A Mechanism to Mix Gases from Two Tanks to Produce a Resulting Mixture with a Specified Oxygen Concentration

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A mechanism to combine gases from two tanks with specified oxygen concentrations to produce a mixture with a specified oxygen concentration using electrically actuated valves is presented. The mechanism requires that the flowrate from each source tank be controlled. Flow from each source tank is enabled and disabled in an alternating, intermittent pattern, with each tank having different mean flowrates. The mean flowrate from each tank is controlled with valves to modulate the oxygen concentration of the resulting mixture. If the valves are controlled programmatically, the oxygen concentration of the resulting mixture can be varied over time. Furthermore, different combinations of valves can be used to obtain more than one resulting gas mixture from two different input gases, and gases different from oxygen can also be combined.

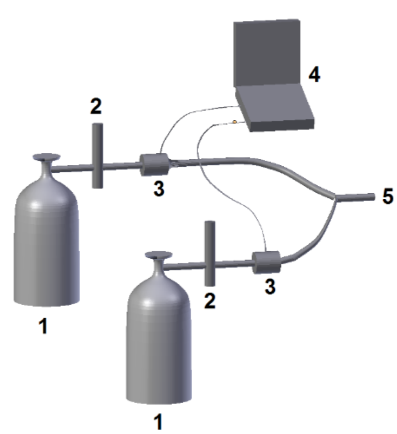
Introduction

In microfluidics, the control of the oxygen concentration in the air supplied to cell cultures inside microfluidic devices is often necessary. Moreover, the variation of the oxygen concentration inside microfluidic devices over time during certain experiments can be of interest. One way to control the oxygen concentration in gases supplied to microfluidic devices is by systematically mixing gases from tanks with different oxygen concentrations. This paper presents a mechanism that functions by the variation of the flowrate from both input gases. In the presented mechanism, the instantaneous flowrate from each tank is controlled with rotameters and valves that open and close intermittently. The mean flowrate from each tank is varied by the open and closed times of each control valve. These times are determined from the desired oxygen concentration of the output gas mixture, the oxygen concentration of the input gases, and the instantaneous flowrate of the input gases when their control valves are open.

Basic Unit of Mechanism

In its most basic form, the presented mechanism requires two gas tanks with different concentrations of oxygen, one rotameter for each tank, one valve for each tank, one computer, and tubing. Before mixing, the gases from each tank flow first through the rotameters, which fix the instantaneous flowrate from each tank, then through the valves, which open and close for durations of time determined computationally to control the mean flowrate from each tank. The duration of time of the open configuration of each valve is computed from a formula derived in this paper. Figure 1 shows a diagram of the basic unit of the proposed mechanism.

Figure 1. The basic unit of the proposed mechanism is shown. Input gas tanks are labeled 1, rotameters are labeled 2, valves are labeled 3, the controlling computer is labeled 4, and the output conduit is labeled 5.



Computation of the Valve Opening Times

Valves should open and close cyclically with small enough cycles to allow for the mixing of the input gases before the mixture reaches the output conduit. Depending on the desired output oxygen concentration and the oxygen concentration of the input gases, one valve may be needed to be open for a greater time than the other. The following derivation arrives at a formula for estimating the duration of the time for which each valve should be open.

The formula for estimating the output oxygen concentration of the mixture of gases from two tanks, tank 1 and tank 2, with flowrates controlled by valve 1 and valve 2, ignoring any volume-variation effects due to the mixing of two different gases, can be written as

$$\rho_3 = \frac{m_1 + m_2}{V_1 + V_2}$$

, where ρ_3 is the oxygen concentration of the mixture of input gases, m_1 and m_2 are the masses of the input gases from tank 1 and 2 after their corresponding valves are opened for finite, and possibly different, lengths of time, and V_1 and V_2 are the volumes of the input gases that correspond to m_1 and m_2.

The masses m_1 and m_2 can be written as $\rho_1 F_1$ and $\rho_2 F_2$, where ρ_1 and ρ_2 are the oxygen concentration in the gases from tanks 1 and 2, and F_1 and F_2 are the instantaneous flowrates from tanks 1 and 2 when their corresponding valves are open. Assuming a constant flowrate from each tank when the valves are open, the flowrate F_1 can be integrated over the time Δt_1 that valve 1 is open to write the volume V_1 as

$$V_1 = \int_{t_1^i}^{t_1^f} F_1\,dt = F_1\left(t_1^f - t_1^i\right) = F_1 \Delta t_1$$

, where t_1^i is the time when valve 1 opens, and t_1^f is the time when valve 1 closes.

Similarly, V_2 can be written as

$$V_2 = F_2 \Delta t_2$$

, where Δt_2 is the time when valve 2 is open. Output concentration ρ_3 can be rewritten as

$$\rho_3 = \frac{\rho_1 F_1 \Delta t_1 + \rho_2 F_2 \Delta t_2}{F_1 \Delta t_1 + F_2 \Delta t_2}$$

, from which the ratio of valve opening time durations can be written as

$$\frac{\Delta t_1}{\Delta t_2} = \frac{F_2}{F_1}\left(\frac{\rho_2 - \rho_3}{\rho_3 - \rho_1}\right)$$

One of the valve opening time durations Δt_1 or Δt_2 should be chosen, either arbitrarily or otherwise, to compute the other valve open time duration. Both opening time durations should be kept small to ensure that gases from both input tanks are thoroughly mixed before exiting the output conduit.