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Covid; Sizing Medical Gases

Sizing Medical Gases for Covid 19

How to size a medical gas system for Covid 19 emergency units?

There is a lot of information floating around on how to size medical gases for Covid 19. Because the situation is so fluid, any or all of it may be right and some of it may be wrong. At this writing, the best available information we can gather is summarized below.

The Background:

There are two essential aspects to consider: one is the use of gas and the second is the ratio of air to oxygen. They are closely related because of the devices being used to administer the therapies and the goal of the doctor in using them.

The basic goal is to increase the available oxygen to allow a patient with diminished lung capacity to get enough oxygen into their blood stream. People think ventilator, but this is usually not the biggest concern with sizing.

When thinking about gas consumption in general, and specifically with ventilators, remember that a ventilator does not change physiology. The adult human has only so much lung capacity (tidal volume), and one patient can only demand more than that if their ventilator is leaking, if the machine uses some gas itself (e.g. for fluidics circuitry), or there is a technique being used which uses only part of the gas to breathe the patient and "wastes" the rest (e.g. CPAP, BIPAP, Oxygen tents, Hoods, Oscillating ventilators). This is the case wth Covid patients - not every therapy being applied to treat Covid 19 is classic "ventilation".

If you start by reading specifications on ventilators, it is very easy to be confused by the numbers you read. You will usually see a number like "peak flow" which will be something very large. 180 *l*pm to 200 *l*pm are typical. No patient can absorb this amount of gas, so where does it go?

The confusion comes from the fact that this is a ***rate***, not a ***volume***. A ventilator can be set to fill the patient's lungs at various speeds, and that is what this number reflects. This is therefore not a consumption concern (gas used over time) but a flow rate concern (how fast the gas must move from the outlet into the ventilator). NFPA deals with this by requiring the outlet flow test at 3 scfm (100 *l*pm) and by requiring the 3 second test at 6 scfm (170 *l*pm) for outlets in critical care, where ventilators are likely to be used. It is also the reason that outlet splitters (wyes, "dual outlets" and the like are a bad idea.

Words

Some Terms to know:
SPO_2 - peripheral capillary oxygen saturation. The bloodsteam saturation of oxygen. This is the real goal of all this effort - to maintain the SPO_2 of the patient in a close to healthy range. The target SPO_2 will vary with the patients general health, and how much supplemental oxygen is needed will depend on the condition of their respiratory and circulatory system.

FiO_2 - Fractional Inspired Oxygen Percent. The concentration of oxygen in the gas being breathed. Air contains 20.9% oxygen, so one can say the FiO_2 of normal air is 20.9%. Mixing air with oxygen raises the FiO_2 , but of course a mix of half air and half oxygen is not at an FiO2 of 50% - it actually would be 60.5%. The calculation is a little complicated.

Using a standard ventilator the consumption of gas will closely approximate the patient's minute volume (the amount of gas they breathe in over a minute's time, about 8 *l*pm for a typical adult).

The above applies to *invasive* ventilator techniques (ventilation using an endotracheal tube). There are some non-invasive therapies being used which can draw extravagant quantities of gas, and one specific ventilator technique. These are actually the worrisome uses.

Detail 2.1
Estimates for Gas Consumption by device (usually one per patient)

Therapy Device	*Total gas*	*FiO_2*	*O_2 Consumption*	*Medical Air Consumption*
Masks / standard nasal cannula	8 *l*pm	30%	0.9	7.1
Reservoir masks and venturi masks	15 *l*pm	30 -50%	1.7 - 5.5	13.3 - 9.4
Standard invasive ventilation (e.g. ICU vents) (except oscillating vents)	12 *l*pm	50%	4.4	7.6
Noninvasive high flow (e.g. HFNC)	50 *l*pm	60%	24.7	25.3
High frequency oscillating ventilators	80 *l*pm	50%	50.6	29.4
Noninvasive other devices	120 *l*pm	60%	59.3	60.7

These therapies are more usually associated with CPAP (Continuous Positive Pressure Airway Pressure). The concept is to ensure that the atmosphere the patient breathes is both enriched with oxygen (50% FiO_2 is the typical goal) and at a slight positive pressure. Some versions also act to continuously flush any "old gas" (i.e. CO_2) being exhaled to prevent rebreathing and increase the patient's uptake of oxygen. This flushing is done with massive flows of gas. These devices can run 50 *l*pm with extremes up to 120 *l*pm. Such devices include High Flow Nasal Cannulas and CPAP hoods.

One last device needs to be understood. These are the High Frequency Oscillating ventilators. These do invasively what the CPAP machine does non-invasively, and flushes the lung at a very high rate, trying to ensure that the maximum oxygen exchange can occur inside the lung and that as much as possible of the lung is available for gas exchange. Think hyperventilation - small breaths, fast rate. They are very "inefficient" in that they use a massive amount of fresh gas. These devices can consume up to 80 *l*pm.

With any of the very high flow devices, there actually is a concern that all that vented gas will spray the virus into the atmosphere. Therefore the use of these high flow techniques is sometimes discouraged, but of course the medical people will do what they must. [1]

Reported experience around the world indicates one other grim reality - the less prepared or worse equipped the facility, the more likely the demand will run high. Medical people will resort to any available solution when they don't have the "correct" answer, and these expedients tend to result in very extreme demands on the systems.

Detail 2.2
Medical air to Oxygen Ratio

FiO_2	*Air*
20.9	∞
30	7.7
40	3.2
50	1.7
60	1
70	0.62
80	.35
90	.15
100	0

Actions:

What does this mean for sizing? It is unrealistic to simply apply a worst case 120 *l*pm number, and if we did use that number, the systems might fail to operate at lower usages. A bit more science needs to be applied.

If the information is available, Detail 2.1 should be used for estimation.

If the required information for Detail 2.1 is simply not available, a blanket estimate of 45 lpm per moderate acuity patient, at a 50% FiO_2 seems to be the nearest approach to a consensus value as is available. This means 28 *l*pm (1 scfm) of air and 16.5 *l*pm (0.58 scfm) per patient for oxygen.

These numbers are appropriate for source sizing and main line sizing, where demand averaging will occur. However, they should NOT be used for pipe sizing in zones, as it is entirely possible to have whole units with the sickest patients and the heaviest demand concentrated in a single zone.

Pipe sizing for zones can use the worst case numbers. While 120 l *l*pm is certainly extreme, 50 lpm is not an unreasonable number to use per patient. Yes: piping will get large (we traditionally have used 10 *l*pm per patient for oxygen and 25 *l*pm for medical air).

Assessing what you already have :

The Background:

The urgent questions usually present in the form:

- "I have a compressor plant capable of X scfm, how many patients can I serve?"

- "Can my main line handle the flow?"

- "Are our vaporizers big enough?"

- "How many ventilators can I put on a zone?"

Experience has shown that the oxygen systems generally are struggling more than the air. There are many more variables with oxygen: the amount of liquid or cylinders in place, the ability of the supplier to get more (oxygen suppliers in some places have been bumping against their maximum production capacity), ancillary equipment (liquid oxygen vaporization capability, regulator capacity) and smaller initial sizings (typical historic oxygen sizing is based on 10-20 *l*pm per patient, air is usually 25 *l*pm per patient).

The following worksheet is a summary for quick estimation purposes of the factors in play.

Oxygen Liquid to Gas Equivalancies

Liquid Weight (pounds/ kg)	Liquid Volume at normal boiling point (U.S. Gallons)	Gas Volume at 70°F (21°C) and 1 atmosphere	
		Liters	Cubic Feet
1.0 / 0.45	0.105	342	12
9.5 / 4.3	1.0	3,259	115

[(1)]Note that the definition of the "correct" answer is also very fluid at this writing. See the following article as an example:

https://www.npr.org/sections/health-shots/2020/04/02/826105278/ventilators-are-no-panacea-for-critically-ill-covid-19-patients

The insights of Mr. Paul Edwards of Air Liquide Canada, Mr. George Scott and Mr. Al Moon of Advanced Compliance is gratefully acknowledged.

Assessment Worksheet

AU is *Assessed Usage* (from Detail 2.1). EU is *Estimated Usage* from the rule of thumb estimate.

Sources:

Oxygen Cylinder Manifold

Time

(______ # Cylinders *(one side)* * 6800 *l*/cylinder) ÷ ________ *l* A.U. OR (E.U. x # patients) = minutes between manifold changes.

Flow

_______ *l* Manifold maximum flow rate *(from manufacturer)* ÷ AU OR (EU x # patients)

Oxygen Container Manifold

Time

(______ # containers *(primary side)* * 192,600 *l*/container) ÷ ________ *l* A.U. OR (E.U. x # patients) = minutes between manifold changes.

Flow

______ *l* Manifold maximum flow rate *(from manufacturer)* ÷ AU OR (EU x # patients) = number of patients servable. *(if using AU, compare to the assumed number used for that calculation. Use lower number)*

and also check:

________ *l*/min Vaporizer capacity *(from manufacturer, applying any correction factors)* OR (188 *l*/min {Internal vaporizer capacity} x # containers) ÷ AU OR (EU x # patients) = number of patients servable. *(if using AU, compare to the assumed number used for that calculation. Use lower number)*

Oxygen Bulk Tank or MiniBulk

This analysis should be performed with your supplier

Time

______ # gallons liquid O_2 *(primary side)* * 3,259 l/gallon) ÷ ________ *l* A.U. OR (E.U. x # patients) = minutes in the container *(note that the supplier can also assess the number of gallons to the refill point and therefore the number of fills required)*

Flow

______ *l*/m vaporizer output *(from supplier)* ÷ AU OR (EU x # patients) = number of patients servable. *(if using AU, compare to the assumed number used for that calculation. Use lower number)*

and also check:

________ *l*/min regulator throughput capacity *(from manufacturer)* ÷ AU OR (EU x # patients) = number of patients servable. *(if using AU, compare to the assumed number used for that calculation. Use lower number)*

Liquid Reserve

Time *(This is how long the reserve will last once the main tank is empty)*

______ # gallons liquid O_2 *(reserve tank)* * 3,259 *l*/gallon ÷ ________ *l* A.U. OR (E.U. x # patients) = minutes in the container

Cylinder Reserve *(This is how long the reserve will last once the main tank is empty)*

Time

______ # Cylinders on reserve * 6800 l/cylinder ÷ ________ *l* A.U. OR (E.U. x # patients) = minutes between manifold changes. *(this is how long the reserve will last once the main tank is empty)*

Medical Air Cylinder Manifold

Time

(______ # Cylinders *(one side)* * 6800 *l*/cylinder) ÷ ________ *l* A.U. OR (E.U. x # patients) = minutes between manifold changes.

Flow

_______ *l* Manifold maximum flow rate *(from manufacturer)* ÷ AU OR (EU x # patients)

Medical Air Compressor

Flow

(______ output capacity per NFPA *(from manufacturer)*[A] * *.85 (factor for desiccant dryers purge)* ÷ ________ *l* A.U. OR (E.U. x # patients) = number of patients servable. *(if using AU, compare to the assumed number used for that calculation. Use lower number)*

Surge Capacity

______ output capacity per NFPA *(from manufacturer) x* Total number of compressors/(total number of compressors -1) x 0.85 *(factor for desiccant dryers purge)* ÷ ________ *l* A.U. OR (E.U. x # patients) = number of patients servable. *(if using AU, compare to the assumed number used for that calculation. Use lower number)*

Piping : Main Lines

(note that these pipe sizings are very rough estimates based on a point load sizing method (all the load assumed to be at the most distant outlet) this will overestimate the pressure loss in almost all cases)

Flow and pressure drop

(1) Find pipe size at Source or main line valve.
(2) Estimate run from source to first major branch.
Use Detail 5 to estimate loss at the AU or EU rate of flow for the system in total (remember to include demand other than the emergency uses)

Piping : Zones

(note that these pipe sizings are very rough estimates based on a point load sizing method (all the load assumed to be at the most distant outlet) this will overestimate the pressure loss in almost all cases)

Flow and pressure drop

(1) Find pipe size at zone valve.
(2) Estimate run from source to most distant outlet from the zone valve.
(3) Use Detail 5 to estimate loss at the AU or EU rate of flow for that zone.

(A) to convert from SCFM to liters, multiply by 28.3

Detail 5   55 psi Piping Pressure Loss Data

Air Flow		Pressure Drop for Air in Pounds per Square Inch per 100 feet of Type L Copper Pipe for Air at 55 psi Gauge Pressue and 68ºF Temperature **(Nominal Pipe Diameters are shown in Bold)**				
Liters per Minute	Standard CFM					
@ 68ºF & 14.7 psia						
		1/2"	**3/4"**	**1"**	**1 1/4"**	**1 1/2"**
10	0.3	0.003	0.006			
20	0.7	0.009	0.002			
30	1.0	0.019	0.004			
40	1.4	0.031	0.006			
50	1.7	0.045	0.008			
60	2.1	0.062	0.011			
70	2.4	0.081	0.015			
80	2.8	0.103	0.018			
90	3.1	0.126	0.023			
100	3.5	0.151	0.027	0.008		
120	4.2	0.208	0.037	0.011		
140	4.9	0.272	0.048	0.014		
160	5.6	0.344	0.061	0.018		
180	6.3	0.423	0.075	0.022		
200	7.0	0.509	0.09	0.026		
220	7.7	0.602	0.106	0.031		
240	8.4	0.703	0.123	0.036		
260	9.1	0.809	0.142	0.041		
280	9.8	0.923	0.162	0.046		
300	10	1.04	0.183	0.052		
320	11	1.17	0.205	0.059		
340	12	1.3	0.228	0.065		
360	12	1.44	0.252	0.072		
380	13	1.59	0.276	0.079	**0.03**	
400	14	1.74	0.303	0.087	0.032	
450	15	2.15	0.374	0.107	0.039	
500	17	2.59	0.451	0.129	0.047	
550	19	3.07	0.534	0.152	0.056	
600	21	3.59	0.623	0.178	0.065	
650	22	4.15	0.718	0.205	0.075	
700	24	4.74	0.820	0.234	0.086	
750	26	5.45	0.927	0.264	0.097	**0.042**
800	28		1.04	0.296	0.108	0.047
850	30		1.16	0.330	0.121	0.053
900	31		1.29	0.365	0.134	0.058
950	33		1.42	0.402	0.147	0.064
1000	35		1.55	0.441	0.161	0.070
1100	38		1.84	0.523	0.191	0.083
1200	42		2.15	0.611	0.223	0.097
1300	45		0.705	0.257	0.112	0.11

Detail 5   55 psi Piping Pressure Loss Data

Air Flow		Pressure Drop for Air in Pounds per Square Inch per 100 feet of Type L Copper Pipe for Air at 55 psi Gauge Pressue and 68ºF Temperature **(Nominal Pipe Diameters are shown in Bold)**							
Liters per Minute	Standard CFM								
@ 68ºF & 14.7 psia									
		3/4"	**1"**	**1 1/4"**	**1 1/2"**	**2"**	**2 1/2"**	**3"**	**4"**
1400	49	2.85	0.806	0.293	0.128				
1500	52	3.22	0.912	0.332	0.144	**0.04**			
1600	56	3.62	1.024	0.373	0.162	0.043			
1700	60	4.04	1.142	0.415	0.180	0.048			
1800	63	4.49	1.266	0.460	0.200	0.053			
1900	67	4.95	1.396	0.507	0.220	0.058	**0.02**		
2000	70		1.532	0.556	0.241	0.064	0.023		
2250	79		1.895	0.687	0.298	0.079	0.028		
2500	88		2.293	0.831	0.360	0.095	0.034		
2750	97		2.726	0.987	0.428	0.113	0.040		
3000	105		3.193	1.155	0.500	0.132	0.047		
3250	114		3.694	1.335	0.578	0.153	0.054		
3500	123		4.228	1.527	0.660	0.174	0.062		
3750	132		4.796	1.731	0.748	0.197	0.070		
4000	141			1.946	0.841	0.222	0.078		
4250	150			2.173	0.938	0.247	0.087		
4500	158			2.411	1.041	0.274	0.097		
4750	167			2.661	1.148	0.302	0.107		
5000	176			2.922	1.260	0.331	0.117		
5500	194			3.40	1.47	0.39	0.14		
6000	211			3.99	1.72	0.45	0.16	0.07	
6500	229			4.61	1.99	0.52	0.19	0.07	
7000	247			5.29	2.27	0.6	.021	0.09	
7500	264				2.58	0.68	.024	0.1	
8000	282				2.9	0.76	.027	0.12	0.03
8500	300				3.24	0.85	0.3	0.13	0.03
9000	317				3.6	0.94	0.34	0.14	0.04
9500	335				3.98	1.04	0.37	0.16	0.04
10000	353				4.37	1.14	0.41	0.17	0.04
11000	388				5.21	1.36	0.48	0.21	0.05
12000	423					1.59	0.57	0.24	0.06
13000	459					1.84	0.66	0.28	0.07
14000	494					2.11	0.75	0.32	0.08
15000	529					2.39	0.85	0.36	0.09
16000	565					2.7	0.96	0.40	0.10
17000	600					3.01	1.07	0.44	0.12
18000	635					3.35	1.19	0.50	0.13
19000	670					3.70	1.31	0.55	0.14
20000	706					4.07	1.44	0.59	0.19
21000	741					4.45	1.55	0.65	0.252

Detail 5 55 psi Piping Pressure Loss Data

Air Flow		Pressure Drop for Air in Pounds per Square Inch per 100 feet of Type L Copper Pipe for Air at 55 psi Gauge Pressue and 68°F Temperature **(Nominal Pipe Diameters are shown in Bold)**					
Liters per Minute	Standard CFM						
@ 68°F & 14.7 psia							
		2"	**2 1/2"**	**3"**	**4"**	**6"**	**8"**
22000	776	4.85	1.69	1.060	0.270	0.026	
23000	812	5.26	1.83	0.77	0.20	0.029	
24000	847		1.98	.84	0.21	0.031	
25000	882		2.14	.9	0.23	0.033	
26000	918		2.3	.97	0.25	0.036	
27000	953		2.46	1.04	0.26	0.038	
28000	989		2.63	1.11	0.28	0.041	
29000	1024		2.81	1.18	0.3	0.044	
30000	1059		2.99	1.26	0.32	0.046	
35000	1236		3.97	1.67	0.42	0.061	
40000	1412		5.09	2.14	0.54	0.078	
45000	1589			2.66	0.67	0.097	
50000	1765			3.23	0.82	0.117	0.031
55000	1942			3.85	0.97	0.140	0.037
60000	2118			4.53	1.14	0.164	0.043
65000	2295			5.25	1.32	0.190	0.050
70000	2472				1.52	0.217	0.057
75000	2649				1.73	0.246	0.064
80000	2825				1.98	0.277	0.072
90000	3178				2.46	0.345	0.090
100000	3531				2.94	0.418	0.11
110000	3884				3.51	0.499	0.130
120000	4238				10.8	0.585	0.152
130000	4591					0.679	0.176
140000	4994					0.778	0.202
150000	5297					0.884	0.229
200000	7063					1.509	0.038
250000	8829					2.27	0.586
300000	10594					3.217	0.81
350000	12360					4.296	1.10
400000	14125					5.523	1.38