Predicting Surge Requirements for Medical Gas Consumption

Robert L. Chatburn, MHHS, RRT-NPS, FAARC

Research Manager – Respiratory Institute

Cleveland Clinic

Professor – Department of Medicine

Lerner College of Medicine of Case Western Reserve University

Disclosure

- **I am a paid consultant for**
  - IngMar Medical
  - Hillrom
  - Vyaire Medical

Disclaimer

- **I have no experience in the area of facilities engineering**
- **I do have 40+ years of experience as a medical scientist**
- **All opinions expressed in this talk are my own and do not represent those of the Cleveland Clinic**

Goal of this talk

- **To improve the communication between Medical Gas Professionals and Healthcare Professionals to better prepare for emergency surges in oxygen consumption**

Overview

- **Gas consumption concerns during a surge**
- **Facilities design issues**
  - Limitations on O_2 consumption due to facility design
  - Potential problems with design tolerances
- **Crash course on medical consumption of oxygen**
  - Medical terms
  - Device descriptions
- **Crash course on statistics**
- **How to predict oxygen consumption**
  - Misconceptions about data needed
  - Where to get the data
  - How to use the calculator
- **Practical suggestions**

Caveat

- **The late management guru Peter Drucker considered hospitals to be**
  - "*The most complex human organization ever devised* "
- **According to complex systems theory, chaos theory, graph theory and network theory**
  - The behavior of complex systems is highly sensitive to changes in initial conditions
  - Complex systems are essentially unpredictable
- **You better have a backup plan in case your predictions fail**

Predicting medical gas consumption during surge conditions is a complicated topic

This is because hospitals themselves are extremely complex organizations

By definition, the behavior of complex systems is essentially unpredictable

COVID-19 Epidemic Concerns

- **Increased usage of mechanical ventilators**
  - Increased usage of current inventory
    - *Invasive & non-invasive mechanical ventilators*
  - Rapid increase in new ventilator purchases
- **Increased usage of other oxygen delivery equipment**
  - Conventional and high flow nasal cannulas
- **The limiting factor may not be the number of ventilators but the medical gas supply to operate them**

The COVID-19 epidemic has placed hospitals in dire risk of having insufficient resources to treat the surge in patients.
One critical resource is mechanical ventilation.
As hospitals rush to increase ventilator inventory, they may be overlooking an important limiting resource; perhaps as important as ventilator circuits or even clinicians to operate the machines.
That resource is the facilities medical gas supply.

Facilities Design Issues

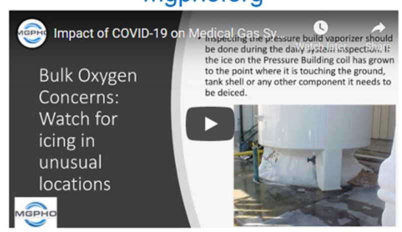
Facilities Design – Storage and Use

- **Limitations on medical oxygen stored in liquid form**
  - Maximum flow due to plumbing resistance
  - Maximum zone and total facility storage capacity
  - Reduced heat exchange due to icing on evaporation coils

APR 2020

SEP 2020

Excellent Resource
mgpho.org



Medical Gas Professional Healthcare Organization

Ventilators used in intensive care units, particularly in the United States, are usually connected to central medical gas supply of oxygen and medicinal compressed air outlets at 50 psig linked by plumbing to huge liquid oxygen storage tanks, filtered air compressors, and dehumidifiers in the building's mechanical and plumbing systems.

When the demand for oxygen flow exceeds the vaporization of oxygen in the coil system, the pressure drops, starving the ventilators of needed flow.

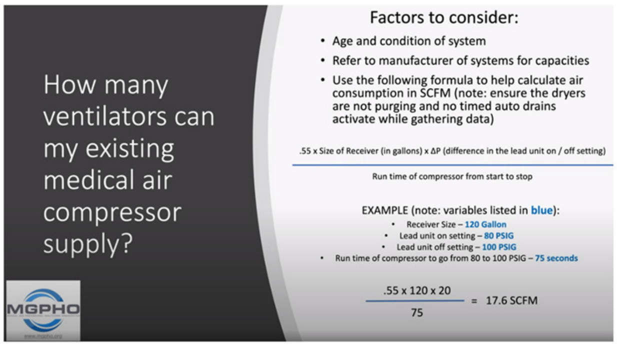
This is often manifested by ice forming on the coils, even in the heat of summer.

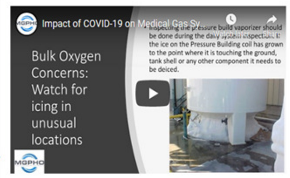
This slide shows icing on my hospital's oxygen system evaporation coils during peak load in April and during a period of reduced usage in September

I recommend that you watch the video provided by the Medical Gas Professional Healthcare Organization

Facilities Design – Medical Air

- **Air is supplied by huge air compressors with dryers to remove water vapor**
  - Failure of dryers will lead to water in plumbing that can damage ventilators





Medical Gas Professional Healthcare Organization

If the air compressor system and its associated dehumidifying system is overloaded, moisture can enter the hospital air lines and reach the ventilators causing ventilator failure.

Facilities Design – Tolerance Limits

- **No standard design procedure for medical gas sizing**
  - Tolerance limits set by engineering experience
  - Clinical experience may be misunderstood or not considered
- **System design surge tolerances may not be adequate**
  - Tolerances may be based on average normal oxygen usage
  - Surge oxygen use may be based on unexpected use of medical equipment (types and numbers)
- **Tolerances must be based on clear communication between clinicians and engineers**
  - Data from current COVID-19 surge should be used to improve prediction accuracy

There is no single set design procedure for medical system gas sizing.

Various companies have their own methods.

When designing a hospital, design professionals typically build in a surge capacity factor for medical gas supply lines.

This factor may be something like 25%-50% above the expected load, which may be considerably less than the surge expectations of clinicians.

Crash Courses in Medical Terminology

Crash Course in Medical Terminology

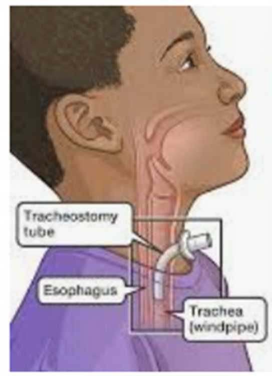
- **Ventilator**
  - Automatic machine use to perform some portion of the work of breathing to assure gas exchange
- **Ventilator-day**
  - Metric for ventilator usage recorded in EMR
  - One ventilator used for 24 hrs = 1 vent day
  - One ventilator used for 2 days = 2 vent days
  - Two ventilators used for 1 day = 2 vent days

In order to understand the basics of predicting medical gas consumption during surges, we need to review some terminology associated with medical gas use

In particular, ventilator usage is recorded in the electronic medical record using a metric called a “ventilator day”

Crash Course in Medical Terminology

- **Invasive ventilation**
  - Intubation with endotracheal tube or tracheostomy tube



Crash Course in Medical Terminology

- **Non-Invasive ventilation**
  - Use of mask or helmet

Classification of Ventilators

- **By Application**
  - General purpose ICU
  - Homecare/transport
  - Pediatric/neonatal
  - High frequency ventilators
  - Noninvasive ventilators

Dräger Evita XL

Textbooks often classify ventilators by how they are used.

For example, there are general purpose ventilators that can be used on any kind of patient from neonates through adults.

This is the most common type of intensive care unit (ICU) ventilator.

Examples of commonly used general purpose ventilators are the Covidien PB 840, the Dräger Evita XL, the Maquet Servo i.

Classification of Ventilators

- **By Application**
  - General purpose
  - Homecare/transport
  - Pediatric/neonatal
  - High frequency ventilators
  - Noninvasive ventilators

Covidien PB 540

Another large and growing category is homecare ventilators.

These devices are much simpler, smaller, and lest costly than general purpose ICU ventilators.

Commonly used homecare ventilators include the Covidien PB 540, the Newport HT 50 and the Carefusion LTV 900.

Transport ventilators are even smaller and simpler, sometimes having only an on-off switch.

They are designed for short term use when moving patients, such as between the ICU and diagnostic areas or between hospitals.

Classification of Ventilators

- **By Application**
  - General purpose
  - Homecare/transport
  - Pediatric/neonatal
  - High frequency ventilators
  - Noninvasive ventilators

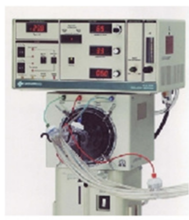
Dräger Babylog VN500

Some ventilators are designed specially for use with neonatal and pediatric patients.

The only commonly used specialty ventilator for infants in the US is the Dräger Babylog.

Classification of Ventilators

- **By Application**
  - General purpose
  - Homecare/transport
  - Pediatric/neonatal
  - High frequency ventilators
  - Noninvasive ventilators



Sensormedics 3100

Bunnell Life Pulse

The ventilators we have mentioned so far are referred to as "conventional" ventilators, meaning that they provide ventilatory patterns similar to normal breathing.

Another category is "high frequency ventilators", so named because they delivery very small breaths at frequencies well above normal breathing frequencies, ranging from about 3 to 15 Hz (cycles per second).

The idea behind high frequency ventilation is to use the smallest possible breaths to avoid stretch injury to the fragile lungs of premature infants or any patient with acute respiratory distress.

Classification of Ventilators

- **By Application**
  - General purpose
  - Homecare/transport
  - Pediatric/neonatal
  - High frequency ventilators
  - Noninvasive ventilators

Philips Respironics V60

Finally, we have the category of noninvasive ventilators, those designed to be used with a mask interface instead of an artificial airway.

Historically, ventilators have been designed with build in air-oxygen blenders to control FiO2

For this reason, they have traditionally required inputs of air and oxygen at high pressure (eg, 30 psi)

However, ventilators designed for home care and some ICU ventilators now replace the need for high pressure air with an internal turbine (aka blower)

Unexpected examples

VOCSN

Ventilation
Oxygen
Cough
Suction
Nebulization

Fitbit's ventilator gets emergency FDA approval

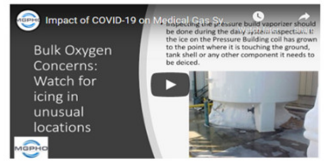
Note that at least one ventilator, the VOCSN, has both a blower and an internal oxygen concentrator to supply its own oxygen needs

In the era of emergency use ventilators quickly approved by the FDA, expect to see some very strange devices with unusual requirements

Fortunately these will probably remain an insignificant part of the hospital's ventilator fleet

Huge variability among ventilators

Oxygen Only	Oxygen & Med Air
Philips Respironics BiPAP V60 • Max Flow 175 LPM • Low 40, High 87	GE Carescape R860 • Max Flow 160 LPM • Low 35, High 94
Respironics Esprit • Max Flow 300 LPM • Low 40, High 90	Carefusion Avea • Low 20, High 80
Allied Healthcare AutoVent 3000 • Flow listed between 16-48 LPM • Low 40, High 60	Carefusion LTV1200 • Low 40, High 80
Allied Healthcare EPV200 • Spec says an oxygen D cylinder will last 65 minutes • Low 40, High 87	Tecme Advance • Low 41, High 87
Respironics Vision BiPAP • Max Flow 120 LPM • Low 50, High 100	Drager Evita XL • Max flow 120 LPM • Low 39, High 87
Trilogy Ventilator • Max Flow 200 LPM • Low 40, High 87	Maquet Servo I • Low 29, High 94
Newport HT70 Transport Ventilator • Max Flow 100 LPM • Low 35, High 90	PB 840 • Flow to 200 LPM • Low 35, High 100



Medical Gas Professional Healthcare Organization

- **Need to consult with clinical representatives to account for ventilator models**
  - Consider constant bias flow (0 – 30 L/min)
  - Consider huge leaks during noninvasive ventilation

There is a wide range of specifications among ventilators in terms of their required oxygen supply pressure and baseline oxygen consumption

Of particular importance is the constant bias flow many ventilators use to maintain baseline pressure in the patient circuit (positive end expiratory pressure or PEEP)

Furthermore, during noninvasive ventilation there are both intentional and unintentional leaks in the system that account for an unmeasured and potentially huge increase in medical gas consumption

If the oxygen system pressure drops below the required ventilator supply pressure, alarms will sound and the ventilator may malfunction

You have to plan to keep the system pressure always above that required by the ventilators with the highest inlet pressure requirement

Crash Course in Medical Terminology

- **Minute Ventilation (L/min)**
  - Flow of fresh gas through the lungs to achieve adequate elimination of carbon dioxide
  - Minute ventilation = tidal volume x respiratory rate
- **Tidal Volume (mL)**
  - The volume of gas inhaled/exhaled during ventilation
- **Respiratory Rate (breaths/min)**
  - Number of breaths per minute during ventilation
- **Inspiratory flow (L/min)**
  - Peak flow into the lungs during inspiration

In order to understand the oxygen consumption of a ventilator, you need to understand the components of ventilation itself

What you need to predict is minute ventilation, which is comprised of tidal volume and respiratory rate

These components are required in data collection because the electronic medical record (EMR) may not include minute ventilation data directly

Such data are usually recorded by respiratory therapists (in North America) during routine ventilator checks that occur several times a day

Note that for most ventilators, minute ventilation is usually an indirect consequence of direct settings for tidal volume and respiratory rate

Minute ventilation, an average across many breaths, has no correlation with inspiratory flow of individual breaths

Oxygen Delivery Devices

Simple Oxygen Mask
(5-10 L/min)

Non-Rebreathing Mask
(10 - 15 L/min)

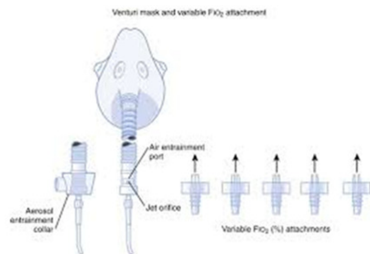
Ventilators account for only a portion of a hospital's total oxygen consumption

Many other devices are used to deliver oxygen to patients

They each have their own range of oxygen supply flows

Oxygen Delivery Devices

Entrainment (Venturi) Oxygen Mask
(4-15 L/min)



Entrainment Large Volume Nebulizer
(15 L/min)

Oxygen Delivery Devices

Standard Nasal Cannula
(1-6 L/min)

High Flow Nasal Cannula
(1-40 L/min)

Current guidance seems to focus on high flow nasal cannula use because it can consume up to 40 L/min for a single patient

However, do not forget that the combined oxygen flow from all other devices may be just as important

Oxygen Delivery Devices

Small Volume Nebulizer
(6-8 L/min)

Note: there could be hundreds of treatments per day at perhaps 10 minutes/treatment

Oxygen Hood
(10-15 L/min)

Of particular concern, and not mentioned in any guidance I have seen, is the use of small volume medication nebulizers

These are often connected to oxygen flowmeters

Because this is perhaps the most common medical treatment given in a hospital, the cumulative oxygen use during peak simultaneous use could be a concern

High simultaneous use is often driven by the common practice of giving aerosol treatments at standard times during the day

Oxygen Metering Devices

Oxygen Flow Meter
(0-15 L/min)

Oxygen Blender
(2 - 120 L/min)

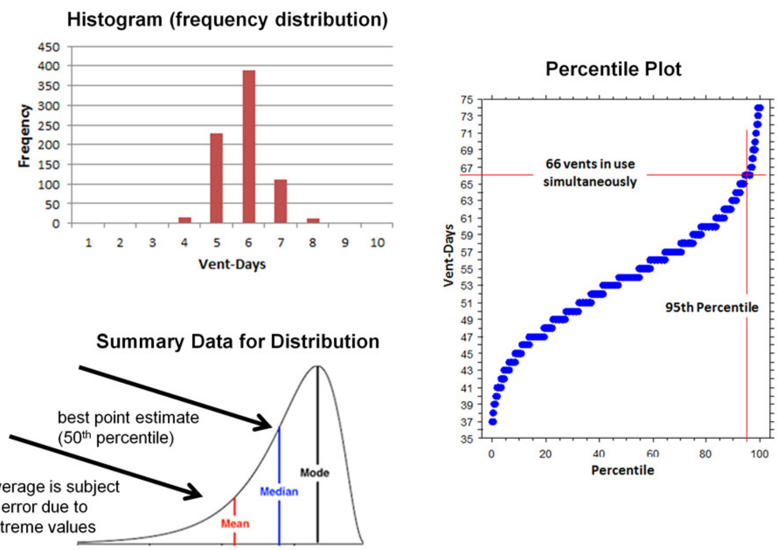
All of these simple oxygen delivery devices are usually connected to oxygen flow meters

Crash Courses in Statistics

Turning Date Into Information

Raw Data

	A
1	Ven-Days
2	48
3	51
4	47
5	50
6	55
7	59
8	60
9	62
10	57
11	48
12	52



To make predictions about hospital medical gas use, we need data

Data are mined from the hospital electronic medical record databases

Unfortunately, these databases were designed for billing purposes and are notoriously difficult to mine to answer clinical research questions

Taking one simple example, data may be obtained for ventilator days for a particular hospital area (eg the medical ICU supplied by a particular oxygen zone valve)

This raw data will be provided as a spreadsheet

Your task is then to turn the date into information answering the question about oxygen use predictions

One common approach is to graph the frequency distribution and calculate some measures of central tendency or "most common" values from which to make predictions

Beware that using the mean or average value may be misleading because this point estimate is affected by extreme values in the data set

It is better to use the median value

But keep in mind that if you predict oxygen usage based on a median value, you will underestimate actual use 50% of the time

More accurate predictions require that the data be summarize with a percentile plot

This allows you to make statements like “95% of the time ventilator usage will be less than 66 vent-days” implying that your prediction is expected to underestimate actual usage only 5% of the time

Predicting Oxygen Consumption

The Basic Problem:

- **What data do we need?**
  - Peak flow of oxygen to a hospital zone
    - *Total flow from ventilators in simultaneous use*
    - *Total flow from oxygen delivery devices in simultaneous use*
    - *Predictive model for turning random usage into probable peak usage*
- **Where will we get it?**
  - Hospital Electronic Medical Record
    - *System for associating billing codes to O_2 devices*
- **How do we analyze it?**
  - Oxygen usage calculator

Let us now unpack the complicated problem of predicting total peak oxygen consumption

The kind of data we need is that for oxygen use by ventilator and other oxygen delivery devices

Avoid thinking that average use over an arbitrary time period is sufficient (something I have seen reported in the medical literature)

This may be sufficient for general design specifications for new construction, but it may be misleading for surge protection

The problem is not only to estimate oxygen use of various devices, but to find some model that predicts the maximum simultaneous use of all oxygen consuming devices

I don’t think anybody knows how to do this and it should be the subject of serious research

On the one hand, to assume some average value seems likely to underestimate oxygen consumption and put patients at risk

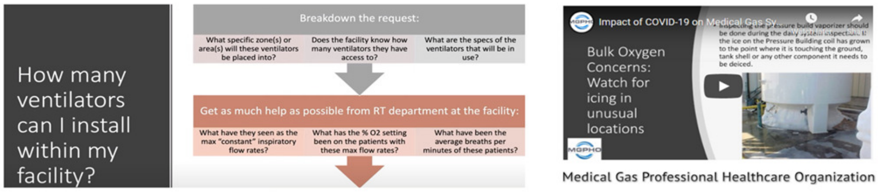
On the other hand, to assume maximum usage of all devices would likely overestimate consumption and waste resources

It seems we have to calculate both limits and simply guess at a target somewhere in between them

Assuming we can get data from the EMR and summarize it with common statistical

metrics, we need a tool to help make the actual predictions
That is where the oxygen gas consumption calculator comes in
We will review that shortly

Some Misconceptions



Medical Gas Professional Healthcare Organization

- **What is max inspiratory flow rate?**
  - This is irrelevant, what you want is minute ventilation
- **What is average breaths per minute**
  - Incomplete data, what you need is:
  - Minute Ventilation = Breath Rate x Tidal Volume
- **What is % O_2 on max flow settings**
  - Inadequate data
  - Better to use O_2 consumption calculator
- **The average respiratory therapist cannot supply the information you need**
  - What you need is a task force and EMR data mining

First, I want to review that seems to me to be some misconceptions in the video from the MGPHO

A table in that lecture suggests some data needed to estimate the maximum number of ventilators that can be used simultaneously without overloading the medical gas supply system

The first misconception is that peak inspiratory flow rate is relevant – it is not

As mentioned earlier, what you need is the average flow of oxygen through the ventilator per minute, which is not related to the peak inspiratory flow setting

In theory, if all ventilators were set with the same peak inspiratory flow and they all delivered breaths to all patients in perfect synchrony, then there could be an oxygen overload situation

But I believe this is obviously not a practical reality for many reasons beyond the scope of this talk

The second misconception is that average breath rate is important

It is, but this is only half of the needed data

Again, the metric of interest is minute ventilation and this is the product of breath rate and tidal volume – tidal volume is not mentioned here

The third misconception is that FiO2 or % O2 on maximum settings is relevant

Maximum settings are not defined

Rather, what you need to know is the range of FiO2 used most commonly

All of the data you need to collect interact in a complicated way that is not intuitively obvious

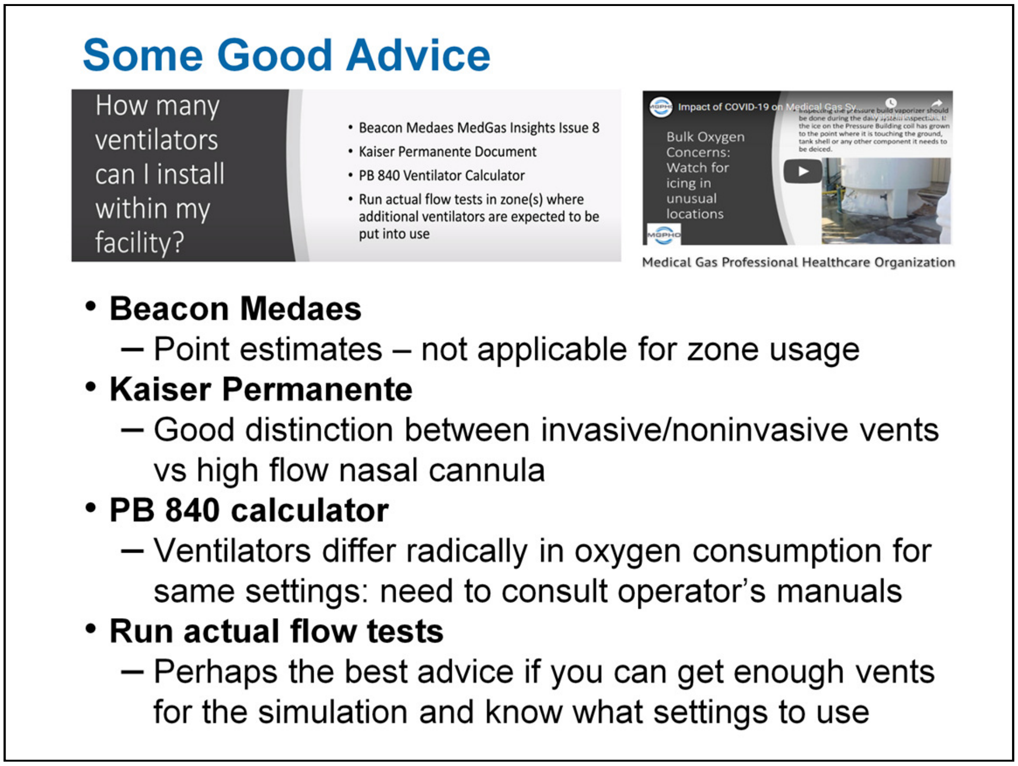
That is why you need a calculator designed to do the job

Finally, you will never be able to get the data you need from casual conversations with random respiratory therapists

They do not have direct access to the data

What you need is a task force with relevant content experts, including a respiratory therapist, that can interpret and mine the data from the electronic medical record

Any effort less than this will yield unreliable prediction models



The MGPHO slide show does mention some sources of good advice

The Beacon Medaes report gives tables of point estimates (probably averages) for oxygen consumption of various devices

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

I was a consultant for the Kaiser Permanente report by Sandy Renshaw P.E. and it has a pretty good summary of the important factors in oxygen consumption and gives tables of pipe sizing

The PB 840 calculator is useful and estimates both air and oxygen use rates and total gas usage if tanks are the source instead of piped gas

However, it is valid only for this ventilator and the ventilator is currently obsolete (although many are still in use)

Perhaps the best way to predict medical gas consumption is not using mathematical models but by means of simulated usage with actual ventilators and expected ventilator settings

I know of at least one hospital that has performed this successfully and got some unexpected results that would have been missed by any mathematical model

Very Basic Prediction Model

Mathematics of Oxygen Use

- **F_{IO_2}**
  - Fraction of inspired oxygen
  - Expressed as fraction or percent
  - F_{IO_2} of room air = 21%

$$F_{IO_2} = \frac{O_2\ \text{flow} + (0.21 \times \text{airflow})}{\text{total flow}}$$

$$= 0.21 + \frac{(0.79 \times O_2\ \text{flow})}{\text{total flow}}$$

$$O_2\ \text{flow} = \frac{\text{total flow} \times (F_{IO_2} - 0.21)}{0.79}$$

A simple model that I have seen use by facilities engineers involves just two variables

The first is the estimated average or maximum FiO2

These equations relating FiO2 to air and oxygen flow are familiar to respiratory therapists because they are used to deliver oxygen therapy to patients

Simplified Estimate of Oxygen Flow

- **Estimate oxygen use by ventilators**
  - Estimate ventilators in simultaneous use
  - Estimate total minute ventilation across all ventilators
  - Add estimate of bias flows of all ventilators
- **Estimate oxygen flow to all oxygen delivery devices**
- **Sum to calculate total oxygen flow**

You need estimates for oxygen use by ventilators and all other types of oxygen delivery devices for a particular area controlled by an oxygen zone valve

As you have seen, creating such an estimate is easier said than done

Estimate of Oxygen Consumption

$$O_2(L/min) = Total\ Flow \times \frac{FiO_2 - 0.21}{0.79}$$

- **Convert L/min to ft^3/hr**
  - Cubic Feet/min = Liters/min x 0.0353
  - One hour = 60 minutes

This is the simple prediction model for average oxygen use based on very crude estimates of oxygen delivery device performance

The larger the area it is applied to, the less accurate the prediction will be due to variations in oxygen use across multiple zone valves

More Accurate Prediction

Gas Conditions for Volume Calculations

- **STPD**
  - Standard temperature (273°K), standard pressure (760 mm Hg), dry (no water vapor)
- **ATPS**
  - Atmospheric temperature (as measured), atmospheric pressure (as measured), dry (no water vapor)
  - This is the assumption used by oxygen flowmeters
- **BTPS**
  - Body temperature (37°C), atmospheric pressure, saturated with water vapor (47 mm Hg)
  - This is the value reported by ventilators

It is possible to make a more accurate prediction model

First you need to understand that flow calculations are highly affected by the temperature and pressure conditions under which flow is measured

For example, facilities engineers typically assume gas conditions are standard, meaning zero degrees centigrade or 273 degrees kelvin, one atmosphere of pressure and zero pressure due to water vapor

In contrast, simple oxygen delivery devices are calibrated for atmospheric temperature and pressure dry, as for example, the way gas flows through an oxygen flow meter connected to an oxygen mask or nebulizer

At the other extreme is body temperature and pressure as reported by most (but not all) mechanical ventilators

Gas Conditions for Volume Calculations

- **Proper conversion is essential**
  - Huge difference when converted to cubic feet

Target at BTPs	500 mL	Δ
STPD	413 mL	-17%
	15 ft^3	-97%

As you can see from this example, proper conversion is essential, especially when estimating gas consumption by ventilators

Gas volume (or flow) at STPD conditions is about 17% less than gas volume at BTPS due to cooling and removal of water vapor

Not accounting for this discrepancy can cause important errors in your gas consumption predictions

Medical Gas Calculator – Inputs

- Calculator built as an Excel file (free download)
  - http://www.aarc.org/wp-content/uploads/2020/04/calculator-medical-gas-consumption.xlsx
- Runs on any computer that has Microsoft Excel
- Simple numerical inputs from clinical planners

To address the specific concerns about increased ventilator usage, we created a calculator that is an Excel file

It can run on any computer that has Excel installed

The required inputs are obtained from estimates of ventilator usage that can be obtained from clinical planners

Medical Gas Calculator – Inputs

- **Atmospheric temperature and pressure**
- **Total ventilator minute ventilation**
  - Can substitute peak O_2 usage from other devices
- **FiO_2**
  - Ignore air consumption if vent has a blower
- **Predicted peak ventilator census**

CRITICAL ASSUMPTIONS	High	Median	Low
Daily Ventilator Census (vents)	800	500	100
Duration of Ventilation (d)	14	12	10
Total vent-days	11,200	6,000	1,000
Capacity of Oxygen H-Tanks (L/tank)	7,080		
Capacity of Air H-Tanks (L/tank)	7,080		

Specific inputs include atmospheric conditions at the usage location

Estimated ranges for ventilator minute ventilation

Ranges of FiO_2

Predicted ventilator census, meaning the maximum number of ventilators in use simultaneously

The estimated duration of ventilation from actual experience with COVID -19 patients

Medical Gas Calculator - Outputs

- **Outputs relevant to clinicians and engineers**
  - Adjustable reporting units
    - *Cubic meters (liters) per minute*
    - *Cubic feet per hour*
- **Oxygen and Air Use Rates**
  - Per minute, hour, day

RESULTS for PIPING SYSTEMS (STPD)	High	Median	Low
Oxygen Consumption Rate (per min)	280	56	4
Oxygen Consumption Rate (per hr)	16,806	3,388	211
Oxygen Consumption Rate (per day)	403,335	81,305	5,052
Air Consumption Rate (per min)	0	58	11
Air Consumption Rate (per hour)	0	3,475	665
Air Consumption Rate (per day)	0	83,390	15,955

○ cubic decimeters (L) ◉ cubic feet

The outputs are in units that are familiar either clinicians or engineers

The calculator shows the oxygen and air usage rates per minute, hour, or day

Medical Gas Calculator - Outputs

- **Total Gas Consumption for Duration of Ventilation**
  - Oxygen and air tanks required if no piped oxygen

RESULTS for TANK SYSTEMS (STPD)	High	Median	Low
Required Oxygen H-Tanks per Day (tanks per day)	57	11	1
Required Oxygen H-Tanks per Population Duration of Ventilation (total tanks)	798	138	7
Required Air H-Tanks per Day (tanks per day)	0	12	2
Required Air H-Tanks per Population Duratoin of Ventilation (total tanks)	0	141	23

The total gas consumption over the duration of ventilation is relevant if tanks of compressed gas are required for locations without central plumbing for medical gases

Practical Suggestions

1. **Consider simulation testing**
   - Place running ventilators with test lungs in each zone that might be used for critical care during surge
2. **Turn off oxygen to manual resuscitators until used**
   - Automatic shut-off devices are available
3. **Use minimal FiO_2 for adequate oxygenation**
4. **Reduce use of high flow nasal cannula for oxygen delivery**
5. **Find a way to monitor flow through zone valves**
   - Is it possible to use thermal probes across valves to represent flow?

In addition to estimating gas usage for mechanical ventilation, consider these other practical activities

Additional Resources

American Association for Respiratory Care

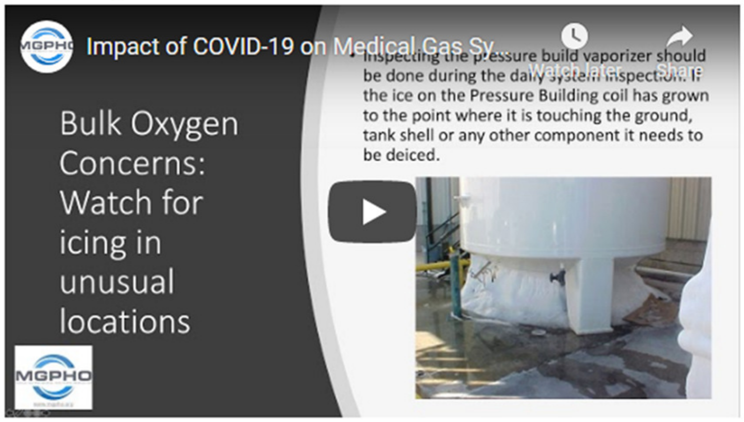
Guidance Document

Additional Ventilators May Pose a Risk to Hospital Gas Systems

https://www.aarc.org/additional-ventilators-may-pose-risk-to-hospital-gas-systems/

Medical Gas Professional Healthcare Organization

Leading through education, we save lives



https://mgpho.org/

MedGas Insights

from BEACONMEDÆS®

Issue 8, April 2020 *Covid; Sizing Medical Gases*

Sizing Medical Gases for Covid 19

https://www.ashe.org/system/files/media/file/2020/04/MedGasSizing-updated.pdf

KAISER PERMANENTE
National Facilities Services
Facilities Strategy Planning & Design

Medical Air and Oxygen Capacity

Medical Air and Oxygen Capacity

April 5, 2020

Edward (Sandy) Renshaw, P.E.
Principal Mechanical Engineer
NFS- FSPD

Phone: 714-329-5402
E-mail: Edward.X.Renshaw@kp.org

https://www.dropbox.com/s/nbh6sitchxzbg36/KP%20White%20Paper%20Medical%20Air%20and%20Oxygen%20Capacity%20v3.pdf?dl=0

The Joint Commission

Maximizing Medical Gas Flow Capacity

SURGING VENTILATOR USAGE DURING THE COVID-19 PANDEMIC MEANS HEALTH CARE FACILITIES NEED TO ENSURE THEIR MEDICAL GAS SUPPLY SYSTEMS CAN DELIVER LARGER AMOUNTS OF OXYGEN AND AIR

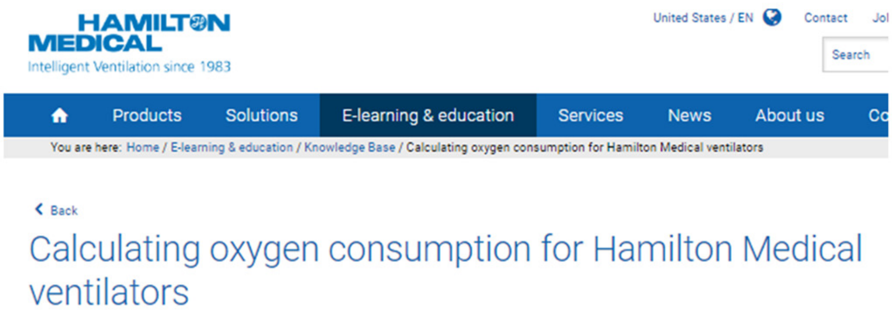
https://www.jcrinc.com/-/media/jcr/jcr-documents/products/consulting/covid-recovery-services/max-medical-gas-ec-news.pdf

CGA
Compressed Gas Association

CGA Industry Toolkit for COVID-19 Response

(Last updated: June 26, 2020)

https://www.cganet.com/resources/cga-covid-19-toolkit/



https://www.hamilton-medical.com/en_US/E-Learning-and-Education/Knowledge-Base/Knowledge-Base-Detail~2020-07-07~Calculating-oxygen-consumption-for-Hamilton-Medical-ventilators~c1b09f7f-3224-45b9-aa12-4cfd37e6d5ff~.html

Take-Home Messages

- **Medical oxygen and air supply systems may not be able to handle the increased usage during emergency surges (eg COVID-19)**
- **Accurate prediction of medical gas consumption during extreme surges requires a combination of both clinical and engineering information**
  - Simple questions to stakeholders will not suffice
  - Create a task force with content experts
    - *Facilities engineers*
    - *Respiratory therapists*
    - *Statistician*

Take-Home Messages

- **A calculator is available to make accurate estimates useful to engineers based on relevant ventilator usage data from clinical experience**
- **Other practical actions should be taken to assure adequate oxygen supplies**
- **Predicting the behavior of complex systems is extremely difficult**
  - Simplified models are tempting but may be misleading
  - This subject requires more study to improve our ability to cope with future surges