Part 2. Measurements of Air Flow Rates  
(Weeks 3-4)

In practically all situations in atmospheric air quality monitoring, a known quantity of air is extracted from the atmosphere through an inlet, conducted to the detector through a sampling line, and then analyzed for constituents of interest. Among other things, this requires 1) a pump to move the air and 2) a way to monitor or determine the amount of air sampled (e.g., a flow meter). The schematic below shows a typical arrangement of components.

![Diagram of air flow measurement setup](attachment:air_flow_diagram.png)

**Air Movers** can be classified into three basic groups: volumetric displacement, centrifugal acceleration, and momentum transfer. Volumetric displacement usually involves an air-tight chamber in which the internal volume is changed by mechanical means. These are generally referred to as pumps. In a diaphragm pump a flexible wall in a chamber is oscillated, and through a series of valves air is drawn into the chamber when the chamber is expanded and air forced out when the chamber is compressed. A piston pump is similar to diaphragm except that a piston sliding in a cylinder is used instead of the diaphragm. Bellows can also be used instead of a diaphragm or piston. Piston and bellows pumps are capable of developing higher vacuum and positive pressures than diaphragm pumps. For these pumps, because of the low frequency of the chamber volume oscillation, a pulse dampening system is often required to smooth out pressure variability. Rotary vane pumps are use extensively and are composed of a rotor with vanes mounted off-center in a cylindrical chamber. Rapid rotation of the rotor and the lack of valves produce a smooth vacuum or pressure. A commonly employed rotary vane pump uses non-lubricated carbon vanes held against the cylinder walls by centrifugal force. The pressure side of these pumps must be filtered since vane wear produces larger concentrations of aerosol particles that should not be inhaled and must be isolated from sample air. Similar concerns pertain to oil mist from lubricated pumps. A schematic of an oil lubricated rotary vane pump is given below.

![Diagram of rotary vane pump](attachment:rotary_vane_pump_diagram.png)

The second basic method is centrifugal acceleration. These are often referred to as blowers when the airflow is radial, and fans when the flow is axial (fans are not used in air quality work). Blowers are typically used in applications where high flow rates and low differential pressures are required, whereas pumps are used in situations of low flow rates and high differential pressures.

The type of air mover used for a specific application will depend on the pressure differential the pump must maintain at a specified flow rate. Pump performance curves showing differential pressure versus flow rate is typically reported for specific pumps.
Flow Meters To determine concentrations of atmospheric constituents, a known quantity of air must be analyzed. Typically, this requires a measurement of a flow rate (i.e., how much air was sampled over a period of time). Flow meters can be divided into two types, mass and volumetric, and the corresponding flow rates given on a mass or volumetric basis. Measurements of trace gases typically involve mass flow rates, whereas aerosol measurements are most often done on a volumetric basis.

Volumetric flow rate (e.g. unit, cm³/s) depends on the gas T and P. However, concentrations are often reported at some reference condition, i.e., standard T and P (20°C, 1 atm). One can convert between different states by the ideal gas law.

That is \( Q_s = Q_a \frac{P_a}{P_s} \frac{T_s}{T_a} \) where \( s = \) standard conditions; \( a = \) ambient conditions

The concentration will then be: \( C_s = C_a \frac{Q_a}{Q_s} \)

Mass flow meters (e.g. unit, g/cm³) and mass flow controllers are ubiquitous and more readily available than volumetric meters and flow controllers. Using mass flow rates trace gas concentrations are reported as mixing ratios (e.g., ppbv, pptv, etc—see any chemistry or atm. chemistry text for more info on mixing ratios).

Flow rate Measurement Methods (see Appendix 1: Measurement of Flows). (Reference: Aerosol Measurement; Principles Techniques and Applications, Editor Willeke and Baron, Chapter 22) Also see Appendix

Methods to measure flow rates include:
- Pitot tube (measures velocity that can be converted to a flow rate)
- Hot wire or film anemometer (velocity measurement)
- Obstruction Meters
  - Venturi or orifice meter (measures \( \Delta P \) across calibrated resistance)
  - Critical orifice (used to maintain constant volumetric flow)
  - Rotameter (variable area)
- Laminar flow meter (useful since can transmit particles/gases efficiently)
- Positive displacement meters
  - soap bubble
  - piston, which includes gas meters
- Mass flow meter

A note of caution when measuring volumetric flow rates; care must be taken as to where the flow meter is placed since volumetric flow depends on P. Typically a volumetric flow meter is situated so that one side of the flow meter is at ambient P. In this way the measurement is of the flow rate at standard conditions.

**Details on Some Specific Flow Meters**

Positive displacement meters are primary standards because their calibrations can be determined by direct physical measurement. The simplest and most accurate of these meters use a water surface (spirometer), or a soap bubble film (bubble flow meter) to produce a variable volume sealed chamber. In these instruments water vapor is added to the gas since after exiting the meter the sample air has increased in RH, typically reaching 100%. Often a saturator is placed in front of the wet meter to produce a 100% RH air stream entering the meter. This eliminates uncertainties due to continued addition of water vapor within the meter. Assuming the meter is measuring a flow of saturated air, the ideal gas law can be employed to calculate the actual dry-air flow rate.

Laminar Flow meters are commonly employed in aerosol science since the flow meter is simply a straight narrow-bore tube that will efficiently transports particles (minimal wall losses). Thus a laminar flow meter can be used to monitor a sample flow upstream of the detector. The device is based on measuring the pressure drop through a known length of tube under fully developed laminar flow conditions. Under so-called Hagen – Poiseuille flow pressure drop is directly proportional to volumetric flow rate. For circular tubes, laminar flow requires a Reynolds Number less than ~ 2000. Laminar flow meters can typically only measure flow rates up to approximately 2 L/min

A critical orifice is a small circular restriction placed in a tube to maintain a constant flow when upstream conditions are constant. If the absolute pressure downstream of an orifice is less than 0.53 times the upstream pressure the flow in the orifice throat will be sonic and further reduction in pressure does not change the flow rate. These devices are useful for taking constant flow rate samples with a vacuum pump. (E.g., often used in integrated filter measurements).

**Flow Controllers:** A flow controller combines a flow measurement with a metering valve. A feedback loop is used to maintain a constant user preset flow rate by automatic adjustment of the valve. Mass flow controllers are common and used extensively in trace gas measurement systems.