Supplemental Information 1: System Assumptions

Starting from the mass transfer equation:

$$\frac{\partial C}{\partial t} + \vec{\upsilon} \cdot \nabla C = D \nabla^2 C + R$$

(a) Distance between the droplet and air channels, O(10^{-4}) m is much smaller than the distance between the droplet channel PDMS device boundary O(10^{-2}) m, so little mass transfer is out of the device and most mass transfer is into the air channel.

(b) Assume the oil provides no resistance as compared to the PDMS.

(c) Assume psuedo-steady state since the PDMS boundaries and concentration boundary conditions are fixed:

$$\frac{\partial C}{\partial t} = 0$$

(d) No convection

$$\vec{\upsilon} = 0$$

(e) No reaction

R = 0

(f) Since the oil provides little resistance to mass transfer, the end of the droplets can be assumes as a constant value with surface area equal to the height of the droplet, *h,* multiplied by the width of the droplet

(g) The concentration out the top is a function of the distance between droplet and air channels and will related to mass transfer out the sides for fixed droplet/air separations. This mass transfer can be represented by multiplying by an effective area. Therefore the system is simplified to one dimension.

$$\frac{\partial^2 C}{\partial x^2} = 0$$

BC1 $\quad C(x = 0) = C_{sat,PDMS}$

BC2 $\quad C(x = d) = \frac{C_{sat,PDMS}}{C_{sat,air}} C_{air} = HC_{air}$

$$C = C_{sat,PDMS} - \frac{\left(C_{sat,PDMS} - HC_{air}\right)}{d} x$$

$$J = -D\frac{dC}{dx} = D\frac{\left(C_{sat,PDMS} - HC_{air}\right)}{d}$$

Supplemental Information 2: Droplet Change

This derivation and model is derived assuming an approximate rectangular block shaped droplet with constant fluxes (J_{top}, J_{end}, J_{side}) out of each the top, the ends and the side of the drop (A_{top}, A_{end}, A_{side}) in Equation S1.

$$\dot{V} = A_{Top}J_{Top} + A_{End}J_{End} + A_{Side}J_{Side} \qquad \text{(S1)}$$

The values of these areas are listed in Equations S2. It can be seen that two of these values are linearly dependent on the projected droplet area, *A*.

$$A_{Top} = A_c$$
$$A_{End} = wh$$
$$A_{Side} = \frac{A_c h}{w} \qquad \text{(S2)}$$

Droplet volumes can be approximated as cylindrical, for diameters greater than channel height, so the volumetric transport per second is the change of projected area with respect to time, multiplied by the channel height, *h*. This equation can be simplified by combining Equation S1 and S2, collecting constants to, c_1 and c_2 and the result is listed in Equation S3.

$$\dot{V} = h\frac{dA}{dt} = c_1 A + c_2 \qquad \text{(S3)}$$

Solving this linear ODE with boundary condition Equation S4, results in the area versus time equation of Equation S5, (Fig. 4b).

$$A(t=0) = A_o \qquad \text{(S4)}$$

$$A = \left(A_o + \frac{c_2}{c_1}\right)\exp(c_1 t) - \frac{c_2}{c_1} \qquad \text{(S5)}$$

Therefore, the change in area and volumetric transport rate can be predicted with Equation S6. (Fig. 4c).

$$\frac{dA}{dt}(A_o, t=0) = A_o c_1 + c_2 \qquad \text{(S6)}$$

Supplemental Information 3: Air Channel

The concentration of water in the air channel should be uniform because diffusion time is much less than the time for mass transfer of the water into the flowing air. Water in the air channel's concentration versus residence time in the air channel can be directly calculated by Equation S7.

$$2V_{air}\frac{\partial C_{air}}{\partial t} = N \qquad \text{(S7)}$$

Position of air in the channel, *y,* is related to residence time, *t,* by Equation S8.

$$y = Ut, \quad \frac{dy}{dt} = U \qquad \text{(S8)}$$

Where, U, is air flow average velocity. Equation S7 can be changed to being dependent on position in the channel by Equation S9.

$$\frac{dC}{dt} = \frac{dC}{dy}\frac{dy}{dt} = U\frac{dC}{dy} \qquad \text{(S9)}$$

By combining Equation 1 with Equations S7 and S8, a separable ODE can be set up (Equation S10) which describes air channel water concentration versus known parameters. The boundary conditioned used is that air enters completely dry when introduced (Equation S11).

$$2V_{air}U\frac{\partial C_{air}}{\partial y} = N = \frac{2A_E D}{d}\left(C_{sat,PDMS} - HC_{air}\right) \qquad \text{(S10)}$$

$$C_{air}(y=0) = 0 \qquad \text{(S11)}$$

The ratio A_E/V_{air} arises which is solved in Equation S12.

$$\frac{A_E}{2V_{air}} = \frac{\frac{w_{drop}h}{L_{drop}} + h + f(d)}{hw_{air}} \qquad \text{(S12)}$$

With Equation S10 solved, combined with Equation S12 the driving force can be solved for in Equation S13.

$$\left(C_{sat,PDMS} - HC_{air}\right) = C_{sat,PDMS}\exp\left(-\frac{\frac{w_{drop}h}{L_{drop}} + h + f(d)}{hw_{air}}H\frac{Dy}{d}\frac{1}{U}\right) \quad \text{(S13)}$$

And, this can be combined with expression Equation 1 to describes mass transfer from the droplet into the air channel (Equation S14).

$$N = \frac{2A_E C_{sat} D}{d}\exp\left(-\frac{\frac{w_{drop}h}{L_{drop}} + h + f(d)}{hw_{air}}H\frac{Dy}{d}\frac{1}{U}\right) \quad \text{(S14)}$$

By changing the inlet pressure of the nitrogen stream, and estimating a velocity based on laminar (Re < 1000) Pousille flow in Equation S15, the average velocity can be calculated from pressure.

$$U = \frac{1}{12}\frac{h^2}{\mu L_{channel}}\Delta P \quad \text{(S15)}$$