57:020 Mechanics of Fluids & Transfer Processes

Exercise Notes for Fluid Property TM

Measurement of Density and Kinematic Viscosity

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1. Purpose

The purpose of this investigation is to provide *Hands-on* experience using a table-top facility and simple measurement systems to obtain fluid property measurements (density and kinematic viscosity), comparing results with manufacturer values, and implementing standard EFD uncertainty analysis. Additionally, this laboratory will provide an introduction to camera settings and flow visualization for the ePIV system with a circular cylinder model.

2. Experimental Design

2.1 Part 1: For Determination of Fluid Properties

Common methods used for determining viscosity include the rotating-concentric-cylinder method (Engler viscosimeter) and the capillary-flow method (Saybolt viscosimeter). In the present experiment we will measure the kinematic viscosity through its effect on a falling object in still fluid (figure1). The maximum velocity attained by an object in free fall (terminal velocity) is inversely proportional to the viscosity of the fluid through which it is falling. When terminal velocity is attained, the body experiences no acceleration, and so the forces acting on the body are in equilibrium.

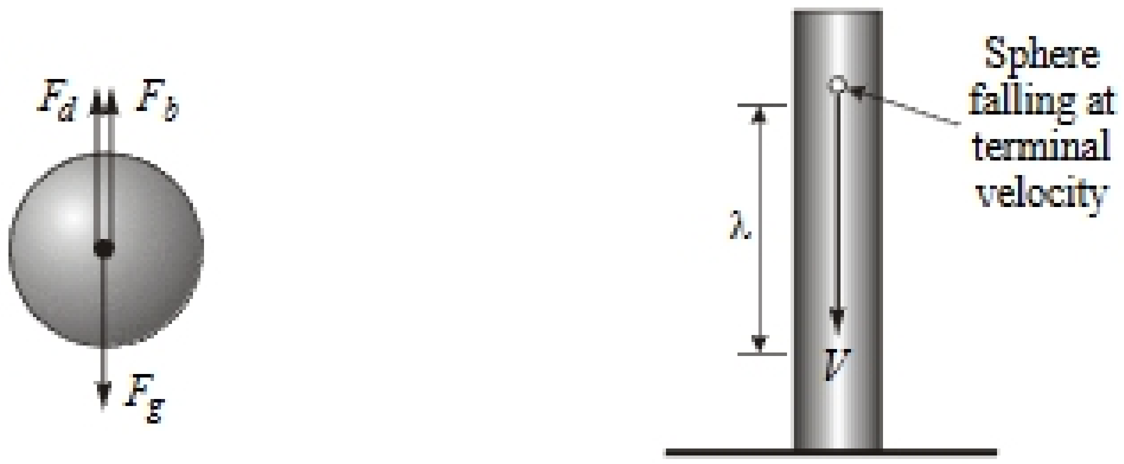

Figure 1. Schematic of the experimental setup

The forces acting on the body are the gravitational force,

$$F_g = mg = \rho_{sphere} \pi \frac{D^3}{6} g \tag{1}$$

the force due to buoyancy,

$$F_b = \rho_{fluid} \pi \frac{D^3}{6} g \tag{2}$$

and the drag force, the resistance of the fluid to the motion of the body, which is similar to friction. For $Re << 1$ (Re is the Reynolds number, defined as $Re = VD/\nu$), the drag force on a sphere is described by the Stokes expression,

$$F_d = 3 \rho_{fluid} \pi \nu V D \tag{3}$$

where, D is the sphere diameter, ρ_{fluid} is the density of the fluid, ρ_{sphere} is the density of the falling sphere, ν is the kinematic viscosity of the fluid, V is the velocity of the sphere through the fluid (in this case, the terminal velocity), and g is the acceleration due to gravity (White 1994).

Once terminal velocity is achieved, a summation of the vertical forces must balance. This gives:

$$\nu = (D^2 g (\rho_{sphere} / \rho_{fluid} - 1) t) / 18 \lambda \tag{4}$$

where t is the time taken for the sphere to fall the vertical distance λ.

Using equation (4) for two different materials, Teflon and steel spheres, the following relationship for the density of the fluid is obtained, where subscripts *s* and *t* refer to the steel and Teflon spheres, respectively.

$$\rho_{fluid} = (D_t^2\, t_t\, \rho_t - D_s^2\, t_s\, \rho_s)/(D_t^2\, t_t - D_s^2\, t_s) \tag{5}$$

In this experiment, we will drop spheres (Steel and Teflon), each set of spheres having a different density and diameter, through a long transparent cylinder filled with glycerin (Figure 1). Two horizontal lines are marked on the vertical cylinder. The sphere will reach terminal velocity before entering this region, and will fall between these two lines at constant velocity. We will measure the time required for the sphere to fall through the distance λ. The measurement system includes:

- A transparent cylinder (beaker) containing glycerin
- A scale to measure the distance the sphere has fallen
- Teflon and steel spheres of different diameters
- A stopwatch to measure fall time
- A micrometer to measure sphere diameter
- A thermometer to measure room temperature

An Excel worksheet (***Lab1_Data_Reduction_Sheet under "EFD Lab1"***) is provided on class website (http://css.engineering.uiowa.edu/~fluids)to facilitate data acquisition, data reduction, and uncertainty analysis.

2.2 Part 2: For Flow Visualization using ePIV

Particle image velocimetry, or PIV, is an advanced experimental method used for measuring the velocity field in fluid flow. In PIV, a fluid is seeded with small particles which have similar density to the fluid, so that the particles are able to follow the fluid motion. A laser sheet is shone through the flow being observed, causing the seeding particles to be illuminated, and a camera is used to take rapid photographs of the seeded fluid. Software is used to analyze the images captured, tracking the motion of the seeding particles to determine the fluid velocity at all points in the illuminated plane.

This laboratory involves an Educational PIV system, or ePIV system, which is capable of performing PIV analysis on a small scale, using water. The ePIV system consists of:

- A box, to house all of the physical components
- A closed-circuit flow channel, in which different model geometries can be inserted for testing
- A variable-speed pump, to drive the water through the system.
- A reservoir that holds the seeded fluid that is pumped through the system
- A Class II laser, used to illuminate the seeded flow
- A camera, which transmits captured images to a computer
- A computer, with software to capture images and perform PIV analysis

In addition to performing PIV calculations, the ePIV system can be used for flow visualization, and it is for this purpose that the system will be used in this investigation. The ePIV system will be fitted with a circular cylinder insert and streamlines will be observed for different Reynolds numbers, $Re = VD/v$, where V is the fluid velocity, D is the cylinder diameter, and v is the kinematic viscosity of water. For the circular cylinder, the ePIV device can generate Reynolds numbers ranging from approximately 2 to 90.

A number of camera parameters can be modified, using the provided "Camera Control" software, to achieve optimal flow visualization settings. In this laboratory, the following parameters will be adjusted:

- Brightness – This controls the overall brightness of the image. For the best flow visualization results, brightness should be set to a medium-high value
- Contrast – This controls the contrast ratio of the image. This should be adjusted to provide clear distinction between seeding particles and the background of the image.
- Exposure – This controls how long the camera sensors are exposed per image frame taken. Higher values correspond to shorter exposure times, and lower values correspond to longer exposure times. The longer the sensors are exposed per frame, the brighter the image, and the more the individual particles will visually appear to stretch, showing an approximation of flow streamlines.
- Gain – This controls the sensitivity of the sensors per unit time. Using higher gain will amplify the signal obtained by the sensors, so typically higher gain values are needed for images taken with short exposure times, which would otherwise be very dark.
- Focus – This controls the camera focus. It should be set to provide the sharpest possible image.

3. Experimental Process

3.1 Part 1: Determination of Fluid Properties

The diagram of the experimental process is provided in Figure 2.

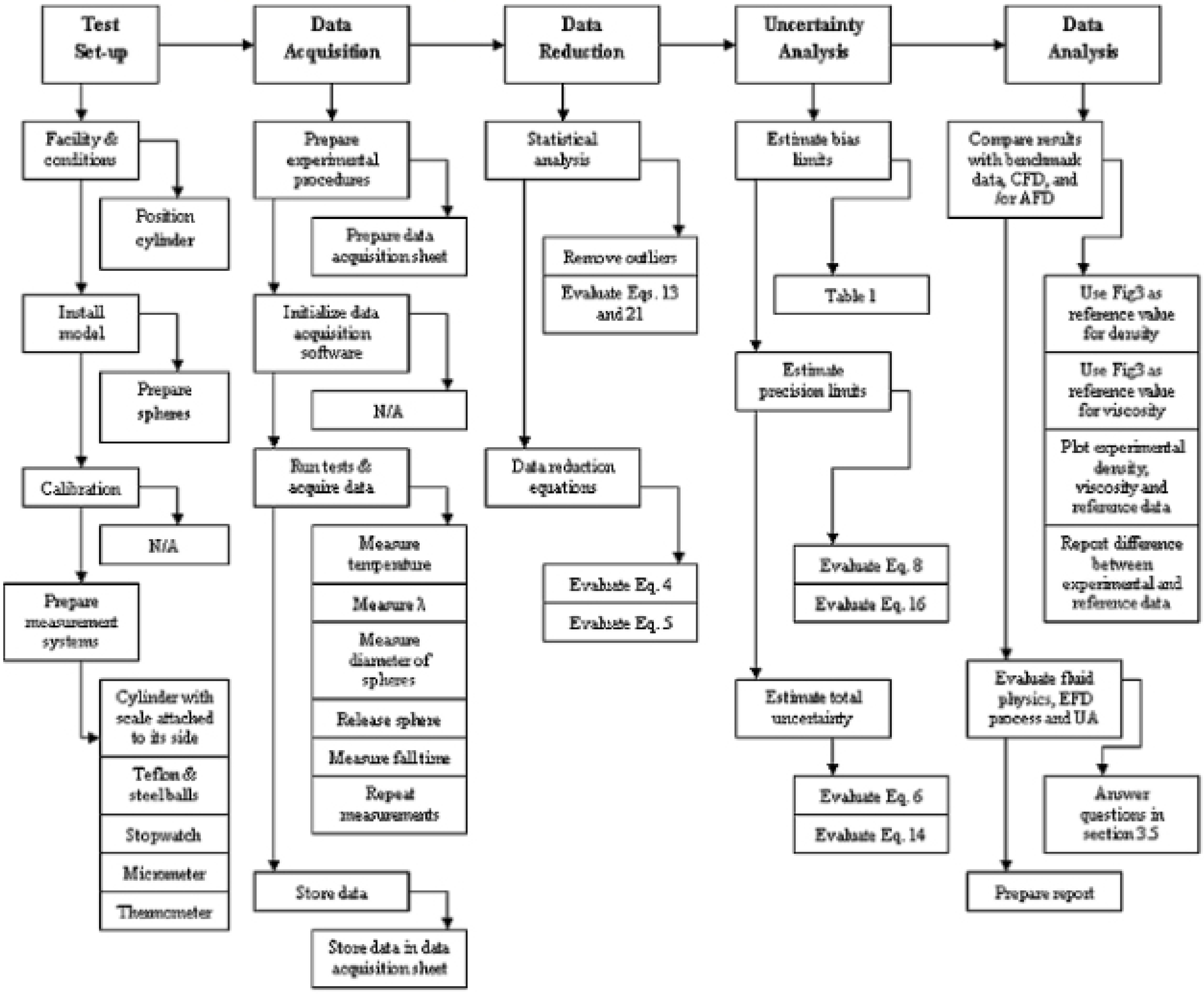

Figure 2. Diagram of the EFD process

3.1.1 Test Setup

Before starting the experiment, verify that the cylinder is vertical and then open the cylinder lid. Prepare 10 Teflon and 10 Steel spheres, making sure that the spheres are clean. Test the functionality of the stopwatch, micrometer, and thermometer.

3.1.2 Data Acquisition

The experiment procedure follows the sequence described below:

1. Measure the temperature of the room.
2. Measure the distance between the two lines, λ.
3. Measure the diameter of the first sphere (teflon or steel) using the micrometer.
4. Release the sphere at the surface of the fluid in the cylinder.
5. Once the sphere has settled, release the gate handle to begin the sphere's descent.
6. Measure the time taken for each sphere to travel the distance λ
7. Repeat steps 3- 6 for 10 spheres of each material.

Since the fall time of the sphere is very short, it is important to measure the time as accurately as possible. Start the stopwatch as soon as the bottom of the ball hits the first mark on the cylinder, and stop it as soon as the