the dimensions of the fitting. For a sudden contraction or expansion it is based on the area ratio. For a bend, it is based on the bend radius and pipe diameter.

Note that the K value is only reliable when predicting flow at high Reynolds number. It is not reliable when experimenting with laminar flow.

$$K = \frac{h_L}{V^2/2g} \quad \dots\dots\dots\dots\dots (1)$$

Equation 1 gives the standard relationship loss coefficient and head loss for a fitting at a given flow velocity.

A French engineer, Henry Darcy experimented with fluid flow through pipes **in turbulent conditions**, proving a relatively accurate equation that is commonly named after him. It quantifies the frictional losses and helps predict a reasonably accurate value for the head loss due to friction along the pipe, based on actual results:

$$\mathrm{h_f} = \frac{\mathrm{f.L.V^2}}{\mathrm{2dg}} \quad \dots\dots\dots\dots\dots. (2)$$

Where f is the Friction factor and it is a dimensional value.

But only for flows with Reynolds numbers of less than 2100 **(generally laminar flow):**

$$\mathrm{f} = \frac{64}{\mathrm{Re}} \quad \dots\dots\dots\dots\dots.. (3)$$

A German physicist (Paul Blasius) created an alternative equation, that works for Reynolds numbers greater than 4000 (turbulent flow) **in smooth pipes**.

$$\mathrm{f} = \frac{0.316}{Re^{0.25}} \quad \dots\dots\dots\dots. (4)$$

For both the contraction and enlargement, it is important to know that the total head loss is the sum of the measured head loss across the fitting and the loss due to the change in velocity head

$$h_L = measured\ value + \frac{V_1^2 - V_2^2}{2g} \quad \dots\dots. (5)$$

To calculate the head loss due to the bends (h_B), you must allow for the additional loss caused by the pipe work that the bend is made from and which creates the entrance and exit to the bend as shown below:

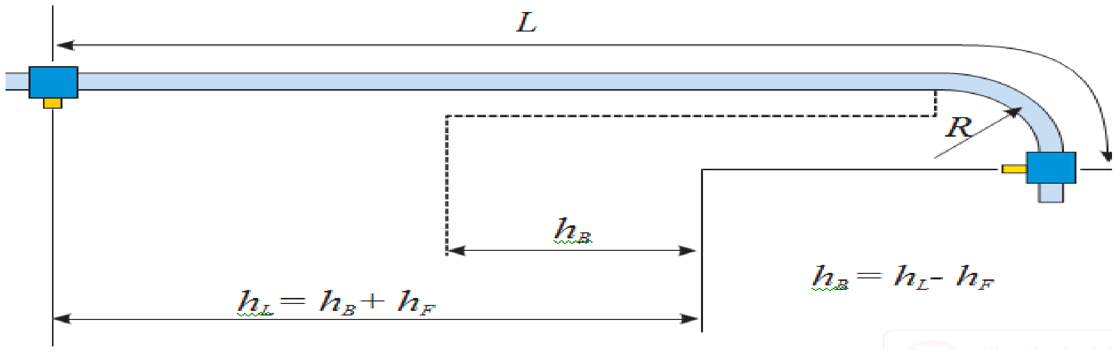


Figure 5: Losses in bends and their pipe work.

Rough and Smooth pipes:

Blasius's work defined two types of pipe friction for turbulent flow:

Smooth turbulent pipe friction - where fluid viscosity becomes the most important factor and *f* is virtually proportional to Reynolds number Re.

Rough turbulent pipe friction - where both viscosity and pipe wall roughness are the most important factors.

A German engineer Johann Nickuradse also experimented with pipe flow during the first half of the twentieth Century. He added small grains of sand to the inner wall of pipes, so that he could produce a measurable relative roughness (*k/D*), and then tested the pipes to find how the roughness affected flow.

For example, for a roughness height *k* of 0.6 mm in a pipe of internal diameter 18 mm, the relative roughness *k/D* = 0.6/18 = 0.033.

The H16p has a pipe internal diameter of 20 mm and the sand grains give a roughness of between 0.3 and 0.6 mm, giving a *k/D* of between 0.3/20 = 0.015 and 0.6/20 = 0.03. This gives an average relative roughness of around 0.0225.

Figure 6 shows typical results of Nickuradse tests for pipes of between 0.001 and 0.033 relative roughness.

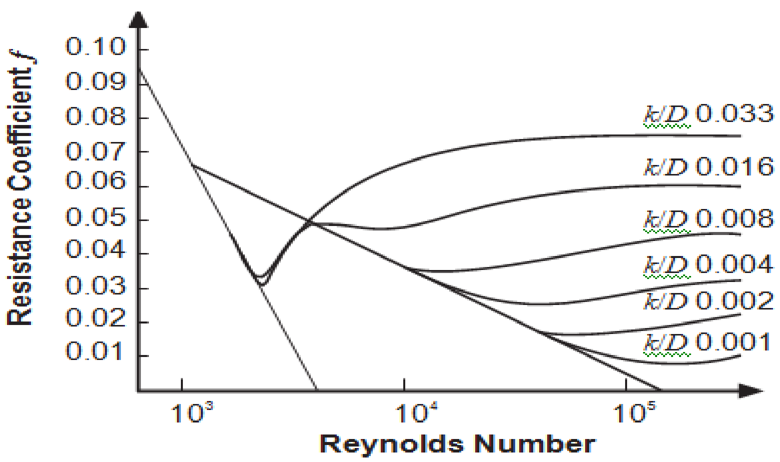


Figure 6 : Nickuradse Curves.

Procedures:

Procedure 1 – Dark Blue Circuit and Gate valve:

- Connect the hydraulic bench supply to the inlet pipe of the H16. Directing the outlet of the H16 into the hydraulic bench tank for flow measurement.
- Start your hydraulic bench and adjust for full flow. Fully shut the globe valve and fully open the gate valve.
- Measure and record the water temperature for reference.
- Make sure to remove all trapped air in the piezometer tubes before start taking readings by gently taps them with your finger.
- Slowly shut the gate valve until the pressure drop across it reaches 0.1 bar.
- Wait for conditions to stabilize, making a small adjustment of flow at the hydraulic bench or the valve if necessary.
- Record the flow rate using the hydraulic bench.
- Record the pressure drop across each piezometer (in mm of water) around the circuit.
- Slowly shut the valve until the pressured drop across it reaches 0.2 bar and repeat.
- Repeat in steps of 0.05 bar to the maximum you can achieve from your hydraulic bench (usually around 0.45 to 0.5 bar).

Procedure 2 – Light Blue Circuit and Globe valve:

- Connect the hydraulic bench supply to the inlet pipe of the H16. Directing the outlet of the H16 into the hydraulic bench tank for flow measurement.
- Start your hydraulic bench and adjust for full flow. Fully shut the gate valve and fully open the globe valve.
- Measure and record the water temperature for reference.
- Make sure to remove all trapped air in the piezometer tubes before start taking readings by gently taps them with your finger.
- Slowly shut the gate valve until the pressure drop across it reaches 0.1 bar.
- Wait for conditions to stabilize, making a small adjustment of flow at the hydraulic bench or the valve if necessary.
- Record the flow rate using the hydraulic bench.
- Record the pressure drop across each piezometer (in mm of water) around the circuit.
- Slowly shut the valve until the pressured drop across it reaches 0.2 bar and repeat.
- Repeat in steps of 0.05 bar to the maximum you can achieve from your hydraulic bench (usually around 0.45 to 0.5 bar).

Calculations:

For Dark Blue Circuit – Straight pipe:

For each flow rate:

- Convert piezometer 3-4 or 8-9 results into meters of water. Ignore any results that produce piezometer differences of less than 20 mm (0.02 m), as readings errors increase at these points and produce unwanted scatter in your results.
- Calculate the flow velocity.
- Find the Reynolds number.
- Calculate the friction factor from actual dimensions using equation 2 and from simpler Blasius equation.
- Calculate the log of the head loss and the volume flow rate , then produce a chart of log head loss against log volume flow and find the gradient n. How does it compare with theory??
- Create a chart of friction factor (vertical axis) against Reynolds number. Add your actual and Blasius results for comparison and comment on the differences.

For Light Blue Circuit – Bends:

For each flow rate:

- Convert piezometers readings for the five bends (including the mitre and elbow) into meters of water. Ignore any results that produce piezometer differences of less than 20 mm (0.02 m), as readings errors increase at these points and produce unwanted scatter in your results.
- Calculate the flow velocity.
- Find the Reynolds number.
- Calculate $V^2/2g$.
- Calculate the friction factor from the Blasius equation.
- Calculate the loss due to the pipe work h_F .
- Subtract h_F from your actual piezometer readings h_L to get the loss due to the bend h_B .
- Create a chart of hB against $V^2/2g$ and find its gradient.
- Compare your **average** K_B values with the theoretical values.

For Light Blue Circuit – Sudden Expansion and Contraction:

For each flow rate:

- Calculate the flow velocities in the standard bore and larger bore sections of pipe, and the velocity head.
- Convert piezometers readings (actual head loss) into meters of water.

- Calculate the total head loss for the contraction and enlargement.
- Create a chart of head loss (vertical axis) against the standard bore velocity head $V^2/2g$.
- Find the gradient of your actual results to find the K value and compare with the theoretical one.

Experiments with Optional Rough pipe (H16p):

Objectives:

To measure the pressure losses along a roughened pipe at different flow rates and compare results with those predicted by Moody and Nikuradse.

Procedure:

Piezometer (m water) h_L	Volume Flow rate $(m^3.s^{-1})$ Q	Velocity $(m.s^{-1})$ V	Reynolds Number	Actual f

1. Create a blank table of results, similar to the above.
2. Fully open the H16p valve and the hydraulic bench valve.
3. Start the pump of the hydraulic bench and allow water to pass around the circuit for several minutes to remove any trapped air.
4. Measure your water temperature.
5. Use the hydraulic bench to measure the flow rate.
6. Record the pressure drop along the roughened test section.
7. Use the H16p control valve to reduce the flow from maximum to minimum in at least six equal steps.
8. At each step, wait for the pressure readings to stabilize, then record the flow and pressure drop.

Calculations - Roughened Pipe:

- Find the kinematic viscosity of the water.
- For each flow rate, calculate the velocity based on a 19 mm diameter.
- Calculate Reynolds number Re and then use actual results to find friction factor *f*.
- Add your results to the Moody Chart and compare with those of Moody and Nickuradse.

References:

1. Gean Koplis, “Transport Processes Momentum, Heat and Mass", Augn and Bacon, 1983.
2. J.M. Coulson and FF Richardson," Chemical Engineering" Vol.1, Third Edition, 1980, pergamon prss.

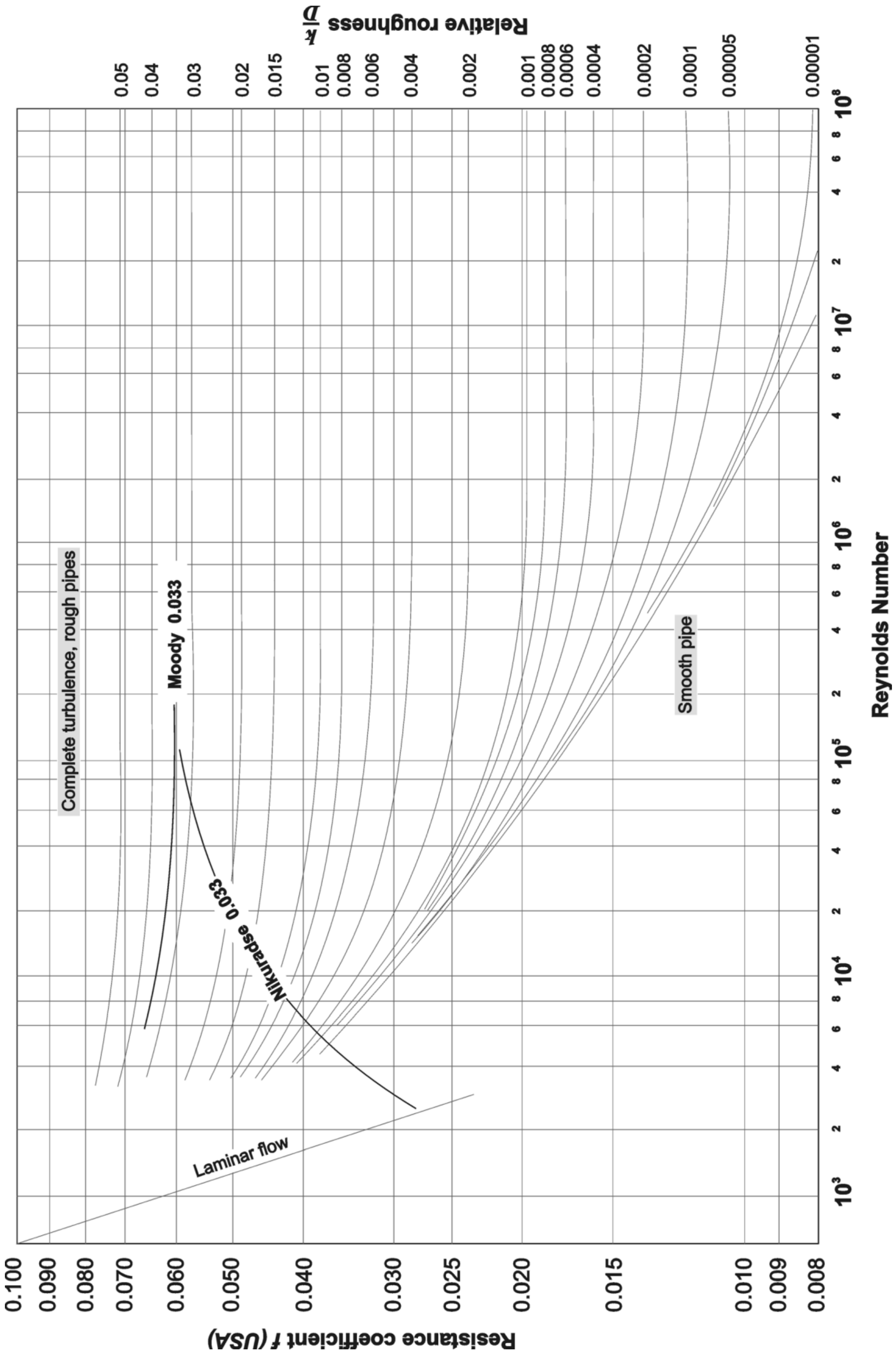
Losses in Pipes Experiment Data Sheet

Dark Blue Circuit and Gate Valve:

Pressure Gauge (bar)	Pressure Gauge (m water)	Flow rate (L/s) (volumetric) or kg/s (gravimetric)	Volume Flow rate ($m^3.s^{-1}$)	Dark Blue circuit piezometer tube heights (mm water)		
				1-2	3-4	5-6
0.1						
0.15						
0.2						
0.25						
0.3						
0.35						
0.4						
0.45						
0.5						
Water Temperature:						

Light Blue Circuit and Globe Valve:

Pressure Gauge (bar)	Pressure Gauge (m water)	Flow rate (L/s) (volumetric) or kg/s (gravimetric)	Volume Flow rate ($m^3.s^{-1}$)	Light Blue circuit piezometer tube heights (mm water)					
				7-8	8-9	9-10	11-12	13-14	15-16
0.1									
0.15									
0.2									
0.25									
0.3									
0.35									
0.4									
0.45									
0.5									
Water Temperature:									



Moody Chart including Nikuradse Results

Experiment Number -2-
Positive Displacement Pumps Characteristics

Objective

To demonstrate how pumps work and show the performance of a selection of positive displacement pumps at constant and variable speeds.

Apparatus

The apparatus consists of the Positive Displacement Pump Module, the Universal Dynamometer, an optional pump (a Vane pump is used here) and TecQuipment's Versatile Data Acquisition System (VDAS). Figure (1) shows the apparatus with its main parts.
The Positive Displacement Pump Module uses oil as the working fluid. The Universal Dynamometer turns the pump which in turn forces the oil around a circuit. The oil comes from an oil reservoir, through an inlet valve and through the pump. It then passes through a pressure relief valve and a delivery valve. It then passes through a gear-type flowmeter and back to the oil reservoir.
Electronic pressure transducers in the circuit measure the oil pressures at the inlet to the pump and at the outlet. A thermocouple mesaures the oil temperature and a flowmeter measures the oil flow in the circuit.
The trancducers, the thermocouple and the flowmeter all connect to a digital display that shows the pressures, temperature and flow.
The TecQuipment's Versatile Data Acquisition System (VDAS) will display, store, chart and export all the important readings from the tests.

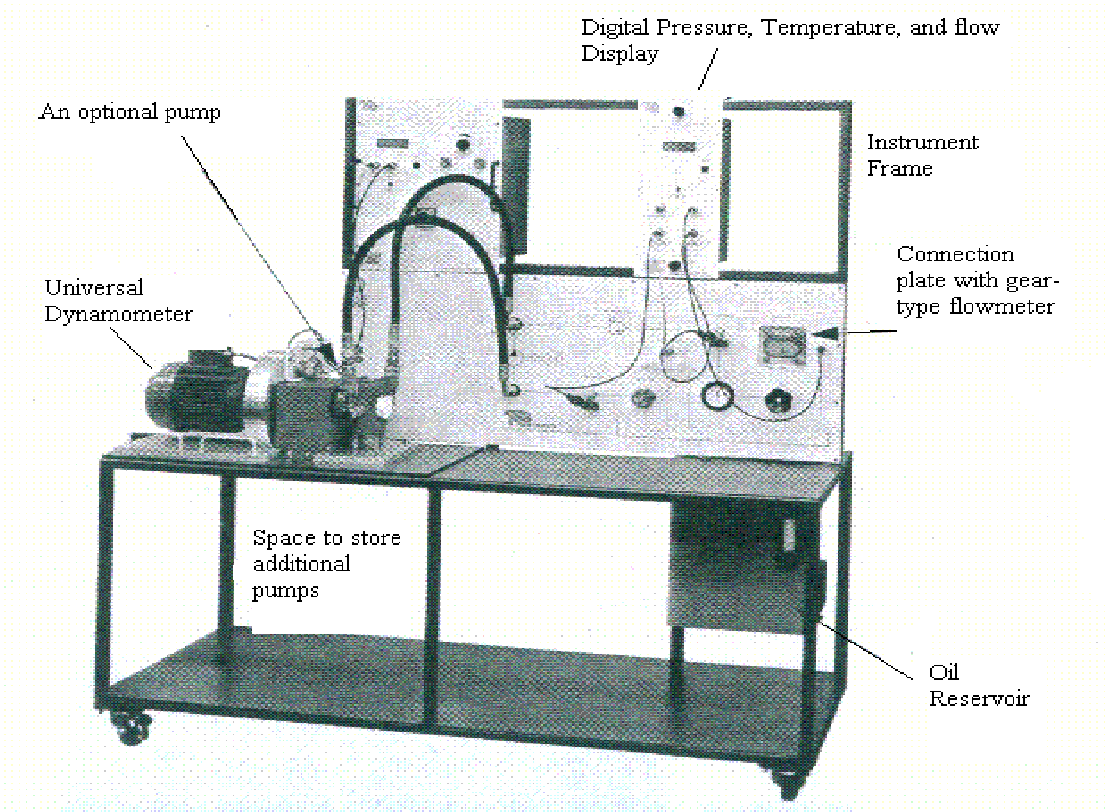


Figure (20): The Positive Displacement Pump Module with its main parts.

Theory

The pressure increase (or head) and flow rate caused by a pump are its two most important qualities. Next most important are its efficiency and power needs. Different types of pumps are designed to process fluids under variable engineering condition.

The pressure increase is simply the difference between the pressures before and after the pump. The flow rate is the amount of fluid that passes through the pump.

Mechanical power (into pump):
This is simply the shaft power at the pump (W_D).

Hydraulic power (from the pump):
The hydraulic power that the pump adds to the fluid is a product of the flow through the pump and the increase in pressure it gives.

$$W_P\ (kW) = (p_2 - p_1) * Qv \quad \text{……….} (1)$$

Where:
$(p_2 - p_1)$: Delivery pressure-suction pressure (Pa).
Qv : Volumetric flow rate (m^3/s).

Overall pump efficiency:

$$\eta p = (W_P / W_D) * 100 \quad \text{……….} (2)$$

Volumetric efficiency:
Volumetric efficiency= (Actual volumetric flow rate/Expected volumetric flow rate)* 100

$$\eta v = [\ Qv / (V_S * N_P)\ ] * 100 \ \ldots\ldots\ldots (3)$$

Where:
V_S : Swept volume (cm^3/rev).
N_P: Speed of the pump (rev/min).

Procedure

1. Turn the "Positive Displacement Pump Module" on.
2. To start the software, double click the "TecQuipment VDAS" icon on the desktop. Then click the "connection" button to connect the software to the device.
3. In the" Pump Information" section, fill the pump type and (cc/rev) depending on the type of pump connected to the module.
4. The experiment consists of three parts, follow the instructions illustrated in each part carefully. **And before you start always do the following:**
    a. Fully open the inlet and delivery valves.
    b. Use the button on the pressure display to zero all pressure readings.
    c. Zero the torque reading of the MFP100 Universal Dynamometer.

Part 1: The Effect of Delivery Pressure at Constant Speed.

Aim:
To find how the pump performs for a range of delivery pressures (varied load) at a constant speed.

Procedure

1. Press the start button of the Motor Drive and run the speed to 1600rpm (+/- 5 rpm) for at least five minutes and monitor the oil temperature until it stabilizes. Check that any air bubbles have moved away from the flow meter.
2. Slowly shut the delivery valve and maintain the speed until the delivery pressure reaches 2 bar. Allow a few seconds for conditions to stabilize. Click on the record data values button, to record all data automatically (use 15 seconds time intervals).
3. Continue increasing the delivery pressure in 1 bar steps (while keeping the speed constant) to a maximum of 15 bar. At each step. Allow a few seconds for conditions to stabilize.
4. Take a print out of the results that contains speed, shaft power, swept volume, inlet and outlet pressures and flow rate readings.
5. At the end of test, fully open the delivery valve and slowly decrease the speed to zero before you stop the motor.

6. Repeat the test at two other lower speeds. 1200 rpm and 800 rpm are recommended.

Results Analysis:

At each speed:

1. Find the pressure differences across the pump and calculate the hydraulic power.
2. Calculate the expected flow for the speed of your test and the overall and volumetric efficiencies.
3. Plot curves of (flow rate, shaft power, volumetric and overall efficiencies) against pressure difference and discuss your results.
4. Compare the results at different speeds.

<u>Part 2: </u>The Effect of Speed at Constant Delivery Pressure.

Aim:

To find how the pump performs for a range of speeds at a constant delivery pressure (load).

<u>Procedure:</u>

1. Press the start button of the Motor Drive and run the speed to 1600 rpm (+/- 5 rpm) and run the pump for at least five minutes and monitor the oil temperature until it stabilizes.
2. Wait for any trapped air bubbles to move away from the flowmeter before you continue.
3. Slowly shut the delivery valve and maintain the speed until the delivery pressure reaches 15 bar.
4. Allow a few seconds for conditions to stabilize, then click on the record data values button, to record all data automatically (use 15 seconds time intervals).
5. Reduce the speed by 100 rpm steps while adjusting the delivery pressure to keep it constant at 15 bar until you reach 800 rpm. At each step, allow a few seconds for conditions to stabilize.
6. Take a print out of the results that contains speed, shaft power, swept volume, inlet and outlet pressures and flow rate readings.
7. At the end of test, fully open the delivery valve and slowly decrease the speed to zero before you stop the motor.
8. Repeat the test at two other lower fixed delivery pressures. 5 and 10 bar values are recommended.

Results Analysis:

At each delivery pressure:

1. Find the pressure differences across the pump and calculate the hydraulic power.
2. Calculate the expected flow for each speed and the overall and volumetric efficiencies.
3. Plot curves of (flow rate, shaft power, volumetric and overall efficiencies) against pump speed and discuss your results.
4. Compare the results at different delivery pressures.

Results Analysis:

1. Find the pressure differences across the pump and calculate the hydraulic power.
2. Calculate the expected flow for the speed of your test and the overall and volumetric efficiencies.
3. Plot curves of (flow rate, shaft power, volumetric and overall efficiencies) against the inlet pressure.

References:

1. F.A. Holland, “Fluid Flow for Chemical Engineers ", Arnold, 1980.
2. J.M. Coulson and FF Richardson," Chemical Engineering" Vol.1, Third Edition, 1980, Pergamon Press.

Piston pump / Constant speed / (dis/rev) =

Speed	Torque	Power	Inlet Pressure (P1)	Delivery Pressure (P2)	oil temp	Flow Rate

Piston pump   Constant pressure (dis/rev) =

Speed	Torque	Power	Inlet Pressure (P1)	Delivery Pressure (P2)	oil temp	Flow Rate

Vane pump / Constant speed / (dis/rev) =

Speed	Torque	Power	Inlet Pressure (P1)	Delivery Pressure (P2)	oil temp	Flow Rate

Vane pump   Constant pressure (dis/rev) =

Speed	Torque	Power	Inlet Pressure (P1)	Delivery Pressure (P2)	oil temp	Flow Rate

Experiment Number -3-
Comparative Fluid Flow Measurement

Objective:

1. Determination of the discharge coefficient (C_d) of an orifice meter and a venturi meter at different Reynolds numbers (Re).
2. Comparison of pressure drops across the orifice meter and the venturi meter.
3. To construct a calibration curve for the rotameter.

Equipment:

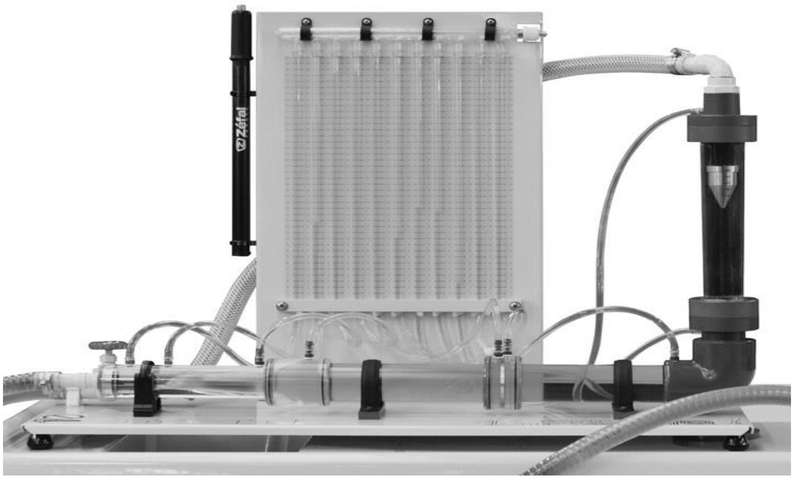


Figure (21): Flow Measurement Methods equipment.

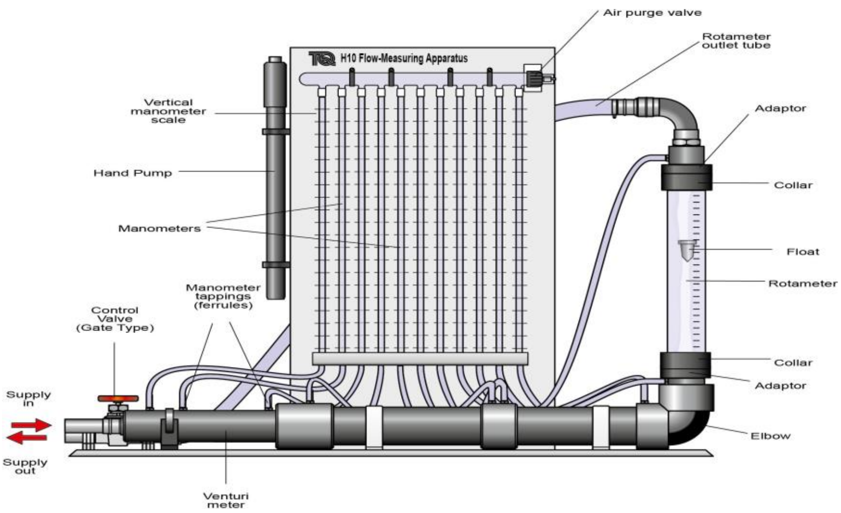


Figure (22): Flow Measurement Methods apparatus.

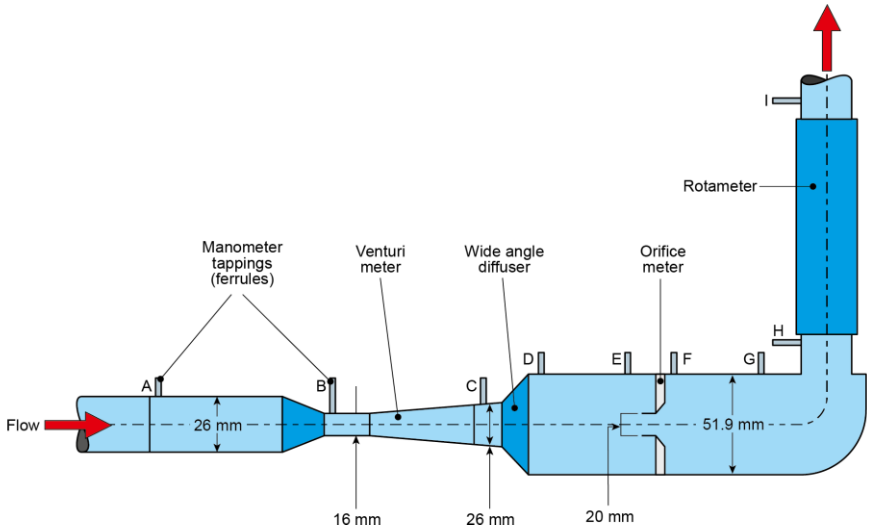


Figure (23): Explanatory Diagram of the Flow Measurement Methods Apparatus.

Figure (24): Digital Hydraulic Bench.

Figures above show the Flow Measurement Methods apparatus, Water-from the Hydraulic Bench-enters the equipment through a Venturi meter, which consists of a gradually converging section, followed by a throat, and a long gradually diverging section. After a change in cross-section through a rapidly diverging section, the flow continues along a settling length and through an orifice meter from a plate with a hole of reduced diameter through which the fluid flows. The water then continues around a bend and up through a rotameter-type flow meter. The H10 has eleven manometers, nine are connected to tappings in the pipework and two are left free for other measurements.

Theory:

The venturi meter, the orifice plate meter and the Rotameter are all dependent upon Bernoulli's equation, for their principle of operation. Bernoulli's equation is given by:

$$\frac{P_1}{\rho . g}+\frac{{u_1}^2}{2. g}+z_1=\frac{P_2}{\rho . g}+\frac{{u_2}^2}{2. g}+z_2+\Delta h_{12} \ldots \ldots \ldots (1)$$

Where (Δh_{12}) is head loss due to friction and localized effects (area change or fitting) and u is the velocity of water.

In order to obtain the total head loss due to fitting we therefore have to correct the measured head loss for the change in velocity head also subtract the head loss due to friction:

$$\Delta H=(h_1-h_2)+\frac{{u_1}^2-{u_2}^2}{2. g}-\Delta h_f \ldots \ldots \ldots (2)$$

where $\Delta h_{12}=\Delta H+\Delta h_f \ldots \ldots \ldots (3)$

where (ΔH) is the head loss due to fitting and (Δh_f)is the head loss due to friction. If the length is small, (Δh_f) can be neglected. The head loss is usually expressed in terms of the loss coefficient (K) defined as:

$$k=\frac{\Delta H}{\left({u^2}/{2g}\right)} \ldots \ldots \ldots (4)$$

where (u) is the velocity in the smaller pipe:

a. Venturi Meter:

Since(Δh_{12}) is negligibly small between the ends of a contracting duct application of equation (1) between pressure tapping's (A) and (B) gives:

$$\frac{P_A}{\rho . g}+\frac{{u_A}^2}{2. g}=\frac{P_B}{\rho . g}+\frac{{u_B}^2}{2. g} \ldots \ldots \ldots (5)$$

and since, by continuity:

$$\dot{m}_A=\rho . u_A . A_A=\dot{m}_B=\rho . u_B . A_B \ldots \ldots \ldots (6)$$

Sub (6) into (1) to get:

$$u_B=\left[\frac{2g}{(1-(A_B/A_A)^2)}\times\left(\frac{P_A}{\rho . g}-\frac{P_B}{\rho . g}\right)\right]^{\frac{1}{2}} \ldots \ldots \ldots (7)$$

Now

$Q_{Th}=A_B . u_B$

$$Q_{Th} = A_B.\left[\frac{2g}{(1-(A_B/A_A)^2)} \times \left(\frac{P_A}{\rho.g} - \frac{P_B}{\rho.g}\right)\right]^{\frac{1}{2}} \dots\dots\dots (8)$$

This is theoretical valve.

$$Q_{act} = C_v.A_B.\left[\frac{2g}{\left(1-\left(\frac{A_B}{A_A}\right)^2\right)} \times (h_A - h_B)\right]^{\frac{1}{2}} \dots\dots\dots (9)$$

where (Q_{act}) is the actual flow rate.
(C_v) may found from experiment.

b. Orifice Meter:

The head losses (Δh_{12}) in equation (1) is by no means negligible when applied between (E) and (F). Rewrite the equation with the appropriate symbols.

$$\frac{{u_F}^2}{2.g} - \frac{{u_E}^2}{2.g} = \frac{P_E}{\rho.g} - \frac{P_F}{\rho.g} \dots\dots\dots (10)$$

Reducing equation (10) in exactly the same way as for venturi meter, the following equation will be obtained:

$$Q_{act} = C_d.A_F.\left[\frac{2g}{\left(1-\left(\frac{A_F}{A_E}\right)^2\right)} \times (h_E - h_F)\right]^{\frac{1}{2}} \dots\dots\dots (11)$$

where C_d is the coefficient of discharge.

Procedure:

1. Press the on/off switch on the hydraulic Bench to start the pump.
2. Open the apparatus valve until the rotameter shows a reading of approximately 10 mm, when a steady flow is maintained measure the flow with the Hydraulic Bench.
3. During this period, record the readings of the manometers.
4. Repeat this procedure for a number of equidistant values of rotameter readings up to the point in which the maximum pressure values can be recorded from the manometer.

Calculation:

1. Calculate (C_v), (C_d), (ΔH), and k for each of (Q).
2. Plot (ΔH) against ($u^2/2g$).
3. Plot (Cv), (Cd), against Re.
4. Which type of flow meter would you choose for a low loss piping system?
5. Plot the actual flow against the rotameter scale reading.

References:

1. F.A. Holland, “Fluid Flow for Chemical Engineers ", Arnold, 1980.
2. J.M. Coulson and FF Richardson," Chemical Engineering" Vol.1, Third Edition, 1980, pergamon press.
3. W.L. McCabe and J.C. Smith, “Unite Operations of Chemical Engineering”, 3rd Edition, 1976.
4. H10, “Flow Measurement Methods ", User Guide.

Comparative Fluid Flow Measurement Data Sheet

Atmospheric pressure: ……………………..

Atmospheric temperature: ………………….

Rotameter (cm)	Flow Rate ($l.m^{-1}$)	h_A (mmH_2O)	h_B (mmH_2O)	h_E (mmH_2O)	h_F (mmH_2O)

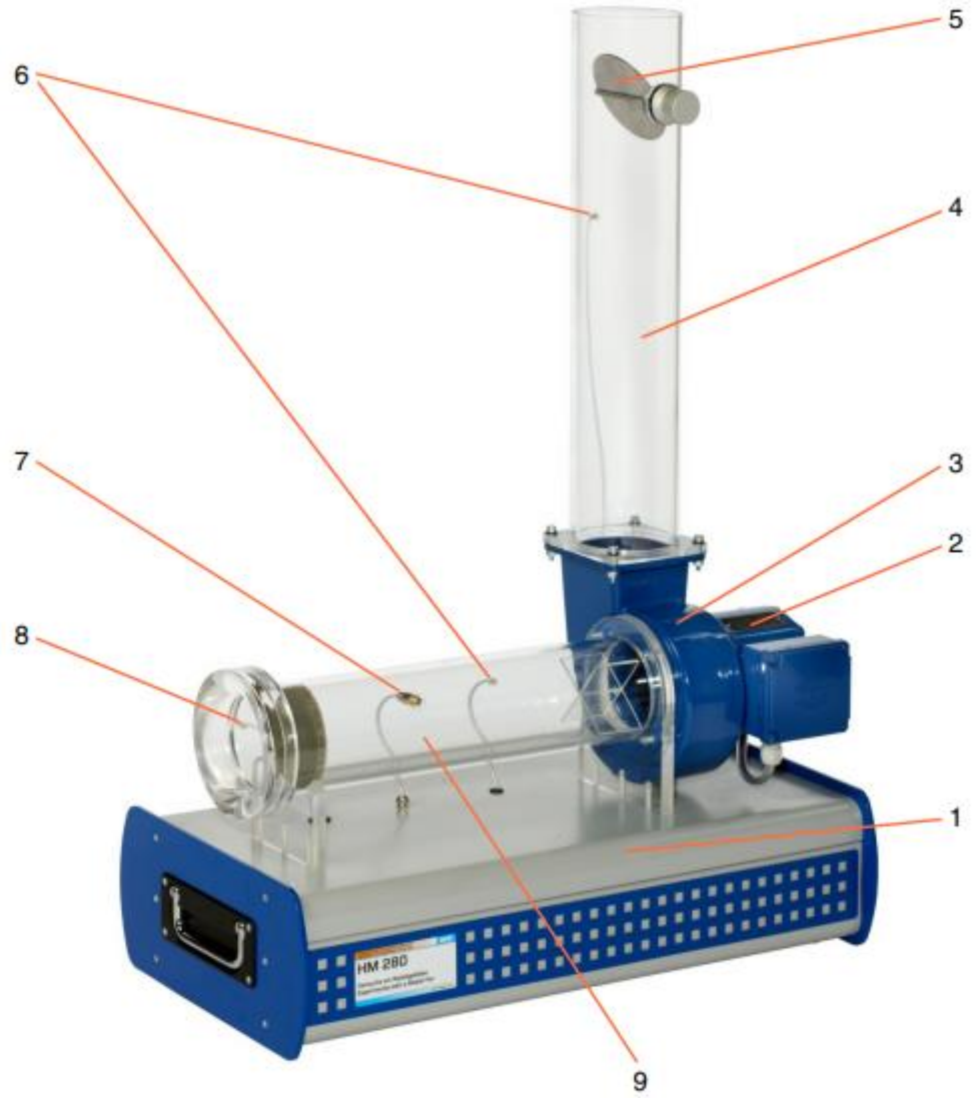
Instructor signature:
Date:

Experiment Number -4-
The Performance of a Radial Fan

Objective:

To examine the performance of a radial flow rotor in air over a wide range of operating conditions for impeller with radial blades.

Equipment:



1 Housing
2 Drive motor (M)
3 Radial fan (V-R)
4 Delivery pipe
5 Throttle valve (V1)
6 Measuring gauge for dp_F
7 Temperature sensor for T_1
8 Measuring gauge for dp_N
9 Intake pipe

Figure (1) HM 280-Radial fan overview

The experimental unit essentially consists of the **radial fan (3)** with flange-mounted **drive motor (2)**, the **intake pipe (9)** and the **delivery pipe (4)** with **throttle valve (5).** The **housing (1)** contains the associated drive technology and instrumentation with a microcontroller board. The drive technology and instrumentation is enabled by **the measurement data acquisition software** and the customer-supplied PC. The **throttle valve** is used to vary the flow resistance in the delivery pipe. The scale on the rotary dial is divided into 10 parts, corresponding to 0°...360°. In position 0,0 the throttle valve is fully closed. The fully open throttle valve is denoted by the position 2,5**. HM 280** has **two impellers**, which each have a different blade shape.

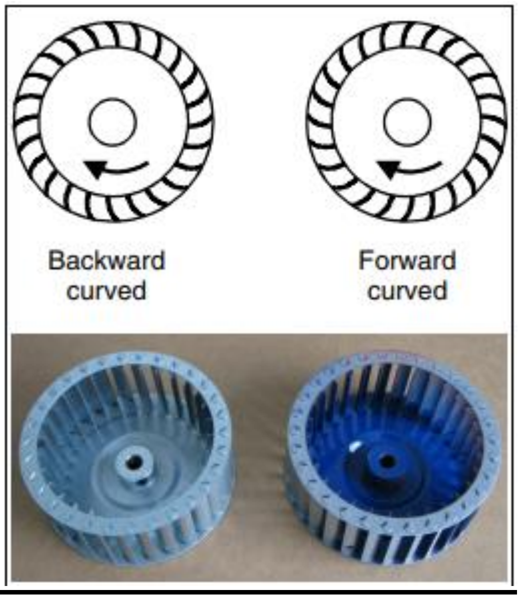


Figure (2) Description of the impellers

Technical data:

Dimensions: Length x width x height: approx. 750 x 350 x 950 mm
Inner diameter intake pipe : 90 mm
Inner diameter delivery pipe: 100 mm

Theory:

Fans are turbo-machines that transfer mechanical energy to a gaseous fluid in the form of hydraulic energy. They convey the gas through a system.

In axial fans, the flow passes through axially to the impeller. In radial fans, the gas exits the impeller radially.

The HM 280 experimental unit is used to measure the differential pressure dp_N between the ambient pressure and the pressure applied at the inflow of the intake pipe. Using dp_N and the known geometry of the intake pipe, the measurement data acquisition program calculate the volume flow of the intake air, known as the suction volume flow $\dot{V}_S$.

The total pressure composed of static pressure and dynamic pressure. This applies both to the environment and to each flow cross section in the intake pipe.

In this apparatus the cross sectional area at inlet and exit of the fan are almost the same, it follows that velocity heads at inlet and outlet are equal and the fan total pressure is equal to the difference between the corresponding static pressures.

Fan total pressure P_N = outlet static pressure – inlet static pressure.

While dp_N is therefore measured as the differential pressure between the ambient static pressure and nozzle static pressure, so dp_N is equal to the dynamic pressure behind the inflow nozzle (fan tatal pressure P_N).

The dynamic pressure dp_N is proportional to the square of the air velocity u. for the calculation:

$$u = \sqrt{\frac{2}{\rho} . dp_N} \quad \dots \dots \quad (1)$$

The suction volume flow $\dot{V_S}$ is proportional to the air velocity u. the proportionality factor is the flow cross section A:

$$\dot{V_S} = u . A \quad \dots .. (2)$$

$$A = \frac{\pi}{4} . d_i^2 \quad \dots \dots ..(3) \quad d_i = 90 \text{ mm}$$

Additional influencing factors are the temperature of the intake air T_1 and the ambient pressure P_{amb} , they affect the density ρ of the intake air according to:

$$\boldsymbol{\rho = \rho_0 \cdot \frac{T_0}{T_1} . \frac{P_{amb}}{P_0}} \quad \dots \dots . \quad (\mathbf{4})$$

Where ρ_0= 1.293 Kg/m^3 is the air density at the reference temperature T_0=273.15 K and the reference pressure P_0=1013 mbar.

In the present conditions, the conveyed air can be considered incompressible. Therefore, the hydraulic power of the air is the product of pressure increase dp_F and the suction volume flow which expressed simply gives:

$$P_{hyd} = dp_F . \dot{V_S} \quad \dots \dots .. (5)$$

Where P_{hyd} : Hydraulic power in W , dp_F: Static pressure in N/m^2 , and $\dot{V}s$: Volume flow in m^3/s .

The efficiency is defined as the ratio of benefit to effort, the benefit here is the hydraulic power, and the electrical power of the drive motor is expended.

$$\eta = \frac{P_{hyd}}{P_{el}}.100\% \quad \ldots\ldots\ldots \ (5)$$

Where η : Efficiency in % , P_{hyd}: Hydraulic power (the benefit) in W , and P_{el}: the electrical power (the effort) in W.

Procedure:

In order to record a fan characteristic, the throttling is varied while under constant fan speed

1. Connect experimental unit to the mains power supply.
2. Turn main switch to (1).
3. Start the PC. Start the measurement data acquisition program.
4. Tare values in the system diagram
5. Enter ambient pressure in the system diagram
6. Select "Measurement Diagram" in the program.
7. Enable new series of measurement. Make any setting for the measurement file.
8. Switch on radial fan, select speed of 80%.
9. For the first measurement, close the throttle valve completely(position 0,0)
10. Wait until the displayed measurement is stable.
11. Record measurements (the current measurement data set is written to the **measurement file**).
12. Open the throttle valve a little bit according to the desired number of measurement points.
13. Repeat last two points until the last measurement point is taken with the throttle valve fully open (position 2.5).
14. Repeat steps (4-13) with newly selected seeds 90%, 100%.
15. Save measurements file.
16. Switch of radial fan.
17. Stop the measurement data acquisition program.
18. Main switch to "0".

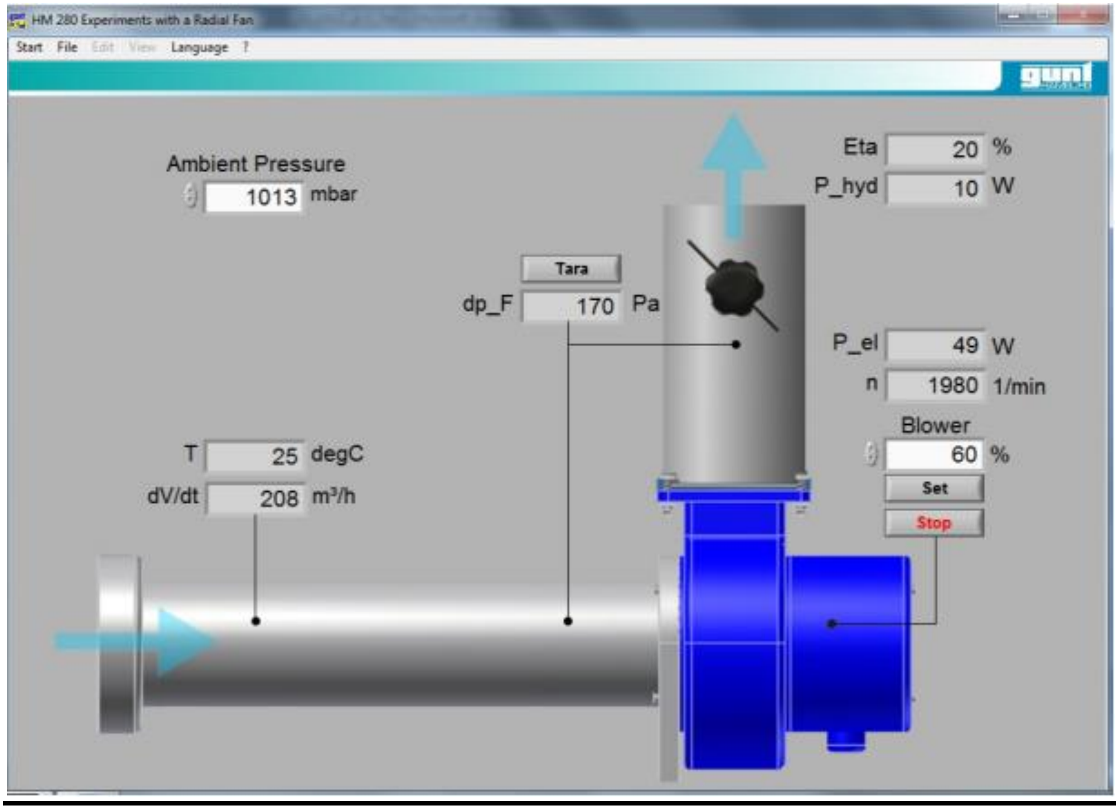


Figure (3) system diagram in the measurement data acquisition program

Calculation:

1. For 80%, 90%, and 100% fan speed, on the same figure using different scales, plot the electrical power of the motor, pressure increase (dp_F), hydraulic power, and the efficiency against the volumetric flow in m^3/h.
2. Comment on any points of general interest which arise from the test results.
3. Can this type of fan test be used to predict the performance of a geometrically similar pump proposed for drainage scheme?

References:

1. F.A. Holland, “Fluid Flow for Chemical Engineers ", Arnold, 1980.
2. J.M. Coulson and FF Richardson," Chemical Engineering" Vol.1, Third Edition, 1980, pergamon press.
3. HM 280 experiments with radial fan experiment instructions, Gunt.

The Performance of a Radial Fan Data Sheet

Description	Unit	Measurements						
Speed 80%								
Fan speed n	min^{-1}							
Differential pressure, inflow dp_N	Pa							
Pressure increase dp_F	Pa							
Temperature of the intake air T_1	°C							
Electrical power of the drive motor P_{el}	W							
Ambient pressure P_{amb}	mbar							
Suction volume flow $\dot{V}_S$	m^3/h							
Hydraulic power P_{hyd}	W							
Efficiency η	%							

Description	Unit	Measurements						
Speed 90%								
Fan speed n	min^{-1}							
Differential pressure, inflow dp_N	Pa							
Pressure increase dp_F	Pa							
Temperature of the intake air T_1	°C							
Electrical power of the drive motor P_{el}	W							
Ambient pressure P_{amb}	mbar							
Suction volume flow $\dot{V}_S$	m^3/h							
Hydraulic power P_{hyd}	W							
Efficiency η	%							
Description	Unit	Measurements						
Speed 100%								

Fan speed *n*	**min^{-1}**							
Differential pressure, inflow dp_N	**Pa**							
Pressure increase dp_F	**Pa**							
Temperature of the intake air T_1	**°C**							
Electrical power of the drive motor P_{el}	**W**							
Ambient pressure P_{amb}	**mbar**							
Suction volume flow $\dot{V}_S$	**m^3/h**							
Hydraulic power P_{hyd}	**W**							
Efficiency η	**%**							

Instructor signature:
Date

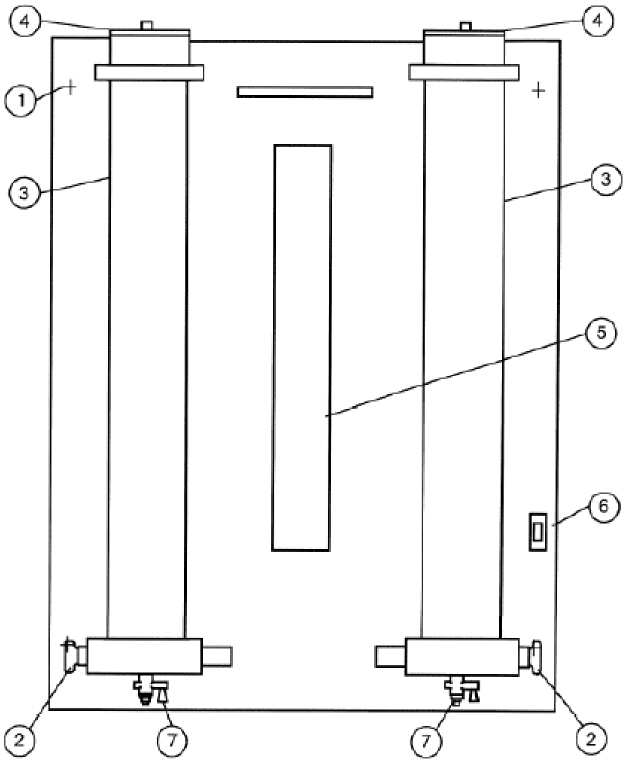
Experiment Number -5-

Drag Coefficient of Particles

Objective:

1. To measure of drag coefficients for different spheres size and material.
2. To demonstrate the effect of particle shape on rate of fall for sphere and a streamlined shape in a viscous fluid.
3. To show the variation of drag coefficient of particles over a wide range of Reynolds number.

Equipment:



1 Hole

2 Rotary valves

3 Tubes

4 Caps

5 Strip light

6 On/off switch

7 Drainage taps

Figure (1): Drag Coefficient of Particles Apparatus

The equipment consists essentially of two precision glass tubes (3), 1.5m long , 100mm outside diameter and 93 inside diameter mounted vertically on a backboard such that the whole apparatus is wall mounted. A guide is provided at the top of each tube to introduce the particles with the minimum of disturbance to the liquid.
A rotary valve device (2) at the bottom of each tube allows the particles to be removed with the minimum loss of liquid.
A fluorescent tube light (5) is mounted behind a shield between the two glass tubes to allow clear observation of the particles falling between the two glass tubes to allow clear observation of the particles falling between the timing marks even when the tubes

contain colored oils. In addition, spheres with different diameter and material, two streamlined shaped objects are supplied to compare between their drag coefficients.

Table (1): Supplied spheres

Stainless Steel Spheres	Ceramic Spheres
3.17 mm diameter	6.35 mm diameter
6.35 mm diameter	9.5mm diameter
7.9 mm diameter	
9.5 mm diameter	

Theory:

The drag force exerted on a solid object moving through a fluid is commonly considered as being made up of two components - Surface Drag and Form Drag.

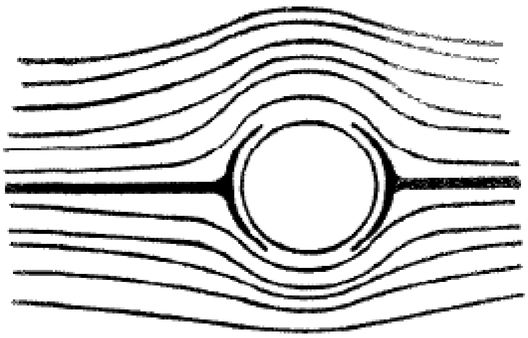


Figure (2): Surface Drag

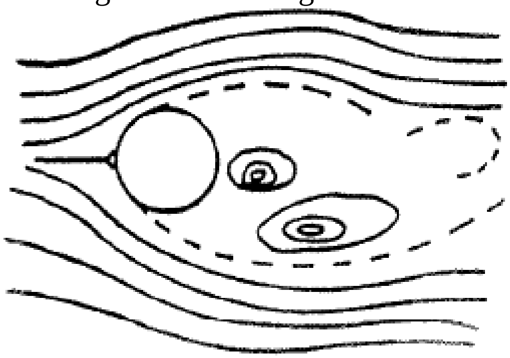


Figure (3): Form Drag

The total drag force can be expressed as:

$$F_D = C_D . A . \frac{\rho . V^2}{2} \quad \dots \dots \dots (1)$$

where:

F_D: drag Force (N).
C_D: drag coefficient.
A: cross-section area of solid object (m^2).
ρ: fluid density (kg/m^3).
V: relative velocity of sphere through fluid (m/s)

The relative magnitudes of these two components are largely dependent on the size and shape of the immersed body. It will be observed that when allowed to fall in a viscous fluid, the streamlined shape will fall slower than the sphere as all the drag is surface area (skin friction) and the streamlined shape has a larger surface area than the sphere. Streamlining is usually associated with a reduction in drag but this is only relevant in fluid of low viscosity where form drag becomes predominant.
From Stokes law:

$$\mu = \frac{2}{9} . \frac{(\gamma_s - \gamma_f)}{V} . r^2 \quad \dots \dots \dots (2)$$

where:
μ: coefficient of dynamic viscosity (N/sm^2).
γ_s: specific weight of solid object (N/m^3).
γ_f: specific weight of fluid($\gamma_f = \rho g$) (N/m^3).
r: radius of sphere (m).
and in the case of surface drag around a sphere we can show that:

$$C_D = \frac{24}{\frac{V.D.\rho}{\mu}} = \frac{24}{Re} \quad \dots \dots \dots (3)$$

where Re is the Reynold number of the sphere moving through the fluid, and D is the diameter of the sphere (m).
The drag coefficient for the sphere can be shown to be "

$$C_D = \frac{8}{3} . \frac{r.(\gamma_s - \gamma_f)}{\rho . V^2} \quad \dots \dots \dots (4)$$

Procedure:

1. Fill the two tubes with clear liquids of different viscosities.
2. Drop the particles one at a time from the top of the tube and record the time required to pass between the 1m marked length.
3. When the sphere arrives at the recess in the base of the tubes, remove it by turning the valve through 180°, by rotating the knob, then sliding the valve outwards by pulling the knob.
   (Note) It is important to remove each sphere as it reaches the valve, as two or more larger spheres will prevent the valve from operating.
4. After rejecting the sphere, the valve should be returned to the operating position. (The knob should be pushed in with the indicator mark uppermost).
5. Carried out the test three times and take the average results.
6. Repeat with different sphere size and different material, also repeat with two streamlined shaped objects.
7. Measure the density of the fluid using the density bottle (Pycnometer).

Calculation:

1. Calculate the velocity for each particle.
2. Calculate the C_D for each particle.
3. Plot the C_D and Re values for each on log paper or scale.

References:

1. F.A. Holland, "Fluid Flow for Chemical Engineers ", Arnold, 1980.
2. J.M. Coulson and FF Richardson," Chemical Engineering" Vol.1, Third Edition, 1980, Pergamon Press
3. Armfield, Instruction manual, issue 11, August 2011

The Drag Coefficient of Particles Data Sheet

Sphere Material	Diameter (mm)	Trial No. 1 (sec)	Trial No. 2 (sec)	Trial No. 3 (sec)	Avg. Time (Sec)	Velocity (m/s)	Re	CD
Stainless Steel	9.5							
Stainless Steel	7.9							
Stainless Steel	6.35							
Stainless Steel	3.17							
Ceramic	9.5							
Ceramic	6.35							
Streamlined Shape	-							
Streamlined Shape	-							

Instructor signature:
Date:

Experiment Number -6-

Statistical Experiment: Measuring the Density Using a density meter

Objective:

To measure the density of a liquid sample using the Anton Paar , and analyze the variation in density measurements based on statistical principles.

Materials and Equipment:

1. Anton Paar DMA 4100 M - Density Meter
2. Liquid sample (e.g., water, ethanol, or any chosen liquid)
3. Calibration Standards (e.g., distilled water, ethanol at known temperatures for calibration)

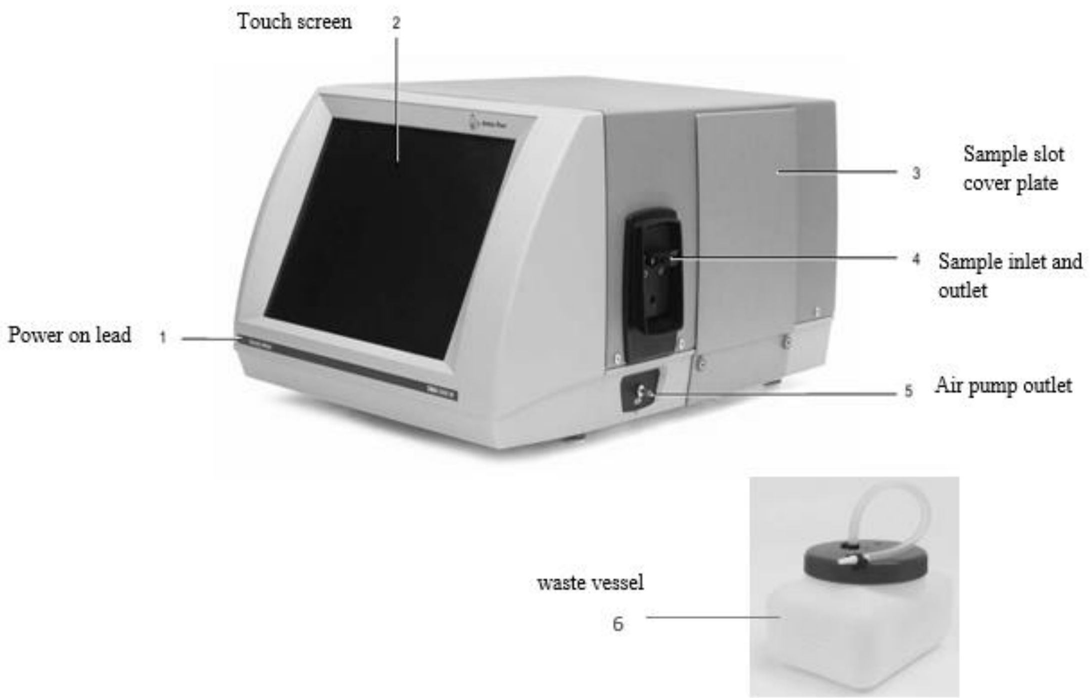


Figure (1): Anton Parr DMA 4100M

The DMA 4100 N uses a U-tube oscillation method to determine density. The device measures the oscillation frequency of the tube filled with the sample, which is then related to the density.

Anton Parr DMA 4100M Main Screen

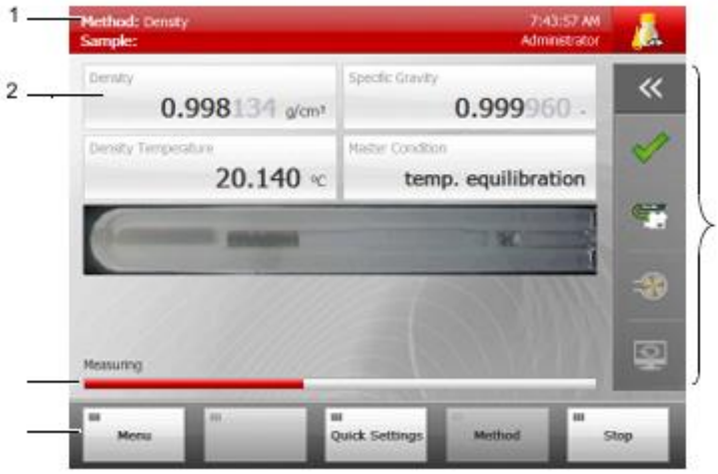


Figure (1): Main Screen Example

Operating Elements on the Main Screen

<table>
<tr><td>1</td><td>Header</td><td>:</td><td>On the left side of the header, you find the name of the currently active method and the sample number. On the right side of the header, you find a clock and the user indicator. The user indicator indicates the type of user that is currently logged on.</td></tr>
<tr><td>2</td><td>Output field</td><td>:</td><td>In the output field, the measuring values are displayed</td></tr>
<tr><td>3</td><td>Content area</td><td>:</td><td></td></tr>
<tr><td>4</td><td>Progress bar</td><td>:</td><td>The progress bar at the bottom of the content area indicates whether the instrument is currently measuring or whether a measurement has finished</td></tr>
<tr><td>5</td><td>Buttons area</td><td>:</td><td>The buttons on the main screen have the following functions:
<table>
<tr><th>Button</th><th>Function</th></tr>
<tr><td><Menu></td><td>Opens the main menu</td></tr>
<tr><td><Quick Settings></td><td>Opens the quick settings list (only available in the "No Sample List" mode instead of the <Sample List> button)</td></tr>
<tr><td><Sample List></td><td>Opens the current sample list</td></tr>
<tr><td><Method></td><td>Opens the method list (to select a method)</td></tr>
<tr><td><Start></td><td>Starts a measurement</td></tr>
<tr><td><Stop></td><td>Stops and aborts a measurement</td></tr>
</table>
</td></tr>
</table>

6	Quick access area	:	Opens the message list. The general instrument status as well as all measuring errors that have occurred during the measurements of the currently active sample list are described in this list. The button changes its appearance depending on the current error status. U-View™: Opens the live camera view of the measuring cell. Starts/stops the air pump. The air pump is off. The air pump is on. Unfreezes the screen after a finished measurement. The screen is frozen. The screen is unfrozen. A continuous reading of the current measuring values is shown.

Theory:

The density ρ of a sample is defined as mass divided by volume

$$\rho = \frac{m}{v} \qquad (1)$$

The specific gravity SG is calculated by dividing the density of a sample by the density of pure water at 20 °C.

$$SG = \frac{\rho_{sample}}{\rho_{water\,(20°C)}} \qquad (2)$$

Density and Specific Gravity values are highly temperature-dependent.

The oscillating U-tube method The sample is introduced into a U-shaped borosilicate glass tube that is being excited to vibrate at its characteristic frequency. The characteristic frequency changes depending on the density of the sample. Through a precise determination of the characteristic frequency and a mathematical conversion, the density of the sample can be measured.

The density is calculated from the quotient of the period of oscillations of the U-tube and the reference oscillator:

$$\rho = A.Q^2.f_1 - B.f_2 \qquad (3)$$

Where:

ρ	:	Density of sample
A, B	:	Instrument specific constant
Q	:	Oscillation period of the U-tube divided by the oscillation period of the reference oscillator
f_1, f_2	:	correction factors for temperature, viscosity, and nonlinearity

Statistical analysis

The Mean density can be calculated by average of the measured samples

$$\overline{D} = \frac{{}_{i=1}^{n} D_i}{n} \qquad (4)$$

Where:

$\overline{D}$	:	Mean
Di	:	Is the density for the i-th measurement
n	:	Is the total number of measurements

- Standard deviation provides a measure of the variability or dispersion of a data set relative to its mean, and also used to assess the spread of the measurements.

The formula for the standard deviation is:

$$\sigma = \sqrt{\left(\frac{1}{n-1}\right) \Sigma_{i=1}^{n} \left(D_i - \overline{D}\right)^2} \qquad (5)$$

Where:

σ	:	Is the standard deviation
$\overline{D}$	:	Is the mean density
Di	:	Is the density for the i-th measurement
n	:	Is the total number of measurements

The coefficient of variation (CV) is a statistical measure of the relative variability of a data set. It's expressed as a percentage and is calculated as the ratio of the standard deviation to the mean, often used to compare the degree of variation between different data sets, especially when the means are different.

The formula for the coefficient of variation is:

$$\text{CV} = \left(\frac{\sigma}{\overline{D}}\right) \text{X } 100 \qquad (6)$$

Where:

CV	:	Is the coefficient variation
σ	:	Is the standard deviation
$\overline{D}$	:	Is the mean density

Procedure:

1. Inject the liquid sample into the density meter measurement chamber. Ensure the sample is free from air bubbles and is at a constant temperature.
2. Start the measurement cycle. The instrument will oscillate the U-tube containing the sample and determine the density by the frequency of oscillation.
3. Record the measured density value, temperature in table (1).
4. To achieve accurate results, perform multiple measurements. It is recommended to take at least 10 separate measurements of the same liquid sample to account for any minor errors or fluctuations.
5. Each measurement should be conducted under identical conditions to avoid discrepancies from varying temperatures, impurities, or instrument calibration.

Calculation

Statistical Analysis:

1. Calculate the mean density and the standard deviation for the measurements across trials.
2. Use Analysis of Variance (ANOVA) by comparing the density across multiple conditions, such as different temprature.
3. Perform regression analysis if examining the relationship between viscosity and temperature.
4. Calculate the coefficient of variation (CV) to assess the precision of the measurements.

Measuring the Density Using a Density Meter Data Sheet

Table (1): Density at ………………^{o}C

No.	Density
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Table (2): Density at different temperature

No.	Density	Temperature ^{o}C
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Instructor signature:
Date:

Experiment Number -7-

Statistical Experiment: Preparation of calibration curves and control charts

Objective:

1. To establish a Relationship Between Response and Concentration: The calibration curve provides a graphical representation of the relationship between the instrument's response and the concentration of the analyte.
2. To detect if a process is in a state of statistical control, meaning it is stable and predictable over time, or if there are any variations that need attention.

Equipment:

The conductivity of solution is measured by applying an alternating voltage between two electrodes in conductivity cell. At any instant time, negatively charged anaions migrate toward the positive electrode and positively charged cations migrate toward the negative electrode. Since the detector applies a known voltage to the cell electrodes and current is measured.

Orion Star A215 pH/Conductivity Meter was used in this experiment as shown in Figure (1).

Figure (1): pH- Conductivity meter

Theory :

Conductivity, is a measure of the ability of an aqueous solution to carry electric current, this ability depends on their total concentration, mobility and temperature of measurement.

1. Calibration Curve

Instrument calibration is an essential stage in most measurement procedures. It is a set of operations that establish the relationship between the output of the measurement system (e.g., the response of an instrument) and the accepted values of the calibration standards (e.g., the amount of analyte present). A large number of analytical methods require the calibration of an instrument. This typically involves the preparation of a set of standards containing a known amount of the analyte of interest, measuring the instrument response for each standard and establishing the relationship between the instrument response and analyte concentration. This relationship is then used to transform measurements made on test samples into estimates of the amount of analyte present, as shown in Figure 1

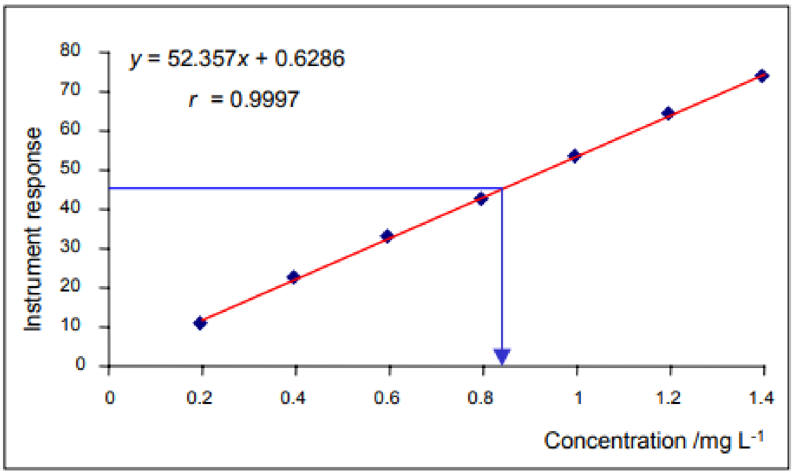


Figure (1): Typical calibration curve

Calibration curves are often used in many fields, including analytical chemistry biochemistry and chemical engineering. A calibration curve is used to determine the concentration of an unknown sample. The curve is created from the instrumental response to a set of standard samples at a range of concentrations. The data are then fit with a function to enable the prediction of unknown concentrations.

2. Control chart

Control chart is a statistical tool used to measure and control a process's performance and to study how a process changes over time. Data are plotted in time order. A control chart always has a central line for the average, an upper line for the upper control limit, and a lower line for the lower control limit. These lines are determined from historical data. By comparing current data to these lines, you can draw conclusions about whether the process variation is consistent (in control) or is unpredictable (out of control, affected by special causes of variation).

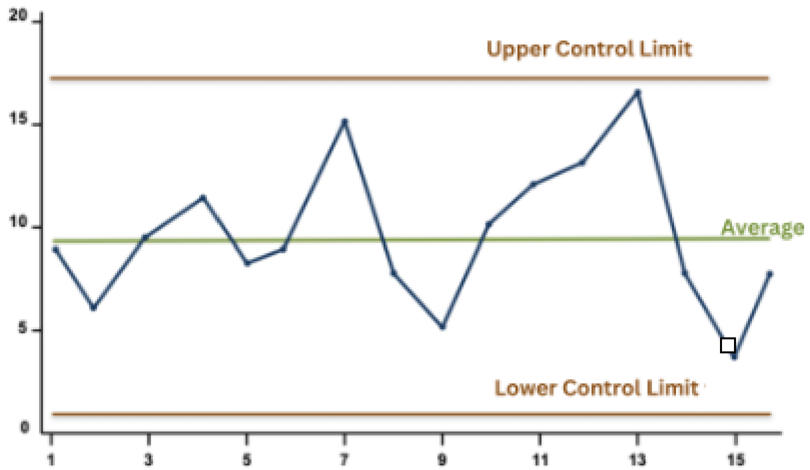


Figure (1): Typical control chart

Procedure:

Calibration curve

1. Dry KCl in an oven at 105 ºC for 2 h.
2. Prepare the following standards as described in table (1).

Table (1): Concentration of solutions and their required weights of KCl

No.	Concentration (M)	Weight (KCl) (g)
1.	0.005	0.03728
2.	0.006	0.04473
3.	0.007	0.05218
4.	0.008	0.05964
5.	0.009	0.06709
6.	0.01	0.07455

3. Dissolve the required amount of KCl in small amount of distilled water.
4. After complete dissolution, transfer the solution to 100 ml volumetric flask and complete the volume.
5. Immerse the electrode in the solution and record the conductivity in table (1).

6. Dissolve two different quantity of KCl in distilled water and measure the conductivity.
7. Record the data in Table(2).

Control chart

1. Read one of the above prepared standards at least 10 times.
2. Record the data in table (3).

Calculation:

1. Plot the results.
2. Perform a linear regression (or other appropriate curve fitting method) to determine the equation of the line. The linear equation will be of the form:

$$Y = mX + b \tag{1}$$

   Where:
   Y : is the measured property (conductivity)
   X : is the concentration,
   m : is the slope, and
   b : is the y-intercept (which ideally should be close to zero for accurate calibration).
3. Ensure the curve is linear and has a good correlation coefficient (R^2 value). A high R^2 (close to 1) indicates a reliable calibration curve.
4. Use the calibration curve to estimate values for unknown samples.
5. By using Excel, creat table (3) and draw the control chart.

Table (3): Control chart calculation

No.	Concentration (M)	Mean	Standard Deviation(σ)	UCL	LCL
1.					
2.					
3.					

References:

1. Grimshaw, S. D., Blades, N. J., & Miles, M. P. (2013). Spatial control charts for the mean. Journal of Quality Technology, 45(2), 130-148.
2. Prichard, L., & Barwick, V. (2003). Preparation of calibration curves: A guide to best practice. LGC Group, Ltd. TR LGC/VAM/2003/032, Teddington, Middlesex, UK.
3. Schoonhoven, M., & Does, R. J. (2012). A robust standard deviation control chart. *Technometrics*, *54*(1), 73-82.

Preparation of calibration curve and control chart Data Sheet

Table (1): Concentration of solutions and their required weights of KCl

No.	Concentration (M)	Weight (KCl) (g)	Conductivity (μS/cm)
1	0.005	0.03728	
2	0.006	0.04473	
3	0.007	0.05218	
4	0.008	0.05964	
5	0.009	0.06709	
6	0.01	0.07455	

Table (2): Concentration of unknown samples

No.	Conductivity (μS/cm)	Concentration (M)
1		
2		

Table (3): Control chart calculation

Sample concentration …………………

No.	Concentration (M)	Mean	Standard Deviation(σ)	UCL	LCL
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					

Instructor signature:
Date:

Experiment Number -8-
Reynolds Number

Objective:

The aim of this experiment is to demonstrate laminar and turbulent flow in a pipe and to determine under which conditions each flow regime occurs.

Practical application:

The Reynolds number has many practical applications, as it provides engineers with immediate information about the state of flow throughout pipes, streams and soils helping them apply the proper relationships to solve the problem at hand. As an example, if forces acting on a ship need to be studied in the laboratory for design purposes, the Reynolds number of the flow acting on the model in the lab and on the prototype in the field should be the same.

Equipment:

The following equipment is required to perform the Reynolds number experiment:

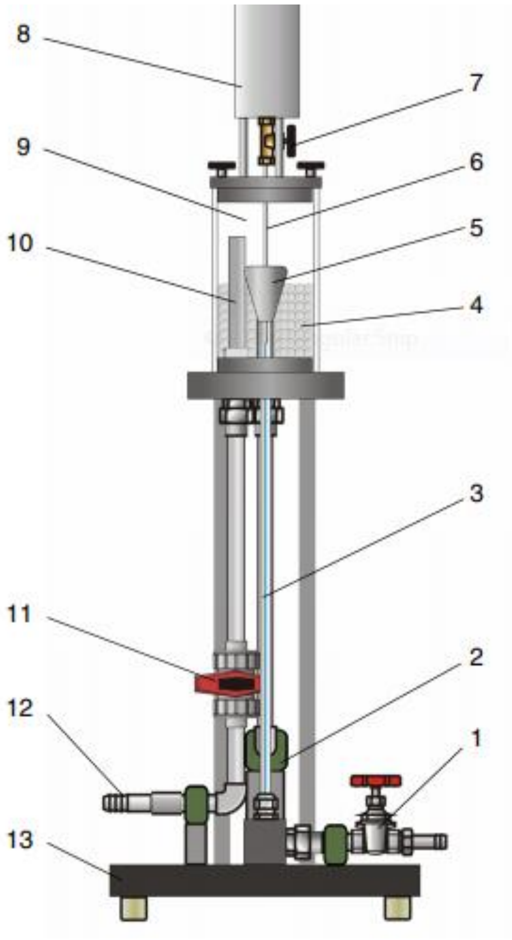
- The HM 150.18 Osborne Reynolds experiment device.
- Cylinder for measuring flow.
- Stopwatch for timing the flow measurement.
- Thermometer.

The experimental setup allows laminar and turbulent flow to be demonstrated. The flow is made visible with an ink trace in a transparent pipe section.

Equipment Description:

The equipment includes a vertical head tank **water reservoir (9)** that provides a constant head of water with a **glass ball layer (4)** to stem the flow of water entering the pipe. The inlet of water is from the laboratory **water supply (12)** and regulated by a **control valve (11),** while the discharge of waste water is from **water discharge (2),** the **overflow section (10)** is to generate a constant pressure level in the reservoir.

An **Aluminum reservoir (8)** for ink is mounted on the top of the head tank with **metering tap (7)** and **brass inflow tip (6),** from which a blue ink can be injected into the water by **test pipe section (3)** with flow **optimized inflow (5)** to enable observation of flow conditions. **Drain valve (1)** to adjust the flow through the test pipe section.



1. Drain valve
2. Waste water discharge
3. Test pipe section
4. Glass ball layer
5. Metering tap
6. Brass inflow tip
7. Metering tap
8. Aluminium reservoir for ink
9. Water tank
10. Overflow section
11. Control valve
12. Water supply
13. Base plate

Figure (1) Unit description HM 150.18

Theory:

Flow behavior in natural or artificial systems depends on which forces (inertia, viscous, gravity, surface tension, etc.) predominate. In slow moving laminar flows, viscous forces are dominated and the fluid behaves as if the layers are sliding over each other. In turbulent flows, the flow behavior is chaotic and changes dramatically, since the inertial forces are more significant than the viscous forces.

In this experiment the ink injected into a laminar flow will form a clear well-defined line. It will mix the water only minimally, due to molecular diffusion. When the flow in the pipe is turbulent, the ink will rapidly mix with the water, due to the substantial lateral movement and energy exchange in the flow.

There is also a transitional stage between laminar and turbulent flows, in which the ink stream will wander about and show intermittent bursts of mixing, followed by a more laminar behavior.

The Reynolds number (Re) provides a useful way of characterizing the flow, it is defined as:

$$Re = \frac{V.d}{\nu} \qquad \ldots\ldots (1)$$

Where :

d : is the inside diameter of pipe section in m

V : is the mean flow velocity in m/s

ν : is the kinematic viscosity of the water in $m^2/s = 1 \times 10^{-6}\ m^2/s$

The flow rate can be calculated from the volume flow, which is determined with a measuring vessel and a stopwatch.

$$Q = V\ x\ A \qquad \ldots\ldots (2)$$

$$A = \frac{\pi d^2}{4} \qquad \ldots\ldots (3)$$

Where :

Q : Volumetric flow rate m^3/s
A : Cross-sectional area of the pipe
d : Pipe diameter , m = 10 mm

Reynolds number is dimensionless parameter that is the ratio of the inertial force to the viscosity force. As Reynolds increases, the inertial force becomes relatively larger, and the flow destabilizes and becomes fully turbulent.

The Reynolds experiment determines the critical Reynolds number for pipe flow at which (critical Re≈2300), and the laminar flow where (Re ≤2300) , while the turbulent flow occurs when (Re ≥2300) .

The diagram below shows the three flow states:

- Laminar flow
- Transition laminar/turbulent flow
- Turbulent flow

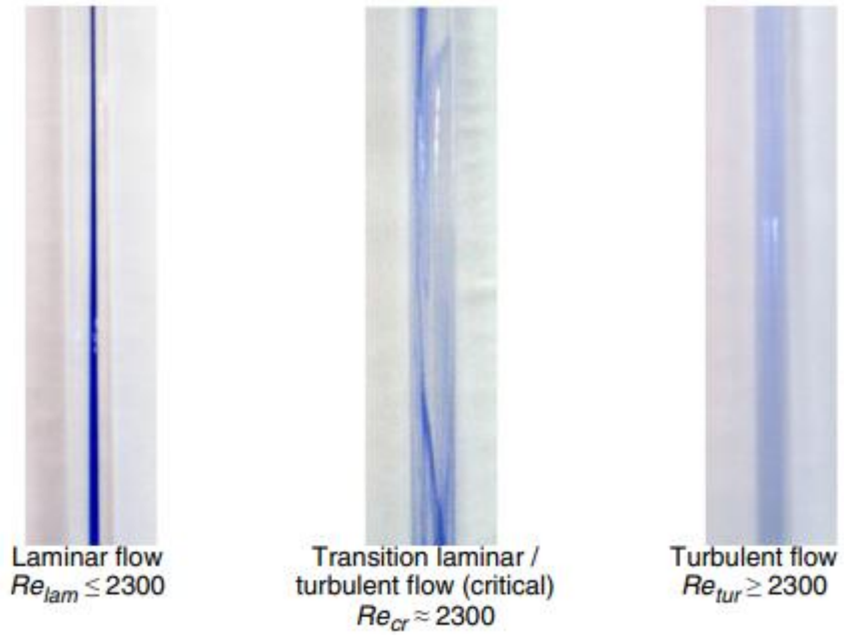


Figure (2) Flow states

Technical data:

1. Length x width x height	420 mm x 420 mm x 1170 mm
2. Water tank capacity	approx. 2.2 L
3. Ink reservoir capacity	approx. 250 ml
4. Test pipe section diameter, length	10 mm, 675 mm

Experimental Procedure:

Notice: The device should be level, fixed, on vibration-free surface, and ensure that the base is horizontal and the test section is vertical.

- Close the drain valve (1)
- Switch on the water supply
- Carefully open the control valve (11). The water supply should be done without air bubbles.
- Adjust the ball valve (11), so that, with the drain tap (1) closed, a constant water level is established above the overflow in the reservoir.

- After a time the test pipe section (8) is completely filled with water. Any entrained air bubbles that still hold between the glass balls should be removed as far as possible.
- The experiment can begin.
- Open the drain cock (1) slightly to produce a low rate of flow into the test pipe section. The colored waste water is best directed down the drain.
- For laminar flow (small flow) the water drain is to be turned so far that only a small jet or drops are to be perceived, then a fine blue line appears until the outlet.
- For turbulent flow (greater flow), the drain cock is opened wider to produce a high flow. The current thread is broken up, it shows turbulence to the out.
- Measure the flow volumetric rate by timed water collection.
- Observe the flow pattern, take pictures, and classify the flow regime.
- Measure water temperature.
- When finished, return the remaining ink to the storage container and rinse the container with clean water to ensure that no ink is left in the tank and valve.
- Drain water from water tank, if necessary clean it.
- Shut of the water supply to the device.
- Open valves and drain residual water from the lines.

Calculations:

Calculate discharge flow velocity and Reynolds number (Re), classify the flow based on the Reynolds number of each trial.

Conclusions:

Discuss your results, focusing on the following:

1. How is the flow pattern of each of the three states of flow different?

2. Does the observed flow condition occur within the expected Reynolds number range for that condition?

3. Discuss your observation and any source of error in the calculation of the number.

4. Compare the experimental results with any theoretical studies you have undertaken.

Reynolds Number Experiment Data Sheet

Raw data:

Trial	Observed flow regime	Volume (L)	Time (sec)	Temperature ° C
1				
2				
3				
4				
5				
6				
7				

Instructor signature:
Date:

Experiment Number - 9 -
Pressure Gauge Calibrator

1. Objective:

To show how the gauge works and how to calibrate it.

2. Equipment and materials:

The TecQuipment Calibration of a Pressure Gauge uses a large Bourdon pressure gauge, with 'dead weights' on a plunger piston to show how the gauge works and how to calibrate it.

Figure (1): Calibration of a Pressure Gauge (H3a)

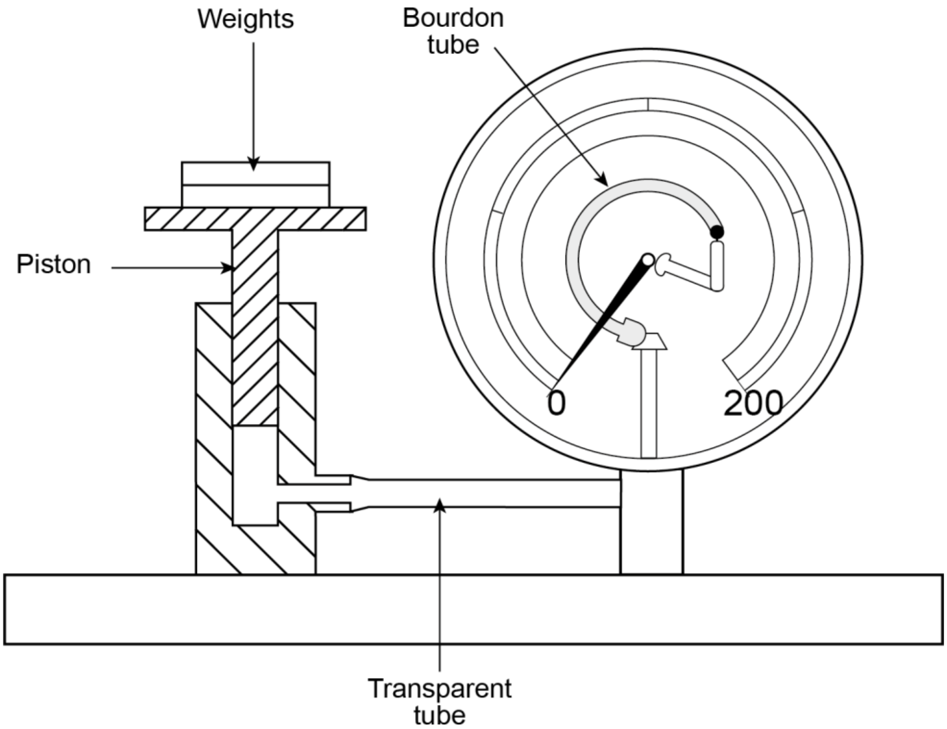


Figure (2) : Principle of the Bourdon Pressure Gauge Calibrator

- The transparent dial of the instrument allows the workings of the gauge to be seen.
- A thin-walled tube with an oval cross-section forms a 270° circular arc.
- The tube has one end fixed and open to the applied pressure. Its other end is sealed but free to move.
- As pressure enters the fixed end, the tube tries to straighten. This causes movement at the free end which moves a mechanical system connected to a pointer.
- The pointer moves around a graduated scale in proportion to the pressure applied. The sensitivity of the gauge depends on the material and dimensions of the Bourdon tube.
- A piston and cylinder assembly to the side of the gauge allows the addition of known values of accurately calibrated weights, which force water towards the gauge, increasing the pressure in the Bourdon tube.
- The pressure shown by the Bourdon gauge should match the pressure calculated from the force created by the weights, with an accuracy determined by experiment.
- The Bourdon gauge may have scales calibrated in both SI derived units of $kN.m^{-2}$ and non-SI units of $lb.in^{-2}$.
- The gauge could be calibrated using the non-SI units but the experiments in this guide only show the use of the SI derived units.
- SI = International System of Units

3. Theory:

Symbol	Meaning	Units
A	Area	m^2
g	Acceleration due to gravity	9.81 $m.s^{-2}$ or 9.81 m/s^2
m	Mass	kg
p	Pressure	Pa or $N.m^{-2}$ or N/m^2
W	Weight (force)	N

Units of Pressure

- The standard units of pressure are the Pascal (Pa) and Newtons per square metre ($N.m^{-2}$), but some sources use the non-standard unit of a 'bar'.
- 1 Pa = 1 $N.m^{-2}$ = 1 $kg.m^{-1}.s^{-2}$) = 10^{-5} bar or 0.01 mbar
- A 10 m high column of clean water at 4°C will produce 98 kPa (0.98 $kN.m^{-2}$) of pressure. A 100 mm high column of clean water at 4°C will produce 980 Pa (980 $N.m^{-2}$) of pressure.

Pressure and Force

Pressure is a measure of force over a given area. Normal atmospheric pressure is an ***absolute pressure*** measurement (with respect to a perfect vacuum) and shown as approximately 15 pounds per square inch (PSI) or 1 bar or 100 kPa or 100 $kN.m^{-2}$.

Normal gauges (such as the gauge in this equipment) show pressure with respect to atmosphere, so when the gauge shows zero pressure, its input is open to atmospheric pressure or at a pressure equivalent to atmospheric. The pressure shown by these gauges is termed '***gauge pressure***'.

With TecQuipment's Calibration of a Pressure Gauge, a known force is applied (the dead weight) to a plunger piston in a cylinder with a certain cross-sectional area.

The force (*W*) that the weight applies to the water in the cylinder is equal to the product of the mass (in kg) and the acceleration due to gravity.

Therefore:

$$W = mg \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

The pressure (*p*) caused by the force is therefore the force divided by the cross-sectional area of the cylinder (*A*), over which the force is applied:

$$p = \frac{W}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2)$$

The relative heights of the cylinder and gauge are similar, so there is very little 'pressure head' difference between them caused by different heights of water.

Therefore, the pressure is constant from the cylinder to the Bourdon gauge, so the gauge should give a direct reading of the pressure caused by the dead weight on the piston.

Calibration Constant

From Equations 1 and 2:

$$p = \frac{mg}{A}$$

Therefore, as the acceleration due to gravity (g) and area (A) are constant for the equipment, then the pressure (p) can be found by a simple calculation of:

$$p = m \text{ X } k$$

where k = a constant found from g/A.

For example, for a piston area of 315 mm^2 (0.000315 m^2) and g = 9.81 $m.s^{-2}$,

then k = 31143. Therefore:

Pressure (in $N.m^{-2}$) = mass (in kg) x 31143

Or

Pressure (in $kN.m^{-2}$) = mass (in kg) x 31.143

4. Procedure:

1. Create a blank table of results, similar to Table 1.
2. Note the cross-sectional area of the piston (indicated on the base of the equipment).

Table 1 Blank Results Table

Piston Area (A):							
Mass (m) (kg)	Force (W) (N)	Applied Pressure (p) $kN.m^{-2}$	Gauge Reading ($kN.m^{-2}$)			Average Error ($kN.m^{-2}$)	Error (% of full scale)
			Increasing	Decreasing	Average		

3. If fitted, carefully lift the piston from the cylinder and check that the gauge reads zero pressure. The gauge may need to be gently 'tapped' to make the indicator settle down to zero.
4. Carefully insert the piston with its loading platform. From the information on the equipment, note the mass of the piston (plunger) and platform, and write this in the first line of the results table. Note the gauge reading in the 'increasing' column of the results table.
5. Add the weights to the loading platform of the piston in at least 8 steps up to an indicated reading of around 170 $kN.m^{-2}$ or a maximum applied mass of around 6 kg including the mass of the piston.
6. At each step, gently rotate the piston to help prevent the piston sticking and record the gauge reading in the ***increasing*** column.
7. Reverse the procedure, reducing the weights and recording the gauge readings as the pressure decreases.

5. Calculation:

1. Using equation 1, multiply the mass of the weight by the acceleration due to gravity to find the force (W) applied to the piston. Using equation 2, divide the force by the piston area to find the applied pressure.
2. Alternatively, find the applied pressure (in $kN.m^{-2}$) by multiplying the mass (in kg) by the calibration constant shown on the equipment.
3. Find the average pressure from the increasing and decreasing pressures. Subtract the applied pressure from the average pressure to find the average errors. Now divide by the full scale reading of the gauge and multiply by 100 to convert this into percentage of full scale.
4. Plot a chart of the increasing and decreasing gauge readings (vertical axis) against the applied pressure to give a visual indication of any hysteresis in the gauge.
5. Now plot a chart of the average error (vertical axis) against applied pressure to give a visual indication of the reading error across the pressure range.

6. References:

1. Kajikawa, H., & Kobata, T. (2016). Pressure gauge calibration applying 0-A-0 pressurization to reference gauge. Acta Imeko, 5(1), 59-63.

2. Sinha, M., Saini, S., Gupta, P., Gulati, N. S., Das, A., Kumar, A., ... & Shekhar, C. (2018). Current status and way forward for National Accreditation Board for testing and calibration laboratories accreditation of laboratories in government organizations. Indian Journal of Pathology and Microbiology, 61(3), 461

Pressure gauge calibrator Data Sheet

Piston Area (A):							
Mass (m) (kg)	Force (W) (N)	Applied Pressure (p) kN.m^{-2}	Gauge Reading (kN.m^{-2})			Average Error (kN.m^{-2})	Error (% of full scale)
			Increasing	Decreasing	Average		

Instructor sign:
Date: