Yeast Flatulence or Eructation (CO$_2$):
What are the effects and how to control it
Dave Huizen, CIH

Professor of Occupational Safety and Health

Grand Valley State University
301 Fulton St W
Grand Rapids MI 49504
huizend@gvsu.edu
Yeast Flatulence or Eructation (CO$_2$):

Why this study?

- Tremendous growth in small brewing operations
- Safety and Health – An after thought?
- Little or no data on CO$_2$ exposures in breweries
- Little data on effects of CO$_2$ at levels < 10,000 PPM
- Curious on the impact of combined risk on health
Yeast Flatulence or Eructation ($CO_2$):

What are the takeaways of this presentation

- What is Combined Risk
- What $CO_2$ levels are found in different sized breweries
- What variables can impact those $CO_2$ levels
- What effect do lower $CO_2$ levels have on heart rate
- What are effective control measures to reduce combined exposure
Combined Risk Exposure
Yeast Flatulence or Eructation ($CO_2$):

What is Combined Exposure Risk?

- Multiple exposures causing the same health effect
- The increase in combined risk is greater than one exposure at a time
- Could be additive, multiplicative, or synergistic
- Could be occupational, environmental, or community exposures.
Risk #1
Carbon Dioxide

What do we know about CO₂

- Odorless – acidic smell at high concentrations (carbonic acid formation)
- Colorless
- Slightly pungent acid taste
- Non-flammable
- Density – 1.98 kgs/m³ - 1.67X greater than air
- Concentration in ambient air ~400 PPM
- Produced by biological methods or combustion
- Variety of uses – photosynthesis to refrigeration
# Risk #1
**Carbon Dioxide**

## Current Exposure levels to CO₂
- OSHA / ACGIH 8 hour – 5000 PPM
- ACGIH TLV STEL* – 30,000 PPM
- NIOSH IDLH – 40,000 PPM

* 15 minute exposure limit

---

## Known Health Effects of CO₂

<table>
<thead>
<tr>
<th>Concentration of CO₂ (PPM)</th>
<th>Health Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,000 to 5,000 PPM</td>
<td>Slight Increase in Respiration</td>
</tr>
<tr>
<td>5,000 PPM</td>
<td>5% Increase in Respiration</td>
</tr>
<tr>
<td>10,000 PPM</td>
<td>Fatigue, Anxiety, Loss of Energy</td>
</tr>
<tr>
<td>20,000 PPM</td>
<td>50% Increase in Respiration, Severe Headache</td>
</tr>
<tr>
<td>50,000 PPM</td>
<td>Violent panting and fatigue to the point of exhaustion merely from respiration &amp; severe headache. Prolonged exposure at this level could result in irreversible health effects</td>
</tr>
<tr>
<td>90,000 PPM</td>
<td>Death in 5 Minutes</td>
</tr>
</tbody>
</table>
Low level CO2 Effects from Literature

- Increased respiration rate
- Increased heart rate
- Headache
- Cognitive impairment
- Increased fatigue
Risk #2
Biomechanical Stress

Health effects of Ergonomic Stressors
- Overexertion injuries
- Musculoskeletal disorders
- Increased physical exertion
- Increased heart rate
- Increased fatigue

Risk #3
Workload

Health Effects of Workload
- Increased stress
- Headaches
- Increased heart rate
- Increased fatigue
Methodology
Methodology: General

Data Gathering: Who and Where

- Small, Medium, and Large “Craft” Breweries
  - Walk around at different days and times
- Three jobs tasks evaluated
  - Cellar
  - Canning/Packaging
  - Barrel Filling
Methodology:
CO2 and Heart Rate Data Collection

Video Exposure Monitoring (VEM™)

- Video Feed
  - VEM system wired camera
  - Garman VIRB
- CO2 Sensor
  - CO2 Meter - MinIR 5% CO2 Smart LED Sensor (NDIR)
- HeartRate Sensor
  - Garmin wrist fitness tracker
- Raspberry PI computer
- Proprietary software
Methodology:
CO2 and Heart Rate Data Collection
Biomechanical Risk Factor

- Rapid Entire Body Assessment - REBA

Methodology:
Biomechanical Stress
Methodology: Workload

NASA – Task Load Index (TLX)

- Six Subscales
- Collected via I-Pad

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental Demand</td>
<td>How much mental activity was required? Was the task easy or demanding, simple or complex?</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>How much physical activity was required? Was the task easy or demanding?</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>How much time pressure did you feel due to the pace of the task? Was the pace slow or rapid?</td>
</tr>
<tr>
<td>Overall Performance</td>
<td>How successful were you in performing the task and how satisfied were you with your performance?</td>
</tr>
<tr>
<td>Frustration Level</td>
<td>How irritated, stressed, or annoyed were you versus relaxed, content or complacent during this task?</td>
</tr>
<tr>
<td>Effort</td>
<td>How hard did you have to work (mentally and physically) to accomplish your level of performance?</td>
</tr>
</tbody>
</table>
Results
Phase 1 – What Are the CO₂ Levels Found in Different Sized Breweries
## Brewery Demographics

<table>
<thead>
<tr>
<th></th>
<th>Brewery</th>
<th>A (Small)</th>
<th>B (Medium)</th>
<th>C (Large)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual Production</strong></td>
<td><strong>Volume</strong></td>
<td>5000 Barrels (bbls)</td>
<td>13,000 bbls</td>
<td>680,000 bbls</td>
</tr>
<tr>
<td><strong>Brewery Physical</strong></td>
<td><strong>Size</strong></td>
<td>5200 ft²</td>
<td>11,000 ft²</td>
<td>133,500 ft²</td>
</tr>
<tr>
<td><strong>Amount Active</strong></td>
<td><strong>Fermentation</strong></td>
<td>180-250 bbls</td>
<td>600 – 660 bbls</td>
<td>600 – 2800 bbls*</td>
</tr>
<tr>
<td></td>
<td><strong>during sampling</strong></td>
<td>periods</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Speed of</strong></td>
<td><strong>Packaging Lines</strong></td>
<td>32 cans/minute</td>
<td>50 bottles per minute</td>
<td>120-750 can/minute</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 cans per minute</td>
<td></td>
<td>450 bottles/minute</td>
</tr>
</tbody>
</table>

*Note: * denotes an estimated range.
# Overall CO₂ Level In Craft Breweries by Size

<table>
<thead>
<tr>
<th>Brewery Size</th>
<th>Arithmetic Mean (ppm)</th>
<th>Standard Deviation (ppm)</th>
<th>95&lt;sup&gt;th&lt;/sup&gt; Percentile Point Estimate (ppm)</th>
<th>UTL&lt;sub&gt;95%,95%&lt;/sub&gt; (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>2710</td>
<td>652</td>
<td>3952</td>
<td>4470</td>
</tr>
<tr>
<td>Medium</td>
<td>2540</td>
<td>880</td>
<td>4509</td>
<td>5510</td>
</tr>
<tr>
<td>Large</td>
<td>4510</td>
<td>2250</td>
<td>8756</td>
<td>10800</td>
</tr>
</tbody>
</table>

![Mean of CO₂ Level (ppm) by Brewery Size](chart.png)
Overall CO$_2$ Levels by Day and Time

Mean CO2 Level (ppm) by Day of the Week

<table>
<thead>
<tr>
<th>Day of the Week</th>
<th>Mean CO2 Level (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MONDAY/TUESDAY</td>
<td>3,227</td>
</tr>
<tr>
<td>WEDNESDAY</td>
<td>3,685</td>
</tr>
<tr>
<td>THURSDAY/FRIDAY</td>
<td>3,146</td>
</tr>
</tbody>
</table>

Mean CO2 Level (ppm) by Time of Day

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Mean CO2 Level (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MORNING</td>
<td>3,678</td>
</tr>
<tr>
<td>MIDDAY</td>
<td>3,363</td>
</tr>
<tr>
<td>EVENING</td>
<td>2,955</td>
</tr>
</tbody>
</table>
Overall CO2 Levels By Brewery Area

Mean CO2 Level (ppm) by Brewery Area*

<table>
<thead>
<tr>
<th>Brewery Area</th>
<th>Mean CO2 Level (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CELLAR</td>
<td>3,947</td>
</tr>
<tr>
<td>BREWING</td>
<td>2,803</td>
</tr>
<tr>
<td>PACKAGING</td>
<td>3,447</td>
</tr>
<tr>
<td>ALL OTHER AREAS</td>
<td>3,041</td>
</tr>
</tbody>
</table>
Small Brewery CO\textsubscript{2} Levels by Day and Time

Mean CO\textsubscript{2} Exposure by Day of the Week

- Monday/Tuesday: 2571
- Wednesday: 3094
- Thursday/Friday: 2422

Mean CO\textsubscript{2} Exposure by Time of Day *

- Morning: 2534
- Midday: 3019
- Evening: 2261
# Small Brewery CO2 Levels By Brewery Area

<table>
<thead>
<tr>
<th>Brewery Area</th>
<th>Mean CO2 Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellar</td>
<td>2672</td>
</tr>
<tr>
<td>Brewing</td>
<td>2734</td>
</tr>
<tr>
<td>Packaging</td>
<td>2770</td>
</tr>
<tr>
<td>All Other Areas</td>
<td>2794</td>
</tr>
</tbody>
</table>
Medium Brewery CO₂ Levels by Day and Time

Mean CO2 Exposure by Day of the Week

- Monday/Tuesday: 2441
- Wednesday: 2553
- Thursday/Friday: 1785

Mean CO2 Exposure by Time of Day *

- Morning: 2699
- Midday: 2769
- Evening: 1785
Medium Brewery CO2 Levels By Brewery Area

Mean CO2 Exposure by Brewery Area

- Cellar: 2496
- Brewing: 2235
- Packaging: 2505
- All Other Areas: 2272
Large Brewery CO$_2$ Levels by Day and Time

Mean CO2 Exposure by Day of the Week

<table>
<thead>
<tr>
<th>Day of the Week</th>
<th>Mean CO2 Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday/Tuesday</td>
<td>4289</td>
</tr>
<tr>
<td>Wednesday</td>
<td>4655</td>
</tr>
<tr>
<td>Thursday/Friday</td>
<td>3337</td>
</tr>
</tbody>
</table>

Mean CO2 Exposure by Time of Day

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Mean CO2 Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>4819</td>
</tr>
<tr>
<td>Midday</td>
<td>3425</td>
</tr>
<tr>
<td>Evening</td>
<td>4037</td>
</tr>
</tbody>
</table>
### Large Brewery CO2 Levels By Brewery Area

<table>
<thead>
<tr>
<th>Area</th>
<th>Mean CO2 Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellar</td>
<td>5974</td>
</tr>
<tr>
<td>Brewing</td>
<td>3036</td>
</tr>
<tr>
<td>Packaging</td>
<td>4378</td>
</tr>
<tr>
<td>All Other Areas</td>
<td>3355</td>
</tr>
</tbody>
</table>
Phase 2 – Do Lower Levels of CO2 Effect a Brewer’s Heart Rate
Brewery Mean CO2 Levels and REBA Score by Job Task

**CO2 Level By Job Task**
- Barrel Filling: 5046
- Canning: 8813
- Cellar: 5547

**REBA Score By Job Task**
- Barrel Filling: 5.2
- Canning: 1.75
- Cellar: 2.3
Brewery Mean CO2 Levels and REBA Score by Job Task

**NASA TLX By Job Task**
- Barrel Filling: 68
- Canning: 59
- Cellar: 55.1

**Percent Heart Rate Increase By Job Task**
- Barrel Filling: 28.8
- Canning: 30.4
- Cellar: 25.9
Barrel Filling Mean Percent Heart Rate increase By CO2 Concentration
Canning Mean Percent Heart Rate increase By CO2 Concentration

![Graph showing the relationship between CO2 concentration and mean percent heart rate increase. The x-axis represents different CO2 levels (0-5000 PPM, 5001-7500 PPM, 7501-10,000 PPM, >10,000 PPM), and the y-axis represents mean percent HR. Error bars indicate the 95% CI.]

Error Bars: 95% CI
Cellar Mean Percent Heart Rate increase By CO2 Concentration

- CO2 Level:
  - 0 - 5000 PPM
  - 5001 - 7500 PPM
  - 7501 - 10,000 PPM
  - > 10,000 PPM

Error Bars: 95% CI
Phase 3 – Control Evaluation
Controls Implemented for Each Job Task Evaluated

- New Barrel Filler
- Canning Line Dilution Ventilation
- Cellar Extraction Ventilation
Barrel Filling Control Evaluation

#CraftBrewersCon
## Barrel Filling Control Evaluation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre Control n=250</th>
<th>Post-Control n=1162</th>
<th>t</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Concentration</td>
<td>3927</td>
<td>5808</td>
<td>-22.51</td>
<td>&lt; 0.001</td>
<td>0.79</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>98.73</td>
<td>88.36</td>
<td>10.58</td>
<td>&lt; 0.001</td>
<td>0.29</td>
</tr>
<tr>
<td>Percent Heart Rate Increase</td>
<td>32.75</td>
<td>24.82</td>
<td>11.21</td>
<td>&lt; 0.001</td>
<td>0.49</td>
</tr>
<tr>
<td>REBA Score</td>
<td>5.057</td>
<td>1.687</td>
<td>50.17</td>
<td>&lt; 0.001</td>
<td>0.93</td>
</tr>
<tr>
<td>NASA TLX</td>
<td>58.33</td>
<td>44.33</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Canning Filler Control Evaluation

#CraftBrewersCon
Canning Filler
Control
Evaluation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre Control n = 656</th>
<th>Post-Control n = 929</th>
<th>t</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Concentration</td>
<td>9273</td>
<td>7493</td>
<td>16.03</td>
<td>&lt; 0.001</td>
<td>0.41</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>104.0</td>
<td>92.42</td>
<td>22.33</td>
<td>&lt; 0.001</td>
<td>0.55</td>
</tr>
<tr>
<td>Percent Heart Rate Increase</td>
<td>37.72</td>
<td>30.17</td>
<td>22.18</td>
<td>0.005</td>
<td>0.52</td>
</tr>
<tr>
<td>REBA Score</td>
<td>1.484</td>
<td>1.662</td>
<td>-2.83</td>
<td>&lt; 0.001</td>
<td>0.07</td>
</tr>
<tr>
<td>NASA TLX</td>
<td>50</td>
<td>50</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
## Cellar Control Evaluation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre Control n = 1338</th>
<th>Post-Control n = 1520</th>
<th>t</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Concentration</td>
<td>5780</td>
<td>7783</td>
<td>-11.93</td>
<td>&lt; 0.001</td>
<td>0.27</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>90.09</td>
<td>86.80</td>
<td>8.595</td>
<td>&lt; 0.001</td>
<td>0.16</td>
</tr>
<tr>
<td>Percent Heart Rate</td>
<td>28.12</td>
<td>25.27</td>
<td>9.325</td>
<td>&lt; 0.001</td>
<td>0.17</td>
</tr>
<tr>
<td>REBA Score</td>
<td>2.97</td>
<td>2.01</td>
<td>10.06</td>
<td>&lt; 0.001</td>
<td>0.19</td>
</tr>
<tr>
<td>NASA TLX</td>
<td>60.67</td>
<td>55.67</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Conclusions
Levels of CO\textsubscript{2} in breweries can exceed legal and recommended exposure limits for 8 hours in large and mid-sized breweries.

The cellar and packaging areas of a brewery are of most concern when addressing CO\textsubscript{2} exposures.

The production cycle on a daily basis affects CO\textsubscript{2} levels in small and Mid-Sized Breweries

The more areas are separated in a brewery the greater the CO\textsubscript{2} exposures.

CO\textsubscript{2} exposure levels are dependent on square footage, Fermentation capacity, and production levels.
Workload, Biomechanical Stressors, and CO₂ Exposure Levels Effect on Heart Rate

Conclusions

• Workload had an impact on the barrel filling task (especially the physical demand subscale).

• Biomechanical stressors had the largest impact on heart rate in the barrel filling task.

• Rising Levels of CO₂ had the largest impact on heart rate in the cellar.

• Consistently high levels of CO₂ in the canning filler task had the largest impact on heart rate in any of the three job tasks evaluated.

• The exact contribution of each stressor on heart rate is unknown.
Conclusions

• Ventilation and work station redesign can be effective in reducing heart rates in brewers to reduce fatigue.

• The redesign of tasks with high biomechanical stress makes a large impact on brewer’s heart rate and fatigue.

• Dilution ventilation is effective in areas where work stations are fixed.

• Dilution ventilation is limited by brewery ambient air concentrations.

• Extraction ventilation has limitations in application.
Effectiveness of Controls

Other Controls to Consider

- Push – Pull Ventilation
- Extraction and High Gravity Fermentations
- Piping CO\textsubscript{2} out of Building
- Dedicated line for Fermenter Evacuations
- CO\textsubscript{2} recovery systems
- Raise items to move to waist level
- Eliminate reaching above shoulder level and away from your body
Acknowledgements

• Brewery Vivant – Grand Rapids
• Saugatuck Brewing – Douglas
• Founders Brewing Company – Grand Rapids
• Cody Green – Founders
• Dr. Jim McGlothlin and Kyle Fischer – VEM Systems Developers
Questions

Contact Information:
Dave Huizen
huizend@gvsu.edu
616-331-5596