TECHNICAL APPENDIX FORM (TA5031) FOR PRESSURE VESSELS
PRESSURE VESSEL ENGINEERING NOTE PER CHAPTER 5031

Prepared by: Mark Adamowski
Preparation date: 03/04/11
(updated RV attachment)

1. Description and Identification
Fill in the label information below:

THIS VESSEL CONFORMS TO FERMILAB ES&H MANUAL CHAPTER 5031

Vessel Title: LAPD CONDENSER

Vessel Number: PPD 10146 ←Obtain from Division/Section Safety Officer

Vessel Drawing No.: 8116-5129-1

Maximum Allowable Working Pressure (MAWP)

Internal Pressure: 60 psi at 100 F

External Pressure: ____

Working Temperature Range: -320 °F +100 °F

Contents: Argon liquid/gas

Designer / Manufacturer: Ability Engineering Technology, Inc.

Test Pressure (if tested at Fermilab) Acceptance Date ____ ← Document per Chapter 5034 of the Fermilab ES&H Manual

____ PSIG, Hydraulic ____ Pneumatic ____

Accepted as conforming to standard by

[signature] ←Actual signature required

Of Division / Section: PPD Date: 8/15/11

NOTE: Any subsequent changes in contents, pressures, temperatures, valving, etc., which affect the safety of this vessel shall require another review.

Reviewed by: Jay C Theilacker
(Print Name)

Signature: [signature] Date: 3/4/11

Director's signature (or designee) if the vessel is for manned areas but doesn't conform to the requirements of the chapter.
Signature: ____ Date: ____

Amendment No.:	Reviewed by:	Date:
1	[signature]	11/19/12

Lab Property Number(s):____
Lab Location Code: PC4   (obtain from safety officer)
Purpose of Vessel(s): To separate nitrogen into gas and liquid. Liquid nitrogen is coolant feed to LAPD condenser. Nitrogen gas is vented by backpressure regulator.

Vessel Capacity/Size: _____________ Diameter: 1'-3/8" Length: 1'-8"
Normal Operating Pressure (OP) 1.5 psig
MAWP-OP = (60-1.5)= 58.5 PSI

List the numbers of all pertinent drawings and the location of the originals.

Drawing #	Location of Original
8116-5129-1 (by Ability Engineering)	DOCDB LARTPC-DOC-599

2. Design Verification

Is this vessel designed and built to meet the ASME BPVC or "Experiment Vessel" requirements?
Yes___X __ No_____.

If "No" state the standard that was used _________________.
Demonstrate that design calculations of that standard have been made and that other requirements of that standard have been satisfied. Skip to part 3 "system venting verification."

Does the vessel(s) have a U stamp? Yes__X___ No__ ___. If "Yes", complete section 2A; if "No", complete section 2B.

A. Staple photo of U stamp plate below.
Copy "U" label details to the side

Copy data here:
NAT'L BD. 174
60 PSI at 100 F
-320 F at 60 PSI
SERIAL 174
YEAR BUILT 2010
W
RT-1

Provide ASME design calculations in an appendix. On the sketch below, circle all applicable sections of the ASME code per Section VIII, Division I. (Only for non-coded vessels)

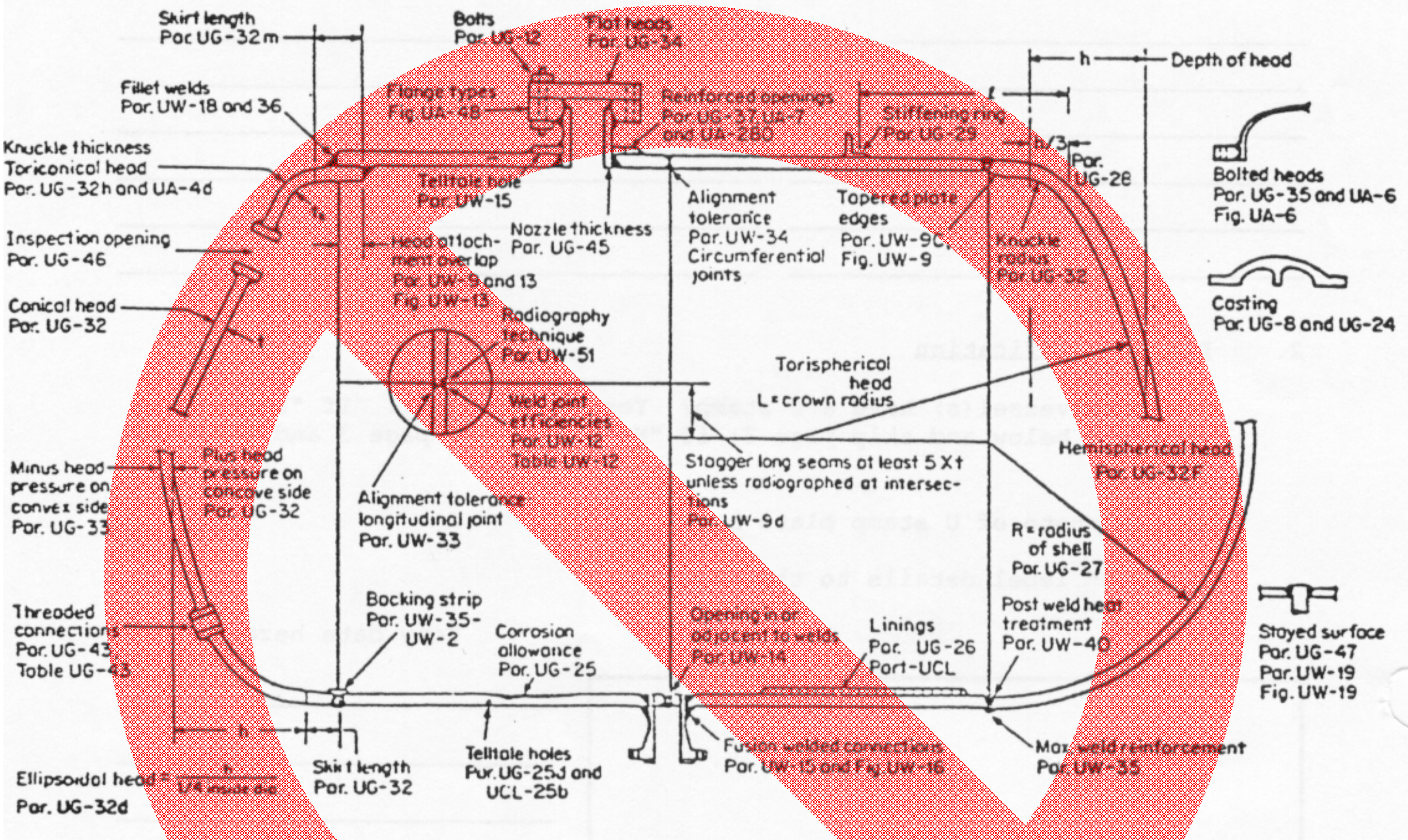


Figure 1. ASME Code: Applicable Sections

2B.

<u>Summary of ASME Code</u>

Item	Reference ASME Code Section	CALCULATION RESULT (Required thickness or stress level vs. actual thickness calculated stress level)
		s
		s
		s
		s
		s

THE LAPD CONDENSER IS A CODE STAMPED ASME VESSEL. THIS SECTION IS NOT REQUIRED.

3. System Venting Verification Provide the vent system schematic.

Does the venting system follow the Code UG-125 through UG-137?
Yes__X_ No___

Does the venting system also follow the Compressed Gas Association Standards S-1.1 and S-1.3?
Yes ______ No___X__

A “no” response to both of the two proceeding questions requires a justification and statement regarding what standards were applied to verify system venting is adequate.

List of reliefs and settings:

Manufacturer	Model #	Set Pressure	Flow Rate	Size
Rockwood Swendeman	RXSO	60 psig	105 SCFM AIR 1930 lb/hr Ar	3/4x1 Seat A

4. Operating Procedure

Is an operating procedure necessary for the safe operation of this vessel?
Yes______ No___X__   (If "Yes", it must be appended)

5. Welding Information

Has the vessel been fabricated in a non-code shop? Yes______ No__X___
If "Yes", append a copy of the welding shop statement of welder qualification (Procedure Qualification Record, PQR) which references the Welding Procedure Specification (WPS) used to weld this vessel.

6. Existing and Unmanned Area Vessels

Is this vessel or any part thereof in the above categories?
Yes______ No___X_____

If "Yes", follow the requirements for an Extended Engineering Note for Existing and Unmanned Area Vessels.

7. Exceptional Vessels

Is this vessel or any part thereof in the above category?
Yes______ No___X_____

If "Yes", follow the requirements for an Extended Engineering Note for Exceptional Vessels.

FORM U-1A MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS
(Alternative Form for Single Chamber, Completely Shop or Field Fabricated Vessels Only)
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by ABILITY ENGINEERING TECHNOLOGY INC. 16140 Vincennes Ave SOUTH HOLLAND IL. 60473
(Name and address of manufacturer)

2. Manufactured for FERMILAB PO BOX 500 BATAVIA, IL 60473 USA
(Name and address of purchaser)

3. Location of installation FERMILAB PO BOX 500 BATAVIA, IL 60473 USA
(Name and address)

4. Type: VERTICAL (Horiz. or vert., tank) 174 (Mfg's serial No.) - (CRN) 8116-5129-1 Rev.1 (Drawing No.) 174 (Nat'l. Bd. No.) 2010 (Year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Rules, Section VIII, Division 1 Edition 2007 (Year)

to Addenda. 2009 (Addenda (Date)) NONE (Code Case No.) NONE (Special Service per UG-120(d))

6. Shell: SA-312-TP-304 (Matl. (Spec., No., Grade)) .1800" (Nom. Thk. (in.)) 0 (Corr. Allow. (in.)) 1'-3/8" (Diam. I.D. (ft. & in.)) 1'-8" (Length (overall) (ft. & in.))

7. Seams: NONE (Long. (Welded, Dbl., Sngl., Lap, Butt)) NONE (R.T. (Spot or Full)) 100 (Eff (%)) - (H.T. Temp. (F)) - (Time (hr)) SGL. BUTT (Girth (Welded, Dbl., Sngl., Lap, Butt)) FULL (R.T. (Spot, Partial or Full)) 100 (Eff (%)) 1 (No. of Courses)

8. Heads: (a) Matl. SA-240-T304 (Spec. No., Grade) (b) Matl. SA-240-T304 (Spec. No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	TOP	0.1250"	0	-	-	2:1	-	-	-	CONCAVE
(b)	BOTTOM	0.1250"	0	-	-	2:1	-	-	-	CONCAVE

If removable, bolts used (describe other fastenings) - (Matl Spec. No., Gr, Size, No.)

9. MAWP 60 (internal) - (external) psi at max. temp. 100 (internal) - (external) °F

Min. design metal temp, -320 °F at 60 psi. Pneu test pressure: 66 psi.

10. Nozzles, inspection, and safety valve openings:

Purpose (Inlet, Outlet, Drain)	No.	Diam. or Size	Type	Matl	Nom. Thk	Reinforcement Matl	How Attached	Location
MISC	6	11/2"	PIPE	SA-312-TP-304	.145"	NONE	UW-1(i)	TOP HEAD
MISC	1	1"	PIPE	SA-312-TP-304	.179"	NONE	UW-1(i)	TOP HEAD
MISC	1	1"	PIPE	SA-312-TP-304	.179"	NONE	UW-1(c)	BOTTOM HEAD
MISC	1	2"	PIPE	SA-312-TP-304	.154"	NONE	UW-1(i)	SHELL
MISC	1	1"	PIPE	SA-312-TP-304	.179"	NONE	UW-1(i)	SHELL

11. Supports: Skirt NO (Yes or no) Lugs 2 (No.) Legs - (No.) Other - (Describe) Attached SHELL/WELDED (Where and how)

12. Remarks: Manufacturer's Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for following items of the report:

(Name of part. Item number. Mfgr's name and identifying stamp)

IMPACT TEST EXEMPT PER UHA-51(d),
OVERPRESSURE PROTECTION PROVIDED BY CUSTOMER

CERTIFICATE OF SHOP/FIELD COMPLIANCE

We certifiy that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1.

"U" Certificate of Authorization No. 26956 expires 4/19/2011

Date 3/22/10 Co. name ABILITY ENGINEERING TECHNOLOGY INC (Manufacturer) Signed [signature] (Representative)

CERTIFICATE OF SHOP/FIELD INSPECTION

Vessel constructed by ABILITY ENGINEERING TECHNOLOGY INC. at 16140 Vincennes Ave. South Holland IL 60473 USA

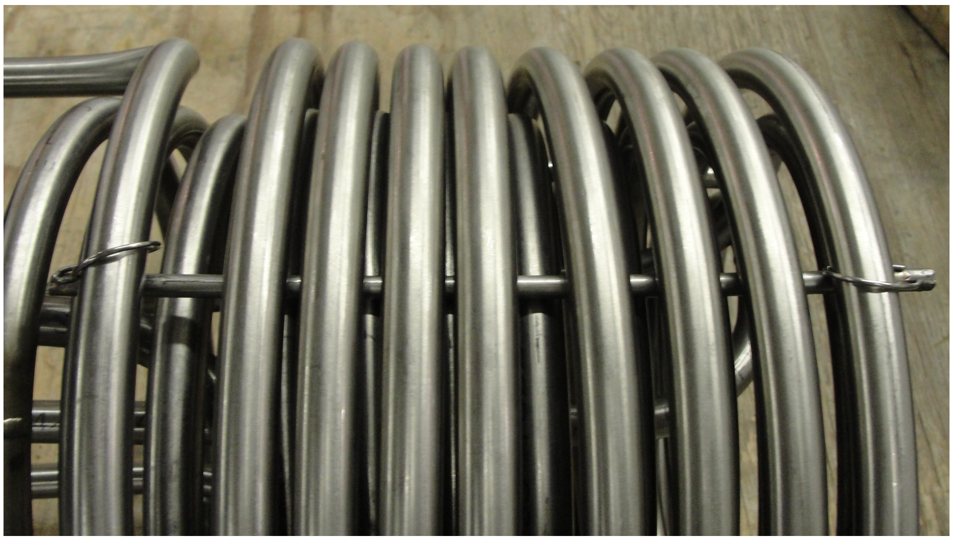
I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of ILLINOIS and employed by HSB CT have inspected the component described in this Manufacturer's Data Report on 3-22-10, and state that, to the best of my knowledge and belief, the Manufacturer has constructed this pressure vessel in accordance with ASME Code, Section VIII, Division 1. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 3-22-10 Signed [signature] (Authorized Inspector) Commissions NB 11557 A IL 21503 (Nat'l Board (incl. endorsements), State, Province and No.)

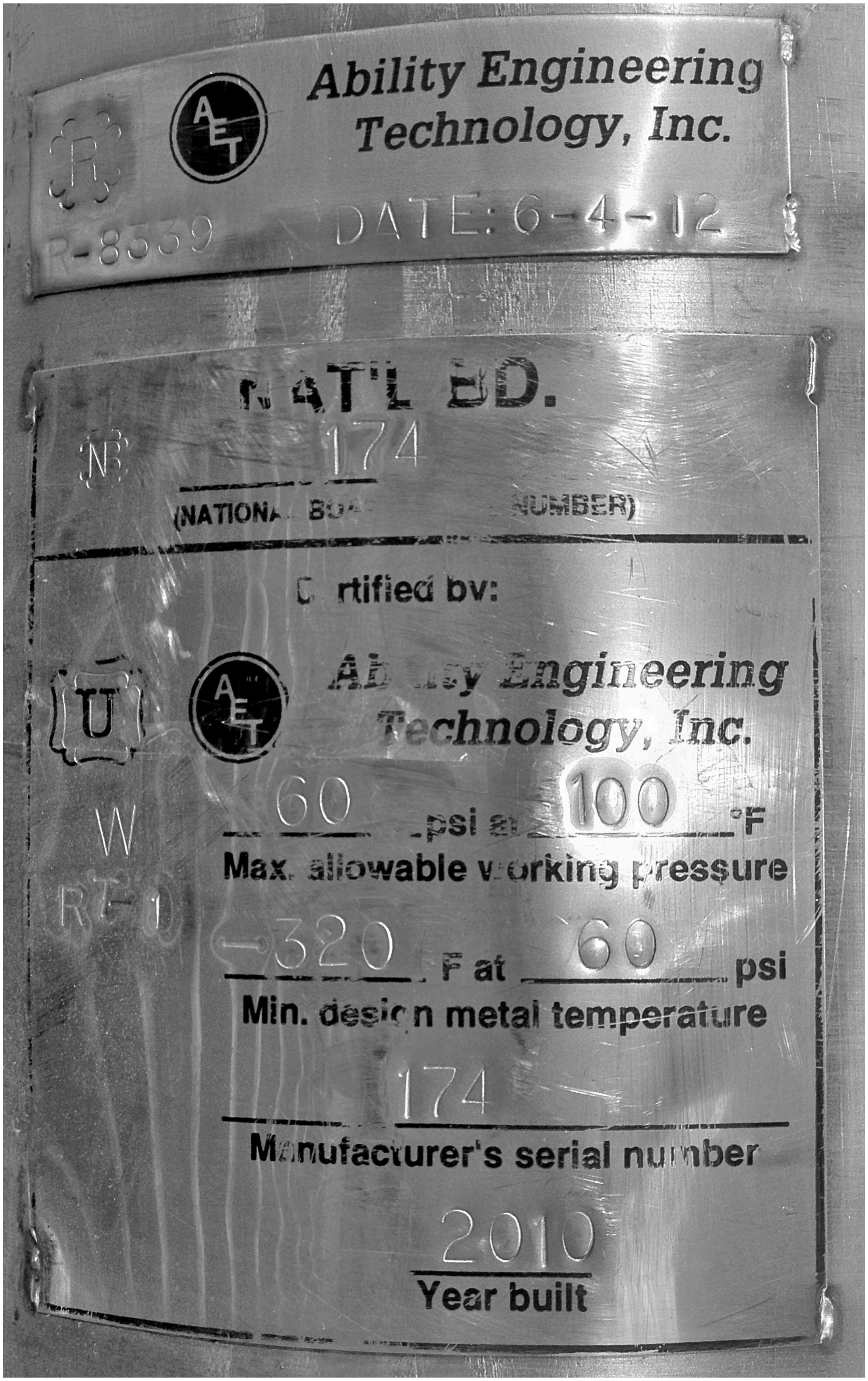
COPY

LAPD Condenser Repair Notes for Pressure Vessel Amendment No. 1

During the 1st LAPD run the LAr condenser exhibited some vibration during cool down. It did not exhibit the vibration under steady state heat loads. It is believed that the vibration was caused by two-phase flow in the LN2 coils which caused the coils to lengthen. To reduce this cool down vibration the condenser has been opened by an ASME code shop and restraints added to prevent the coils from lengthening. While the vessel was open the LN2 coils were inspected and no signs of damage due to vibration were observed. Restraints were added to the two largest coils. The restraints consist of 4 straight tubes that run the length of the coils and cable at each end that wraps around the end coil. This will stop the coil from entering into a lengthening oscillating regime. The pressure retaining features of the vessel are unchanged. This is an amendment to the existing pressure vessel engineering note.



An example coil restraint.



Original ASME code stamp (bottom) and the repair stamp (top).

ORIGINAL

FORM R-1 REPORT OF REPAIR
in accordance with provisions of the *National Board Inspection Code*

1. Work performed by ABILITY ENGINEERING TECHNOLOGY INC. (name of repair organization) — J 8320 (Form Registration No.)
16140 South Vincenness Avenue SOUTH HOLLAND, ILLINOIS 60473 (address) — (PO No., Job No., etc.)

2. Owner FERMI NATIONAL ACCELERATOR LABORATORY (name)
P.O. Box 500 BATAVIA, ILLINOIS 60510 (address)

3. Location of installation FERMI NATIONAL ACCELERATOR LABORATORY (name)
P.O. Box 500 BATAVIA, ILLINOIS 60510 (address)

4. Item identification CONDENSER (boiler, pressure vessel or piping) Name of original manufacturer ABILITY ENGINEERING TECHNOLOGY INC.

5. Identifying nos.: 174 (mfg. serial no.) 174 (National Board No.) - (Jurisdiction No.) - (other) 2010 (year built)

6. NBIC Edition/Addenda: 2011 (edition) - (addenda)

Original Code of Construction for Item: ASME B. & P.V. CODE SECTION VIII DIVISION 1 (name / section / division) 2010 (edition / addenda)

Construction Code Used for Repair Performed: ASME B &P.V. CODE SECT. VIII DIV. 1 (name / section / division) 2010/2011 (edition / addenda)

7. Repair Type: ☑ Welded ☐ Graphite Pressure Equipment ☐ FRP Pressure Equipment

8. Description of work: (use Form R-4, if necessary) ☐ Form R-4, Report Supplementary Sheet is attached ☐ FFSA Form (NB-403) is attached

CUT OUT TOP HEAD, ADD INTERNAL COIL RESTRAINTS, WELD TOP HEAD BACK TO ORIGINAL LOCATION / ORIENTATION , EXTEND (2) 1"-SCH80 PIPES AND (1) 2"-SCH40 PIPE PER ORIGINAL DWG.

Pneumatic Pressure Test, if applied 66 psi MAWP 60 INT. psi

9. Replacement Parts. Attached are Manufacturer's Partial Data Reports or Form R-3s properly completed for the following items of this report:

(name of part, item number, data report type or Certificate of Compliance, mfg. name, and identifying stamp)

10. Remarks:

CERTIFICATE OF COMPLIANCE

I, MAREK HABER, certify that to the best of my knowledge and belief the statements in this report are correct and that all material, construction, and workmanship on this Repair conforms to the *National Board Inspection Code*.
National Board "R" Certificate of Authorization No. R-8339 expires on APRIL 19, 2014
Date 05/31/2012, ABILITY ENGINEERING TECHNOLOGY INC. (name of repair organization) Signed Marek Haber (authorized representative)

CERTIFICATE OF INSPECTION

I, WILLIAM MOERS, holding a valid Commission issued by The National Board of Boiler and Pressure Vessel Inspectors and certificate of competency, where required, issued by the Jurisdiction of ILLINOIS and employed by HSB of CT have inspected the work described in this report on JUNE 04, 2012 and state that to the best of my knowledge and belief this work complies with the applicable requirements of the *National Board Inspection Code*.
By signing this certificate, neither the undersigned nor my employer makes any warranty, expressed or implied, concerning the work described in this report. Furthermore, neither the undersigned nor my employer shall be liable in any manner for any personal injury, property damage or loss of any kind arising from or connected with this inspection.
Date JUNE 04, 2012 Signed [signature] (inspector) Commissions 14061A IL 2235 (National Board and Jurisdiction No.)

This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229 NB-66 Rev. 12

R-1 Report of Repair

Calculation By: M. Adamowski
Project No.: LAPD
Date: 06/15/10

LAPD Condenser Vessel Vacuum Check

These calculations are for the LAPD condenser vacuum rating.

The thickness of metal used in the condensers construction is checked here against full internal vacuum per ASME sect. VIII- Div. 1, UG-28 "Thickness of Shells Under Tubes Under External Pressure".

Length of Section
Length of section between supports

$L := 26 \cdot in$

Condenser Outside Diameter

$D_o := 12.75 \cdot in$

Wall Thickness
(12" sched 10 pipe)

$t_{sched.10} := 0.180 \cdot in$

Min Wall Thickness - per SA-312-TP-304 Matl Spec

$t_{min} := t_{sched.10} \cdot (1 - 12.5 \cdot \%) = 0.158 \cdot in$

Ratio Outside Diameter to min. Wall Thickness

$\frac{D_o}{t_{min}} = 81$

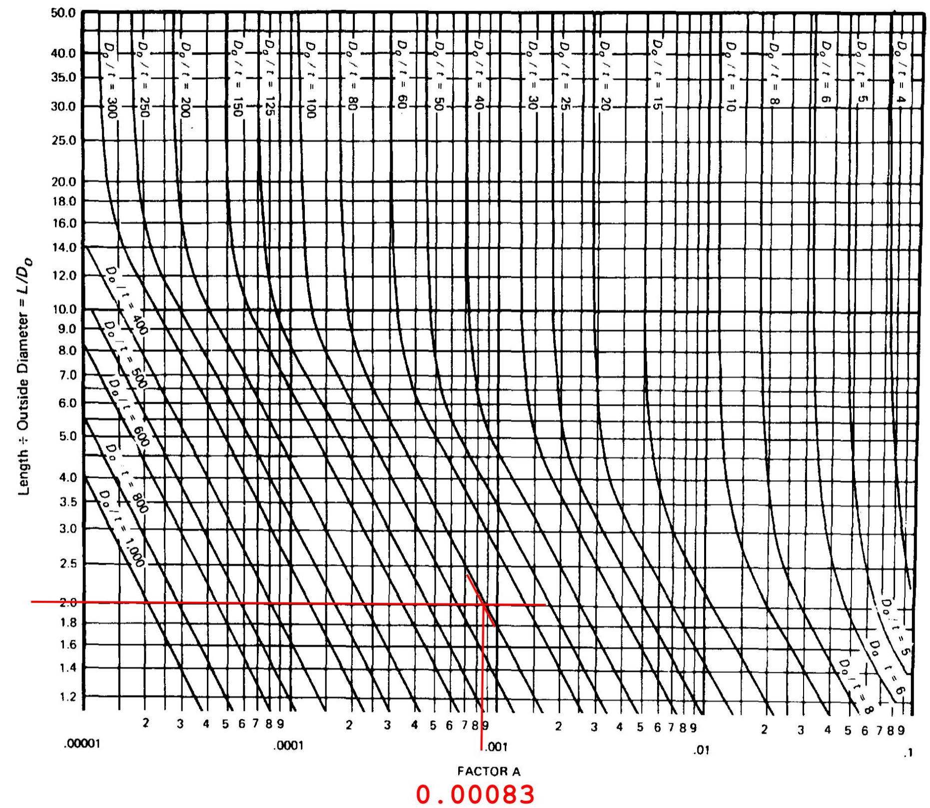
Ratio is greater or equal to 10, therefore falls under UG-28 (c)(1)

Ratio Section Length to Outside Diameter

$\frac{L}{D_o} = 2$

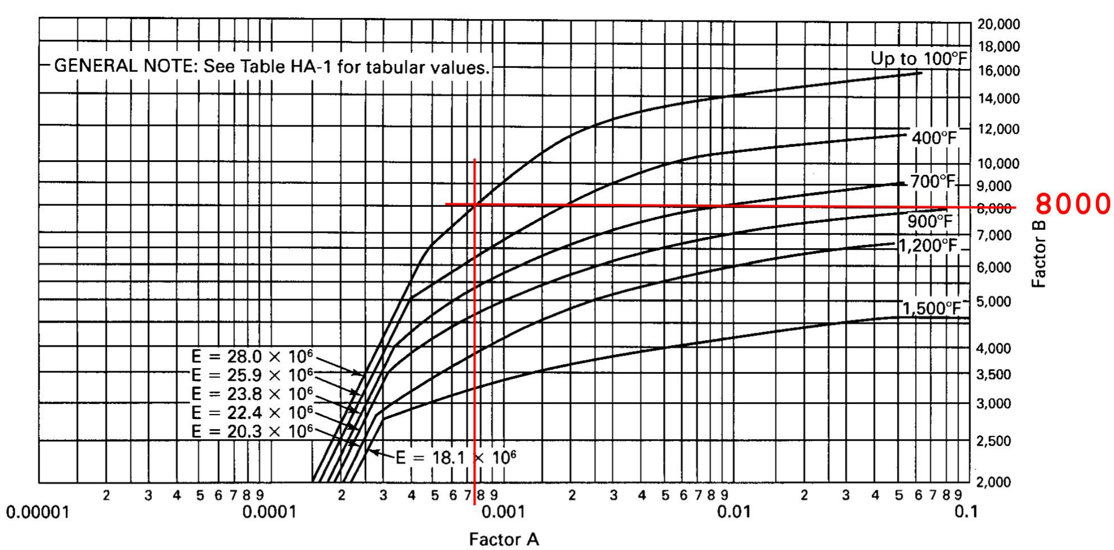
Determination of Factor A from L/Do and D/tmin - per ASME sect II Subpart 3 D

A08 FIG. G GEOMETRIC CHART FOR COMPONENTS UNDER EXTERNAL OR COMPRESSIVE LOADINGS (FOR ALL MATERIALS) [NOTE (14)]



Determination of Factor B from Factor A and Temperature - per ASME sect II Subpart 3 D

FIG. HA-1 CHART FOR DETERMINING SHELL THICKNESS OF COMPONENTS UNDER EXTERNAL PRESSURE DEVELOPED FOR AUSTENITIC STEEL 18Cr–8Ni, TYPE 304



$B := 8000 \cdot psi$ from above graph

Maximum Allowable External Working Pressure

$$P_a := 4 \cdot \frac{B}{3 \cdot \left(\frac{D_o}{t_{min}}\right)} = 131.8 \cdot psi$$ differential

External Design Pressure Required for Full Internal Vacuum

$$P := 14.7 \cdot psi - 0.0psi = 14.7 \cdot psi$$ differential

The allowable external working pressure significantly exceeds the required external pressure for full internal vacuum. The wall thickness of the condenser is more than adequate for full internal vacuum.

LAPD Condenser
Relief Valve and Pipe Sizing

These MATHCAD calculations are for the LAPD condenser pressure relief valve.

The condenser is an ASME stamped pressure vessel and is covered by ASME standards in Section VIII - Div 1. For reference, ASME standards are more stringent than CGA. CGA standards meet DOT specifications, but not ASME standards. Also CGA S-1.3 is not applicable because this vessel is a process vessel not a storage container.

Under ASME VIII-1, overpressure protection is in sections, UG-125 to UG-136.

ASME requires that potential overpressure scenarios are identified and a method of overpressure protection be used to mitigate. Other than for fire, the larger of 10% or 3 psi overpressure is allowed. If fire exposure is possible then 21% overpressure is allowed for the fire scenario. (UG-125)

The International ISO 23251/API 521 standard is used for evaluating the overpressure scenarios and establishing a basis for design. This standard is used in conjunction with API 520 for sizing. The fluid specific methods of API 520 are used instead of the air/steam capacity conversion in ASME Sect. VIII-Div 1.

For evaluating the fire case, credit is taken for the fire resistant insulation and accounted for in the environment factor. The RV inlet and outlet pipe are checked with the flow that will pass through the selected relief valve.

Ref:

- ASME Boiler and Pressure Vessel Code, ASME Section VIII-DIV 1, 2007
- API Standard 520, Part I, 2008 and II, 2003
- ANSI/API Standard 521, 2007 with 2008 addendum
- Chemical Process Safety: Fundamentals with Applications, 2nd ed.
- Crane's Technical Paper 410

Scenario Check List (API 521)

1. Closed outlets
Closed outlets are possible but are not a source of overpressure or under pressure. All vessel connections come from or go to systems that have their own relief protection and are below the reli set pressure of this condenser. This includes the high pressure Ar dewars that have a flow path from connection to the LAPD tank. This is a potential pressure source for the tank but not the condenser because there is no valve available that can block in the condenser with this pressure source. There also Ar purge to the insulation but no flow path into the vessel.

2. Coolant failure
Possible but not a source of overpressure. Without coolant, the condenser simply does not condens argon gas.

3. Top reflux failure - Not applicable.
4. Side reflux failure - Not applicable
5. Lean Oil failure to absorber - Not applicable.

6. Accumulation of noncondensables
Not applicable. System designed for cyrogenic operation. Cryogen vaporizing is noted in item 10.

7. Entrance of highly volatile material - Not applicable. System designed for cyrogenic operation.

8. Overfilling
Overfilling is possible if outlets are blocked or closed. See item 1 above.

9.Control Failure
The condenser coolant could fail closed, but this is not a source of overpressure. The condenser coolant could fail open, but this is not a source of underpressure. The available coolant supply pressure is less than vessel design (MAWP) pressure. Also the vessel can handle full vacuum.

10. Abnormal heat or vapor input
a. Abnormal heat input possible if insulation is damaged.
b. Failure of the vapor barrier and icing of the insulation is possible.
c. Abnormal vapor input is possible but self limiting, available supply pressure less than relief pressu

11. Split exchanger tube
Coil tube split, possible but not a source of over or under pressure. Nitrogen supply pressure is belo relief pressure and vessel can handle full vacuum.

12. Internal explosion - Not applicable, no flammables being used.
13. Chemical reaction - Not applicable, only cryogens in vessel.
14. Hydraulic expansion - Not applicable.

15. Exterior fire
Possible that small quantity of flammables (box/papers) are near this vessel.

16. Power failure (steam, electric, air, other) - same as item 8.

Item **10a**, **10b** and **15** above are identified as possible sources of overpressure.

Constants and Defined values used in subsequent calculations

Gravitational Constant: $g_c = 32.2 \cdot \frac{ft \cdot lbm}{lbf \cdot s^2}$ $g_c = 1.0 \cdot \frac{\frac{kg \cdot m}{s^2}}{N}$

Gas Constant: $R_g := 8.314472 \cdot \frac{joule}{mole \cdot K}$

Atmospheric pressure: $atm = 14.70 \cdot psi$ $atm = 14.70 \cdot \frac{lbf}{in^2}$

Physical Properties of vapor @ 10% Pres. Accumulation (REFPROP V8)

Molecular Weight

$M_w := 39.95 \cdot \frac{kg}{kgmole}$

Saturation temperature at relieving pressure

$T_{in} := 107.3 \cdot K$

Gas Compressibility

$Z := 0.8877$

Gas Heat Capacity Ratio @ relieving Temperature

$\gamma := 1.6667$

Heat of Vaporization

$Hv := 143.00 \cdot \frac{kJ}{kg}$

Prandtl Number

$Pr := 0.8377$

Gas Heat Capacity, Cp

$Cp := 0.6849 \cdot \frac{kJ}{kg \cdot K}$

Gas Density

$\rho := 28.06 \cdot \frac{kg}{m^3}$

Viscosity of vapor

$\mu := 0.009 cpoise$

Gas Thermal Conductivity

$therm_{cond} := 7.427 \cdot \frac{mW}{m \cdot K}$

Evaluation of Overpressure Scenario 10a - Abnormal Heat Input Damaged Insul.

Damage or loss of a portion of insulation is plausible. This is a small vessel and the side insulation will be pre-formed piping insulation. It is assumed that 2 insulation sections fall off, which could expose the sides of the vessel. The insulation on the heads are separate from the side pieces and are assumed to remain in place.

Vessel Height **Vessel ID:** **Heat of Vaporization**

$H := 20 \cdot in$ $D := 12 \cdot in$

$Hv = 143.0 \cdot \frac{kJ}{kg}$ @ relieving conditions

Total Vessel Surface Area:

$$Area_{sides} := H \cdot 2\pi \frac{D}{2} = 5.2 \cdot ft^2$$

$$Area_{sides} = 0.49\, m^2$$

Heat Transfer Coefficient (natural air convection)

$k_{air.conv} := 15 \cdot \frac{W}{m^2 \cdot K}$ Assumed average heat transfer coefficient in air.

$$Q_{air.conv} := k_{air.conv} \cdot Area_{sides} \cdot (300K - 89.1 \cdot K) = 5.3 \times 10^3 \cdot \frac{BTU}{hr}$$

Required Relief Rate for scenario 10a

$Wm_{R.10a} := \frac{Q_{air.conv}}{Hv} = 38.7 \cdot \frac{kg}{hr}$ $Wm_{R.10a} = 85.4 \cdot \frac{lb}{hr}$

Evaluation of Overpressure Scenario 10b - Abnormal Heat Input
Failed Vapor Barrier

A failure of the vapor barrier is plausible. This calculations checks the extreme case of all the insulation becoming impregnated with ice.

Insulation Thickness $Insul_{Th} := 4 \cdot in$

Vessel Height **Vessel ID:**

$H = 20 \cdot in$ $D = 12 \cdot in$

Estimated Elliptical Head Wetted Area:

ref: Applied Process Design for Chemical and Petrochemical Plants, 4 ed.

$$EllipHead_{area} := 1.15 \cdot \left[\pi \cdot \left(\frac{D}{2} \right)^2 \right] = 0.9 \cdot ft^2$$

$$EllipHead_{area} = 0.08\,m^2$$

Total Vessel Surface Area:

$$Area := EllipHead_{area} + H \cdot 2\pi \frac{D}{2} = 6.1 \cdot ft^2$$

(bottom head and sides)

$$Area = 0.57\,m^2$$

Heat of Vaporization

$$Hv = 143 \cdot \frac{kJ}{kg}$$

Ice Thermal Conductivity per Cryogenic Heat Transfer, By Barrons

$$k_{ice} := 1.88 \cdot \frac{W}{m \cdot K}$$

In US units this is 1.09 Btu/hr-ft-F

$$ice_{thick} := Insul_{Th} = 4 \cdot in$$

Assuming, full insulation thickness becomes ice.

$$Q_{ice} := \frac{k_{ice} \cdot Area \cdot [(0.0 + 273.15)K - 89.1 \cdot K]}{ice_{thick}} = 6.6 \times 10^3 \cdot \frac{BTU}{hr}$$

Required Relief Rate for scenario 10b

$$Wm_{R.10b} := \frac{Q_{ice}}{Hv} = 48.9 \cdot \frac{kg}{hr} \qquad Wm_{R.10b} = 107.8 \cdot \frac{lb}{hr}$$

Evaluation of Overpressure Scenario 15 - Exterior Fire

Calculate relief rate based on a blocked in fire scenario

Per API 521 sec. 5.15.1.1
To determine vapour generation, it is necessary to recognize only the portion of the vessel that is wetted by its internal liquid and is equal to or less than 25 ft above the flame.

Relief valve Set Pressure vessel Design P (MAWP)

$P_{set} := 60 \cdot psi$ gauge

Height of high liquid level from bottom tangent:

$H_L := 6 \cdot in$

No liquid level under normal operation.

Vessel ID:

$D = 12 \cdot in$

Estimated Elliptical Head Wetted Area:

ref: Applied Process Design for Chemical and Petrochemical Plants, 4 ed.

$$EllipHead_{area} := 1.15 \cdot \left[\pi \cdot \left(\frac{D}{2}\right)^2\right] = 0.9 \cdot ft^2$$

$$EllipHead_{area} = 0.08\,m^2$$

Total Vessel Wetted Surface Area:

$$Av := EllipHead_{area} + H_L \cdot 2\pi \frac{D}{2} = 2.5 \cdot ft^2$$

(bottom head and sides up to a liquid level)

$$Av = 0.23\,m^2$$

Determination of Insulation Credit (per API 521 5.15.5.4)

This vessel will have Trymer insulation similar to the type on the LAPD tank, that was flame test.

Engineering Judgment:

This insulation was flame tested and can withstand exposure to a propane/air flame (>1700 F) and maintain integrity. Flame test was performed by Jim Priest, Sr. Fire Strategist & Researcher, Fermilab, LArTPC-doc-514.

PC4 will have a fire alarm that will call the Fermilab fire department. Response time would be on the order of minutes.

Fermilab fire department is trained in dealing with cryogen containing vessels. As part of the LAPD project they will receive a walk through of the LAPD tank and associated equipment.

Liquid flammables are not and will not be stored in PC4. It is plausible that there could be a flammable box or papers near this vessel.

Given the above, an insulation credit can be taken in the fire heat input calculation as specified in API 521.

The API 521 fire input rate will be used. This is conservative since there are no flammable fuels in PC4 to make a pool fire.

Insulation Thermal Conductivity (ambient conditions)

$$k_{ins.ambient} := 0.027 \cdot \frac{W}{m \cdot K}$$

Insulation Thickness

$$Insul_{Th} = 4 \cdot in$$

API Calculation for F, with units added to factor for unit consistency

$$F := \frac{k_{ins.ambient} \cdot \left[(904 + 273.15) K - T_{in} \right]}{66570 \cdot \frac{kg}{s^3} \cdot Insul_{Th}} = 0.0043$$

API 521 eq. 13
sect. 5.15.5.4
The implied units of the API conversion factor are kg/sec^3.

CHECK: Same calculation forcing the units choice to use the API formula in unitless fashion. The result is the same.

$$\frac{k_{ins.ambient} \cdot \frac{1}{\frac{W}{m \cdot K}} \cdot \left[(904 + 273.15) K - T_{in} \right] \cdot \frac{1}{degC}}{66570 \cdot Insul_{Th} \cdot \frac{1}{m}} = 0.0043$$

Required Relief Rate for scenario 15 - Exterior Fire

$Qv := 21000 \cdot \left(\frac{BTU}{hr}\right) \cdot F \cdot \left(\frac{Av}{ft^2}\right)^{0.82}$ $Qv = 189 \cdot \frac{BTU}{hr}$ API 521 eq. 6 sect. 5.15.2.2.1

$Hv := 141.7 \cdot \frac{kJ}{kg}$ @ 21% accumulation

$Wm_{R.fire} := \frac{Qv}{Hv}$ $Wm_{R.fire} = 1.40 \cdot \frac{kg}{hr}$ $Wm_{R.fire} = 3.1 \cdot \frac{lb}{hr}$

Comparing Scenario Relief Rates

$Wm_{R.10a} = 38.7 \cdot \frac{kg}{hr}$

$Wm_{R.10b} = 48.9 \cdot \frac{kg}{hr}$

$Wm_{R.fire} = 1.4 \cdot \frac{kg}{hr}$

By inspection, scenario 10b, failed vapor barrier is the largest overpressure scenario and therefore will be used as the sizing basis.

$Wm_R := Wm_{R.10b} = 48.9 \cdot \frac{kg}{hr}$

Relief valve Set Pressure vessel Design P (MAWP)

$P_{set} = 60 \cdot psi$ gauge

Relieving pressure: overpressure of 10% or 3 psi, whichever is larger

$P_R := P_{set} \cdot 1.10 + atm$

$P_R = 80.7 \cdot psi$ abs

Actual Relief Rate - Based on a selected relief valve orifice size

For the selected, relieve valve, the actual orifice size is checked with the certified Kd value (ASME) for that relief valve.

Selected Orifice Size $As := 0.118 \cdot in^2$

Coeff. of Discharge $Kd := 0.605$ >> Specific to RXSO relief valve <<

Back Pressure Factor $Kb := 1.0$

Combination Factor $K_c := 1.0$

API 520.P1 eq. 5
sect. 5.6.3.1.1, with expanded "C" factor and unit consistency and conversion handled by Mathcad. The gas constant and gravitational constant are explicitly shown.

$$Wm_A := Kd \cdot Kb \cdot K_c \cdot P_R \cdot As \cdot \sqrt{\frac{\gamma \cdot g_c \cdot M_w}{T_{in} \cdot R_g \cdot Z} \cdot \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{\gamma-1}}}$$

$Wm_A = 1049 \cdot \frac{lb}{hr}$ $Wm_A = 476 \cdot \frac{kg}{hr}$

The relief valve available capacity is greater than required capacity.
The required capacity is listed here for reference.

$Wm_R = 48.9 \cdot \frac{kg}{hr}$

The reported ASME certified capacities for relief valve made after 1962 are 90% of expected flow per ASME derate requirement. The true expected flow should be used for checking inlet outlet piping.

$$Wm_{A.full} := \frac{Wm_A}{90 \cdot \%} = 528.7 \cdot \frac{kg}{hr}$$

Check of Relief Valve Inlet Pipe Pressure Drop (incompressible flow)

Equivalent length used is conservative representation of short straight pipe and minor fitting losses.

Equivalent Length:

$L := 4.00 \cdot ft$

This eqv. length includes 2.6 ft for pipe entrance loss.

Pipe Inside Diameter:

$D_i := 0.824 \cdot in$

Pipe Roughness:

$\varepsilon := 0.0005 \cdot ft$

Friction Factor Guess:

$f := 0.002$

Pipe Inlet Pressure:

$P_{in} := P_R = 80.7 \cdot psi$ abs

Density of relieving Gas:

$\rho_{gas} := \rho = 28.1 \cdot \frac{kg}{m^3}$

(gas @ relief pressure)

Viscosity of relieving Gas:

$\mu = 0.009 \cdot cP$

Given

Darcy's Friction Factor:

$$\frac{1}{\sqrt{f}} = -2.0 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot D_i} + \frac{2.51}{4 \cdot \frac{Wm_{A.full}}{D_i \cdot \pi \cdot \mu} \cdot \sqrt{f}}\right)$$

Cranes uses Darcy's friction factor.

$f_{pipe} := \mathrm{Find}(f) = 0.0342$

$$vel_{inlet} := \frac{\frac{Wm_{A.full}}{\rho_{gas}}}{\pi \cdot \left(\frac{D_i}{2}\right)^2}$$

$vel_{inlet} = 15.2 \cdot \frac{m}{s}$ $\quad vel_{inlet} = 49.9 \cdot \frac{ft}{s}$

$$\Delta P_{inlet} := \rho_{gas} \cdot f_{pipe} \cdot \frac{L}{D_i} \cdot \frac{vel_{inlet}^2}{2} = 0.939 \cdot psi$$

Crane's 410, eqn. 1.4.
(times g to get lbf so g's cancel)

$\frac{\Delta P_{inlet}}{P_{in}} = 1.2 \cdot \%$ The calculated pressure drop is less than 10% of inlet pressure and therefore use of the inlet density provides reasonable accuracy per Crane Technical Paper No 410.

$\frac{\Delta P_{inlet}}{P_{set}} = 1.6 \cdot \%$ API 520.P2 4.2.2 recommends that the total inlet piping pressure drop not exceed 3% of the set pressure.

Check of Relief Valve Outlet Pipe Pressure Drop (incompressible flow)

The real pipe length will be less than 30 feet. The straight pipe, fittings, elbows, pipe entrance and pipe exit losses are captured by an equivalent length of 200 ft.

The pipe outlet is assumed room temperature and the gas properties at the outlet are used for pressure drop calcs.

$T_{out} := 300 \cdot K$

Equivalent Length:

$L := 200 \cdot ft$

Includes 170 ft for elbows, inlet and outlet losses.

Pipe Inside Diameter

$D_i := 2.907 \cdot in$

Friction Factor Guess

$f := 0.002$

Pipe Roughness:

$\varepsilon = 0.0005 \cdot ft$

Density of relieving Gas @ 300 K & atm

$\rho_{gas.warm} := 1.6238 \cdot \frac{kg}{m^3}$

Viscosity of relieving Gas@ 300 K & atm

$\mu_{warm} := 0.022741 \cdot cP$

Given

Darcy's Friction Factor:

$$\frac{1}{\sqrt{f}} = -2.0 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot D_i} + \frac{2.51}{4 \cdot \frac{Wm_{A.full}}{D_i \cdot \pi \cdot \mu_{warm}} \cdot \sqrt{f}}\right)$$

Cranes uses Darcy's friction factor. (Darcy's f is 4 times the Fanning f)

$f_{pipe} := \text{Find}(f) = 0.0251$

$$vel_{outlet} := \frac{\frac{Wm_{A.full}}{\rho_{gas.warm}}}{\pi \cdot \left(\frac{D_i}{2}\right)^2} \qquad vel_{outlet} = 21.1 \cdot \frac{m}{s} \qquad vel_{outlet} = 69.3 \cdot \frac{ft}{s}$$

$$\Delta P_{outlet} := \rho_{gas.warm} \cdot f_{pipe} \cdot \frac{L}{D_i} \cdot \frac{vel_{outlet}^2}{2} = 1.09 \cdot psi$$

Cranes eqn. 1.4. (times g to get lbf so g's cancel)

$P_{in} := atm + \Delta P_{outlet} = 15.8 \cdot psi$ abs

$$\frac{\Delta P_{outlet}}{P_{in}} = 6.9 \cdot \%$$

Pressure drop is greater than 10% of the inlet pressure. The lower outlet density is used knowing it results in an overestimate of the pressure drop per Crane's Flow of Fluids, Technical Paper No 410.

$$\frac{\Delta P_{outlet}}{P_{set}} = 1.8 \cdot \%$$

It is recommended that the outlet piping pressure drop not exceed 10% of set pressure, API 520.P1 sect. 5.3.3.1.3.

REFERENCE MATERIAL

Pipe Roughness for Reference

Table 4-1 Roughness Factor ε for Clean Pipes[1]

Pipe material	ε (mm)
Riveted steel	1–10
Concrete	0.3–3
Cast iron	0.26
Galvanized iron	0.15
Commercial steel	0.046
Wrought iron	0.046
Drawn tubing	0.0015
Glass	0
Plastic	0

[1]Selected from Octave Levenspiel, *Engineering Flow and Heat Exchange* (New York: Plenum Press, 1984), p. 22.

$0.046 \cdot mm = 0.000151 \cdot ft$

A more conservative value of 0.0005 ft pipe roughness is used in the relief piping evaluations. That translates to a roughness somewhere between galvanized iron and cast iron.

$0.0005 \cdot ft = 0.2 \cdot mm$

Use of Inlet Conditions for Ratio of Specific Heats, k

The eight edition of API 520 contradicts itself in the published standard over the use of the ratio of specific heats at standard conditions or inlet relieving conditions.

API 520 takes the ideal gas equation for choked flow and separates out the estimated critical flow pressure ratio into a separate factor to which they attach lumped unit conversion factors, API refers to as C.

In the 6th edition of 520, C was defined as "coefficient determined from an expression of the ratio of specific heats of the gas or vapor at standard conditions.

Starting with the 7th edition of 520, C was defined as "a function of the ratio of the ideal gas specific heats (k=Cp/Cv) of the gas or vapor at inlet relieving temperature". Other references to C were left unchanged, including indication that only C at standard conditions could be used.

API responded to an request for interpretation on this apparent contradiction. API's reply, was "Yes. Section 3.6.2 (7th ed) recommends that the ratio of specific heats, k , in the sizing equations should be determined at the inlet relieving conditions. This is a departure from previous editions, which said that k should be based on standard conditions (i.e. 60 F and atmospheric pressure)". Between the 7th and 8th, the sizing formula and definition of C moved from section 3.6.2 to section 5.6.3.1.1.

The "new" assumption of at relieving conditions was evaluated by A. Shackelford and reported in "Using the Ideal Gas Specific Heat Ratio for Relief Valve Sizing", Chem. Eng. 110, No. 12, 54-59, Nov. 2003. His work indicated that the heat capacity ratio could be used as an estimate of the isentropic expansion coefficient to provide a good estimate of the mass flux through a nozzle.

Relief conditions near the critical point or at very high pressure are poorly represented by these assumptions and special evaluation is required. API 520, appendix B provides guidance.

API 520 PSEUDO C FACTOR

API 520 takes part of the choked orifice formula and builds it into a pseudo C factor. API further simplifies the C factor formula by hiding the gas constant and gravitational constant in it as well as unit conversions. Unfortunately API saves pages by not showing the derivation of this pseudo C factor. These shortcuts can be convenient but they increase the chance that errors gets missed.

The C factor formula SI units has a fixed multiplier of 0.03948. This multiplier represents the following unit conversions and constant in order to build the meaningless units of the C factor.

- hours to seconds
- kPa to Pa
- gas constant
- gravitational constant
- kPa to Pa (inside SQRT)
- m^2 to mm^2

Here is the math for SI multiplier:

$$3600 \cdot 1000 \cdot 1 \cdot \frac{1}{\sqrt{8.314 \cdot 1000}} \cdot \frac{1}{1000000} = 0.03948$$

Caution on using Hidden Conversion Factors

All in one, built in conversion factors provide convenience at a price. That price is that the results or conclusion are wrong if the hidden conversion factors are wrong. This can be fatal for safety related calculations such as relief valves.

Note: API 521, 5th edition, January 2007. was published with the wrong factors for the SI version of the fire relief calculations for liquid air coolers.