Predicting Surge Requirements for Medical Gas Consumption

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Cleveland Clinic
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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
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 medical consumption
  – Misconceptions about data needed
  – Where to get the data
  – How to use the calculators
• 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
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
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
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

Factors to consider:
• Age and condition of system
• Refer to manufacturer of systems for capacities
• Use the following formula to help calculate air consumption in SCFM (note: ensure the dryers are not purging and no timed auto drains activate while gathering data)

\[ \frac{0.55 \times \text{Size of Receiver (in gallons)} \times \Delta p \text{ (difference in the lead unit on/off setting)}}{75} \]

EXAMPLE (note: variables listed in blue):
• Receiver Size – 120 Gallon
• Lead unit on setting – 80 PSIG
• Lead unit off setting – 100 PSIG
• Run time of compressor to go from 80 to 100 PSIG – 75 seconds

\[ \frac{0.55 \times 120 \times 20}{75} = 17.6 \text{ SCFM} \]
Facilities Design – Tolerance Limits

• No standard design procedure for medical gas sizing
  – Tolerance limits set by engineering experience
  – Clinical expectations 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
Crash Course 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
• 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
Classification of Ventilators

• By Application
  – General purpose
  – Homecare/transport
  – Pediatric/neonatal
  – High frequency ventilators
  – Noninvasive ventilators

Covidien PB 540
Classification of Ventilators

• By Application
  – General purpose
  – Homecare/transport
  – Pediatric/neonatal
  – High frequency ventilators
  – Noninvasive ventilators

Dräger Babylog VN500
Classification of Ventilators

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

Sensormedics 3100
Bunnell Life Pulse
Classification of Ventilators

• By Application
  – General purpose
  – Homecare/transport
  – Pediatric/neonatal
  – High frequency ventilators
  – Noninvasive ventilators

Philips Respironics V60
Some Ventilators Use Blowers

Miniature turbine **avoids** use of medical air supply

Noninvasive

Invasive
Unexpected examples

Fitbit’s ventilator gets emergency FDA approval

Ventilation  
Oxygen  
Cough  
Suction  
Nebulization
### Huge variability among ventilators

<table>
<thead>
<tr>
<th>Oxygen Only</th>
<th>Oxygen &amp; Med Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philips Respironics BiPAP V60</td>
<td>GE Carescap R860</td>
</tr>
<tr>
<td>• Max Flow 175 LPM</td>
<td>• Max Flow 160 LPM</td>
</tr>
<tr>
<td>• Low 40, High 87</td>
<td>• Low 35, High 94</td>
</tr>
<tr>
<td>Respiration lsir</td>
<td>Carefusion Anea</td>
</tr>
<tr>
<td>• Max Flow 300 LPM</td>
<td>• Low 20, High 80</td>
</tr>
<tr>
<td>• Low 40, High 90</td>
<td></td>
</tr>
<tr>
<td>Allied Healthcare AutoVent 3000</td>
<td>Carefusion LTV1200</td>
</tr>
<tr>
<td>• Flow listed between 16-48 LPM</td>
<td>• Low 40, High 80</td>
</tr>
<tr>
<td>• Low 40, High 60</td>
<td></td>
</tr>
<tr>
<td>Allied Healthcare EV2000</td>
<td>Tecme Advance</td>
</tr>
<tr>
<td>• Spec says an oxygen D cylinder will last 65 minutes</td>
<td>• Low 41, High 87</td>
</tr>
<tr>
<td>• Low 40, High 87</td>
<td></td>
</tr>
<tr>
<td>Respiration Vision BiPAP</td>
<td>Drager Evita XL</td>
</tr>
<tr>
<td>• Max Flow 120 LPM</td>
<td>• Max Flow 120 LPM</td>
</tr>
<tr>
<td>• Low 50, High 100</td>
<td>• Low 39, High 87</td>
</tr>
<tr>
<td>Trilogy Ventilator</td>
<td>Maquet Servo I</td>
</tr>
<tr>
<td>• Max Flow 200 LPM</td>
<td>• Low 29, High 94</td>
</tr>
<tr>
<td>• Low 40, High 87</td>
<td></td>
</tr>
<tr>
<td>Newport HT70 Transport Ventilator</td>
<td>PB 840</td>
</tr>
<tr>
<td>• Max Flow 100 LPM</td>
<td>• Flow to 200 LPM</td>
</tr>
<tr>
<td>• Low 35, High 90</td>
<td>• Low 35, High 100</td>
</tr>
</tbody>
</table>

- 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
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
Oxygen Delivery Devices

Simple Oxygen Mask
(5-10 L/min)

Non-Rebreathing Mask
(10 - 15 L/min)
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)
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)
Oxygen Metering Devices

**Oxygen Flow Meter**
(0-15 L/min)

**Oxygen Blender**
(2 - 120 L/min)
Crash Course in Statistics
Turning Date Into Information

Summary Data for Distribution

- best point estimate (50th percentile)
- Average is subject to error due to extreme values

Raw Data

<table>
<thead>
<tr>
<th></th>
<th>A</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Ven-Days</td>
</tr>
<tr>
<td>2</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>51</td>
</tr>
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<td>4</td>
<td>47</td>
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<td>5</td>
<td>50</td>
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<td>6</td>
<td>55</td>
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<td>7</td>
<td>59</td>
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<td>8</td>
<td>60</td>
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<td>9</td>
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<td>10</td>
<td>57</td>
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<tr>
<td>11</td>
<td>48</td>
</tr>
<tr>
<td>12</td>
<td>52</td>
</tr>
</tbody>
</table>

Histogram (frequency distribution)

Percentile Plot

- 66 vents in use simultaneously
- 95th Percentile
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 O₂ devices

- **How do we analyze it?**
  - Oxygen usage calculator
Some Misconceptions

- **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 × Tidal Volume
- **What is % O₂ on max flow settings**
  - Inadequate data
  - Better to use O₂ consumption calculator
- **The average respiratory therapist cannot supply the information you need**
  - What you need is a task force and EMR data mining
Some Good Advice

- Beacon Medaes MedGas Insights Issue 8
- Kaiser Permanente Document
- PB 840 Ventilator Calculator
- Run actual flow tests in zone(s) where additional ventilators are expected to be put into use

- Beacon Medaes
  - Point estimates – not applicable for zone usage

- Kaiser Permanente
  - Good distinction between invasive/noninvasive vents vs high flow nasal cannula

- PB 840 calculator
  - Ventilators differ radically in oxygen consumption for same settings: need to consult operator’s manuals

- Run actual flow tests
  - Perhaps the best advice if you can get enough vents for the simulation and know what settings to use
A Procedure for Risk Prediction
Procedure Overview

1. Create list of ICU with number of beds in each unit
2. Obtain medical gas piping data from facilities engineering
3. Understand location of choke points
Oxygen Tanks - Insufficient Supply
Liquid Oxygen
- Insufficient Supply
- Icing
- De-Ice at 50%
**Piping**
- Flow limited by diameter
- Pressure drop is flow dependent

**Risers**
(piping between floors)

### Medical Air – Hospital Mains and Risers

<table>
<thead>
<tr>
<th>Pipe Size</th>
<th>Pressure Drop/100 Ft (PSIG)</th>
<th>Capacity (LPM)</th>
</tr>
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<tbody>
<tr>
<td>1 ¼”</td>
<td>1.02</td>
<td>2,700</td>
</tr>
<tr>
<td>1 ½”</td>
<td>1.02</td>
<td>4,300</td>
</tr>
<tr>
<td>2”</td>
<td>0.64</td>
<td>7,000</td>
</tr>
<tr>
<td>2 ½”</td>
<td>0.60</td>
<td>12,000</td>
</tr>
<tr>
<td>3”</td>
<td>0.53</td>
<td>18,000</td>
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</table>
Zone Valve
- Choke point in system
- Alarms for pressure drop > 5 psi

<table>
<thead>
<tr>
<th>Pipe Size</th>
<th>Pressure Drop/100 Ft (PSIG)</th>
<th>Capacity (LPM)</th>
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</thead>
<tbody>
<tr>
<td>½&quot;</td>
<td>0.96</td>
<td>260</td>
</tr>
<tr>
<td>¾&quot;</td>
<td>1.06</td>
<td>700</td>
</tr>
<tr>
<td>1&quot;</td>
<td>1.04</td>
<td>1,500</td>
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</table>
Calculator - Medical Gas Flow Limitation

<table>
<thead>
<tr>
<th>River Unit</th>
<th>South</th>
<th>Middle</th>
<th>North</th>
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</thead>
<tbody>
<tr>
<td>Number of beds per unit</td>
<td>50</td>
<td>50</td>
<td>50</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Minute Ventilation (LPM)/Ventilator</th>
<th>10</th>
<th>10</th>
<th>10</th>
<th>10</th>
<th>10</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumed Air flow per bed (LPM)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
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<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
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<td></td>
</tr>
</tbody>
</table>

### Medical Air

<table>
<thead>
<tr>
<th>Target Pressure (PSI) at Zone Valve Box/Unit</th>
<th>South</th>
<th>Middle</th>
<th>North</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

### Medical Oxygens

<table>
<thead>
<tr>
<th>Target Pressure (PSI) at Zone Valve Box/Unit</th>
<th>South</th>
<th>Middle</th>
<th>North</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>60</td>
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<td>60</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

### Air Flow

<table>
<thead>
<tr>
<th>South</th>
<th>Middle</th>
<th>North</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of beds in ICU served by each River</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Capacity of Beds that can be served per Med Air River at a</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>Percentage of Beds that can be served per Med Air River at a</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

### Oxygens

<table>
<thead>
<tr>
<th>South</th>
<th>Middle</th>
<th>North</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity of Beds that can be served per Oxygens at a</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>Percentage of Beds that can be served per Oxygens at a</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

https://1drv.ms/x/s!AuFakBJODC3DgeFo4JcevHaMclp5aw?e=X4alo0
Procedure Overview

4. Identify choke points (gas flow limitations calculator)
   a. Enter riser diameter
   b. Enter zone valve pipe diameter
   c. Enter outlet pipe diameter
   d. Calculate
      ▪ % beds supported
      ▪ Outlet pressure at zone valve
      ▪ Outlet pressure at bed site
Step 4a – Calculate Max Riser Capacity

Worst case scenario
All HFNC @ 60 LPM

<table>
<thead>
<tr>
<th>Riser Unit</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>G60</td>
<td>8</td>
</tr>
<tr>
<td>G50</td>
<td>10</td>
</tr>
<tr>
<td>G51</td>
<td>11</td>
</tr>
</tbody>
</table>

Number of beds per unit:

- G60: 8 beds
- G50: 10 beds
- G51: 11 beds

Assumed flow per bed (L/min): 60 LPM

Med Gas

- Pressure (lbs) at Zone Valve Box: 50 lbs
- Riser Pipe Size (inches): 1.25 inches
- Riser served from:
  - South
- Maximum Capacity in Riser (LPM):
  - G60: 2700 LPM
  - G50: 2700 LPM
  - G51: 2700 LPM
### Step 4b – Calculate Zone Valve Capacity

#### Worst case scenario
All HFNC @ 60 LPM

<table>
<thead>
<tr>
<th>Unit</th>
<th>G60</th>
<th>G50</th>
<th>G51</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of beds per unit</td>
<td>8</td>
<td>10</td>
<td>11</td>
</tr>
</tbody>
</table>

| Assumed flow per bed (L/min) | 60 |

#### Medical Air
- **Target Pressure (PSI) at Zone Valve Box Inlet**: 50, 50, 50
- **Riser Pipe Size (inches)**: 1.25, 1.25, 1.25
- **Riser served from**: South, South, South
- **Maximum Capacity in Riser (LPM)**: 2700, 2700, 2700
- **Maximum Number of Beds per Riser**: 270, 270, 270
- **Zone Valve Pipe Size (inches)**: 0.75, 0.75, 0.75
- **Maximum Capacity through Zone Valve (LPM - 1.06 PSI pressure drop)**: 700, 700, 700

| **Maximum Number of Beds per Zone Valve from Riser** | 70 | 70 | 70 |
| **Outlet Pipe Size (inches)** | 0.5 | 0.5 | 0.5 |
| **Maximum Capacity Through Outlet Pipe (LPM - 1.06 PSI pressure drop)** | 260 | 260 | 260 |
| **Maximum Number of Beds per Outlet Pipe from Zone Valve** | 26 | 26 | 26 |
### Step 4c – Device Capacity

#### Determine risk of zone alarm

<table>
<thead>
<tr>
<th>Number of beds in Unit</th>
<th>8</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total flow at assumed flow/bed</td>
<td>480</td>
<td>600</td>
<td>660</td>
</tr>
<tr>
<td>Outlet pressure (PSIG) at Zone Valve</td>
<td>49</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>Outlet pressure (PSIG) at bed</td>
<td>47</td>
<td>47</td>
<td>46</td>
</tr>
</tbody>
</table>

Percentage of Beds supplied at 49 PSI: 325%, 260%, 236%
# Calculator – Medical Gas Consumption

**Note:** Some ventilators have blowers and do not consume air from the wall outlet.

**Abbreviations:**
- BTPS = body temperature and pressure saturated with water vapor
- STPD = standard temperature and pressure dry
- DOV = duration of ventilation per patient
- L (liter) = $\text{dm}^3$ (cubic decimeter)

### Medical Gas Consumption Calculator

**Created by Prof. Robert L. Cullen, MPH, BCT-MP, PAARC 2020**

### BASIC ASSUMPTIONS (per ventilator)

<table>
<thead>
<tr>
<th>Unit</th>
<th>High</th>
<th>Median</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barometric Pressure</td>
<td>mmHg</td>
<td>760</td>
<td></td>
</tr>
<tr>
<td>Atmospheric Temperature</td>
<td>°C</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Minute Ventilation</td>
<td>L/min</td>
<td>12.0</td>
<td>7.8</td>
</tr>
<tr>
<td>Minute Ventilation</td>
<td>L/min</td>
<td>9.9</td>
<td>6.5</td>
</tr>
<tr>
<td>FiO₂</td>
<td></td>
<td>1.0</td>
<td>0.60</td>
</tr>
<tr>
<td>Oxygen Flow</td>
<td>L/min</td>
<td>3.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Oxygen Flow</td>
<td>L/min</td>
<td>695</td>
<td>192</td>
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<tr>
<td>Oxygen Flow</td>
<td>L/min</td>
<td>14,276</td>
<td>4,405</td>
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<tr>
<td>Air Flow</td>
<td>L/min</td>
<td>0.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Air Flow</td>
<td>L/min</td>
<td>0</td>
<td>197</td>
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<tr>
<td>Air Flow</td>
<td>L/min</td>
<td>0</td>
<td>4,723</td>
</tr>
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### CRITICAL ASSUMPTIONS

<table>
<thead>
<tr>
<th>Unit</th>
<th>High</th>
<th>Median</th>
<th>Low</th>
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<tbody>
<tr>
<td>Daily Ventilator Census</td>
<td>units</td>
<td>800</td>
<td>500</td>
</tr>
<tr>
<td>Duration of Ventilation</td>
<td>days</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Total Vent-dags</td>
<td>Vent-dags</td>
<td>11,200</td>
<td>6,000</td>
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<tr>
<td>Capacity of Oxygen H-Tanks</td>
<td>L/tank</td>
<td>7,080</td>
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<tr>
<td>Capacity of Air H-Tanks</td>
<td>L/tank</td>
<td>7,080</td>
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</table>

### RESULTS for PIPING SYSTEMS (STPD)

<table>
<thead>
<tr>
<th>Unit</th>
<th>High</th>
<th>Median</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen Consumption Rate/min</td>
<td>cubic feet</td>
<td>280</td>
<td>56</td>
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<tr>
<td>Oxygen Consumption Rate/hr</td>
<td>cubic feet</td>
<td>16,808</td>
<td>3,388</td>
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<td>Oxygen Consumption Rate/day</td>
<td>cubic feet</td>
<td>403,335</td>
<td>81,305</td>
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<tr>
<td>Air Consumption Rate/min</td>
<td>cubic feet</td>
<td>0</td>
<td>56</td>
</tr>
<tr>
<td>Air Consumption Rate/hr</td>
<td>cubic feet</td>
<td>0</td>
<td>3,475</td>
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<tr>
<td>Air Consumption Rate/day</td>
<td>cubic feet</td>
<td>0</td>
<td>83,390</td>
</tr>
</tbody>
</table>

### RESULTS for TANK SYSTEMS (STPD)

<table>
<thead>
<tr>
<th>Unit</th>
<th>High</th>
<th>Median</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Oxygen H-Tanks per Day</td>
<td>tanks</td>
<td>57</td>
<td>11</td>
</tr>
<tr>
<td>Required Oxygen H-Tanks per Population Duration of Ventilation</td>
<td>tanks</td>
<td>798</td>
<td>138</td>
</tr>
<tr>
<td>Required Air H-Tanks per Day</td>
<td>tanks</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Required Air H-Tanks per Population Duration of Ventilation</td>
<td>tanks</td>
<td>0</td>
<td>141</td>
</tr>
</tbody>
</table>

https://1drv.ms/x/s!AuFakBJODC3DgeFm6t2Pc4mxBHcg-g?e=wCysro
5. Create oxygen use budget (medical gas consumption calculator)
   a. Enter estimates for FiO$_2$ and ventilator census
      - Can also be used for HFNC instead
   b. Enter average duration of ventilation
   c. Enter capacity of compressed oxygen tanks
   d. Calculate
      - Oxygen consumption
      - Air consumption
      - Required compressed gas tanks
# Step 5a – Recalculate Oxygen Budget

## BASIC ASSUMPTIONS (per ventilator) [units]

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Median</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barometric Pressure [mmHg]</td>
<td>760</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric Temperature [°C]</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minute Ventilation [L/min/vent; BTPS]</td>
<td>12.0</td>
<td>7.8</td>
<td>5.0</td>
</tr>
<tr>
<td>Minute Ventilation [L/min/vent; STPD]</td>
<td>9.9</td>
<td>6.5</td>
<td>4.1</td>
</tr>
<tr>
<td>FiO₂</td>
<td>1.0</td>
<td>0.60</td>
<td>0.4</td>
</tr>
<tr>
<td>Oxygen Flow [L/min/vent; STPD]</td>
<td>9.9</td>
<td>3.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Oxygen Flow [L/hr/vent; STPD]</td>
<td>595</td>
<td>192</td>
<td>60</td>
</tr>
<tr>
<td>Oxygen Flow [L/d/vent; STPD]</td>
<td>14,276</td>
<td>4,605</td>
<td>1,431</td>
</tr>
<tr>
<td>Air Flow [L/min/vent; STPD]</td>
<td>0.0</td>
<td>3.3</td>
<td>3.1</td>
</tr>
<tr>
<td>Air Flow [L/hr/vent; STPD]</td>
<td>0</td>
<td>197</td>
<td>188</td>
</tr>
<tr>
<td>Air Flow [L/d/vent; STPD]</td>
<td>0</td>
<td>4,723</td>
<td>4,518</td>
</tr>
</tbody>
</table>

## CRITICAL ASSUMPTIONS [units]

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Median</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Ventilator Census [vents]</td>
<td>800</td>
<td>500</td>
<td>100</td>
</tr>
<tr>
<td>Duration of Ventilation [days]</td>
<td>14</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Total vent-days [vent-days]</td>
<td>11,200</td>
<td>6,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Capacity of Oxygen H-Tanks [L/tank]</td>
<td>7,080</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity of Air H-Tanks [L/tank]</td>
<td>7,080</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Step 5b – Recalculate Oxygen Budget

#### RESULTS for PIPING SYSTEMS (STPD)

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Median</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oxygen Consumption Rate/min</strong></td>
<td>280</td>
<td>56</td>
<td>4</td>
</tr>
<tr>
<td><strong>Oxygen Consumption Rate/hr</strong></td>
<td>16,806</td>
<td>3,388</td>
<td>211</td>
</tr>
<tr>
<td><strong>Oxygen Consumption Rate/day</strong></td>
<td>403,335</td>
<td>81,305</td>
<td>5,052</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Median</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air Consumption Rate/min</strong></td>
<td>0</td>
<td>58</td>
<td>11</td>
</tr>
<tr>
<td><strong>Air Consumption Rate/hour</strong></td>
<td>0</td>
<td>3,475</td>
<td>665</td>
</tr>
<tr>
<td><strong>Air Consumption Rate/day</strong></td>
<td>0</td>
<td>83,390</td>
<td>15,955</td>
</tr>
</tbody>
</table>

© cubic decimeters (L)  © cubic feet

#### RESULTS for TANK SYSTEMS (STPD)

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Median</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Required Oxygen H-Tanks per Day</strong></td>
<td>57</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td><strong>H-Tanks per Population Duration of Ventilation</strong></td>
<td>798</td>
<td>138</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Median</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Required Air H-Tanks per Day</strong></td>
<td>0</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td><strong>H-Tanks per Population Duration of Ventilation</strong></td>
<td>0</td>
<td>141</td>
<td>23</td>
</tr>
</tbody>
</table>
Alternative Calculator
https://opencriticalcare.org/oxygen-supply-demand-calculator/

Step 1. Select Oxygen Source (not sure?)
Select facility's most common source of oxygen
Oxygen Plant (PSA)
Select manufacturer and model

Step 2. Enter Total Supply
Enter the maximum volume of oxygen your generator can produce

0 cubic meters per hour

Enter the average number of hours per day the generator can safely and reliably run
12 hours/day

Cylinders vs. Oxygen Pipes
Oxygen cylinders

Step 3. Enter Patient Need

ESTIMATE FOR ME
Modeled Ward Scenario

I WILL ENTER NUMBER OF PATIENTS & FLOW RATES

Total # patients requiring oxygen
Severity of hypoxemia in modeled scenario

Supply will last
hours 0 days 0

Total Supply per 24h period (Liters)
0

Consumption per Day (Liters)
0

Tanks per Day
0

<table>
<thead>
<tr>
<th># Patients</th>
<th>Delivery Device</th>
<th>Flow Rate (LPM)</th>
<th>Liters per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 50%</td>
<td>Nasal Cannula</td>
<td>3</td>
<td>120,960</td>
</tr>
<tr>
<td>3 0%</td>
<td>Facemask</td>
<td>8</td>
<td>34,560</td>
</tr>
<tr>
<td>3 0%</td>
<td>Nonrebreather</td>
<td>15</td>
<td>64,800</td>
</tr>
<tr>
<td>7 14%</td>
<td>Ventilator</td>
<td>18</td>
<td>181,440</td>
</tr>
<tr>
<td>8 10%</td>
<td>High Flow Nasal Cannula 100%</td>
<td>40</td>
<td>460,800</td>
</tr>
<tr>
<td>1 2%</td>
<td>CPAP or NIPPV</td>
<td>20</td>
<td>28,800</td>
</tr>
</tbody>
</table>
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 \( \text{FiO}_2 \) 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?
Additional Resources
Additional Ventilators May Pose a Risk to Hospital Gas Systems

Medical Gas Professional Healthcare Organization
Leading through education, we save lives

Impact of COVID-19 on Medical Gas Systems

Bulk Oxygen Concerns:
Watch for icing in unusual locations

Inspecting the pressure build vaporizer should be done during the daily system inspection. If the ice on the Pressure Building coil has grown to the point where it is touching the ground, tank shell or any other component it needs to be deiced.

https://mgpho.org/
Sizing Medical Gases for Covid 19

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

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.

CGA Industry Toolkit for COVID-19 Response

(Last updated: June 26, 2020)

Calculating oxygen consumption for Hamilton Medical ventilators

This Lecture

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

https://1drv.ms/p/s!AuFakBJODC3DgqYHpES2jibCGaioTA?e=PCNHHHz
Take-Home Messages

• Medical oxygen and air supply systems may not be able to handle the increased usage during emergency surges (e.g., COVID-19)

• Accurate prediction of medical gas use 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

• Calculators are 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