Appendix

Mathematical Derivation of Rebreathing Fraction and Absorbed CO:

Variables:	Units	Symbol	Formula
Inspiratory rate	liters/sec	$\mathbf{Q_{in}}$	V_T / t_{in}
Expiratory rate	liters/sec	$\mathbf{Q_{ex}}$	V_T / t_{ex}
Elapsed time	sec	$\Delta \mathbf{t}$	
Inspiratory time	sec	$\mathbf{t_{in}}$	
Expiratory time	sec	$\mathbf{t_{ex}}$	
Respiratory rate	breaths/sec	**RR**	$1/(t_{in} + t_{ex})$
Fresh gas flow	liters/sec	$\mathbf{Q_{fgf}}$	
Tidal volume	liters/breath	$\mathbf{V_T}$	$Q_{in} * t_{in} = Q_{ex} * t_{ex}$
Fresh gas volume	liters/breath	$\mathbf{V_{fg}}$	
Rebreathed gas volume	liters/breath	$\mathbf{V_{rb}}$	
Minute ventilation	liters/sec	$\mathbf{Q_{Ve}}$	$(Q_{in} * t_{in})*RR = (Q_{ex} * t_{ex})*RR = V_T*RR$
Fraction Rebreathed	none	$\mathbf{f_{RB}}$	
quantity of CO bound to COHb at start of interval t		$\mathbf{CO_{COHb(t)}}$	(calculated from CFK equation each interval)
quantity of CO bound to COHb at end of interval t		$\mathbf{CO_{COHb(t+1)}}$	
quantity of CO absorbed during interval t		$\mathbf{CO_{abs}}$	$CO_{COHb(t)} - CO_{COHb(t+1)}$
quantity of CO produced during interval t		$\mathbf{CO_{prod}}$	measured from ref. 11
quantity of gas phase CO at start of interval t		$\mathbf{CO_t}$	
quantity of gas phase CO at end of interval t		$\mathbf{CO_{t+1}}$	

Assumptions:

A circle system is used where the fresh gas flow enters at the inspiratory limb. The exhaust valve, scavenger, and either bag or ventilator bellows are in the expiratory limb, and the CO_2 absorbent canister is located between the fresh gas flow inlet and the bag or ventilator on the opposite side of circle from the patient connector. The tidal volume is defined as the quantity of gas delivered by the ventilator, not what is delivered by the ventilator + fresh gas which flows during the inspiratory time interval. Although some of the following assumptions are not strictly true, they approximate the actual situation sufficiently closely that significant simplifications in gas composition and flow patterns can be derived instead of creating empirically derived estimates. It is assumed that there is no mixing of gas in the canister or pipes, and that the system has a constant volume. It is assumed that the fresh gas flow rate is less than the minute ventilation otherwise rebreathing does not occur. It is also assumed that the gas exiting the scavenger has the same composition as the average gas in the circuit.

Derivation of the rebreathing fraction: During expiration, fresh gas travels backwards through canister, flushing canisters free of expired, rebreathable gas. The first component is fresh gas: $V_{fg} = (Q_{fgf} * t_{in})$. The second component is expired gas which has been recirculated = V_{rb}. During inspiration, fresh gas travels forward into the patient; fresh gas stored in the inspiratory limb also enters the patient, and the rest of the gas which is inspired is rebreathed gas. $V_{fg} = [(Q_{fgf} * t_{in}) + (Q_{fgf} * t_{ex})]$

$V_{rb} = V_T - V_{fg} = V_T - [(Q_{fgf} * t_{in}) + (Q_{fgf} * t_{ex})]$ substituting: $(t_{in} + t_{ex}) = 1/RR$ we get:

$V_{rb} = V_T - (Q_{fgf} * (t_{in} + t_{ex})) = V_T - (Q_{fgf} /RR)$

$Q_{Ve} = V_T * RR$ Therefore, the rebreathing fraction is:

$\mathbf{f_{RB}} = V_{rb} / V_T = [V_T - (Q_{fgf} /RR)]/ V_T = 1 - (Q_{fgf} /RR) / V_T = \mathbf{1 - Q_{fgf} / Q_{Ve}}$

Calculation of CO in breathing circuit at the end of interval = $\mathbf{CO_{t+1}}$

= CO_t = CO present at start of interval

- $CO_t * (1- f_{RB})$ the CO removed in the scavenged gas.

+ CO_{prod} the CO produced during the time interval

- $CO_{abs} * (f_{RB})$ The CO absorbed by the patient which comes from the rebreathed gas

$\mathbf{CO_{t+1}} = CO_t - CO_t * (1- f_{RB}) + CO_{prod} - CO_{abs} * (f_{RB})$ $\mathbf{= (CO_t + CO_{abs}) * f_{RB} + CO_{prod}}$

Calculation of CO concentration in breathing circuit:

= $\mathbf{CO_{t+1}}$ divided by the total volume of gas which contains CO.

Since we assume scavenged gas to have the same composition as gas within the circuit, the total gas containing CO during any time interval = scavenged gas + circuit volume. If the volume in the circuit is constant, scavenged gas * Δt = fresh gas which enters the circuit, = $Q_{fgf} * \Delta t$. Substituting this, the total volume of gas which contains CO during any interval = circuit volume + $Q_{fgf} * \Delta t$. The concentration of CO then becomes **CO_{t+1} /(circuit volume + (Q_{fgf} * Δt))** This calculation is necessary for entry into the CFK equation because this determines the driving force for the absorption of CO to hemoglobin.

Table #1

The following table shows the inspiratory CO concentrations in ppm when using 1.5% end tidal isoflurane or 7.5% end tidal desflurane with absorbents desiccated by the flow of 10 liters per minute dry oxygen for the number of hours indicated. D.T. represents drying time in hours, C = complete dryness. Anes represents the anesthetic (Iso = isoflurane. Des = desflurane) These data are taken from reference 11, but are not explicitly shown therein.

Anes	Iso	Iso	Iso	Iso	Iso	Des	Des	Des	Des	Des
D.T.	C	66	48	24	14	C	66	48	24	14
Time (min)										
0	0	0	0	0	0	0	0	0	0	0
5	2650	2050	1300	400	90	78000	52800	22100	7800	3300
10	5500	4100	2300	2100	340	109000	64200	24700	8800	3750
15	5400	4950	3250	3300	330	79200	54000	18900	6500	3000
20	5100	4550	2900	3050	260	60900	30500	13200	7400	2550
25	5050	4400	2500	2150	220	57000	59700	9150	2750	1850
30	4650	4450	2650	1550	130	55700	56500	6500	1950	1350
35	4300	4600	3100	1250	110	48000	48600	4200	1550	770
40	4100	4600	3450	810	80	37400	40300	3600	1200	590
45	3650	4500	3300	760	60	22100	33300	2800	1000	310
50	3800	4400	3200	700	30	22600	28200	2220	780	180
55	3800	4150	3400	580	30	18300	24500	1850	640	140
60	3800	4200	3100	440	30	16600	21400	1450	540	60