C&L Instruments, Inc.
Hummelstown, PA

http://www.fluorescence.com

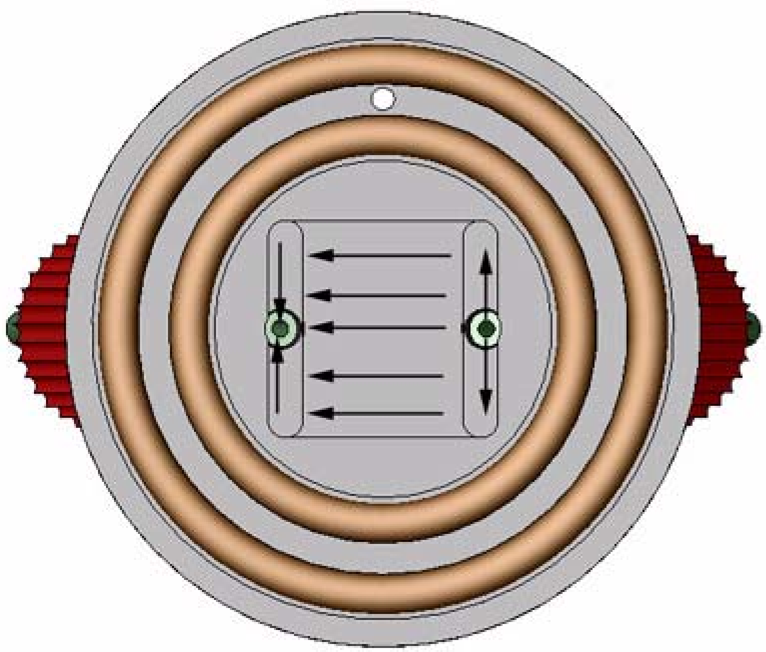
Instruments for Fluorescence

Application Note

Using the Laminar Flow Chamber for Shear Stress Experiments

Introduction

The figure below illustrates the fluid flow pattern through the VC-LFR model series of laminar flow chambers. This chamber is formed by attachment of the device to a coverslip or any flat surface using the force created by a vacuum. This chamber is one of many devices in the Vacu-cell™ line of perfusion chambers available from C&L Instruments. Other models use rectangular coverslips (e.g. VC-RPC-TW) or are designed for ultra-low dead volumes (e.g. VD-MPC-TW).



Fluid enters from an entrance tube on one side of the chamber where it is directed to flow through a rectangular space before being collected by a second tube. When fluid flow is directed through the chamber, a shear stress is generated against the flat bottom surface. The magnitude of the shear stress is dependent on the fluid flow rate through the chamber and can be easily calculated.

Conditions for Laminar Flow

Flow through the chamber can be either laminar or turbulent. To predict whether or not laminar flow will occur, the Reynolds number for the flow system is calculated. A Reynolds number less than 1600 indicates that the flow profile is laminar. The Reynolds number (Re) is calculated from the following relationship:

$$\mathrm{Re} = \frac{\rho V h}{\mu}$$

Where:

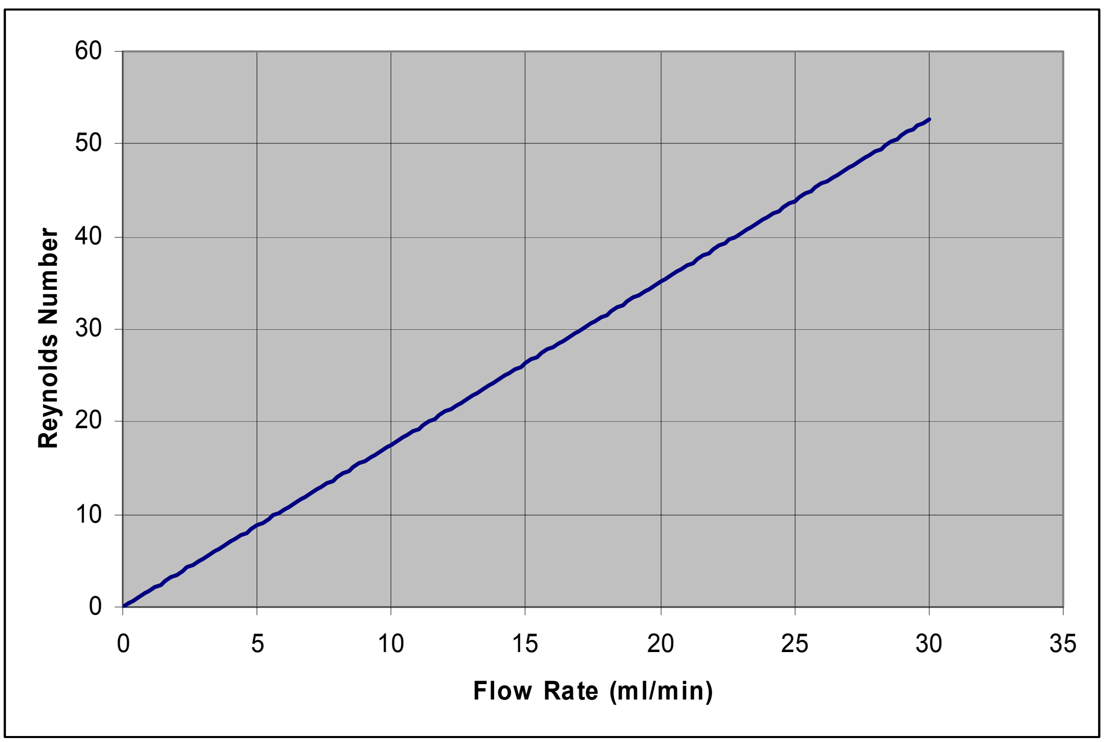
ρ is the fluid density (1025 kg/m^3 for saline),

V is the average fluid velocity in the chamber (in m/s),

h is the chamber height (meters), and

μ is the fluid viscosity (0.001 N m/s^2 for water at 20^{o}C).

The Reynolds number is linear with respect to the flow rate. The flow chamber of a VC-LFR-BA-250 chamber has a nominal height of 250 microns and a width of 9.7 mm. Using these dimensions, a plot of the Reynolds number as a function of flow rate is shown in the following graph. These data indicate that the flow profile through the chamber is laminar over a wide range of flow rates. As discussed below, the Reynolds number decreases as the temperature of the fluid increases.



Shear Stress

Shear stress is a flow-induced force exerted on the walls of the flow chamber. This force has the units of force per unit square area. In a chamber of this design, the shear stress can be calculated from the following relationship:

$$\tau = \frac{6\mu Q}{bh^2}$$

Where:

τ is the shear stress (in N/m^2),

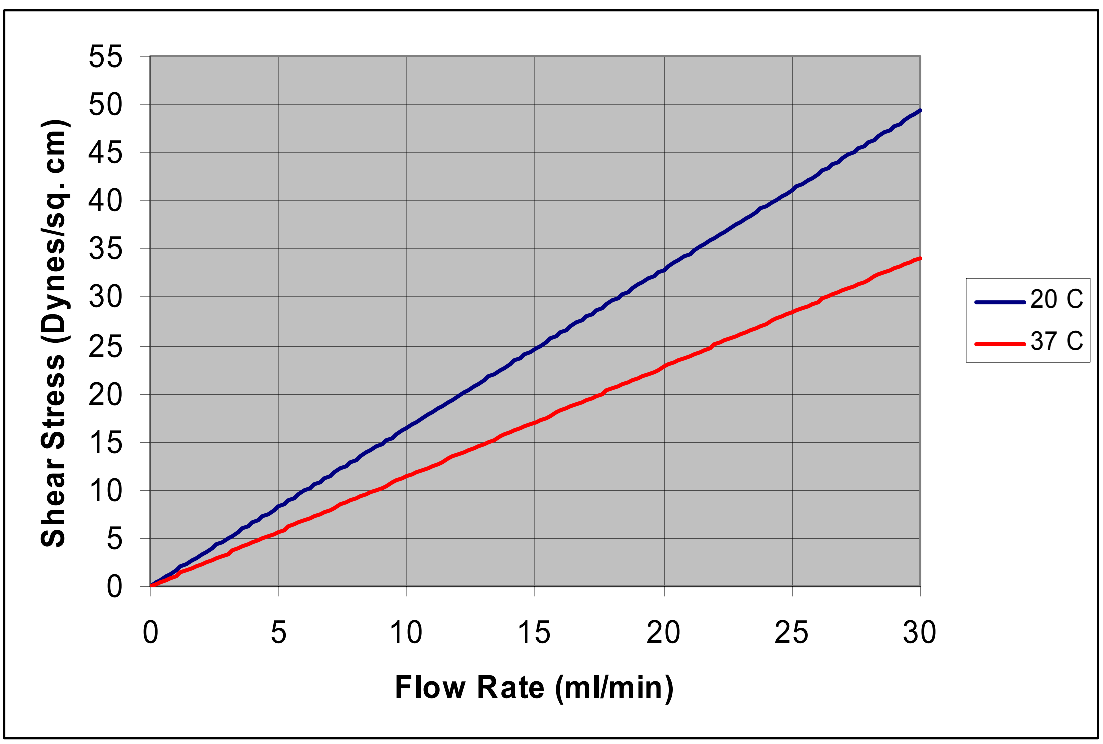
μ is the fluid viscosity (0.001 N m/s^2 for water at 20^oC),

Q is the fluid flow rate (m^3/sec),

b is the chamber width (meters), and

h is the chamber height (meters).

Note that the magnitude of the shear stress is also linearly dependent on the fluid flow rate. This relationship at both 20 and 37^oC is shown in the following graph for the VC-LFR-BA-250 chamber that has a height of 250 microns. In this instance, the shear stress is shown in units of dynes/cm^2 (1 N/m^2 = 10 Dynes/cm^2). The effect of temperature is discussed below.



Entrance Length

Entrance length is the distance required for the flow to become laminar within the chamber. This distance can be conservatively estimated as:

$$\text{Entrance Length } = 0.06 \, \mathrm{Re} \, h$$

This calculation is also dependent of the flow rate. At a flow rate of 10 ml/min, this distance is 0.26 mm at 20^{o}C. This indicates that the flow may not be laminar until a distance of 0.26 mm into the chamber has been reached. Thus, measurements should not be made of events within this distance from the entrance of the chamber.

Effects of Temperature

Since the parameters of fluid viscosity and density are temperature dependent, changes in temperature affect the magnitudes of shear stress, the Reynolds number and the entrance length at a given flow rate. The effect of temperature, however, on the density of water is small (-0.6% from 20 to 40^{o}C) and this effect can be ignored. The above graph illustrates the shear stress calculated at room temperature (20^{o}C) and at 37^{o}C.

The viscosity of water, however, displays much stronger temperature dependence, as shown in the following graph. The viscosity of water at 37^{o}C is 0.0006915 N m/s^{2} (e.g., 0.6915 cPoise).