IIAR Research Related to Ammonia and CO2 Systems

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What is the relationship between IIAR and NRF?

The Natural Refrigeration Foundation (NRF) is a non-profit foundation dedicated exclusively to financially supporting certain activities of the IIAR, namely:

- Education
  - Engineering Student Scholarships
  - Development of Academy of Natural Refrigerants course curriculum
- Research
  - Direct funding of IIAR research projects

Funding comes from private individual and trustee-level donors.

Funds are managed (invested and disbursed) by a volunteer Board of Directors elected from the IIAR Board of Directors and membership.

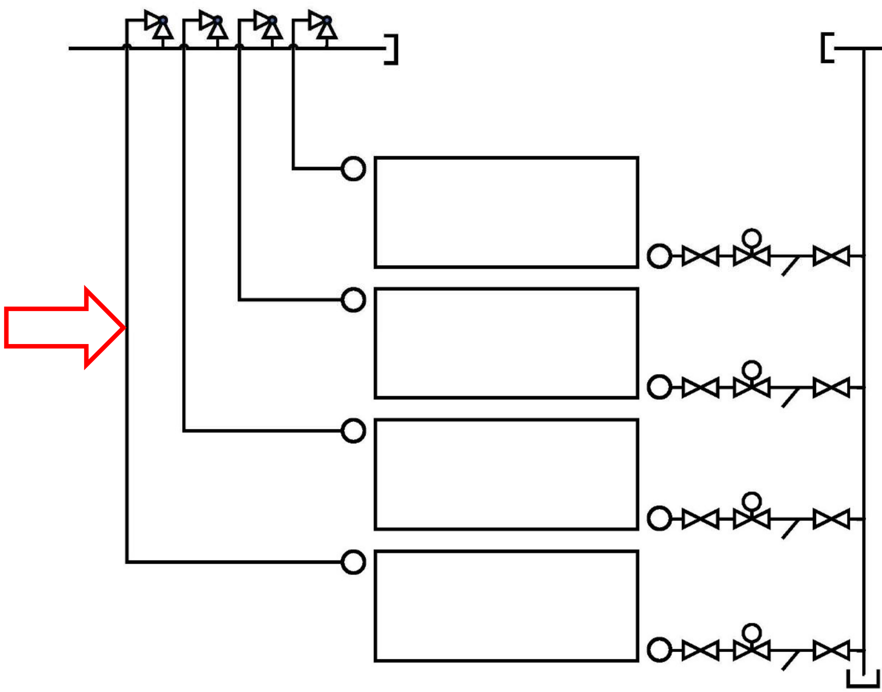
100% of funds go directly to supporting IIAR education and research activities.

Review of recent IIAR research activities

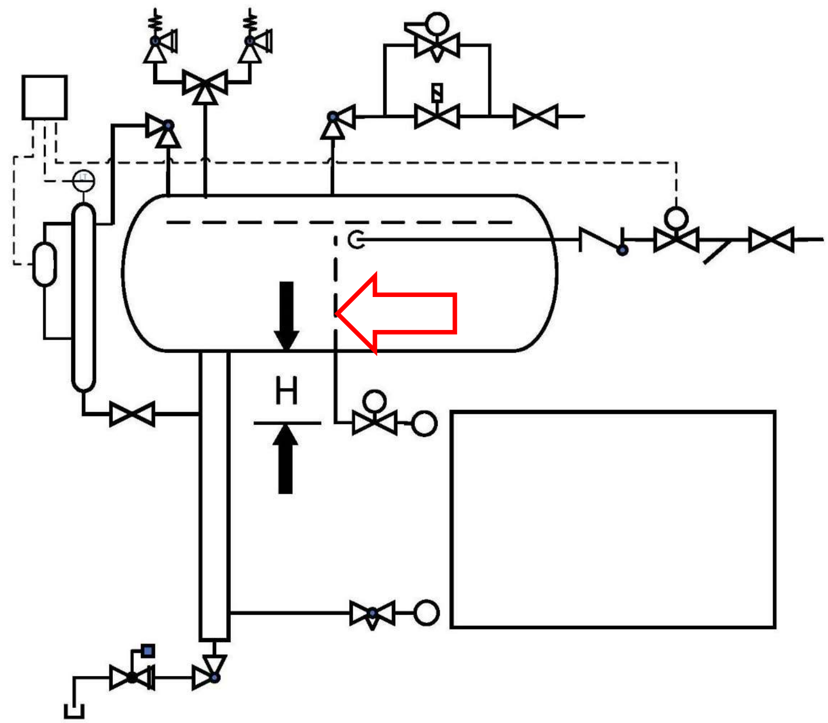
1. Testing, analysis, and design of vertical ammonia suction risers
2. Estimation of accidental refrigerant releases
3. Supercritical CO2 safety relief valve selection

Vertical Ammonia Suction Risers - Examples

Spiral Freezer Evaporators

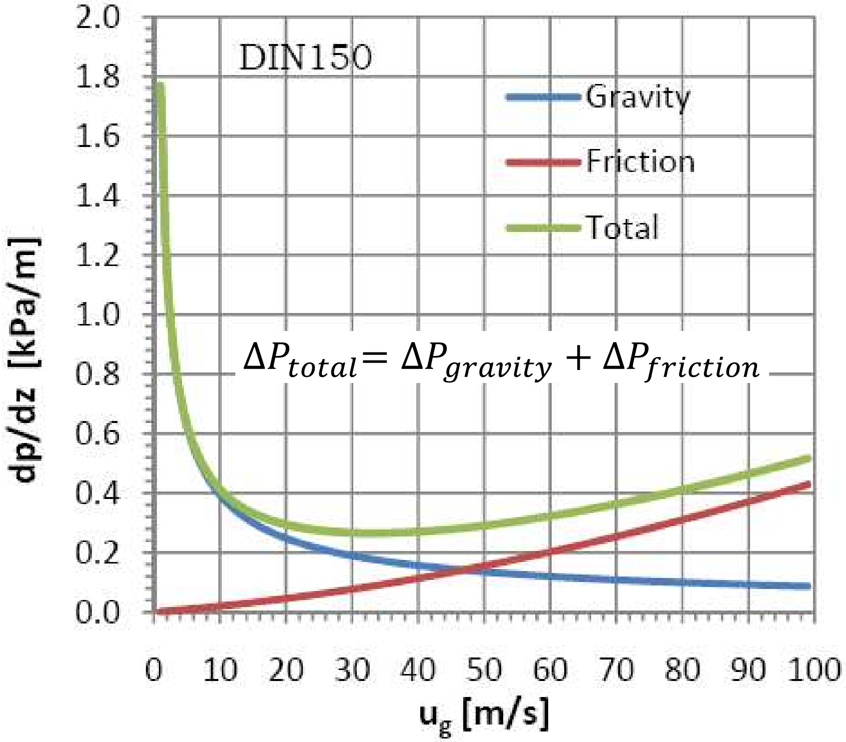


Gravity Flooded Evaporator



Vertical Ammonia Suction Risers - Theory

Two-phase Pressure Drop in Vertical Pipes



Questions to answer:

1. How to calculate gravity (static) pressure loss?
2. How to calculate frictional pressure loss?
3. How to avoid flow reversal and instability?

Static pressure loss: Use void fraction correlation to determine two-phase density. *No measured ammonia data available. Three NRF-funded research projects provided this data.*

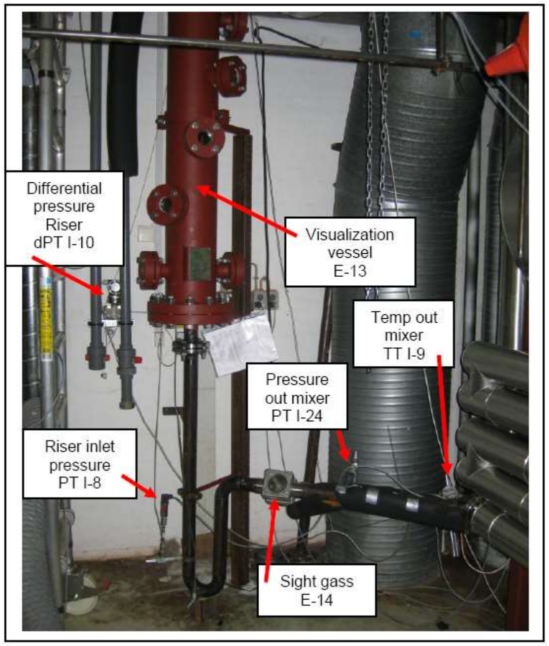
Frictional pressure loss: Use the well-known correlation of Friedel.

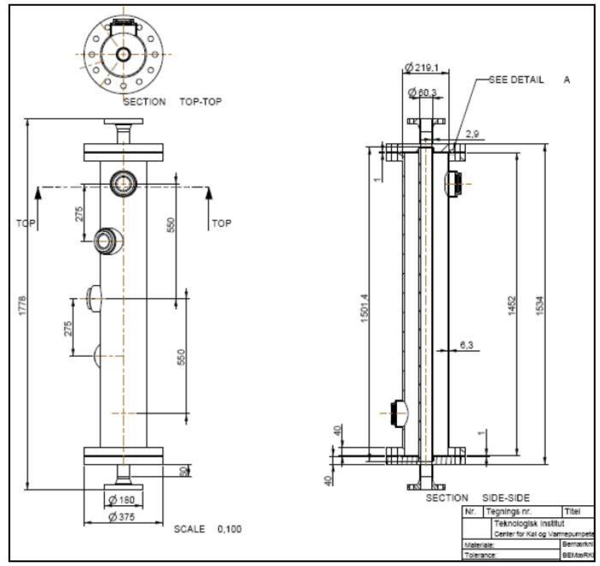
Flow reversal: Validate Ku=3.2 for determining minimum velocity / maximum pipe size.

Vertical Ammonia Suction Risers - Research

- ASHRAE RP-1327 awarded to Danish Technological Institute (DTI). Project co-funded by NRF.
- Measured dP in ammonia wet suction risers 19.3 ft high, 2” and 4” pipe sizes, n = 2 to 10, +20 to -40 deg F.
- NRF funded a second project using same DTI test rig to examine effects of riser inlet on dP (P-trap vs 90 deg elbow).
- NRF funded a third project to analyze the DTI data and develop an accurate void fraction correlation for calculating static pressure loss.

DTI Test Rig (-40 deg Ammonia)





Void Fraction Correlation: Thome (2019)

Yashar et al. (2001):

$$\varepsilon = \left[1 + \frac{1}{Ft} + X_{tt}\right]^{-0.321}$$

$$Ft = \left(\frac{G^2 x^3}{(1-x)\rho_G^2 g D}\right)^{0.5}$$

$$X_{tt} = \left(\frac{1-x}{x}\right)^{0.9} \left(\frac{\rho_G}{\rho_L}\right)^{0.5} \left(\frac{\mu_L}{\mu_G}\right)^{0.1}$$

where:

X_{tt} = Martinelli parameter, dimensionless

Ft = Froude rate, dimensionless

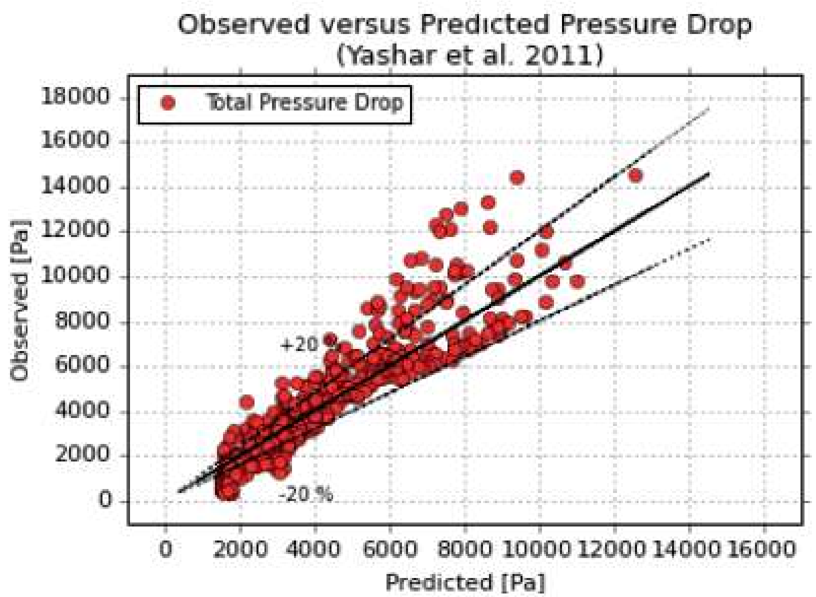


Figure 3. Comparison of predicted pressure drops to the original values using the Yashar et al. (2001) void fraction method.

Flow Reversal and Ku

Kutateladze Number:

$$Ku_{vap} = J_{vap} \cdot \frac{{\rho_{vap}}^{1/2}}{[\sigma \cdot g \cdot (\rho_{liq} - \rho_{vap})]^{1/4}} \quad \text{(SI)}$$

$$Ku_{vap} = J_{vap} \cdot \frac{{\rho_{vap}}^{1/2}}{[\sigma \cdot g \cdot 32.174 \cdot (\rho_{liq} - \rho_{vap})]^{1/4}} \quad \text{(IP)}$$

where:

$$J_{vap} = \frac{G_{total} \cdot x}{\rho_{vap}}$$

For practical purposes, sizing wet suction risers to operate at a Ku number of 6.4 is recommended. This allows the riser load to fall to 50% of design before reaching the point of flow reversal (Ku = 3.2).

Ammonia Suction Risers – Design Tools

Design process:

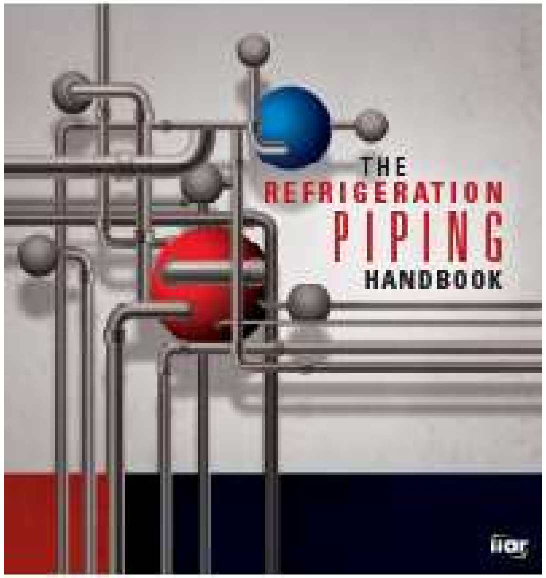
1. Select riser pipe size based on Ku = 6.4
2. Calculate static pressure drop using Yashar void fraction correlation for change in elevation
3. Calculate frictional pressure drop using Friedel correlation with total equivalent length of riser piping

References:

- IIAR Refrigeration Piping Handbook (2019 version)

Software tools:

- IIAR Riser Calculation program (included with Handbook)
- Danfoss CoolSelector
- Colmac Coil Engineering Toolbox



Ammonia Suction Riser Design – Example

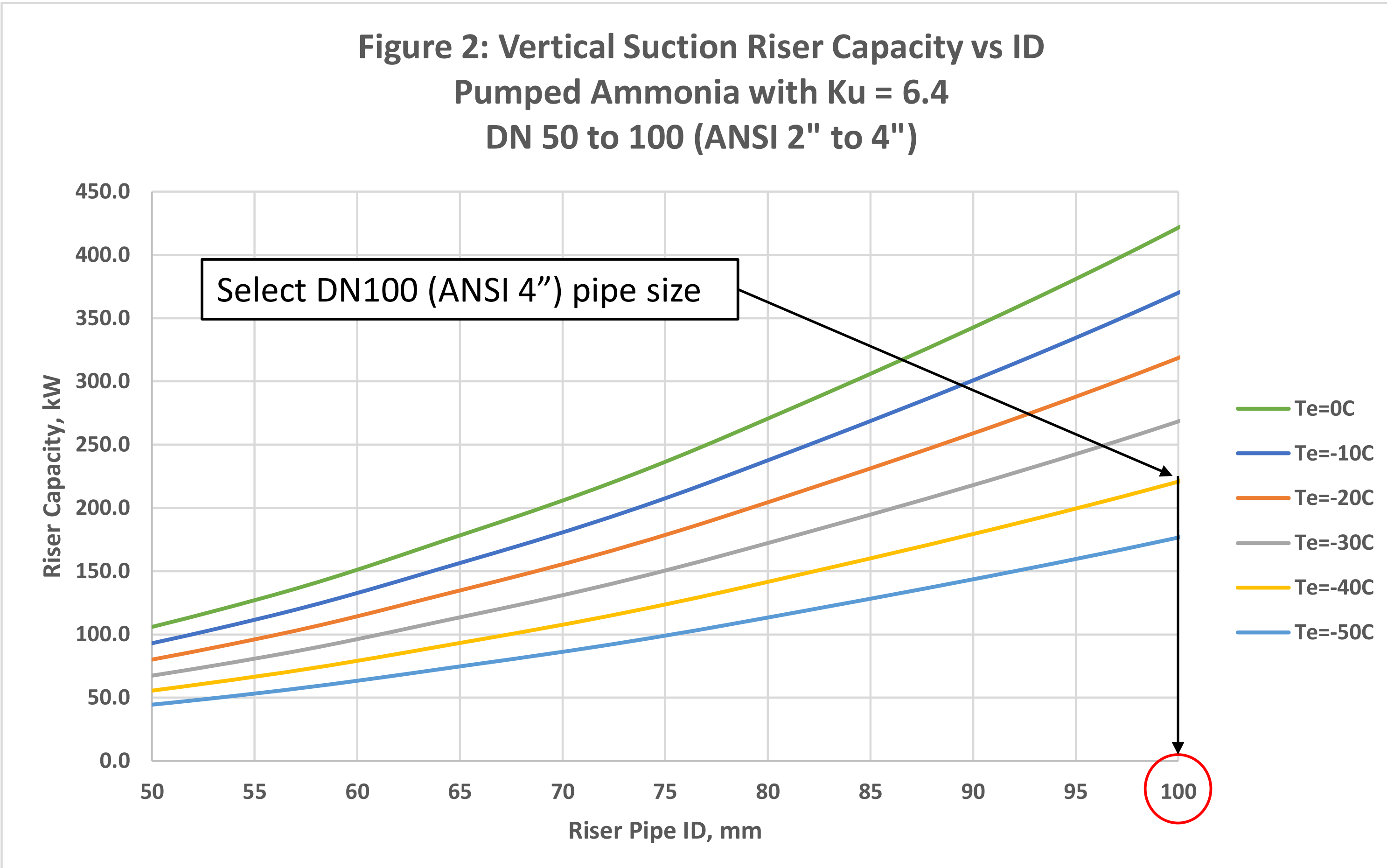
Given:

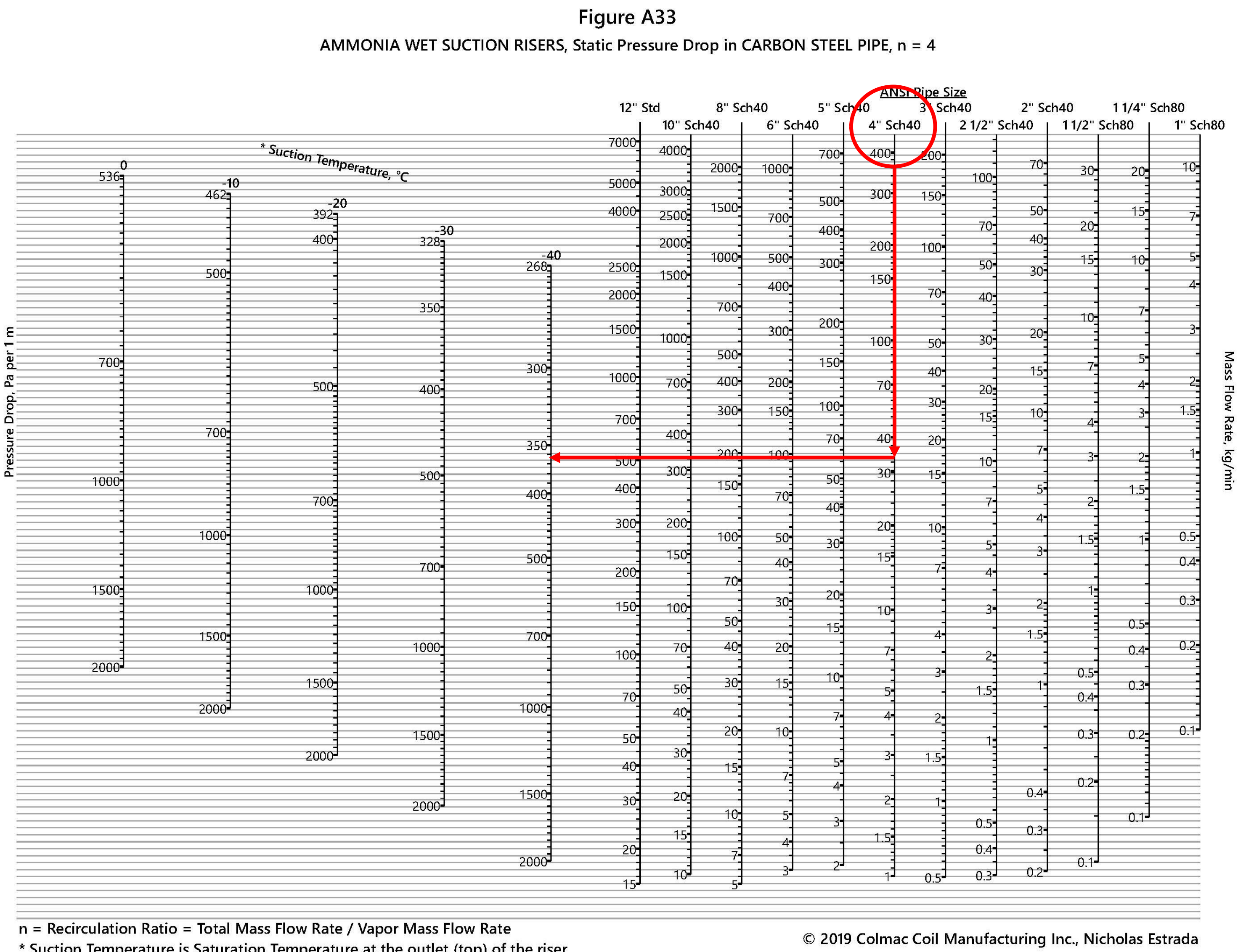
- Evaporator Duty: 200 kW
- Evaporating Temperature: Te = -40
- Circulation Number: n = 4
- Riser Elevation Change: H = 10 m
- Riser Total Equivalent Length: Lequiv = 30 m

Calculated:

- Latent Heat of Vaporization: 1388.6 kJ/kg
- Ammonia Mass Flowrate: (200 / 1388.6) x 4 = 0.576 kg/s = 34.6 kg/min

Ammonia Suction Riser Design – Step 1





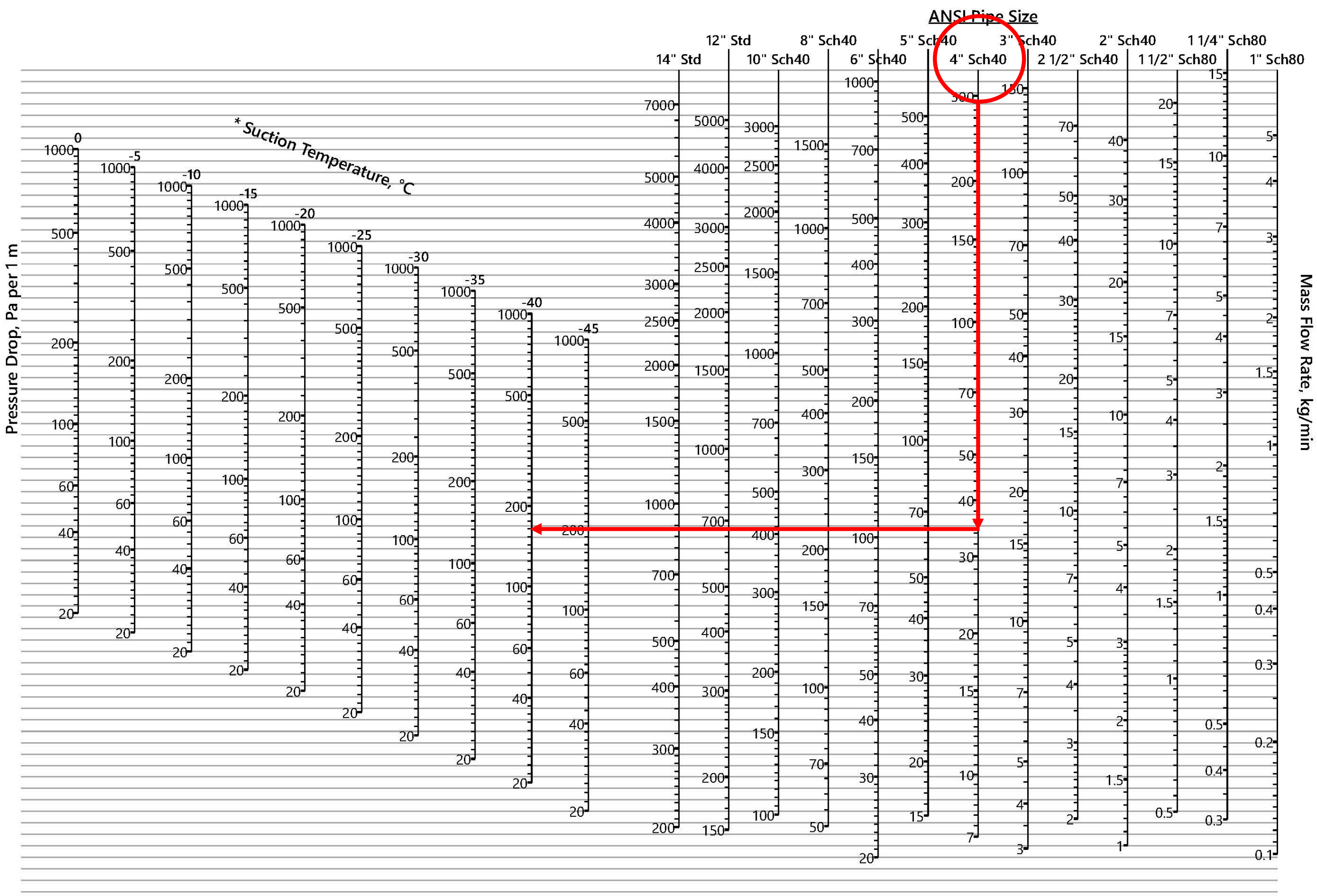
Ammonia Suction Riser Design – Step 2

Static pressure drop = Pa/m x lift = 365 x 10 = 3650 Pa = 3.65 kPa

Ammonia Suction Riser Design – Step 3

Figure A26

AMMONIA WET SUCTION LINES, Frictional Pressure Drop in CARBON STEEL PIPE, n = 4



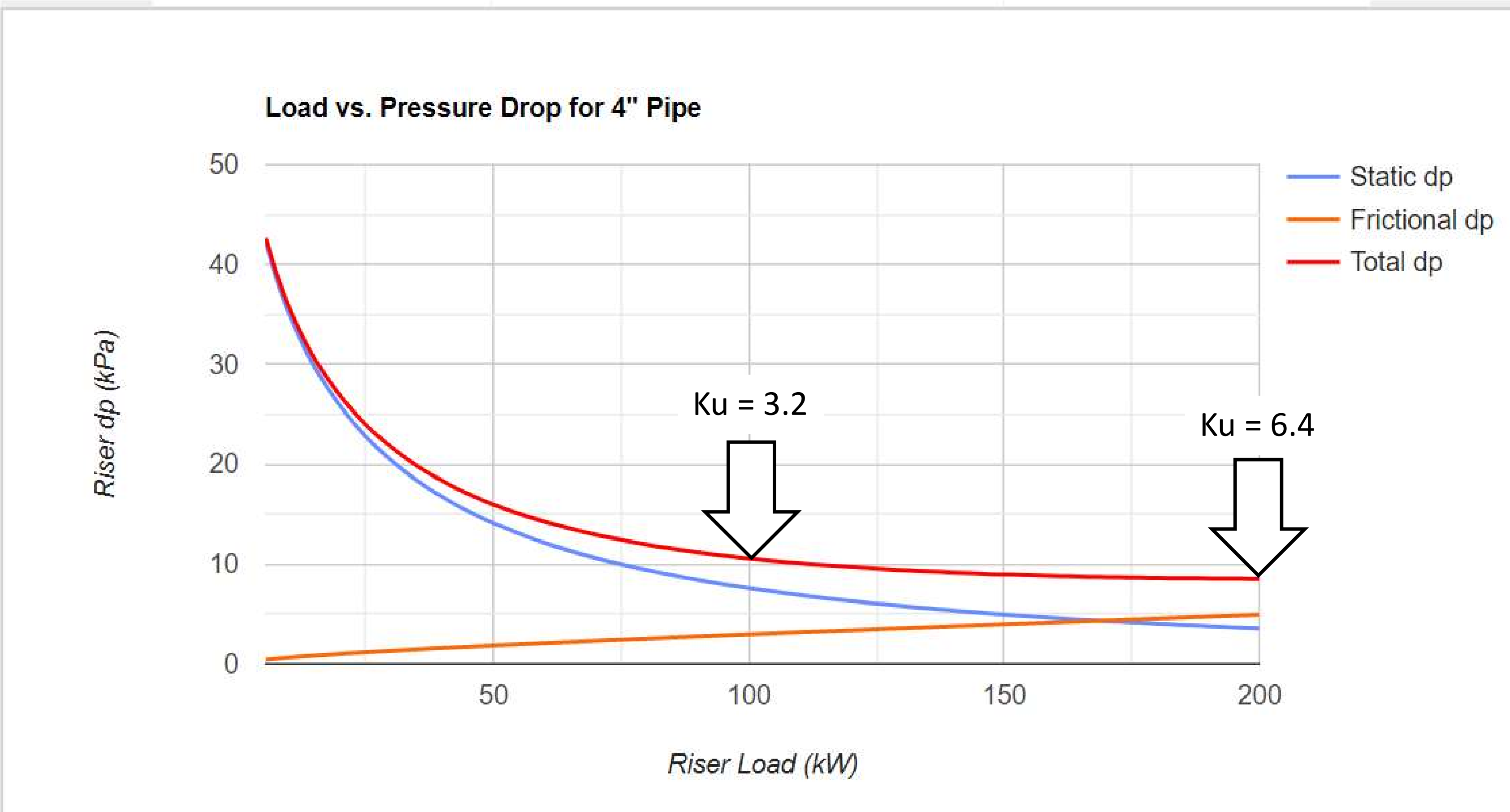
n = Recirculation Ratio = Total Mass Flow Rate / Vapor Mass Flow Rate

* Suction Temperature is the saturated temperature at the pipe exit.

Frictional pressure drop = Pa/m x Lequiv = 170 x 30 = 5100 Pa = 5.1 kPa

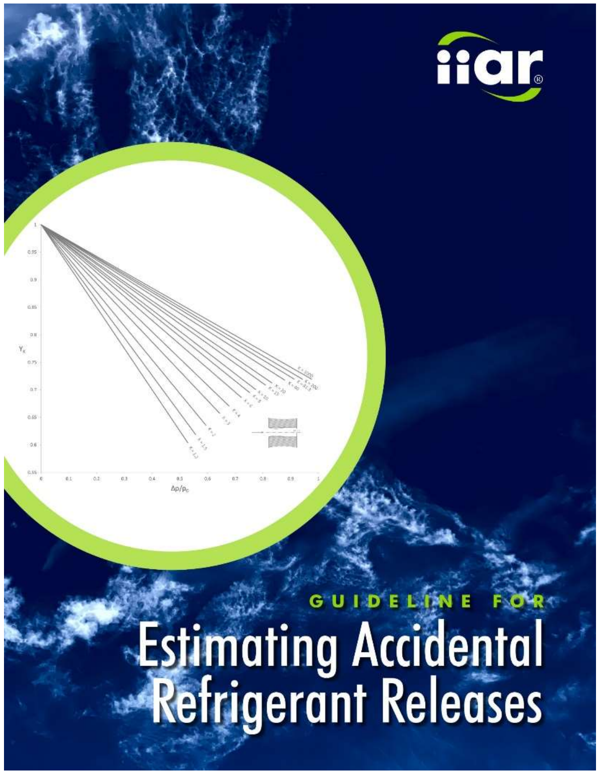
Total riser pressure drop = 3.65 + 5.1 = 8.75 kPa

Ammonia Suction Riser Design – (Colmac Coil Engrg Toolbox)



Estimation of Accidental Refrigerant Releases

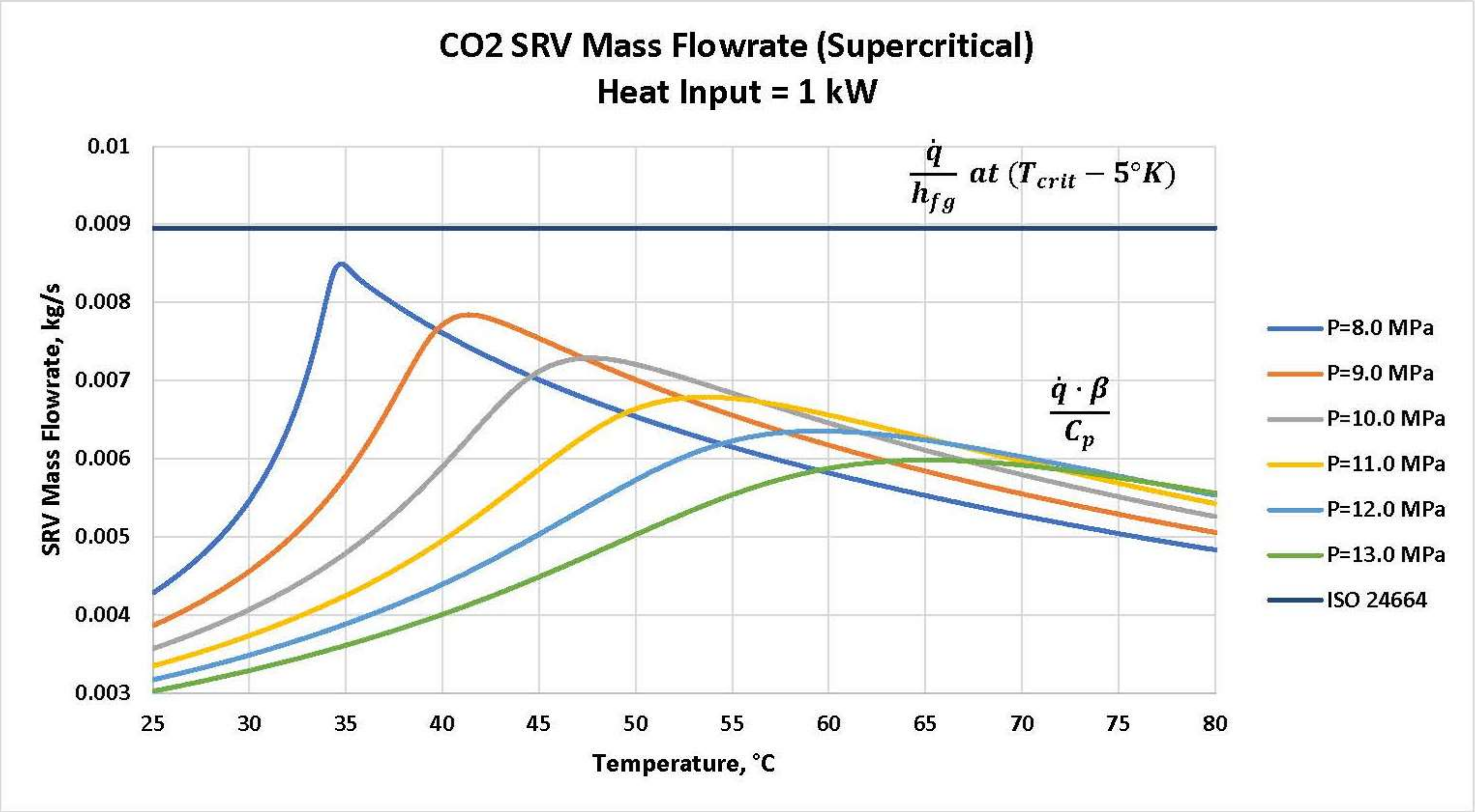
- Owners and operators of refrigerated facilities may be required by regulators to report accidental releases of refrigerant to the environment.
- Estimating the amount of a release can be challenging.
- An NRF-funded project (Wiencke 2022) produced a science-based method for estimating the amount of these releases. The guideline was published in 2022 accompanied by an Excel calculation tool.



Sizing of CO2 Safety Relief Valves at Supercritical Relieving Pressures

- IIAR has recently published a safety standard covering safe design, installation, and operation of CO2 refrigeration systems.
- Vessels operating on the high side of transcritical CO2 systems (i.e. flash tanks) may require protection at supercritical relieving pressures.
- ASHRAE Std 15 does not cover SRV sizing at pressures over 6 MPa (abs).
- A method for correctly sizing SRV at these pressures is needed for inclusion in the IIAR CO2 standard and is currently being investigated by the IIAR Research Committee.
- A paper (Greulich 2023) was presented at the annual IIAR conference which will likely form the basis for the SRV sizing method.

Comparison of Supercritical CO_2 SRV Mass Flow Calculations



CO2 Safety Relief Research Topics

- In certain cases, safety relief valves will see very high temperatures before they reach relieving pressure. What happens to the integrity of these valves at high temperatures?
- Can the assumption of isentropic expansion be used to accurately predict CO2 relief valve performance?
- Under what conditions can/will dry ice form in SRV vent piping?
- Note: Ideas for new research projects are welcome!

References

Ammonia Vertical Suction Risers

IIAR 2019. "Ammonia Refrigeration Piping Handbook". International Institute of Ammonia Refrigeration". Alexandria, Virginia USA

Thome, J. Marcinichen, J. 2019. "Prediction of Void Fraction and Pressure Drops in Vertical Ammonia Risers". 2019 Annual Conference Proceedings, Phoenix, AZ. International Institute of Ammonia Refrigeration (IIAR), Alexandria, Virginia USA

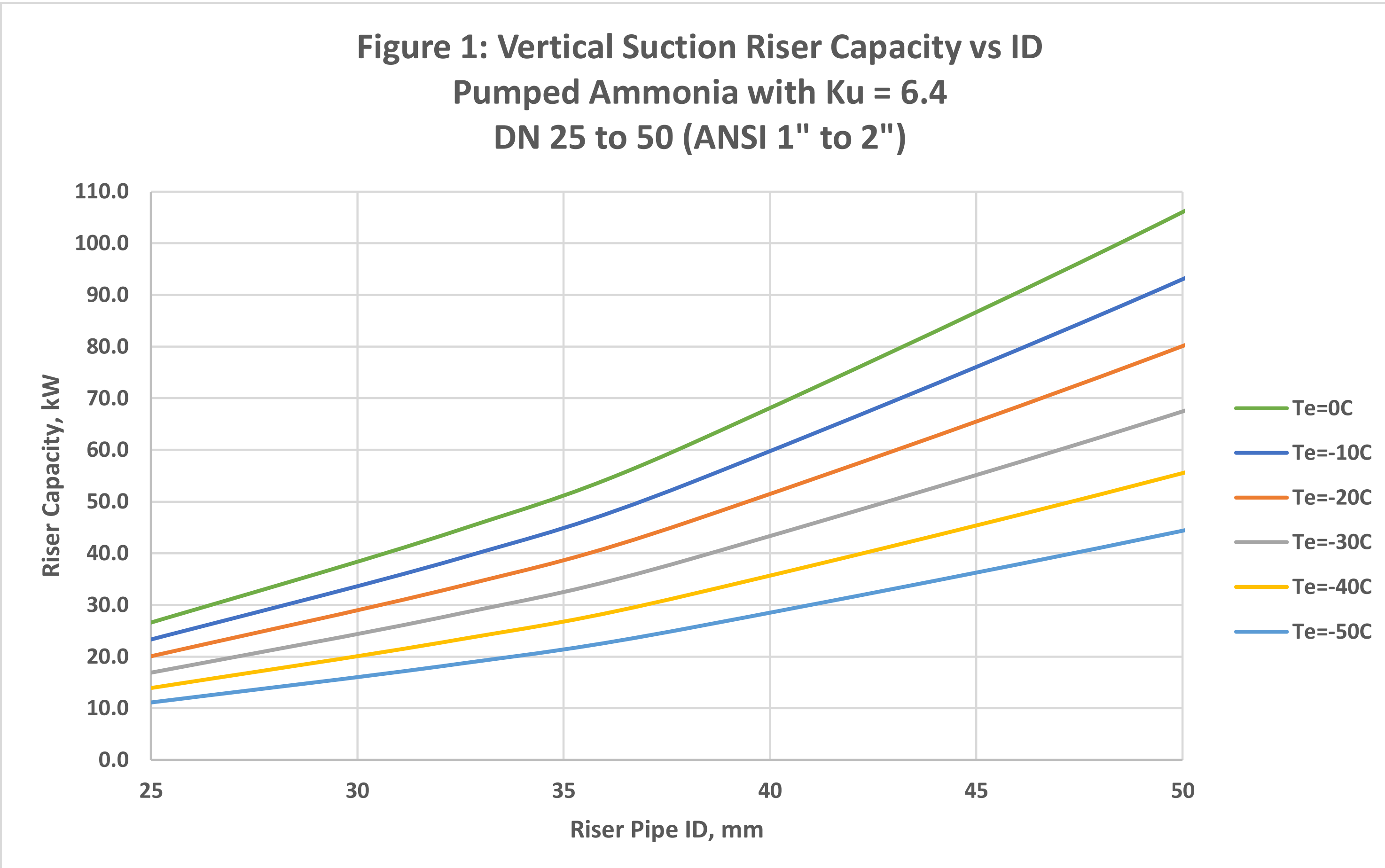
Estimating Accidental Refrigerant Release

IIAR 2022. "Estimating Accidental Refrigerant Releases". International Institute of Ammonia Refrigeration". Alexandria, Virginia USA

Supercritical CO2 Safety Relief Sizing

Greulich, W. 2023. "Carbon Dioxide System Relief Sizing". 2023 Annual Conference Proceedings, Long Beach, CA. International Institute of Ammonia Refrigeration (IIAR), Alexandria, Virginia USA

Ammonia Suction Riser Sizing



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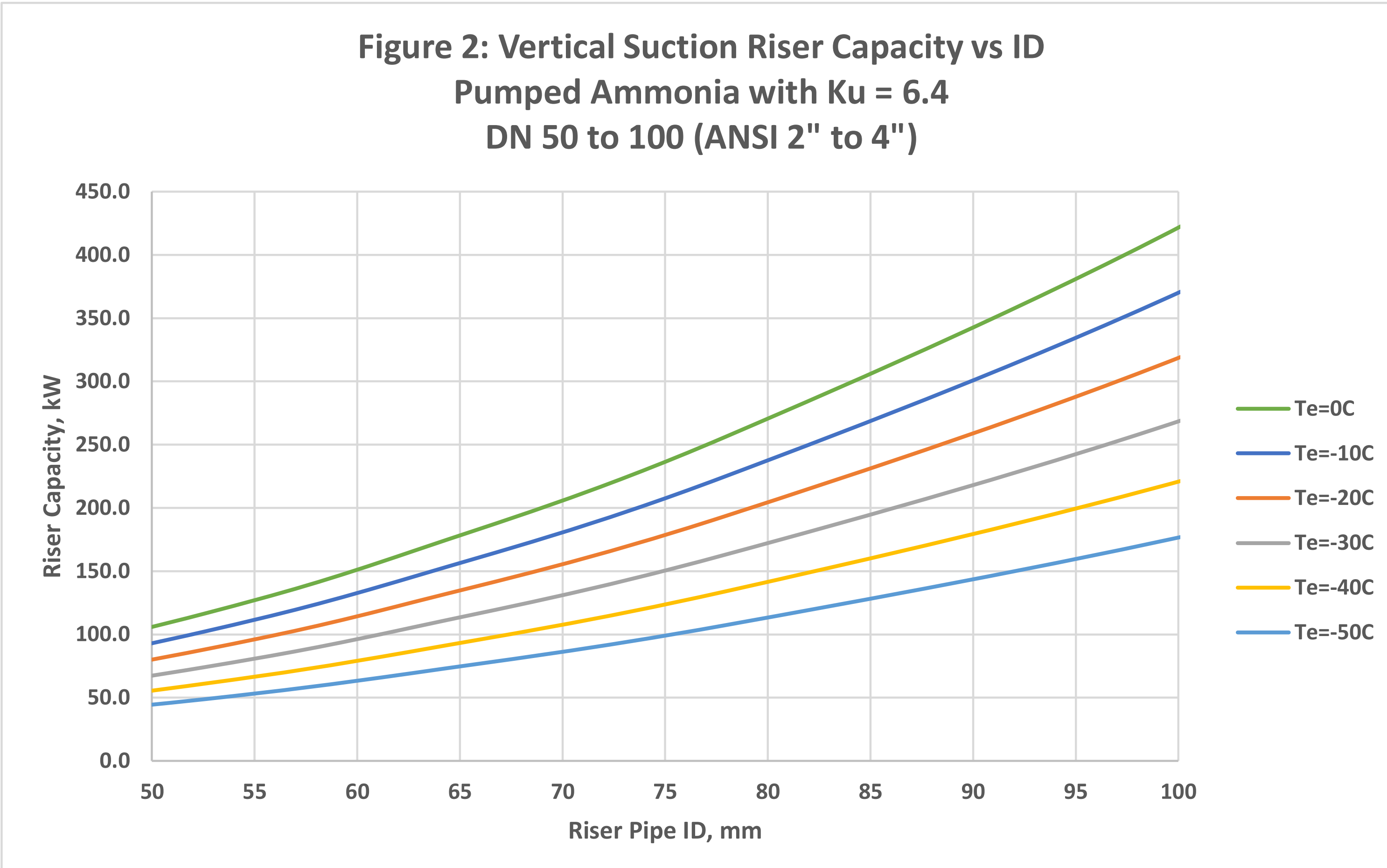

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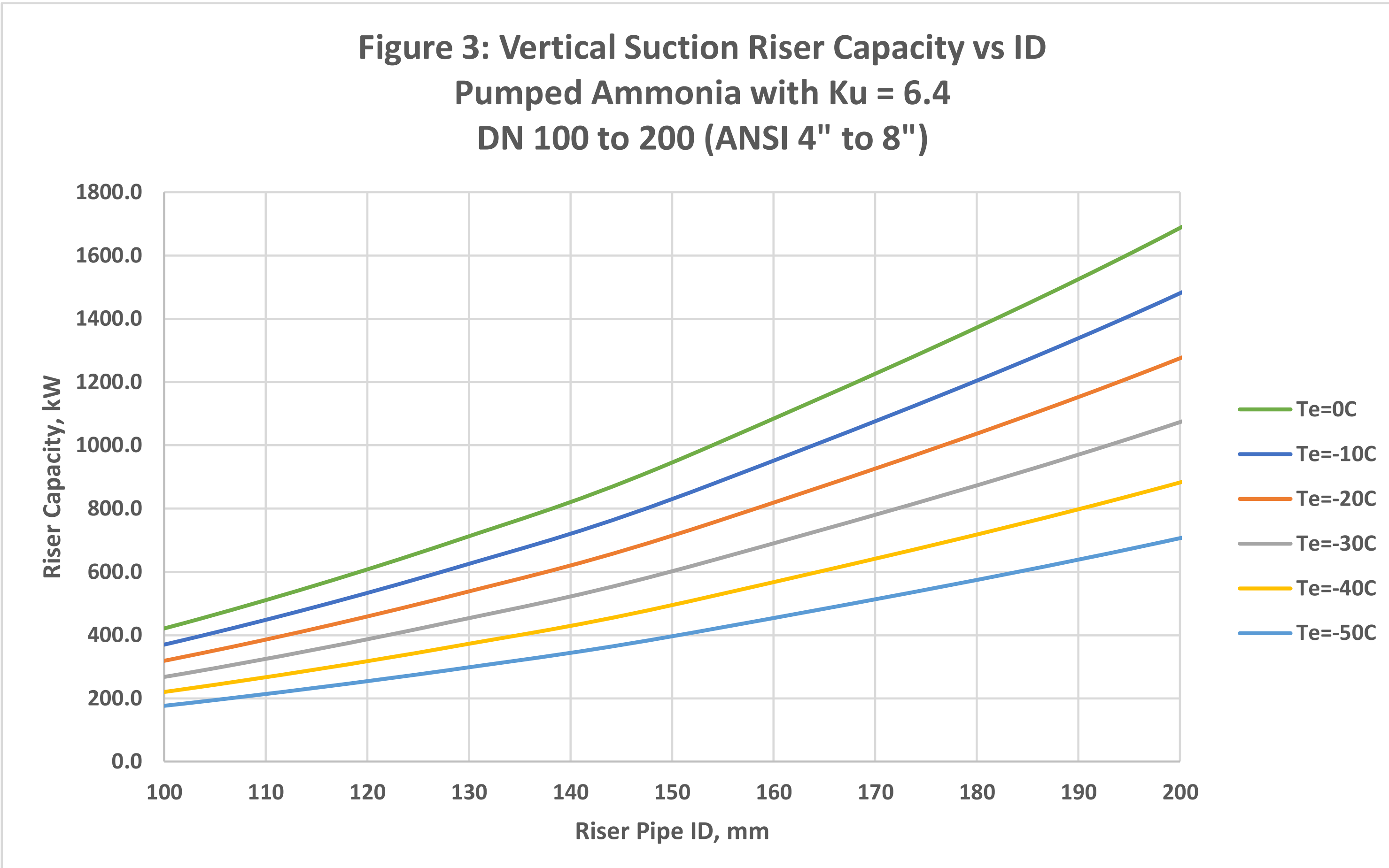

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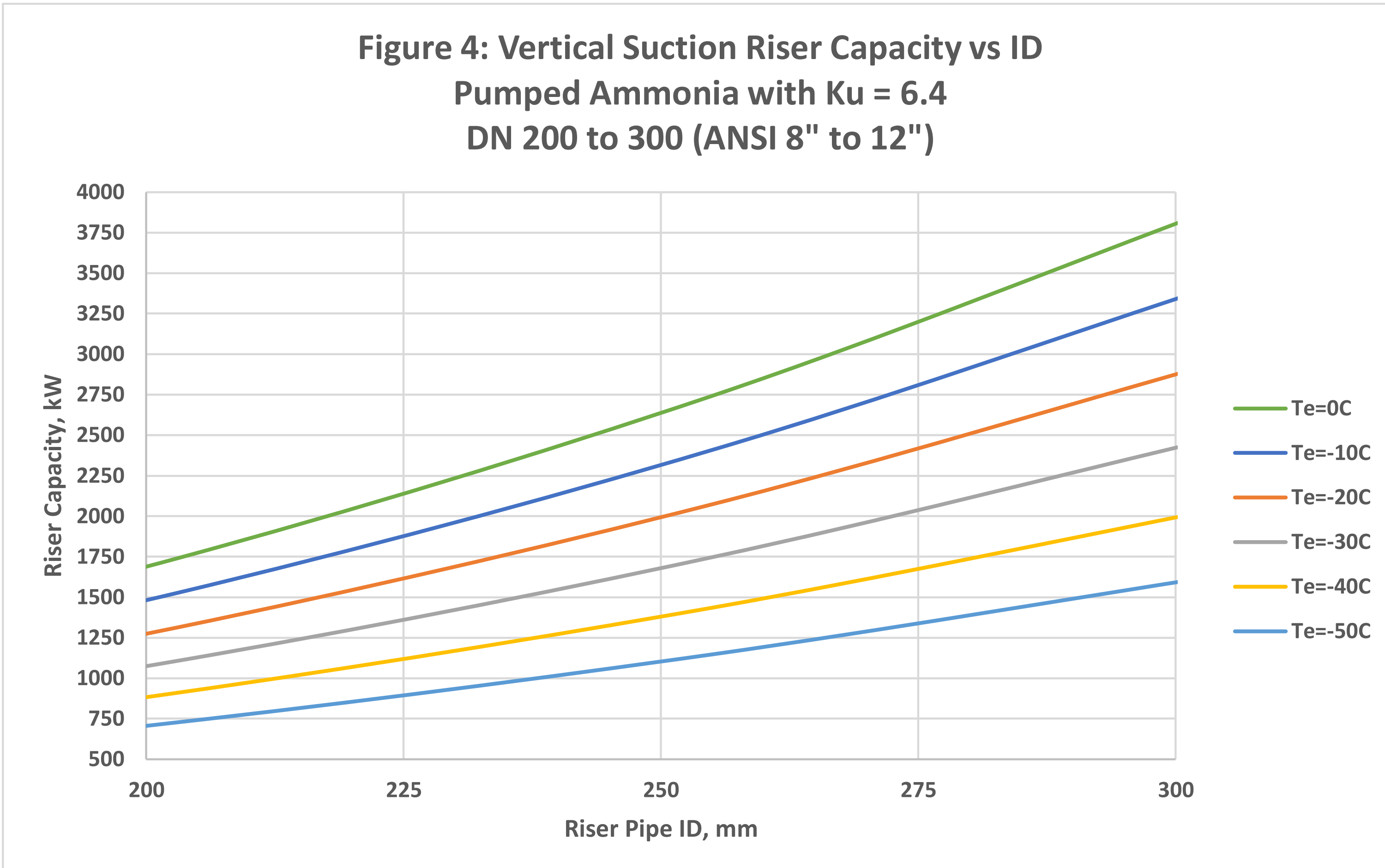

THANK YOU
Questions?

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