Part II: Best Practices for Reducing Fugitive Emissions from Ammonia Refrigeration Systems used in the Food and Beverage Sector

Douglas Reindl, Ph.D., P.E., Professor & Director
Marc Claas, Researcher
John Davis, P.E. Researcher
Todd Jekel, Ph.D., P.E., Scientist
Jake Grayless, Undergraduate Research Intern

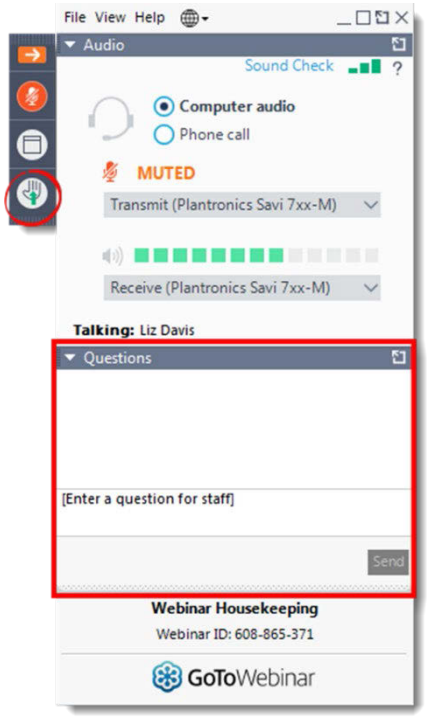
Industrial Refrigeration Consortium
University of Wisconsin-Madison

College of Engineering
UNIVERSITY OF WISCONSIN–MADISON

Webinar Housekeeping

- Please feel free to chat your questions in during the presentation and we will have time at the end to answer

- During Q&A, two options to submit questions:
  - Click the “Raised Hand” icon and we will unmute you to ask your question verbally.
  - Type your question into the Questions box in the Control Panel.



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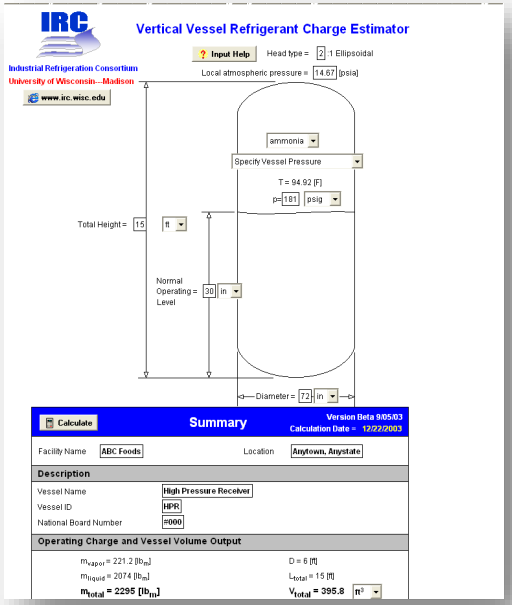
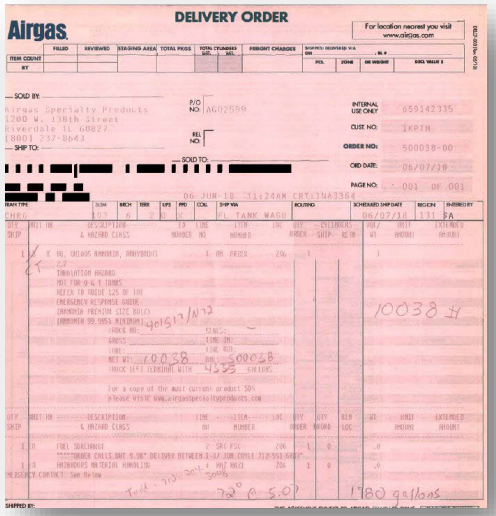
Reducing fugitive emissions

- Goal: reduce fugitive emissions from ammonia refrigeration systems
  - Basics of refrigerant inventory calculations
  - Application of the inventory determination with the *Dynamic Charge Calculation Tool*
  - RAGAGEP associated with logging refrigerant losses/additions and emphasizing ammonia specifications for topping-off refrigerant in ammonia systems

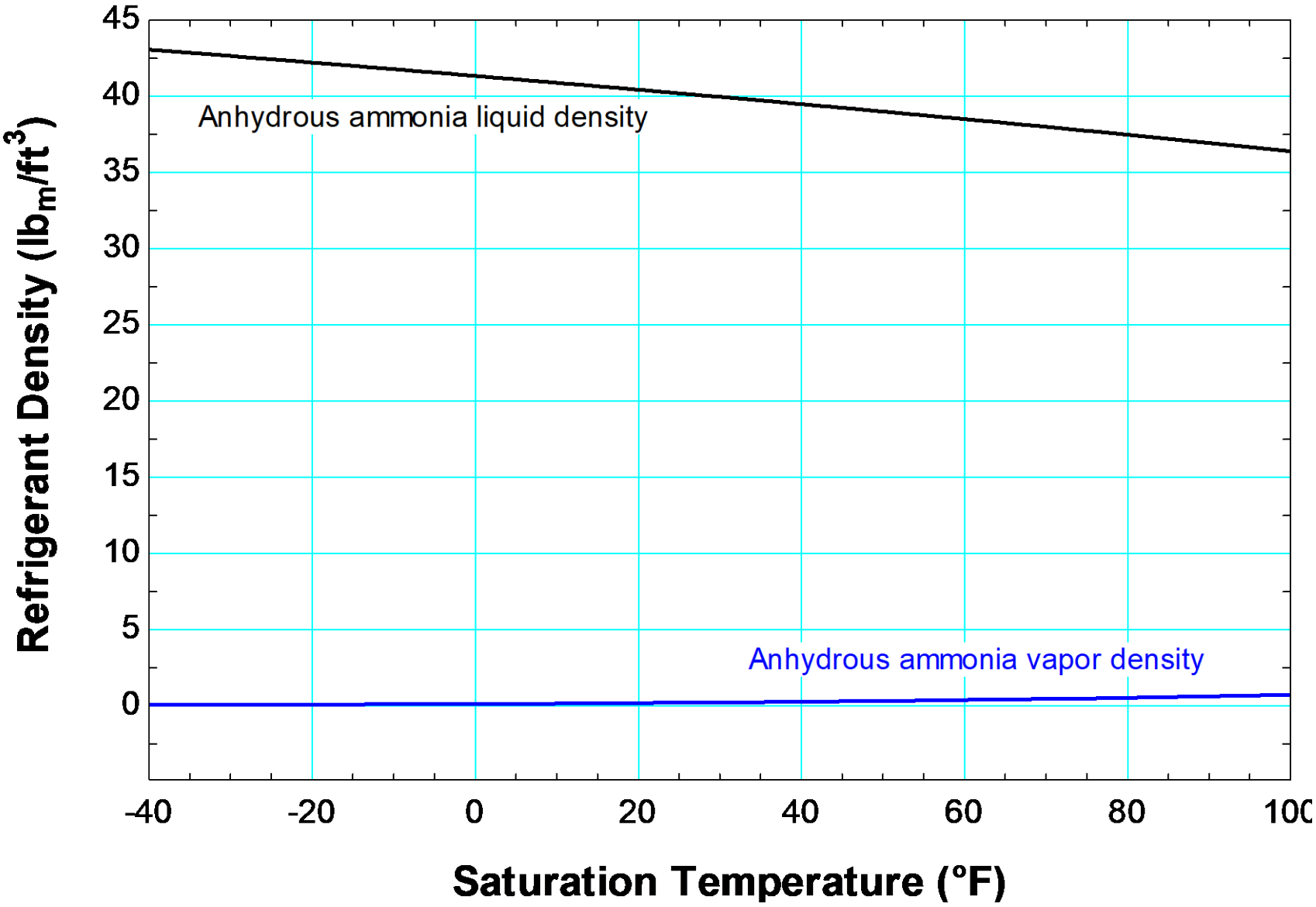
Approaches to determine refrigeration system refrigerant inventory

1. Engineering calculations
2. Material receipts (new facilities)
3. Gravimetric (requires a complete system pump-down)

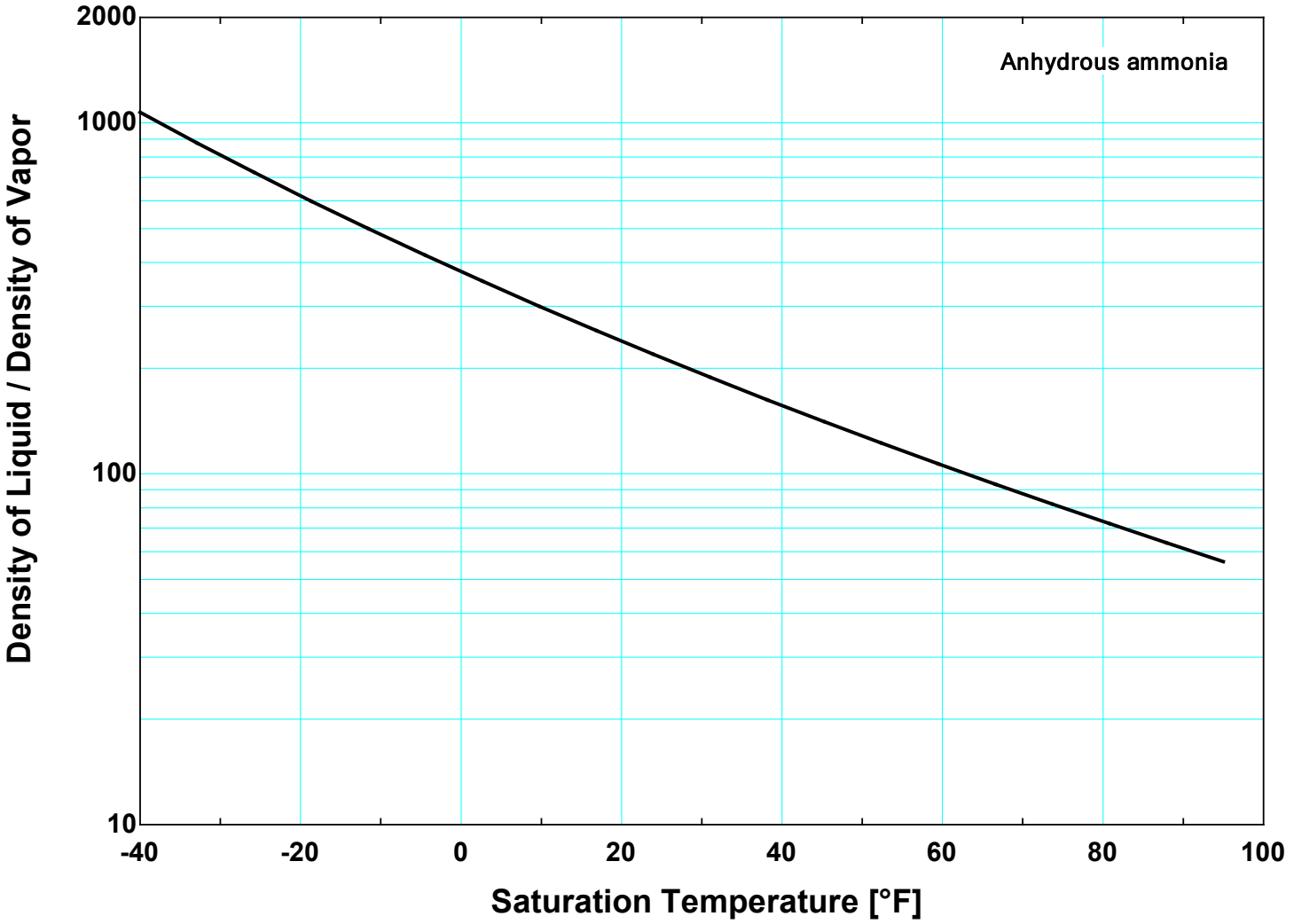




Density characteristic, ammonia



Ratio of liquid to vapor density, ammonia



Focus on quantifying components with liquid-phase ammonia.

Places to look for ammonia

- **Cold liquid**
  - Vessels: low temp. recirculators, surge drums, intercoolers
  - Piping: pumped liquid lines
  - Heat exchangers: flooded evaporators (chillers and air-cooling evaporators), overfed evaporators, DX evaporators
- **Warm liquid**
  - Vessels: high-pressure receivers, controlled-pressure receivers, thermosiphon pilot receivers
  - Piping: high-pressure liquid, subcooled high-pressure liquid
  - Heat exchangers: condensers, oil coolers

Refrigeration system inventory calculation

1. Determine those locations throughout the system with liquid-phase ammonia
2. Establish the volume of liquid ammonia residing in those component locations
3. Mass = volume x density
4. Sum individual component inventory for system total

Vessel inventory considerations

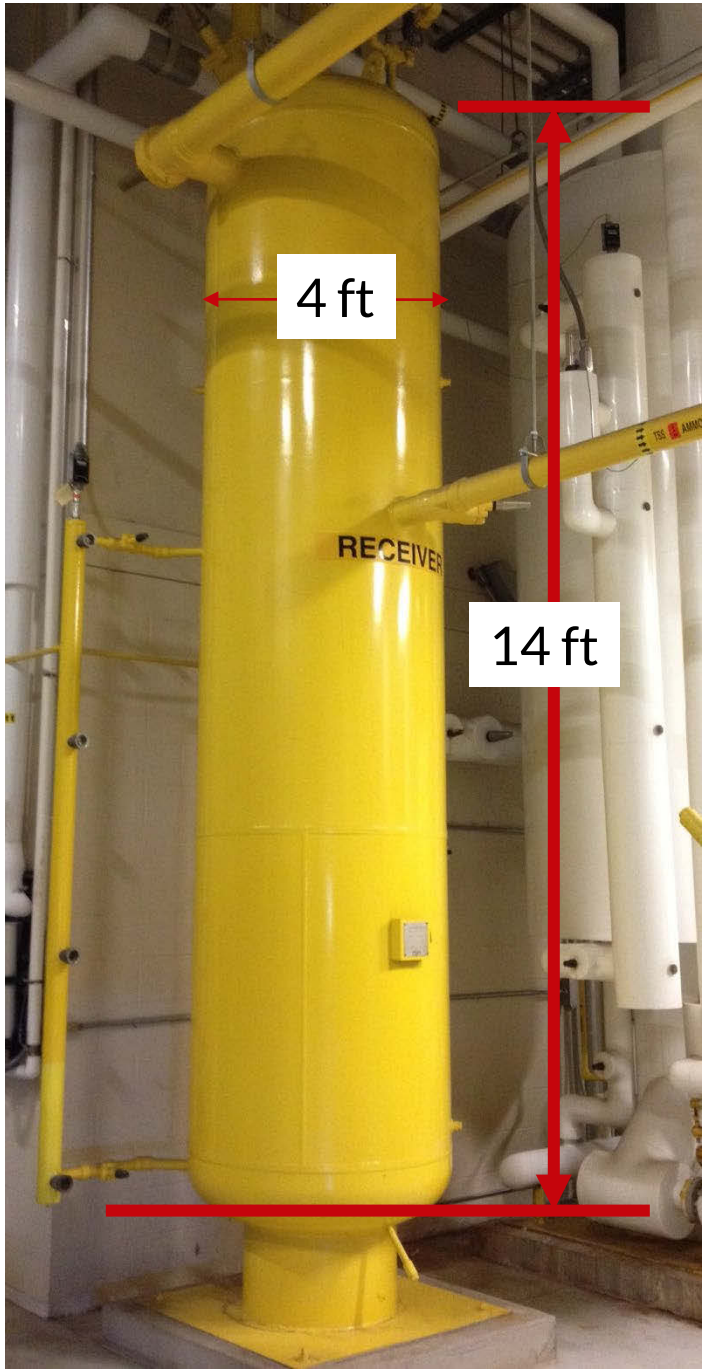
- Orientation: horizontal, vertical
- Level: normal operating and high level
- Types:
  - High pressure receiver
  - Thermosiphon pilot receiver
  - Intercooler
  - Accumulator
  - Recirculators (medium- and low-temperature), controlled-pressure receivers, oil pots, …
  - Transfer drums

Need vessel dimensions and liquid level

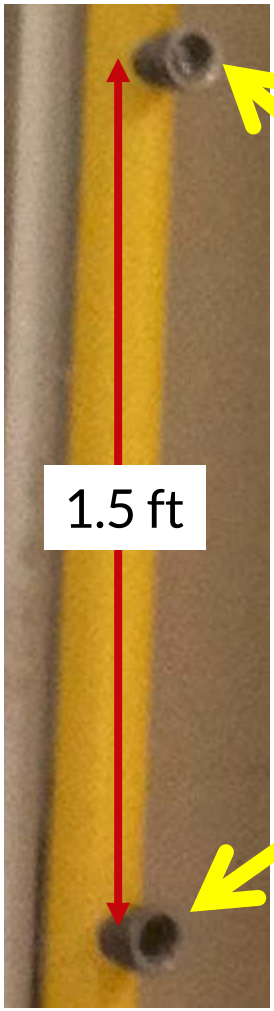
- Vessel dimensions (readily available using U1 data report)
- Liquid level determination
  - Vessels with a level column & sight glasses
  - Vessels equipped with a continuous level probe
    - Considerations using level probe
      - *Is the level probe reading from the bottom of the vessel, or the level column?*
      - *Has the level probe been properly calibrated?*
      - Double check the reading with a sight glass or other means if possible!

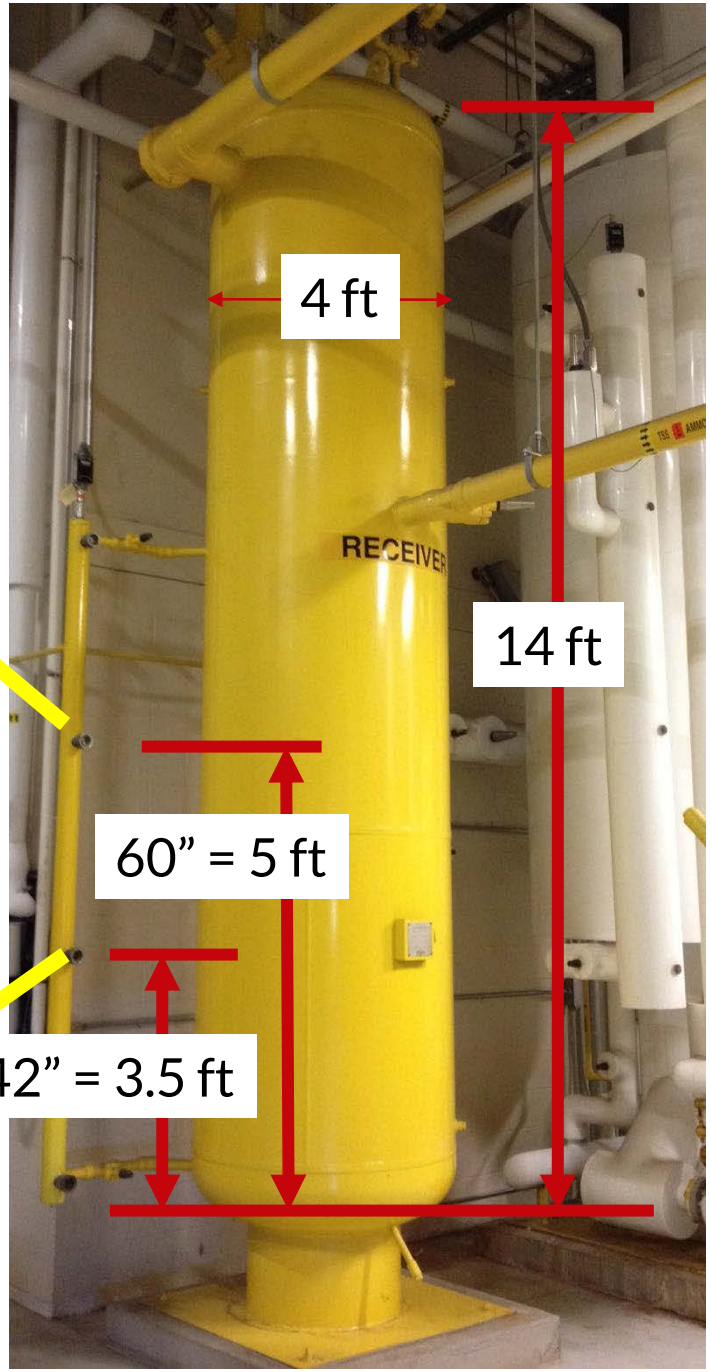
Dark glass – liquid present
Light glass – vapor present

Vertical high-pressure receiver



Some vessels have sparse sight glass locations





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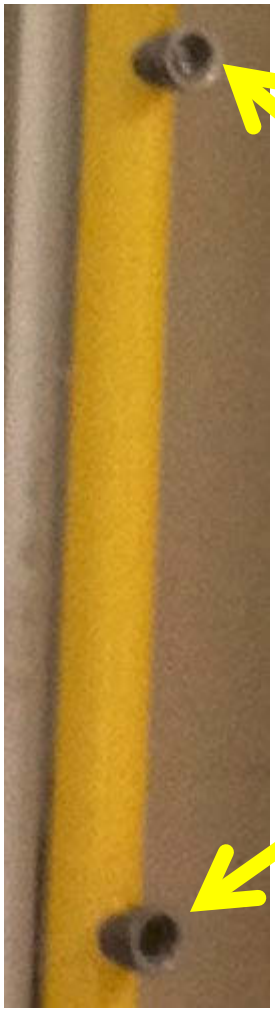
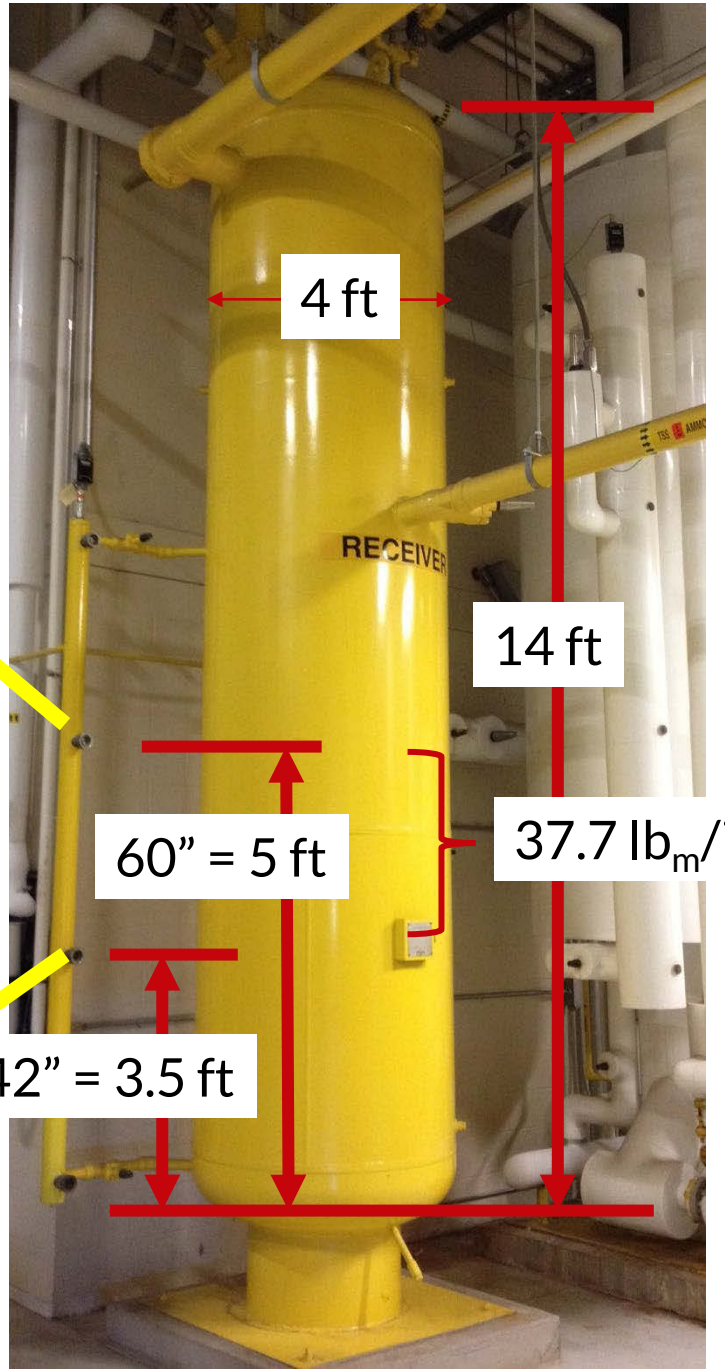
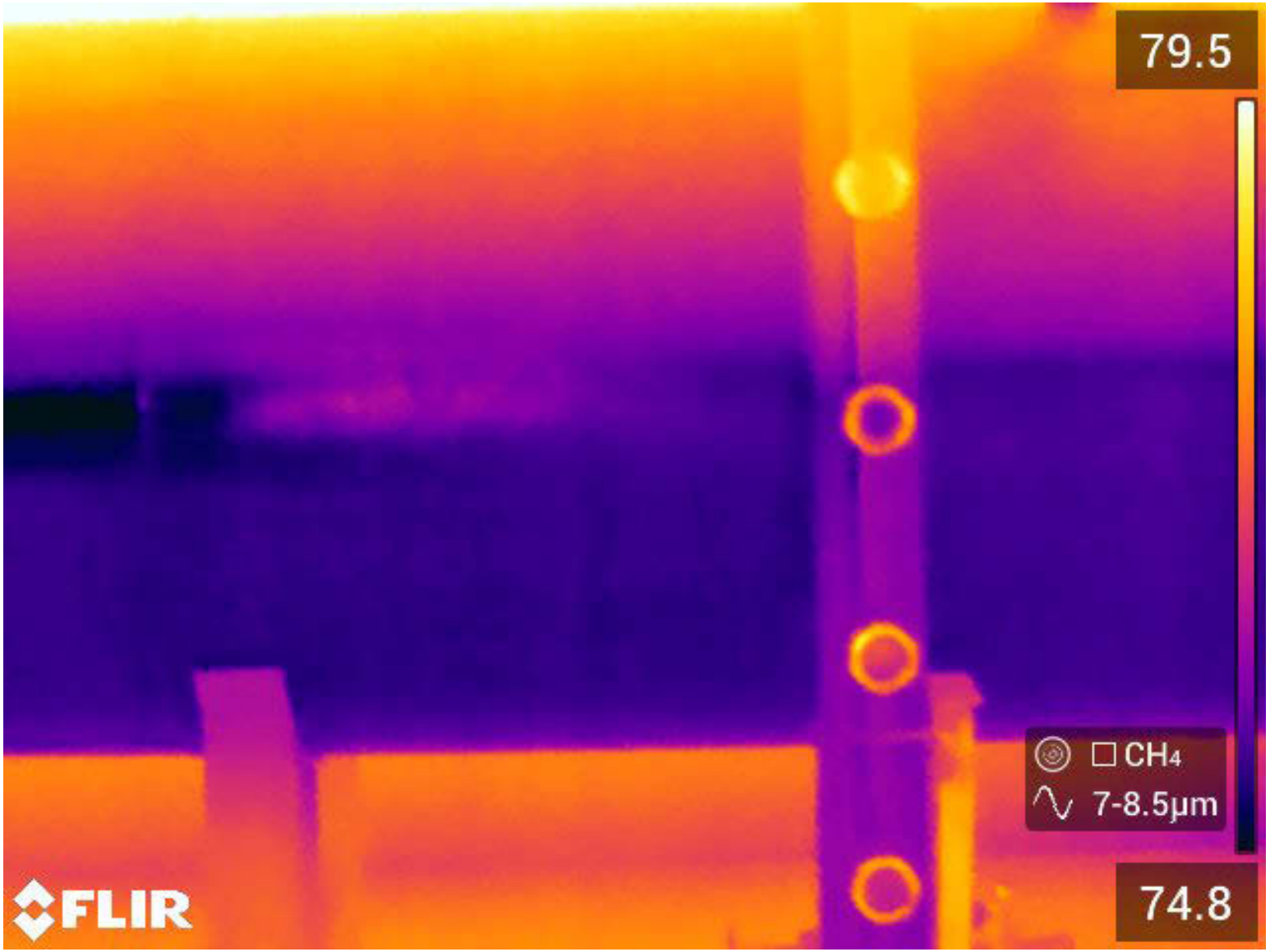
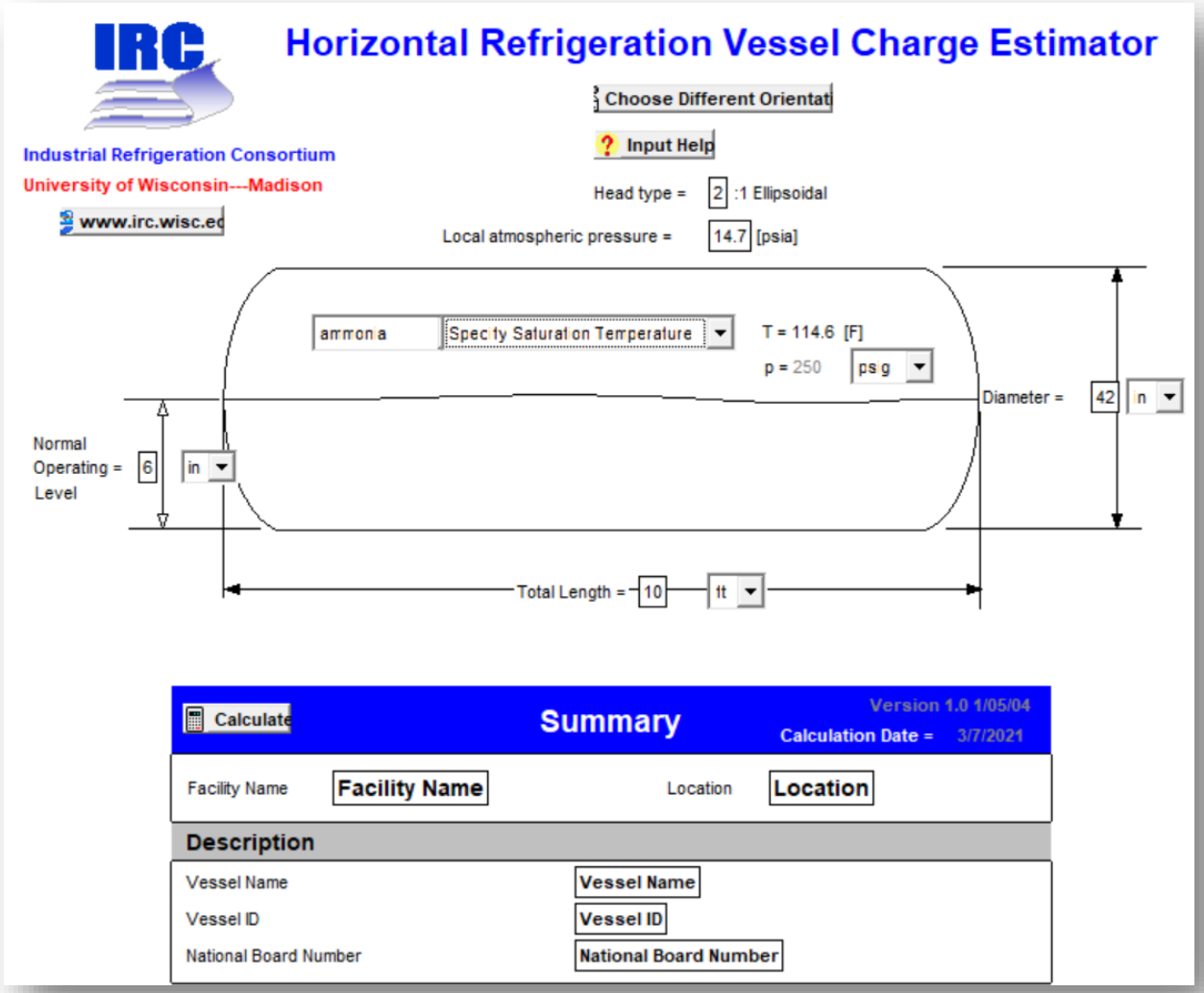




Thermography or infrared temperature scanning can provide more precision for determining liquid levels



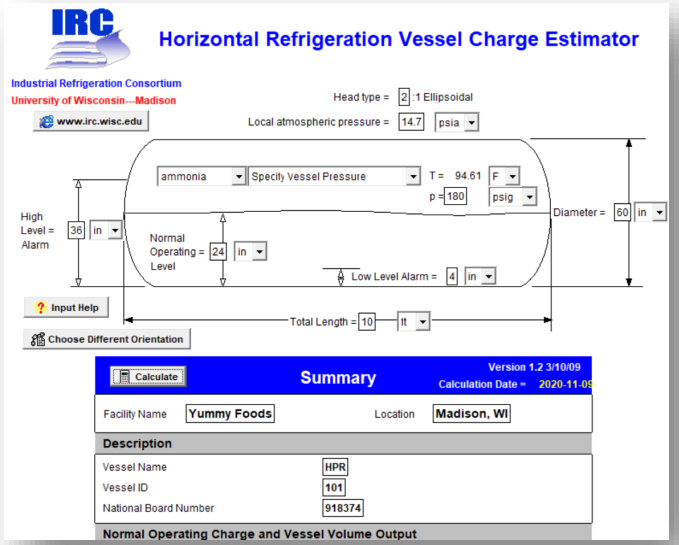
Vessel charge estimator tool



Available at: https://irc.wisc.edu/helpers/file.php?ID=435

Downloadable charge calculators

- Vessels
  - https://irc.wisc.edu/file.php?ID=435
- Evaporators
  - https://irc.wisc.edu/file.php?ID=436
- Compressors
  - https://irc.wisc.edu/file.php?ID=438



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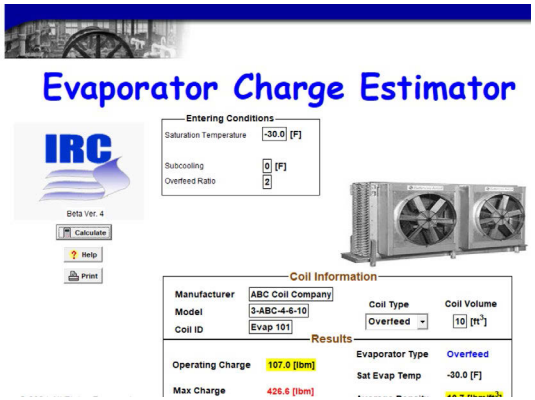

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Refrigeration system refrigerant inventory

- Sum of the refrigerant inventory in individual components comprising the system
  - Vessels
  - Piping
  - Heat exchangers

$$\sum$$

Distribution Center — Ammonia Inventory Determination
ABC Food Company — 1910.119(a)(1)(i)

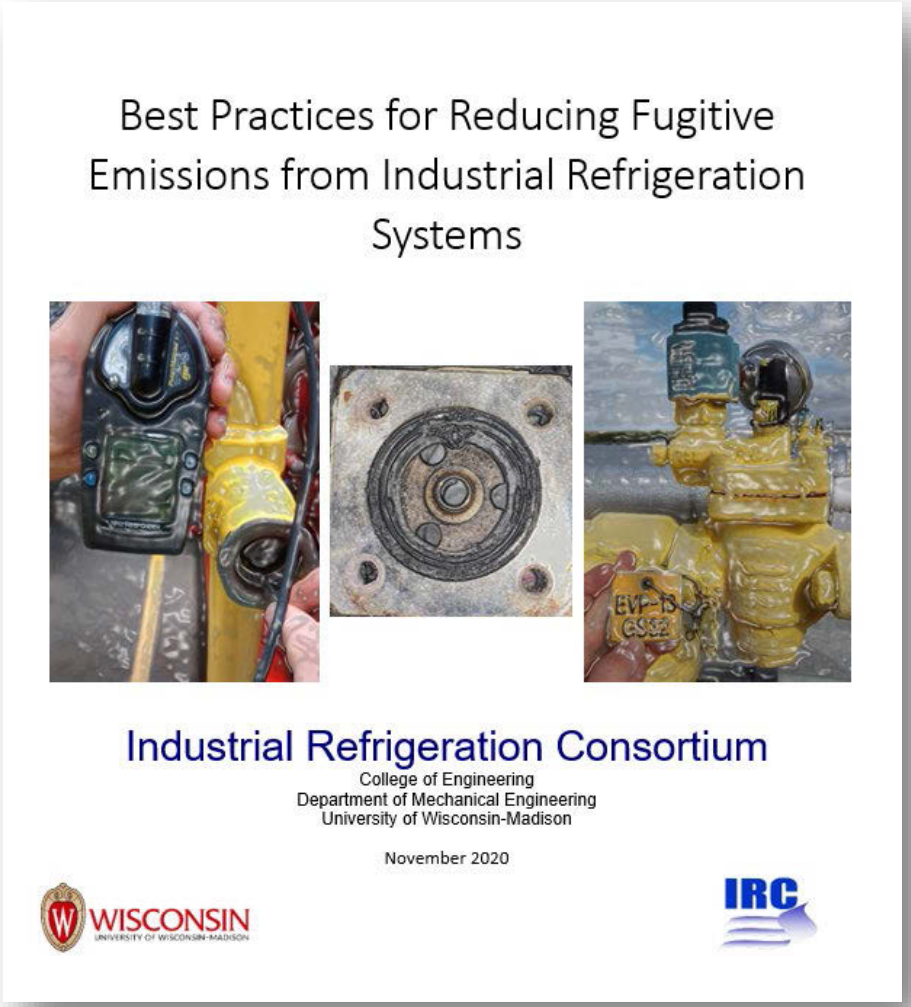
Executive Summary

This report was generated on March 15, 2021. This report contains an executive summary, an overview of the plant (system), and sections describing the individual equipment areas in detail. Information on referenced documents and standards has also been included in this report. The purpose of the executive summary is to provide key statistics about the charge present in this system.

A total of 13,672.9 lb is estimated to reside in this system during normal operating conditions. The following table breaks down the total inventory into subtotals for each area of the system.

Area	Inventory	Percent
Unassigned	1,780.0 lb	13 %
Clubhouse	106.1 lb	1 %
Cooler 500	748.5 lb	5 %
Cooler 600	748.5 lb	5 %
Freezer	147.4 lb	1 %
Machine Room	9,621.9 lb	70 %
Pallet Transfer	57.4 lb	0 %
Superchill	231.6 lb	2 %

More details on the engineering calculations are available in the following guidance document



Available at: https://irc.wisc.edu/helpers/file.php?ID=510

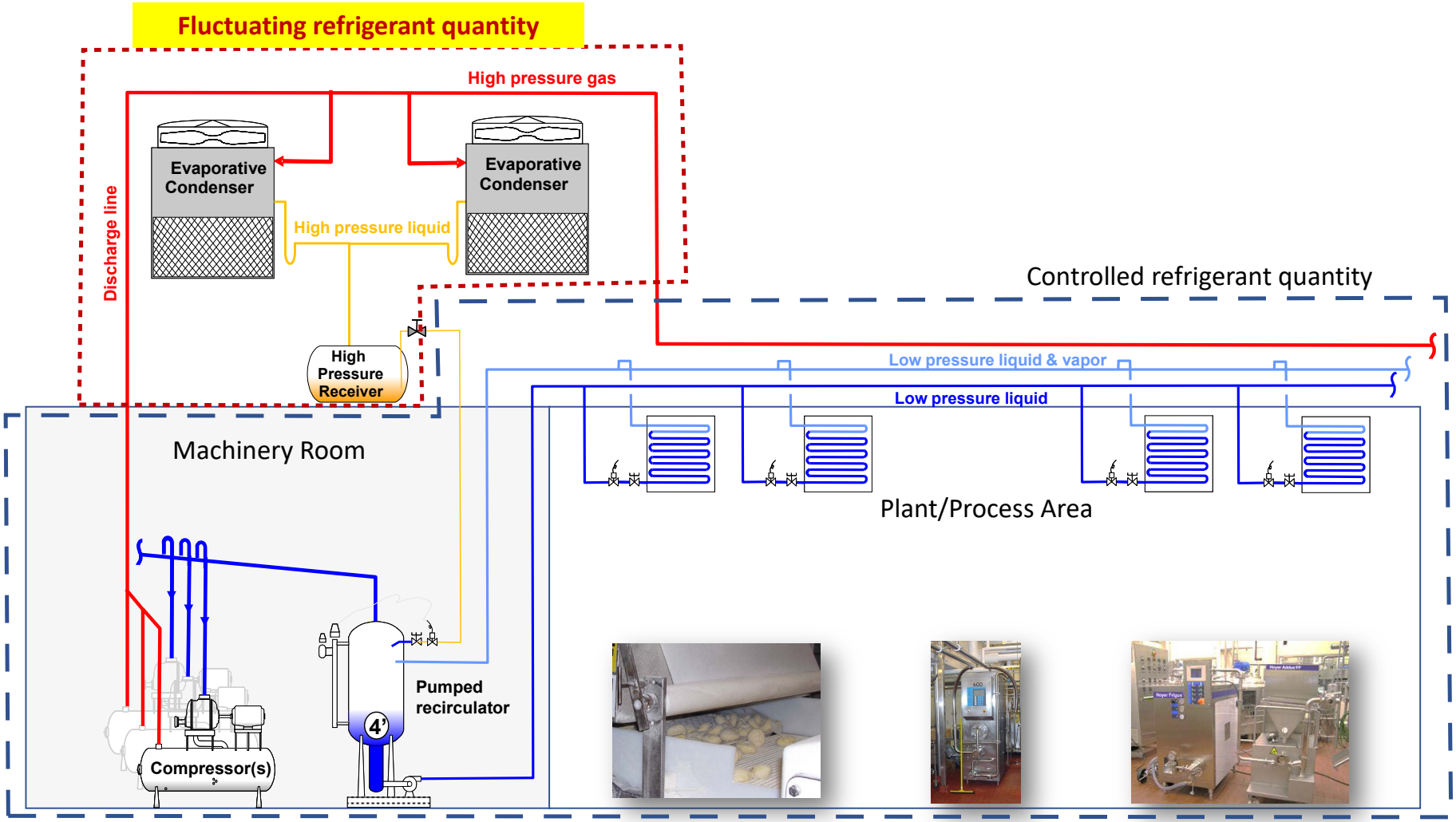
Reducing fugitive emissions

- Goal: reduce fugitive emissions from ammonia refrigeration systems
  - Basics of inventory calcs
  - Application of the inventory calcs with the use of dynamic charge calc tool
  - RAGAGEP associated with logging refrigerant losses/additions and emphasizing ammonia specifications for topping off refrigerant in ammonia systems

Dynamic refrigerant charge calculation

1. Divides refrigeration system into
   - "Controlled" refrigerant inventory
   - "Fluctuating" refrigerant inventory (usually HPR)
2. Baseline fluctuating component (HPR) quantity
3. Longitudinally track charge of HPR
   - Document temperature and HPR liquid levels during daily rounds with system operation "normal"
   - Log HPR inventory over several weeks
   - Trend inventory to estimate annual loss rate
4. Manage system expansions or decommissioning to adjust baseline charge

Refrigeration system partitioning illustration

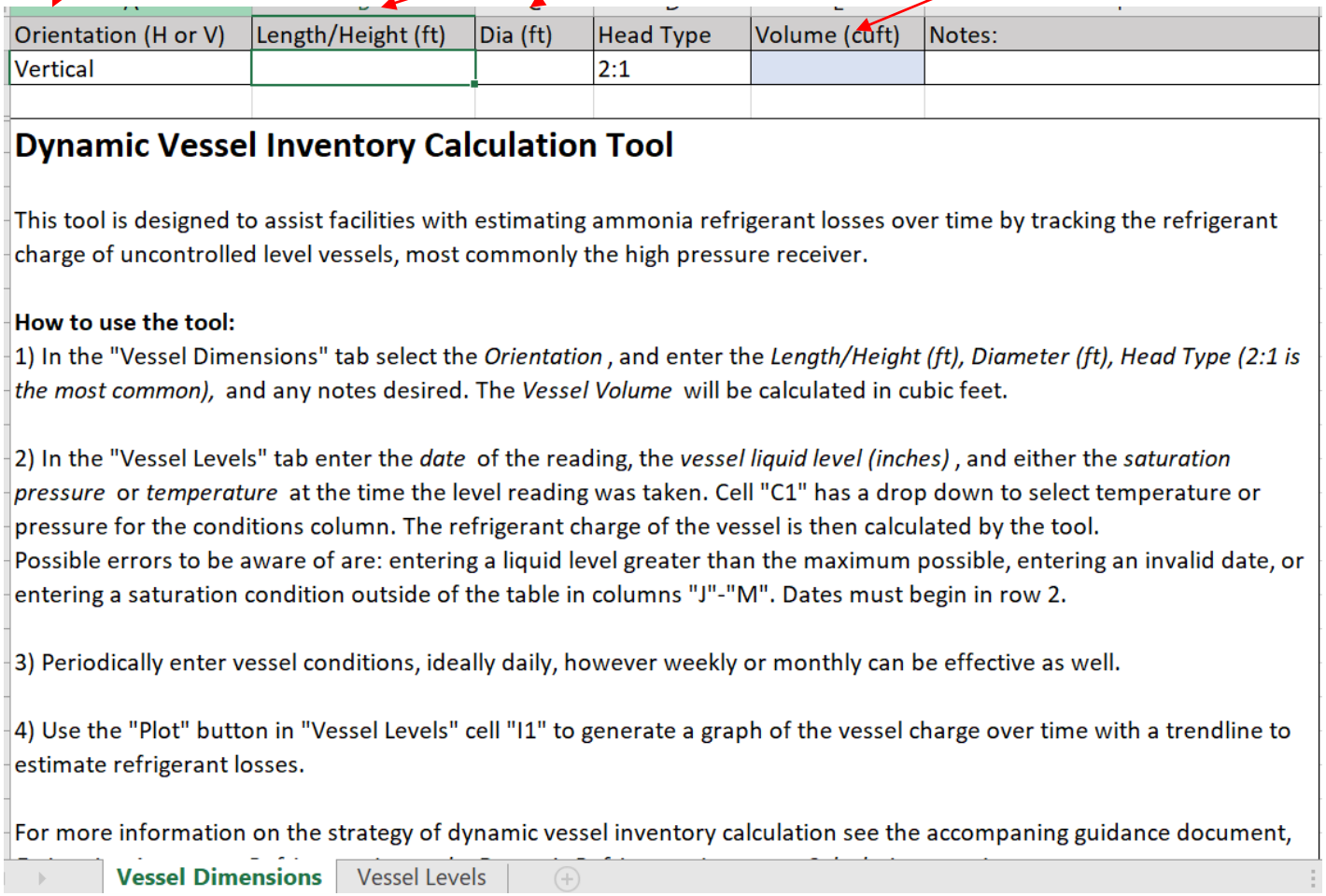


Dynamic charge calculation tool

Select vessel orientation

Enter HPR length (height) and diameter

Tool calculates volume



Orientation (H or V)	Length/Height (ft)	Dia (ft)	Head Type	Volume (cuft)	Notes:
Vertical			2:1		

Dynamic Vessel Inventory Calculation Tool

This tool is designed to assist facilities with estimating ammonia refrigerant losses over time by tracking the refrigerant charge of uncontrolled level vessels, most commonly the high pressure receiver.

How to use the tool:

1) In the "Vessel Dimensions" tab select the *Orientation* , and enter the *Length/Height (ft), Diameter (ft), Head Type (2:1 is the most common),* and any notes desired. The *Vessel Volume* will be calculated in cubic feet.

2) In the "Vessel Levels" tab enter the *date* of the reading, the *vessel liquid level (inches)* , and either the *saturation pressure* or *temperature* at the time the level reading was taken. Cell "C1" has a drop down to select temperature or pressure for the conditions column. The refrigerant charge of the vessel is then calculated by the tool.
Possible errors to be aware of are: entering a liquid level greater than the maximum possible, entering an invalid date, or entering a saturation condition outside of the table in columns "J"-"M". Dates must begin in row 2.

3) Periodically enter vessel conditions, ideally daily, however weekly or monthly can be effective as well.

4) Use the "Plot" button in "Vessel Levels" cell "I1" to generate a graph of the vessel charge over time with a trendline to estimate refrigerant losses.

For more information on the strategy of dynamic vessel inventory calculation see the accompaning guidance document,

Vessel Dimensions | Vessel Levels

Tool is available for download at: https://irc.wisc.edu/file.php?ID=508

Dynamic charge calculation tool

Enter longitudinal HPR level and pressure or temperature data

Sat. Temp (F)

1	Date	Liquid Level (inches)	Sat. Press (psig)	Liquid Density (lb/cuft)	Vapor Density (lb/cuft)	Liquid Volume (cuft)	Vapor Volume (cuft)	Total Charge (lbs)	Plot Data
2	8/21/2019	21	121	37.9	0.5	47.5	69.8	1830.5	
3	8/21/2019	21	119	37.9	0.4	47.5	69.8	1832.1	
4	8/21/2019	21	141	37.4	0.5	47.5	69.8	1815.0	
5	8/22/2019	21	109	38.1	0.4	47.5	69.8	1840.6	
6	8/22/2019	21	120	37.9	0.5	47.5	69.8	1831.3	
7	8/22/2019	27	130	37.7	0.5	66.6	50.7	2532.6	
8	8/23/2019	27	119	37.9	0.4	66.6	50.7	2546.5	
9	8/23/2019	21	115	38.0	0.4	47.5	69.8	1835.2	
10	8/23/2019	21	134	37.6	0.5	47.5	69.8	1820.3	
11	8/24/2019	27	110	38.1	0.4	66.6	50.7	2558.5	
12	8/25/2019	27	109	38.1	0.4	66.6	50.7	2559.9	
13	8/26/2019	27	118	37.9	0.4	66.6	50.7	2547.7	
14	8/26/2019	21	127	37.7	0.5	47.5	69.8	1825.8	
15	8/26/2019	24	133	37.6	0.5	58.6	58.6	2233.6	
16	8/27/2019	21	125	37.8	0.5	47.5	69.8	1827.3	
17	8/27/2019	21	123	37.8	0.5	47.5	69.8	1828.9	
18	8/28/2019	21	110	38.1	0.4	47.5	69.8	1839.7	
19	8/28/2019	27	110	38.1	0.4	66.6	50.7	2558.5	
20	8/28/2019	21	133	37.6	0.5	47.5	69.8	1821.0	
21	8/29/2019	27	110	38.1	0.4	66.6	50.7	2558.5	
22	8/29/2019	21	122	37.8	0.5	47.5	69.8	1829.7	
23	8/29/2019	21	143	37.4	0.5	47.5	69.8	1813.6	
24	8/30/2019	27	110	38.1	0.4	66.6	50.7	2558.5	

Vessel Dimensions | Vessel Levels | Chart1

Dynamic charge calculation tool

Enter longitudinal HPR level and pressure or temperature data

After entering several weeks of data, plot

Sat. Temp (F)

1	Date	Liquid Level (inches)	Sat. Press (psig)	Liquid Density (lb/cuft)	Vapor Density (lb/cuft)	Liquid Volume (cuft)	Vapor Volume (cuft)	Total Charge (lbs)	Plot Data
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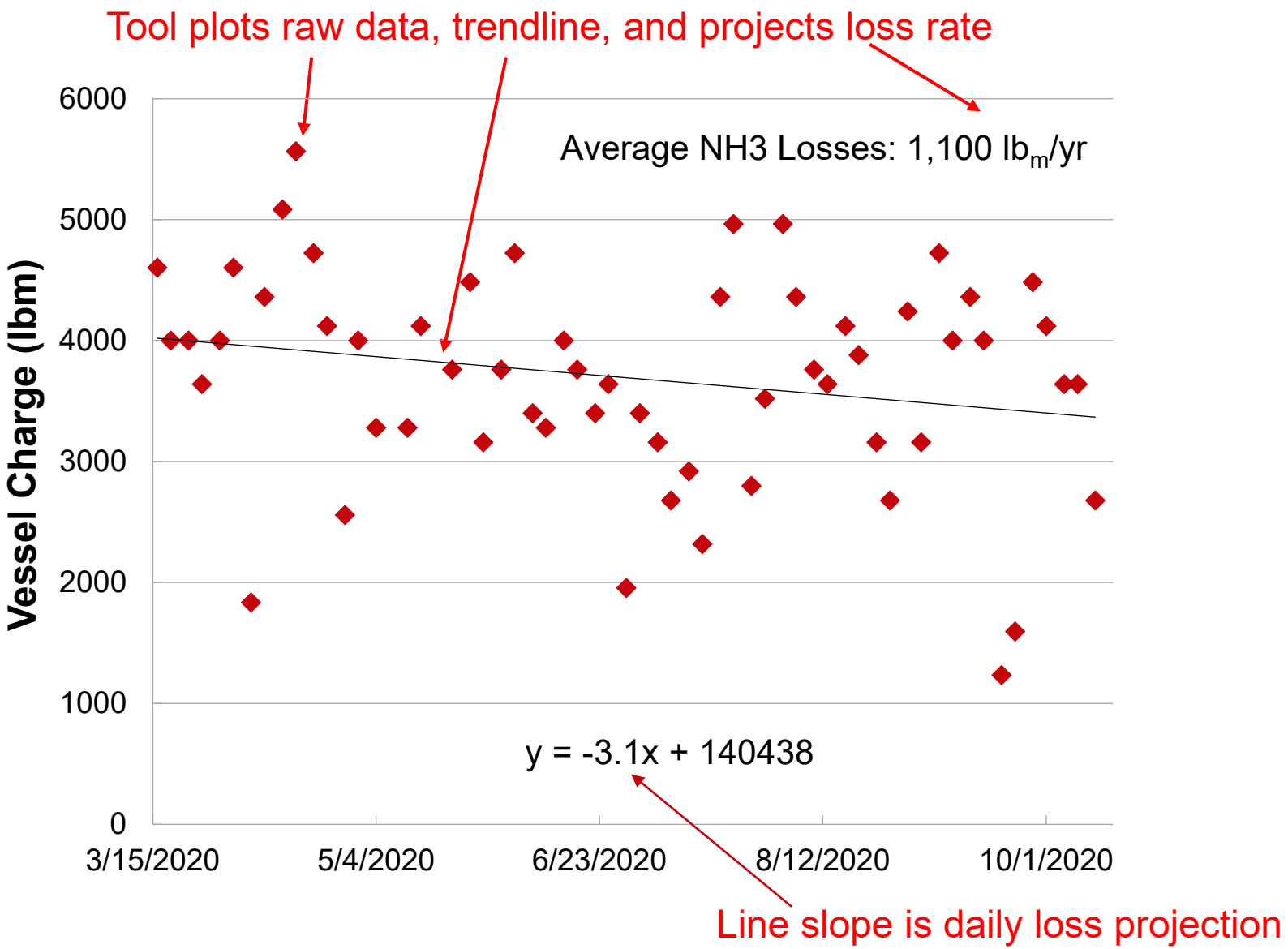
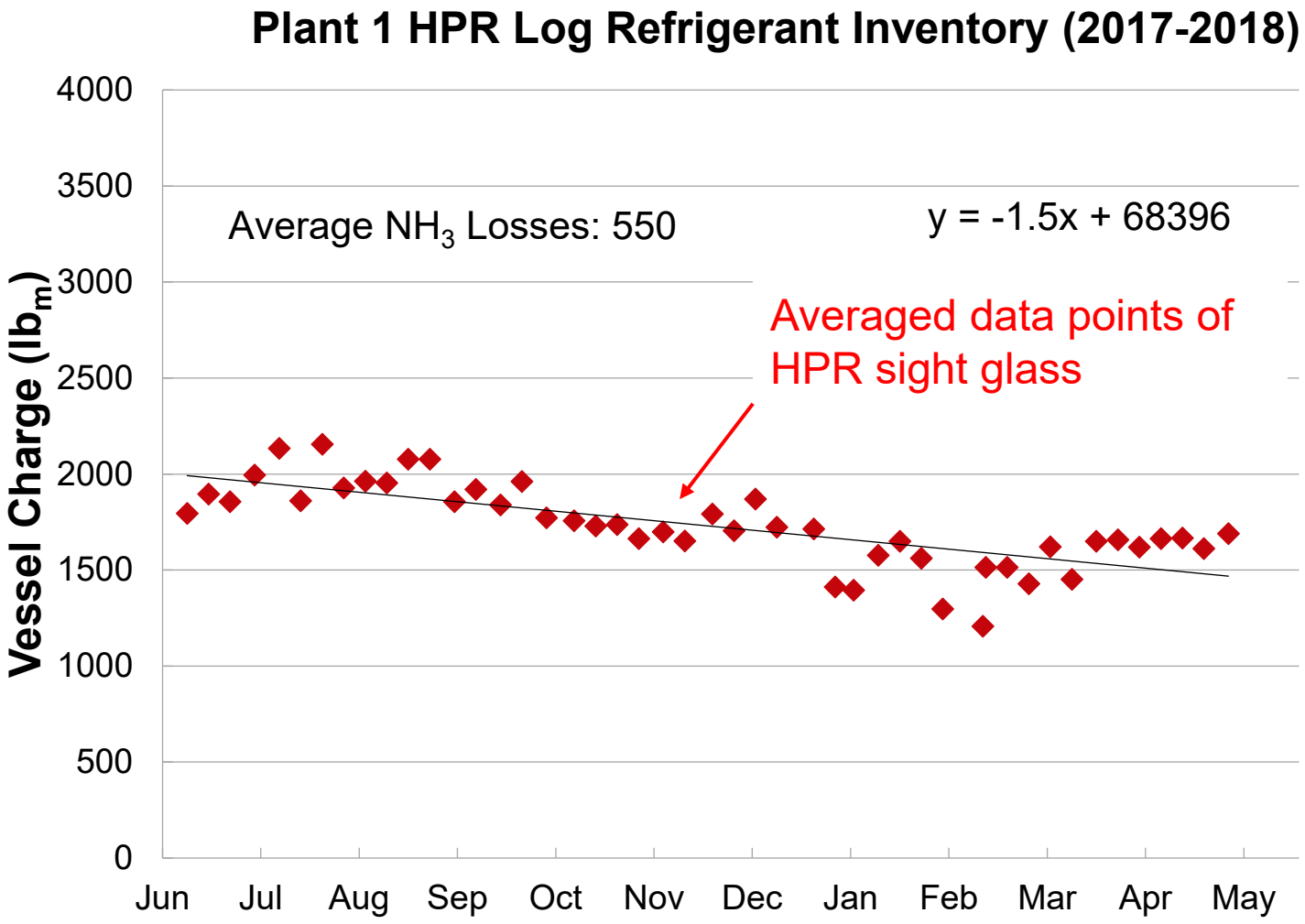
Vessel Dimensions | Vessel Levels | Chart1

Dynamic charge calculation tool

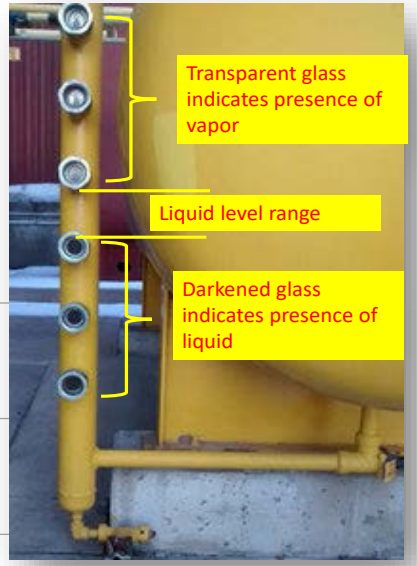


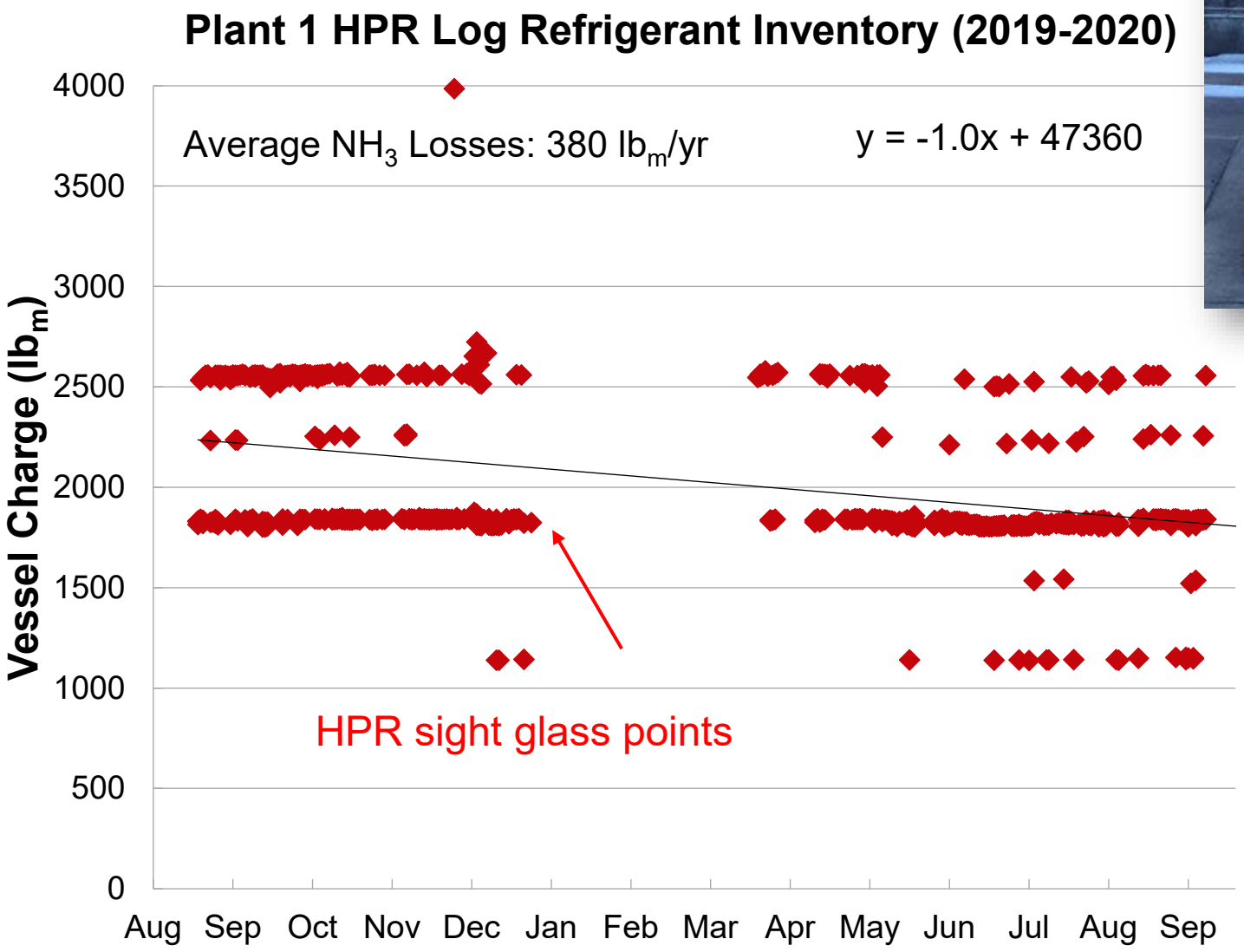
Applying technique to Plant 1



Loss rate based on actual ammonia purchases 2017-2018, **496 lb_m/yr**

Plant 1 – Post P2 visit





Loss rate based on ammonia purchases 2019-2020, **??? lb_m/yr**

Dynamic charge calculation caveats

- Consider how system operation may bias results
  - Portions of plant refrigeration processes operating or shutdown
- Consider how refrigeration system changes will impact the results
  - Decommissioning refrigeration equipment can mask refrigerant loss (false negative)
  - Equipment addition/expansion can suggest refrigerant loss (false positive)

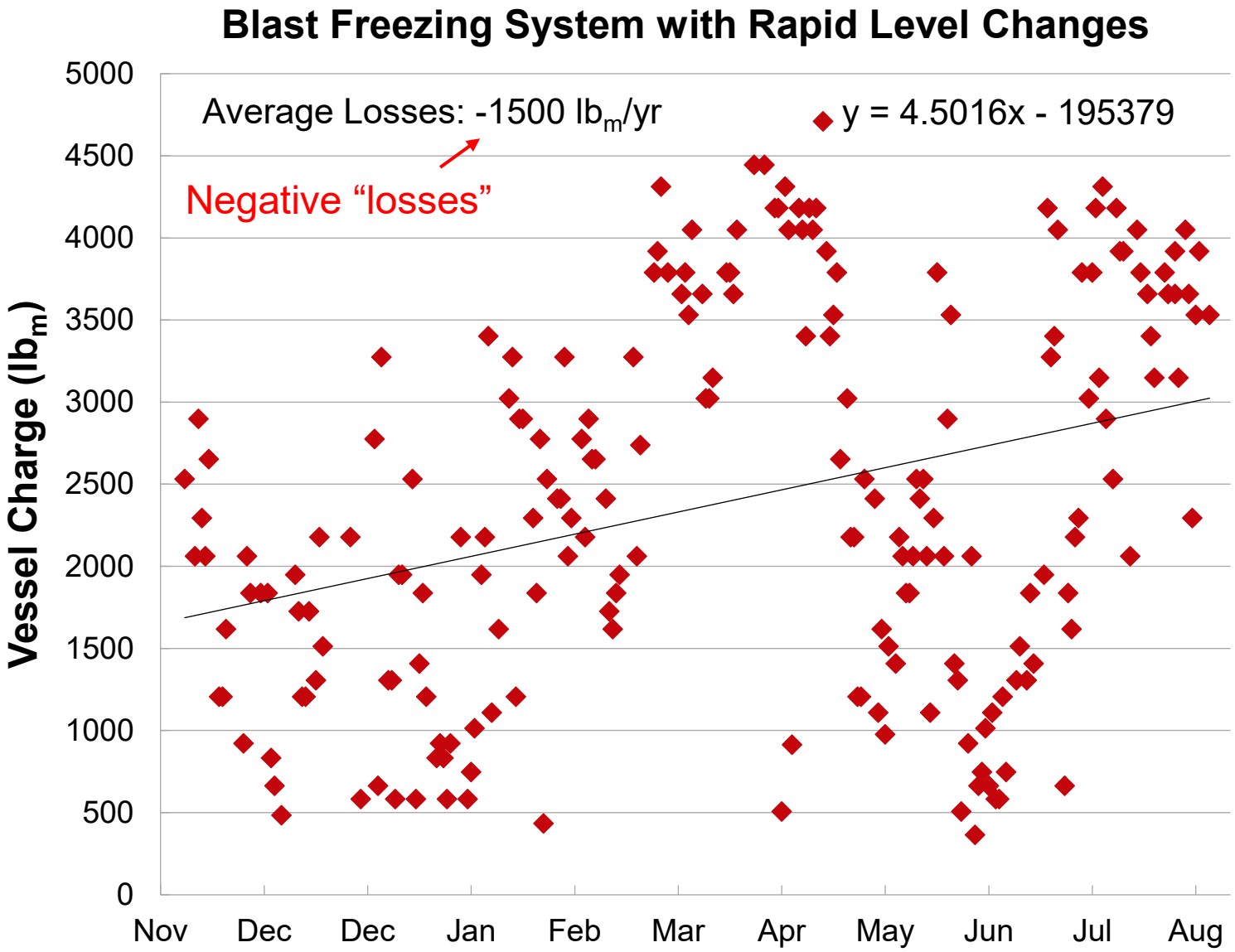
Dynamic charge calculation caveats

- Consider how system operation may bias results
  - Portions of plant refrigeration processes operating or shutdown
- Consider how refrigeration system changes will impact the results
  - Decommissioning refrigeration equipment can mask refrigerant loss (false negative)
  - Equipment addition/expansion can suggest refrigerant loss (false positive)
- Using rounds data may not work for all systems!
  - The following system is an example

System which did not track well

- Refrigeration system serves only blast freezing tunnels
  - Rounds only taken during system operation
- Frequent liquid transfers between vessels
  - Liquid separated in the suction accumulator transfers back to the intercooler every 2-5 minutes
- Data taken during system operation did not track inventory
  - Recording vessel levels during off-cycle is a more effective way to track inventory

Example of rapidly changing levels



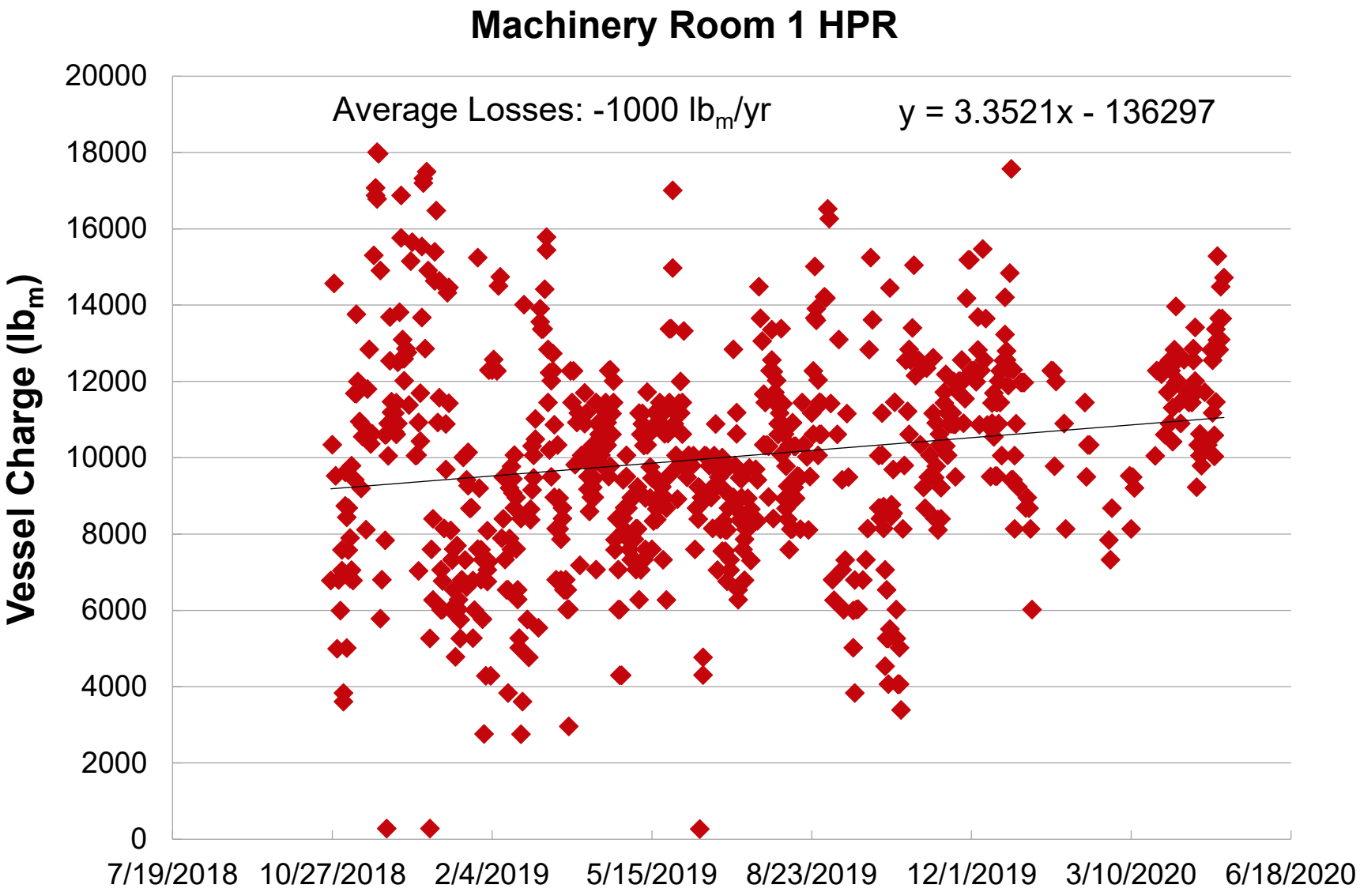
Multiple uncontrolled level vessels

- System has three interconnected machinery rooms
  - Two high-pressure receivers
  - One controlled-pressure receiver
- *Can we still track refrigerant inventory?*

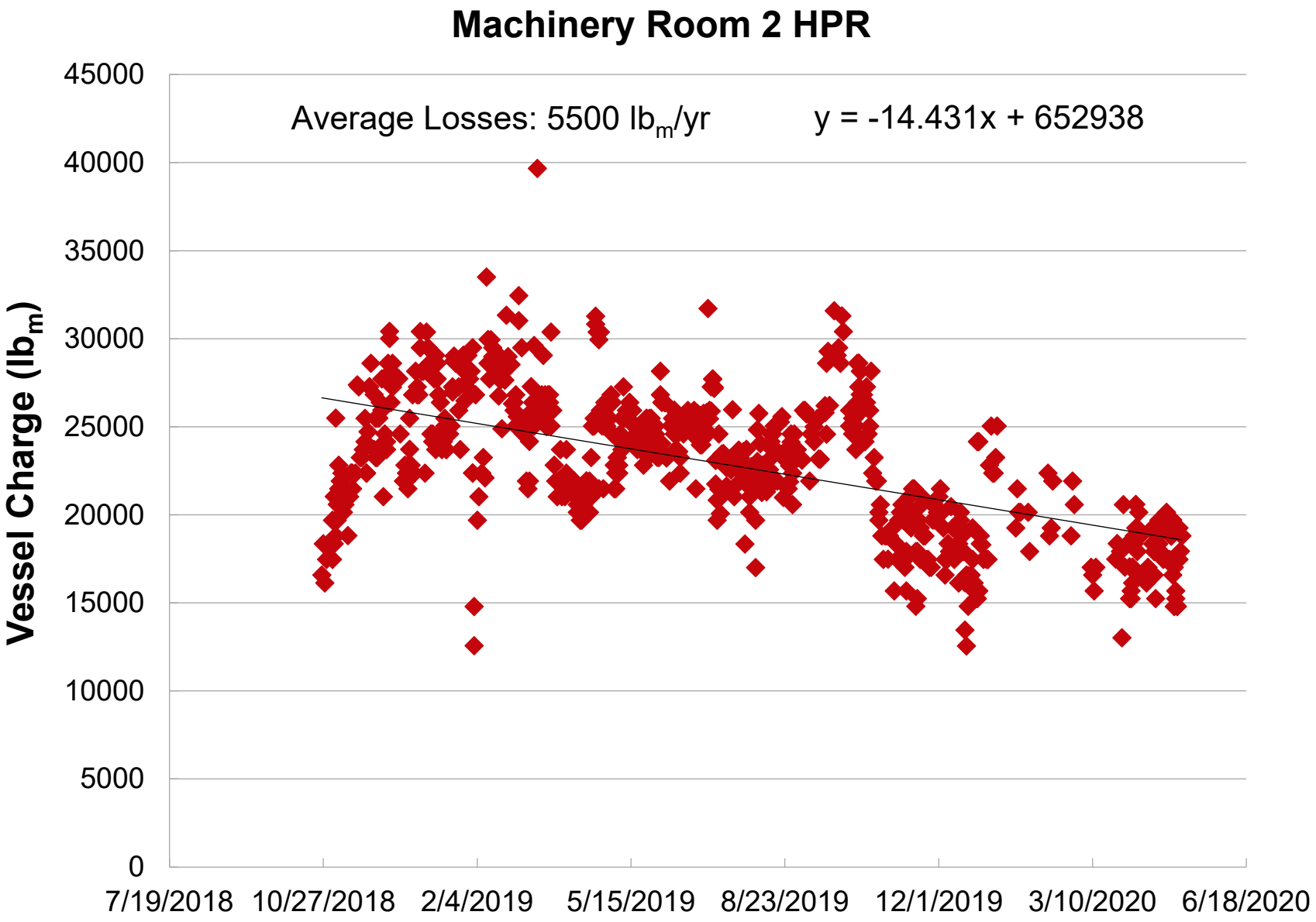
Multiple uncontrolled level vessels

- System has three interconnected machinery rooms
  - Two high-pressure receivers
  - One controlled-pressure receiver
- *Can we still track refrigerant inventory?* **YES**
- Must track each vessel independently and combine
  - Works best if all readings taken at or near the same time
    - To avoid double-counting or missing migrating refrigerant liquid

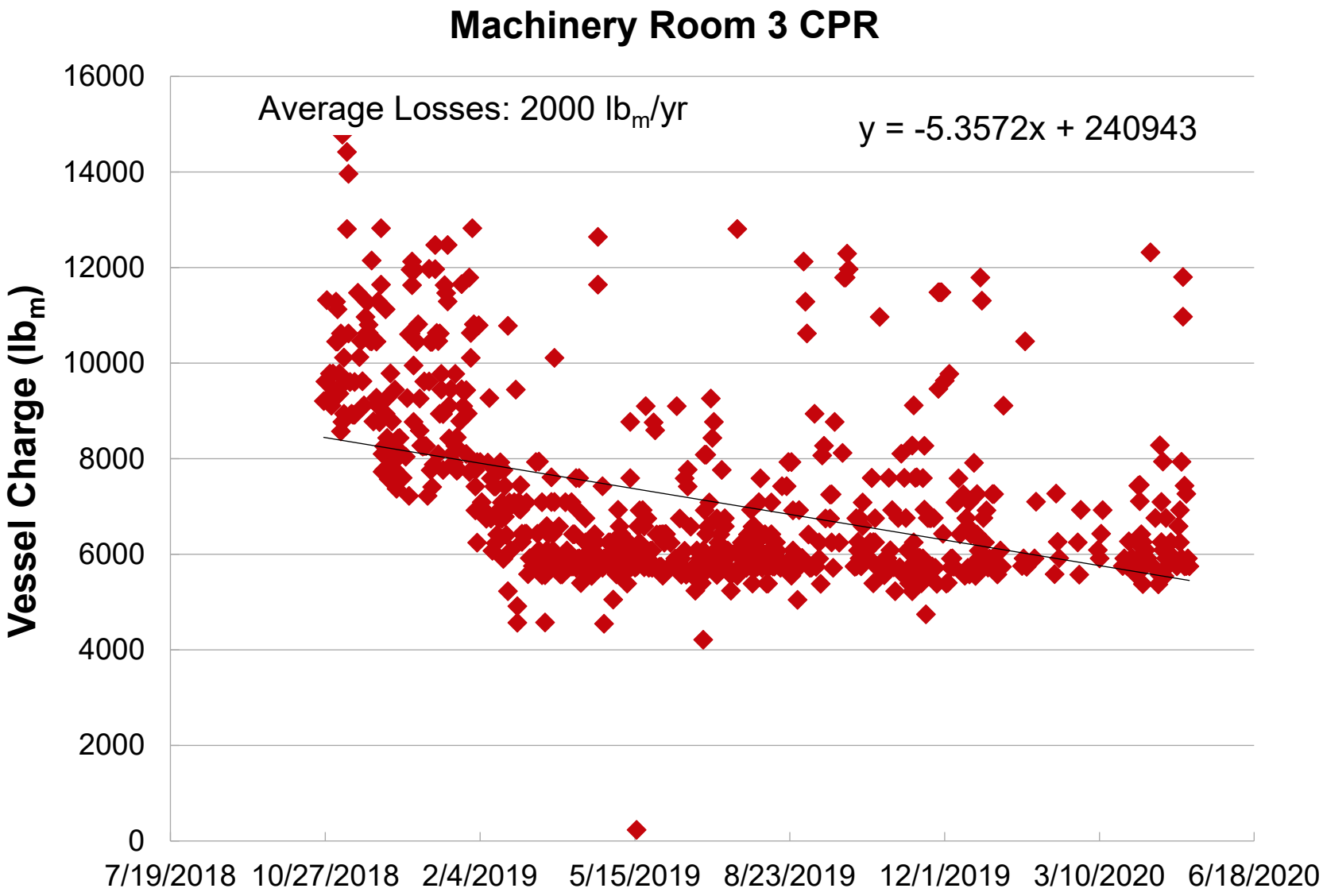
Multiple uncontrolled level vessels



Multiple uncontrolled level vessels



Multiple uncontrolled level vessels



Multiple uncontrolled level vessels

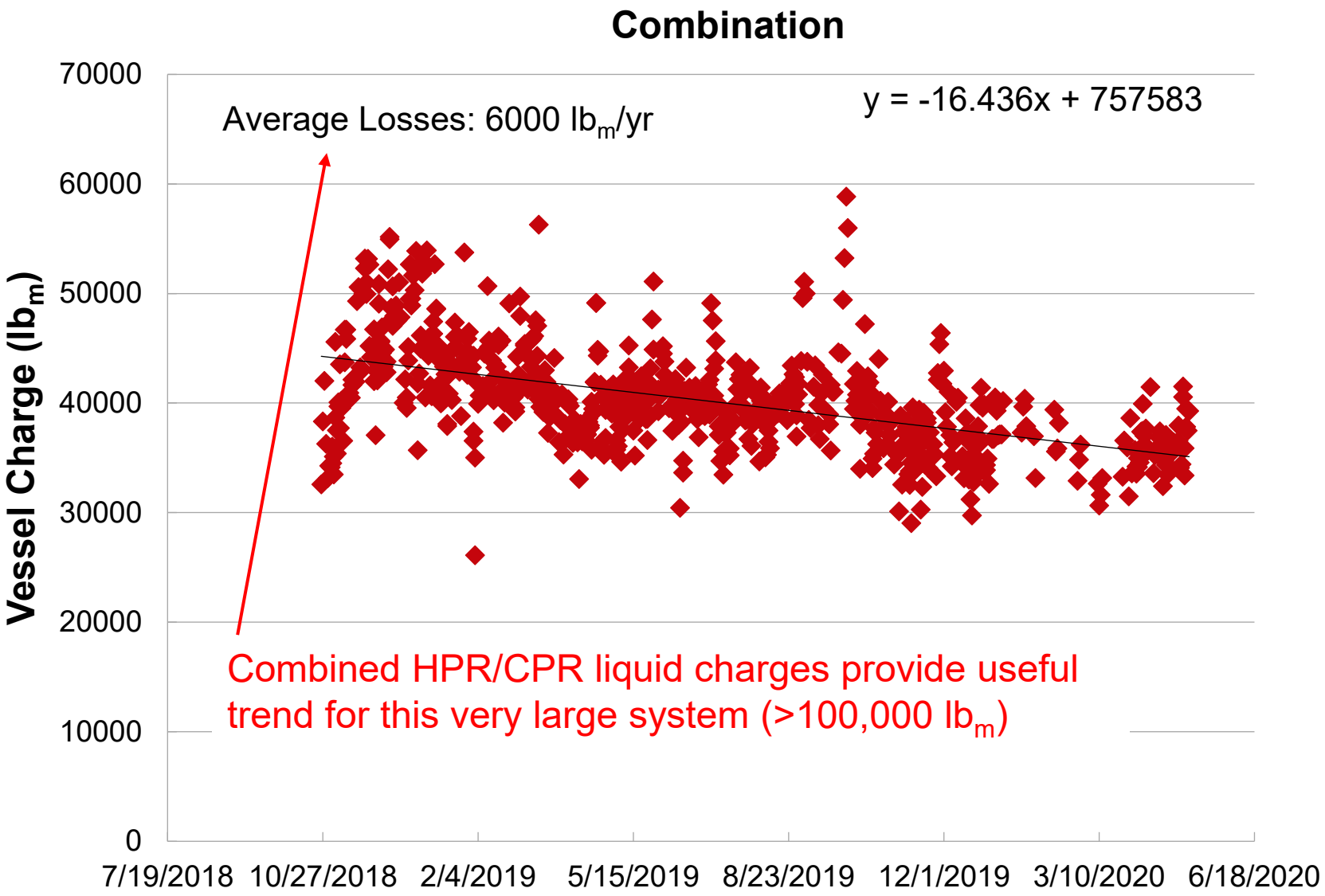
Check that dates correspond for each reading

Date	HPR 1 Charge (lb_m)	HPR 2 Charge (lb_m)	CPR Charge (lb_m)	Total Charge - Vessels (lb_m)
10/26/2018	16575	6778	9209	32561
10/27/2018	18356	10341	9614	38311
10/28/2018	16129	14569	11317	42015
10/29/2018	17465	9522	9277	36265
10/30/2018	18356	4988	9782	33127
10/31/2018	18356	6792	9109	34258
11/1/2018	18356	5989	9782	34128
11/2/2018	19692	7038	9270	36000
11/2/2018	17465	7580	9443	34488
11/3/2018	18356	3830	11286	33472
11/3/2018	21039	3608	10452	35099
11/4/2018	18802	8731	11127	38660
11/4/2018	25495	9613	10453	45561
11/5/2018	20593	5009	9782	35384
11/5/2018	19692	8438	9361	37492
11/6/2018	21474	7577	10623	39674
11/6/2018	22810	8680	8575	40065

Sum for total charge at each reading

- Combine the three vessel inventories at each reading and plot

Multiple uncontrolled level vessels



Dynamic refrigerant inventory calculation tool

Orientation (H or V)	Length/Height (ft)	Dia (ft)	Head Type	Volume (cuft)	Notes:
Vertical			2:1		

Dynamic Vessel Inventory Calculation Tool

This tool is designed to assist facilities with estimating ammonia refrigerant losses over time by tracking the refrigerant charge of uncontrolled level vessels, most commonly the high pressure receiver.

How to use the tool:

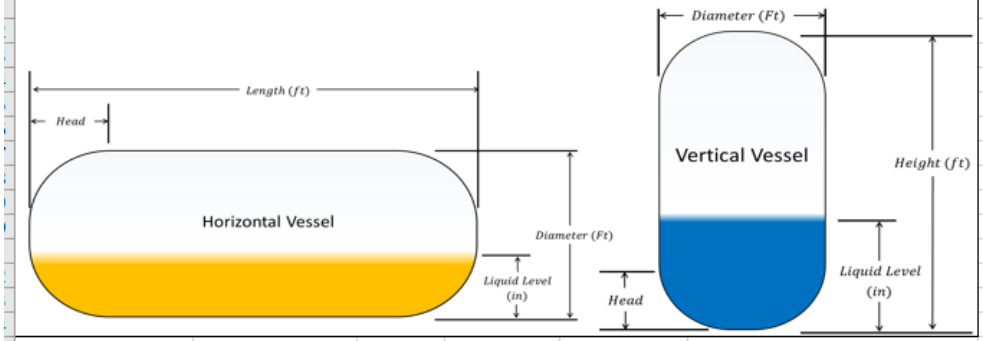
1) In the "Vessel Dimensions" tab select the *Orientation* , and enter the *Length/Height (ft), Diameter (ft), Head Type (2:1 is the most common),* and any notes desired. The *Vessel Volume* will be calculated in cubic feet.

2) In the "Vessel Levels" tab enter the *date* of the reading, the *vessel liquid level (inches)* , and either the *saturation pressure* or *temperature* at the time the level reading was taken. Cell "C1" has a drop down to select temperature or pressure for the conditions column. The refrigerant charge of the vessel is then calculated by the tool.
Possible errors to be aware of are: entering a liquid level greater than the maximum possible, entering an invalid date, or entering a saturation condition outside of the table in columns "J"-"M". Dates must begin in row 2.

3) Periodically enter vessel conditions, ideally daily, however weekly or monthly can be effective as well.

4) Use the "Plot" button in "Vessel Levels" cell "I1" to generate a graph of the vessel charge over time with a trendline to estimate refrigerant losses.

For more information on the strategy of dynamic vessel inventory calculation see the accompaning guidance document, *Estimating Aggregate Refrigerant Losses by Dynamic Refrigerant Inventory Calculations* section.



IRC, "Guidance Document – Best Practices for Calculating Refrigerant Inventory and Identifying and Reducing Fugitive

Available for download at: https://irc.wisc.edu/file.php?ID=508

Reducing fugitive emissions

- <u>Goal:</u> reduce fugitive emissions from ammonia refrigeration systems
  - Basics of inventory calcs
  - Application of the inventory calcs with the use of dynamic charge calc tool
  - RAGAGEP associated with logging refrigerant losses/additions and emphasizing ammonia specifications for topping off refrigerant in ammonia systems

Regulatory requirements (RMP)

- §68.69[1]: **Operating Procedures**
  - §68.69(a) Develop and implement operating procedures …
    - (3) *Safety and health considerations*

      (i) Properties of, and hazards presented by, the chemicals used in the process; …

      (iv) Quality control for raw materials and control of hazardous chemical inventory levels;

[1] 40 CFR §68

Regulatory requirements (RMP)

- §68.69(a)(3)(iv) [and 1910.119(f)(1)(iii)(D)][1]:
  - Quality control for raw materials and control of hazardous chemical inventory levels;

How do I "control" the inventory?

[1] 40 CFR §68 and 20 CFR 1910.119

Regulatory requirements (RMP)

- §68.69(a)(3)(iv) [and 1910.119(f)(1)(iii)(D)][1]:
  - Quality control for raw materials and control of hazardous chemical inventory levels;

How do I "control" the inventory?

1. Develop initial inventory calculation and maintain ongoing inventory determination
2. Track system ammonia levels
3. Determine how quantity and when ammonia additions are necessary

[1] 40 CFR §68 and 20 CFR 1910.119

Regulatory requirements (RMP)

- §68.65: **Process Safety Information**
  - §68.65(c) Information pertaining to the technology
    - (1) Information concerning the technology of the process shall include at least the following:

      (i) A block flow diagram …

      (iii) Maximum intended inventory;

Discussion

- What does *“maximum intended inventory”* mean?

Discussion

- What does *"maximum intended inventory"* mean?
  - "Maximum intended system inventory" means the greatest quantity the entire system is designed hold at any instant in time i.e. this is the "top off" amount

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- What does *"maximum intended inventory"* mean?
  - "Maximum intended system inventory" means the greatest quantity the entire system is designed hold at any instant in time i.e. this is the "top off" amount
  - "Maximum intended sub-system or component inventory" is the largest quantity that can be held in a subsystem (recirculator package) or component (evaporator, condenser)

Adding refrigerant to the system

- How to determine when to add ammonia
  - Develop an inventory calculation corresponding to the minimum refrigerant inventory needed to operate the plant
- *How much refrigerant needs to be added?*
  - Add the difference between the current calculated inventory and the maximum intended inventory
  - Do not exceed the maximum intended inventory!

Calculating amount to add

- Can be complex and complete calculations for highest accuracy
- Can also be simplified in many cases and focus on vessel levels
- Example:

Vessel	Accumulator	HPR	Flash Tank	Recirculator 1	Recirculator 2
Preferred Levels	30%	30%	42%	30%	30%
Current Levels	25%	18%	42%	27%	24%
% Low	5%	12%	0%	3%	6%

Additional Ammonia (lbm) required to obtain maximum intended inventory

Vessel	Diameter(in)	Height(ft)	Delta Height(ft)	Delta Volume (ft^3)	Vessel Temp(F)	Liquid Density	Vapor Density	Delta (lb_m)
HPR	60	15.92	1.91	37.49	60	38.50	0.36	1429.93
Accumulator	72	11.9	0.55	15.47	30	39.96	0.21	614.91
Recirculator 1	72	13.16	0.39	11.16	18	40.66	0.16	451.86
Recirculator 2	72	13.16	0.79	22.31	-25	42.44	0.06	945.67
							Total to Add	**3442.38 lb_m**

Ammonia purity requirements

When adding ammonia, IIAR 2-2014 (Addendum A) requires:

Table 5.2.2 Ammonia Purity Requirements	
Ammonia Content	99.5% minimum
Water content	**50 ppm minimum** **5,000 ppm maximum**
Oil	50 ppm maximum
Salt (calculated as NaCl)	None
Pyridine, hydrogen sulfide, naphthalene	None

In conclusion,

- Establish a clear baseline maximum intended refrigerant inventory for your refrigeration systems
- Alter maintenance practices to recover/reuse refrigerant rather than venting to reduce emissions
- Consider using the dynamic charge calculation tool to track refrigerant inventory and trend potential refrigerant loss rate
- Add refrigerant as-required and ensure the refrigerant meets the requirements set forth in IIAR 2 (ammonia)

Acknowledgements

- Thank you to the end-users who agreed to be a part of the field work associated with this project
- Thank you to EPA Staff for their support:
  - Christine Anderson, P2 Coordinator & our primary contact
  - Antionette Hall, Project Officer

Summary of tools

- Downloadable tools:
  - Component ammonia charge calculations:
    - Vessels: https://irc.wisc.edu/file.php?ID=435
    - Evaporators: https://irc.wisc.edu/file.php?ID=436
    - Compressors: https://irc.wisc.edu/file.php?ID=438
  - Dynamic charge calculation tool:
    - https://irc.wisc.edu/file.php?ID=508
  - Fugitive emissions bagging tool:
    - https://irc.wisc.edu/file.php?ID=509
- Online tool:
  - Ammonia charge calculation tool:
    - https://irc.wisc.edu/charge2/

Summary of additional ammonia refrigeration-related resources

- **IIAR – International Institute of Ammonia Refrigeration** www.iiar.org
  - provides advocacy, education, and standards for the benefit of the global community in the safe and sustainable design, installation and operation of ammonia and other natural refrigerant systems
- **IRC – Industrial Refrigeration Consortium** www.irc.wisc.edu
  - improving the safety, reliability, efficiency, and productivity of industrial refrigeration systems
- RETA – Refrigerating Engineers Technicians Association reta.com
  - dedicated to the professional development of industrial refrigeration operators and technicians

Questions?