MedGas Insights
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Sizing Medical Gases for Covid 19

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 - Functional 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.

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.

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				
Therapy	*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 *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.

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	1
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 ℓpm is certainly extreme, 50 lpm is not an unreasonable number to use per patient. Yes: piping will get large (we traditionally have used 10 ℓpm per patient for oxygen and 25 ℓpm 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 ℓpm per patient, air is usually 25 ℓpm per patient).

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

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

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

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					
AU or EU Liters per Minute @ 68ºF & 14.7 psia	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				
	1/2"	**3/4"**			
40	0.037	0.006			
50	0.055	0.008			
60	0.075	0.011			
70	0.098	0.015			
80	0.123	0.019			
90	0.151	0.023	**1"**		
100	0.182	0.028	0.008		
120	0.250	0.038	0.011		
140	0.327	0.049	0.014		
160	0.413	0.062	0.018		
180	0.508	0.076	0.022		
200	0.612	0.092	0.026		
220	0.724	0.108	0.031		
240	0.844	0.126	0.036		
260	0.972	0.145	0.041		
280	1.109	0.165	0.046		
300	1.253	0.187	0.052		
320	1.405	0.209	0.059		
340	1.565	0.233	0.065		
360	1.733	0.258	0.072		
380	1.908	0.283	0.079	**1 1/4"**	
400	2.091	0.310	0.087	0.032	
450	2.581	0.382	0.107	0.039	
500	3.117	0.461	0.129	0.047	
550	3.698	0.546	0.152	0.056	
600	4.323	0.637	0.178	0.065	
650	4.993	0.735	0.205	0.075	
700	5.707	0.839	0.234	0.086	
750		0.949	0.264	0.097	**1 1/2"**
800		1.065	0.296	0.108	0.047
850		1.187	0.330	0.121	0.053
900		1.315	0.365	0.134	0.058
950		1.449	0.402	0.147	0.064
1000		1.589	0.441	0.161	0.070
1100		1.886	0.523	0.191	0.083
1200		2.206	0.611	0.223	0.097
1300		2.548	0.705	0.257	0.112
1400		2.913	0.806	0.293	0.128
1500		3.300	0.912	0.332	0.144

Detail 5 55 psi Piping Pressure Loss Data							
AU or EU Liters per Minute @ 68ºF & 14.7 psia	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						
	3/4”	**1”**	**1 1/4”**	**1 1/2”**	**2"**		
1600	3.709	1.024	0.373	0.162	0.043		
1700	4.140	1.142	0.415	0.180	0.048		
1800	4.592	1.266	0.460	0.200	0.053		
1900	5.066	1.396	0.507	0.220	0.058	**2 1/2"**	
2000		1.532	0.556	0.241	0.064	0.023	
2250		1.895	0.687	0.298	0.079	0.028	
2500		2.293	0.831	0.360	0.095	0.034	
2750		2.726	0.987	0.428	0.113	0.040	
3000		3.193	1.155	0.500	0.132	0.047	
3250		3.694	1.335	0.578	0.153	0.054	
3500		4.228	1.527	0.660	0.174	0.062	
3750		4.796	1.731	0.748	0.197	0.070	
4000			1.946	0.841	0.222	0.078	
4250			2.173	0.938	0.247	0.087	
4500			2.411	1.041	0.274	0.097	
4750			2.661	1.148	0.302	0.107	
5000			2.922	1.260	0.331	0.117	
5500			3.477	1.499	0.394	0.139	**3"**
6000			4.077	1.756	0.461	0.162	0.069
6500			4.721	2.032	0.533	0.188	0.080
7000				2.326	0.609	0.214	0.091
7500				2.638	0.691	0.243	0.103
8000	**4"**			2.969	0.777	0.273	0.116
8500	0.033			3.318	0.867	0.305	0.129
9000	0.037			3.684	0.962	0.338	0.143
9500	0.041			4.069	1.062	0.373	0.158
10000	0.045			4.471	1.166	0.409	0.173
10500	0.049			4.890	1.275	0.447	0.189
11000	0.053				1.388	0.486	0.206
11500	0.057				1.505	0.527	0.223
12000	0.062				1.627	0.570	0.241
13000	0.072				1.884	0.659	0.279
14000	0.082	**6"**			2.158	0.755	0.319
15000	0.093	0.013			2.449	0.856	0.362
16000	0.104	0.015			2.758	0.963	0.407
17000	0.116	0.017			3.083	1.076	0.455
18000	0.129	0.018			3.425	1.195	0.505
19000	0.142	0.020			3.784	1.320	0.557
20000	0.156	0.022			4.160	1.450	0.612

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AU or EU Liters per Minute @ 68ºF & 14.7 psia	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				
	2 1/2”	**3”**	**4”**	**6”**	
21000	2.349	0.989	0.252	0.024	
22000	2.518	1.060	0.270	0.026	
23000	2.693	1.133	0.289	0.029	
24000	2.873	1.208	0.308	0.031	
25000	3.058	1.286	0.327	0.033	**8"**
26000	4.067	1.708	0.434	0.036	0.009
27000		2.185	0.554	0.038	0.010
28000		2.717	0.688	0.041	0.011
29000		3.302	0.835	0.044	0.011
30000		3.941	0.995	0.046	0.012
35000		4.633	1.169	0.061	0.016
40000		5.378	1.355	0.078	0.020
45000			1.554	0.097	0.025
50000			1.765	0.117	0.031
55000			1.989	0.140	0.037
60000			2.475	0.164	0.043
65000			3.011	0.190	0.050
70000			3.596	0.217	0.057
75000			4.230	0.246	0.064
80000			4.912	0.277	0.072
90000			5.643	0.345	0.090
100000				0.418	0.109
110000				0.499	0.130
120000				0.585	0.152
130000				0.679	0.176
140000				0.778	0.202
150000				0.884	0.229
200000				1.509	0.390
250000				2.287	0.590
300000				3.217	0.827
350000				4.296	1.102
400000				5.523	1.414