MedGas Insights
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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). HTM deals with this in Table 12, particularly in respect of the test flows requirement, which are many times greater than the sizing value (e.g. oxygen is sized at 6 lpm but tested at 40) 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 *l*pm 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*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 lpm, 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 (liters)	Gas Volume at 70°F (21°C) and 1 atmosphere	
		Liters	Cubic Meters
1.0 / 0.45	0.397	339	0.339
9.5 / 4.3	1.0	860	0.86

[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* (total from Detail 2.1). EU is *Estimated Usage* from the rule of thumb estimate. Below, A.U. (averaged) means that value divided by the number of individual pieces of equipment or the average value per patient

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)* ÷ ________ *l* A.U. (averaged) OR (E.U. x # patients)

Oxygen Container Manifold (Cryogenic Liquid Containers)

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)* ÷ A.U. (averaged) OR E.U. = 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) ÷ A.U. (averaged) OR (E.U. x # patients) = number of patients servable. *(if using A.U., 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
______ # litres liquid O_2 *(primary side)* * 860 *l gas* / litre liquid) ÷ ________ *l* A.U. (averaged) 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)* ÷ ________ *l* A.U. (averaged) OR EU = number of patients servable. *(if using A.U., compare to the assumed number used for that calculation. Use lower number)*

and also check:

________ *l*/min regulator throughput capacity *(from manufacturer)* ÷ ________ *l* A.U. (averaged) OR EU = number of patients servable. *(if using A.U., 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)*

______ # litres liquid O_2 *(reserve tank)* * 860 *l gas* / litre liquid ÷ ________ *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)* [A] ÷ ________ *l* A.U. (averaged) OR EU = number of patients servable. *(if using A.U., compare to the assumed number used for that calculation. Use lower number)*

Medical Air Compressor

Flow
(______ output capacity to HTM rules *(from manufacturer)* [B] *x .85 (factor for desiccant dryers purge)* ÷ ________ *l* A.U. (averaged) OR EU = number of patients servable. *(if using A.U., compare to the assumed number used for that calculation. Use lower number)*

Surge Capacity
______ output capacity to HTM rules *(from manufacturer)* [B] *x* Total number of compressors/(total number of compressors -1) x 0.85 *(factor for desiccant dryers purge)* ÷ ________ *l* A.U. (averaged) OR E.U. = number of patients servable. *(if using A.U., 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 A.U. or E.U. rate of flow for that zone.

(A) Testing has shown that some manifolds have been greatly overrated by their manufacturers and may not in fact be able to deliver at the flow rate and pressure drop expected by HTM 02-01 or displayed in the literature. In addition, old manifolds can lose capacity. High Flow testing to confirm the actual manifold capacity and pressure drop is highly recommended.
(B) Note this will vary with the edition of HTM used at the time the plant was installed. HTM 2022 required n + 1, HTM 02-01 requires n + 1 +1

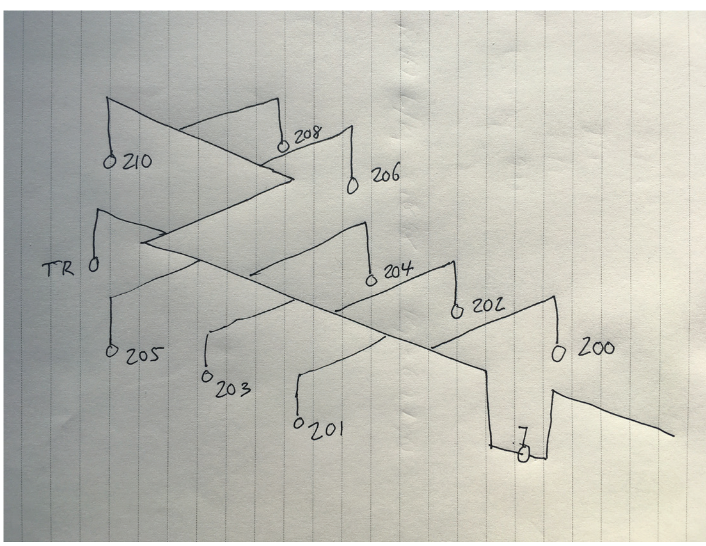
Estimating pipe losses and Use of the BMed PipeSizer Calculator

Preparation:
Determine the expected maximum or total flow through the piping in question. This can be A.U. (total from Detail 2.1) or E.U. using the rule of thumb estimate.

Determine the distance run to the most distant outlet. Unless you are fortunate enough to have detailed as built drawings, this will be a best estimate made by pacing off the distance or measuring most the likely piping runs from original drawings, combined with any knowledge of actual runs from previous experience.

Determine the pipe size. This will probably be most easily done by looking at the line valves or zone valves where the piping is visible.

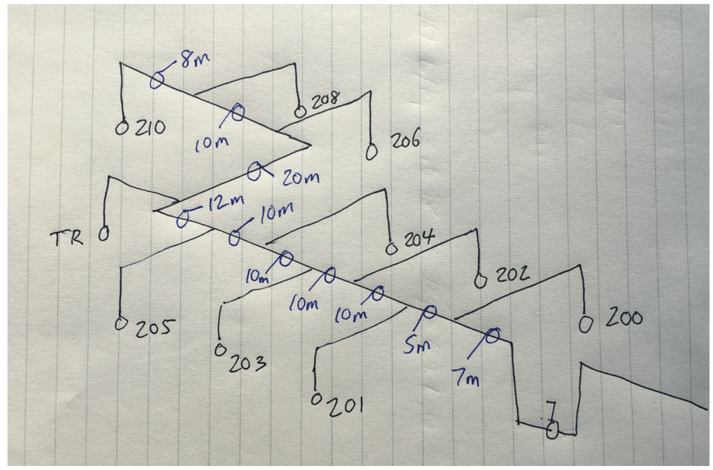
The method used here is a point-load method, assuming the entire flow will pass through the entire piping. That will in almost every case result in an over estimate. The more granular one can be with the piping the more accurate the final result can be. Being realistic with what could be done quickly in an operating hospital, we might have a diagram similar to Detail 6.



Detail 6.0 - Our sketch layout with room numbers and rough layout.

To this , we want to add the best estimate we can make as to pipe runs, as shown in Detail 6.1

By looking at the zone valve we can see roughly what pipe size we have. For example, a unit like this might have a 12 mm oxygen pipe.



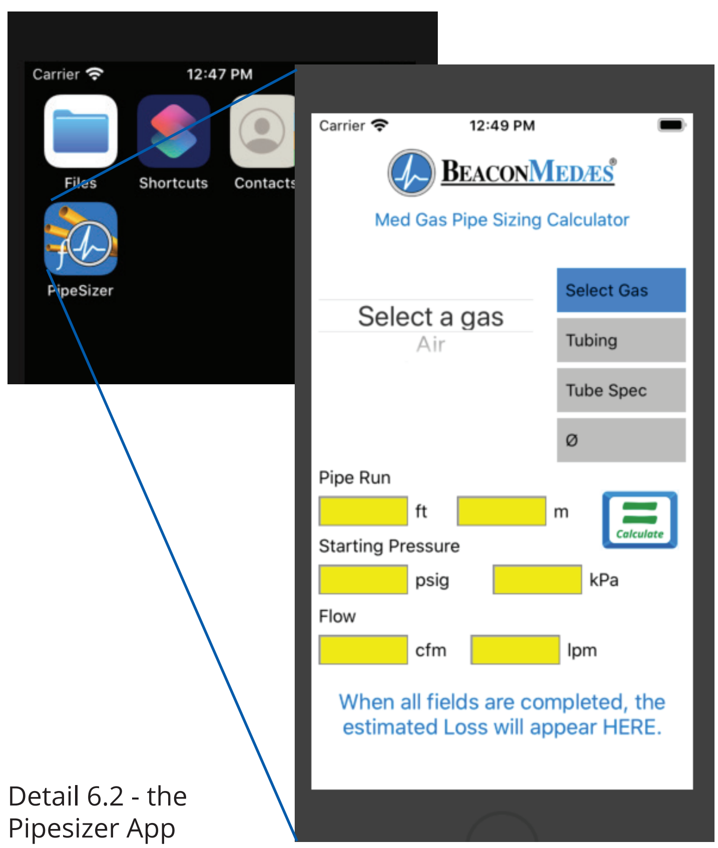
Detail 6.1 - Our sketch layout with estimated dimensions (in blue)

Based on those estimates it is possible to simply estimate a point-load loss to the furthest outlet by totalling the length of the run (102 m in this example), and totalling the flow (45 *l*pm x 10 rooms = 450 *l*pm).

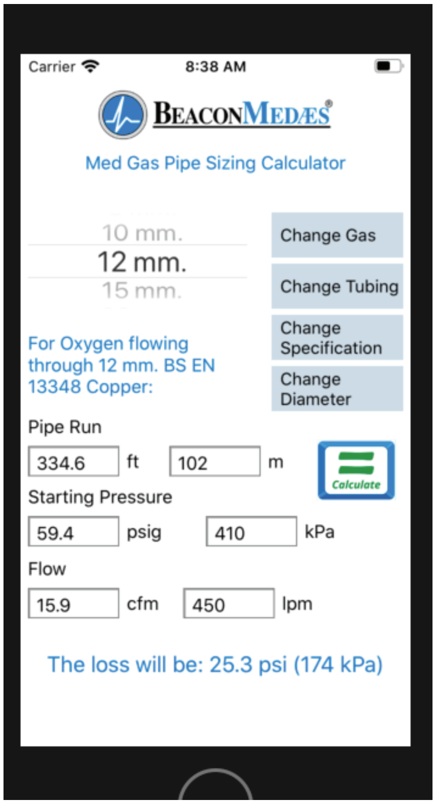
Bring up the calculator (see Detail 6.2) or use the tables in Detail 5.

Enter in the values obtained earlier (see Detail 7.1)

The PipeSizer app will then show you the estimated loss across the pipeline under these conditions or with one additional step (factoring for loss per 10 m) required to use the tables in Detail 5.



Detail 6.2 - the Pipesizer App



Detail 7.1 - the point load estimate for this sketch

The loss will almost always be an overestimate when calculated this way. It is also possible to use the calculator to make a more granular analysis by estimating each section individually, as shown in Detail 7.2.

As is obvious, the point-load method is much faster, but will usually overestimate the loss (6.8 psi vs. a more realistic 2.1 psi in this example)

We have made no allowances for fittings, vagaries of installation, down drops, etc. As this is only intended to be a rough estimate for checking capabilities, these finer details are ignored.

Naturally, the user can take the process to any desired level of precision by following the same basic process but increasing the detail used in making the calculations.

Start	Finish	Run	Flow	Loss in Section	Running total of losses
210	208	8 m	45 lpm	0.24	0.24
208	206	10 m	90 lpm	1	1.24
206	TR	20 m	135 lpm	4.1	5.34
TR	205	12 m	180 lpm	4.1	9.44
205	204	10 m	225 lpm	4.9	14.3
204	203	10 m	270 lpm	6.8	21.1
203	202	10 m	315 lpm	9	30.1
202	201	10 m	360 lpm	11	41.1
201	200	5 m	405 lpm	7	48.1
200	valve	7 m	450 lpm	12	60.1

Detail 7.2 - The sketch more exactly estimated

Detail 6   4.1 bar Piping Pressure Loss Data

Oxygen Flow Liters per Minute	Pressure Drop for Oxygen in kPa per 10 meters of BS/EN 13348 Copper Pipe for Air at 4.1 bar Pressure and 20°C Temperature **(Nominal Pipe Diameters are shown in Bold)**				
	10 mm	**12 mm**	**15 mm**	**22 mm**	**28 mm**
20	0.24	0.07			
30	0.52	0.16			
40	0.8	0.24	0.08		
50	1.2	0.37	0.12		
60	1.6	0.48	0.16		
70	2.2	0.65	0.22		
80	2.6	0.8	0.27		
90	3.3	1.0	**0.33**		
100	3.9	1.2	0.39		
120	5.4	1.6	0.54		
140	7	2.1	0.7		
160	9	2.7	.9		
180	11	3.4	1.1		
200	14	4	1.4		
220	16	4.8	1.6		
240	18	5.6	1.8		
260	22	6.4	2.2		
280	25	7	2.4		
300	28	8	2.7		
320	31	9	3.1		
340	35	10	3.4	0.51	
360	39	11	3.8	0.57	
380	43	13	4.1	**0.62**	
400	47	14	4.5	0.68	
450		17	5.6	0.8	
500		21	6.8	1	
550		24	8	1.2	
600		29	9	1.4	
650		33	11	1.6	0.47
700		38	12	1.8	0.53
750		43	14	2.1	**0.6**
800		48	16	2.3	0.67
900			20	2.9	0.8
1000			24	3.5	1.0
1100			28	4.1	1.2
1200			33	4.9	1.4
1300			38	5.6	1.6
1200			33	4.9	1.4
1300			38	5.6	1.6

Continued overleaf

Detail 6 (con't) 4.1 bar Piping Pressure Loss Data

Oxygen Flow Liters per Minute	Pressure Drop for Oxygen in kPa per 10 meters of BS/EN 13348 Copper Pipe for Air at 4.1 bar Pressure and 20°C Temperature **(Nominal Pipe Diameters are shown in Bold)**							
	15 mm	**22 mm**	**28 mm**	**35 mm**	**42 mm**	**54 mm**	**66 mm**	**76 mm**
1400	44	6.4	1.8	0.64				
1500	50	7	2.1	0.7				
2000		12	3.5	1.2				
2500		18	5.2	1.8	0.7			
3000		26	7	2.5	1			
3500		34	10	3.3	1.3			
4000		44	1.8	4.3	1.7			
4500		54	15	5.3	2.1	0.58		
5000			18	6.4	2.5	0.7		
5500			22	8	3	0.8		
6000			26	9	3.5	1		
6500			30	10	4	1.1		
7000			34	12	4.6	1.3		
7500			39	13	5.2	1.5		
8000			44	15	5.9	1.6		
8500			49	17	6.5	1.8	0.63	
9000				19	7	2	0.7	
10000				23	9	2.4	0.8	
11000				27	11	2.9	1	
12000				32	12	3.4	1.2	
13000				37	14	4	1.4	
14000				43	16	4.5	1.6	
15000				48	19	5.1	1.8	
20000					32	9	3	1.6
25000					48	13	4.5	2.4
30000						18	6.3	3.4
35000						25	8	4.5
40000						32	11	5.7
45000						39	13	7
50000						48	16	9