RESOLUTION A.829(19) adopted on 23 November 1995
GUIDELINES FOR THE EVALUATION OF THE ADEQUACY
OF TYPE C TANK VENT SYSTEMS

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THE ASSEMBLY,

RECALLING Article 15(j) of the Convention on the International Maritime Organization concerning the functions of the Assembly in relation to regulations and guidelines concerning maritime safety,

RECALLING ALSO resolution MSC.32(63) on the adoption of amendments to the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code),

RECALLING FURTHER paragraph 8.2.18 of the revised IGC Code which provides that the adequacy of the vent system fitted on tanks is to be demonstrated by using the guidelines developed by the Organization,

HAVING CONSIDERED the recommendation made by the Maritime Safety Committee at its sixty-fifth session,

1. ADOPTS the Guidelines for the Evaluation of the Adequacy of Type C Tank Vent Systems set out in the Annex to the present resolution;

2. INVITES Governments to apply the Guidelines when establishing the adequacy of the vent systems fitted on tanks in accordance with relevant provisions of the IGC Code;

3. REQUESTS the Maritime Safety Committee to keep the Guidelines under review and to amend them as necessary.

ANNEX

GUIDELINES FOR THE EVALUATION OF THE ADEQUACY OF TYPE C TANK VENT SYSTEMS

Contents

1 General

1.1 The tank outlet to the pressure relief valves (PRVs) should remain in the vapour phase at the 98% liquid level and Code specified list and trim.

1.2 PRVs which have been sized using the GC Codes, have adequate capacity.

1.3 To assure adequate relieving capacity condition, 1.3.1 is required and to assure adequate blowdown condition, 1.3.2 is required.

1.3.1 The pressure drop in the vent pipe from the cargo tank to the PRV inlet (Δp_{inlet}) should not exceed 3% of MARVS, at the Code PRV capacity from equation (1) at $1.2 \cdot MARVS$ on all vapour flow.

1.3.2 The blowdown (Δp_{close}) should not be less than (Δp_{inlet}) plus $0.02 \cdot MARVS$ at the installed rated vapour capacity where required to assure stable operation of the PRV. This calculation should be performed at *MARVS* on all vapour flow.

Pilot-operated valves can tolerate higher inlet-pipe pressure losses when the pilot senses at a point that is not affected by the inlet-pipe pressure drop.

1.4 The built-up back pressure in the vent piping from the PRV outlet to the location of discharge to the atmosphere, and including any vent pipe interconnections which join other tanks, should not exceed the following values:

.1 for unbalanced PRVs: 10% *MARVS*.

Special consideration may be given in cases where the back pressure exceeds 10% of *MARVS* at a tank pressure of $1.2 \cdot MARVS$; and

.2 for balanced PRVs and pilot-operated PRVs as advised by manufacturer; normally 30% of *MARVS* for balanced PRVs and 50% of *MARVS* for pilot-operated PRVs,

when assuming isenthalpic expansion of saturated liquid, at 1.2 x MARVS, through the PRV with the vent piping under fire exposure. A heat flux of 108 kW/m^2 is assumed for uninsulated vent piping.

1.5 The built-up back pressure in the vent piping may be estimated by the procedures outlined in section 2.

1.6 A more accurate procedure for evaluating tank vent systems on flashing two-phase flow should be consulted if these simplified procedures do not demonstrate compliance with the requirements stated in 1.3 and 1.4 above.

1.7 *MARVS* means the maximum allowable relief valve setting of a cargo tank (gauge pressure).

2 Procedures

The following procedures will demonstrate the adequacy of a tank vent system to limit the pressure rise in a cargo tank to not greater than 1.2 x MARVS during all conditions, including fire conditions implicit in 8.5.2 of the IGC Code .

2.1 Prepare a simplified flow sheet of the cargo tank vent system, identifying the fittings and the actual diameters and lengths of pipe. (See annex 2 for an example.)

Divide the system into sections between nodes at changes in pipe diameter and at interconnections with flows from other relief valves.

List the fittings and their dynamic loss coefficients. Calculate the external surface area of the piping sections between the nodes.

2.2 Calculate the Code PRV capacity (Q_{GCC}) of each tank PRV, in m^3/s of air at standard conditions in accordance with 8.5.2 of the IGC Code and note the installed rated capacity (Q_{IR}) of each PRV in m^3/s air at standard conditions at $1.2 \cdot MARVS$. The calculation should be done for the highest gas factor of the products included in the cargo list. N-butane has often the highest value for gas factor "G" in the Code and usually determines the Code minimum capacity.

Determine the mass flows for cargo conditions at $1.2 \cdot MARVS$ through each PRV for the Code PRV capacity and for the installed rated capacity for both all vapour flow and for two-phase cargo flow. Also calculate the mass flow at *MARVS* for the installed rated capacity on all vapour flow.

Equation (1) may be used for all vapour mass flow and equations (2), (3) and (4) may be used for two-phase mass flow. Equation (2) may be applied to multicomponent mixtures whose boiling point range does not exceed 100° *K*.

2.3 Estimate all the vapour flow pressure drop in the pipe from the cargo tank connection to the PRV inlet flange, working from the known tank pressure towards the PRV. This pressure drop is calculated by using the difference in stagnation pressures. Therefore, the second term of equation (5) may be used for pipe sections of constant diameter. For contractions, equation (5.1) may be used.

2.4 Check that the pressure drop at each PRV inlet complies with 1.3.1 at the Code PRV capacity for all vapour flow to assure adequate relief capacity. For the calculation, the vapour mass flow of product (W_g) from equation (1) should be used.

For control purposes, 1.3.1 should be repeated using the Code PRV two-phase flow (W', equation (4)) at $1.2 \cdot MARVS$ and 1.3.2 by using the installed rated two-phase flow at *MARVS*. Both calculations should give a smaller inlet pressure loss than the corresponding all vapour pressure loss.

Check that the blowdown Δp_{close} complies with 1.3.2 to assure stable operation.

2.5 Estimate the two-phase flow pressure in the discharge pipe at the location of discharge to the atmosphere. Equation (6) may be used, with the Code PRV two-phase mass flow (W', equation (4)) to assure adequate relief capacity, to check if the exit pressure is greater than 1 bar a.

2.6 Estimate the vapour fraction and two-phase density in the vent pipe at the exit to the atmosphere, assuming transfer of the fire heat flux of 108 kW/m^2 through the uninsulated vent piping. Equations (7) and (8) may be used.

2.7 Estimate the built-up back pressure at the PRV outlet flange, commencing from the known vent pipe exit pressure, calculating the pressure drop between pipe nodes and working, section by section, back up the pipe to the PRV.

Equations (7), (8), (9) and (5) may be used with iteration until the upstream node absolute pressure, vapour fraction and specific volume are justified and assuming that vapour is saturated.

At pipe diameter expansion fittings where fluid velocity is reduced, a pressure recovery generally occurs. This recovery is overestimated in case of two-phase flow when dynamic loss coefficients for single-phase flow are used. For the purpose of these guidelines, the static exit pressure of a conical expansion fitting is assumed to be equal to the static inlet pressure.

2.8 Estimate the choking pressure (p_{ec}) at the exit of every section with the mass-flux (G_p) in that section for the pipeline between the PRV and the vent exit. Equation (6) may be used.

Compare the pressure distribution along the vent line as derived from item 2.5 to 2.7, with the different choking pressures for each section as derived from equation (6).

If choking pressure at any location exceeds the corresponding calculated pressure derived from 2.5 to 2.7, the calculation as described in 2.5 to 2.7 should be repeated commencing from choking point location and corresponding choking pressure, working back up the pipe to the PRV.

If choking pressure at more than one location exceeds the corresponding calculated pressure derived from 2.5 to 2.7, the commencing point of the recalculation should be taken as the choking location point giving the highest built-up back pressure.

2.9 Check that the built-up back pressure at each PRV outlet complies with 1.4, at the Code PRV capacity for two-phase mass flow (W', equation (4)), to assure stable operation of the valves, thus assuring adequate relief capacity.

2.10 For conventional unbalanced valves only:

.1 If back pressure as derived from 2.5 to 2.8 is within the range of 10% to 20% of *MARVS*, an additional evaluation should be performed in order to decide whether the system is acceptable.

.2 The system should perform with the following requirement: With one valve closed and all others discharging at the installed rated PRV capacity, the back pressure should be less than 10% of *MARVS*.

3 Equations

The following equations may be used to demonstrate the adequacy of the vent system.

Equation (1) for all vapour mass flow rate from tank through PRVs:

$$W_g = \frac{71 \cdot 10^3 \cdot F \cdot A^{0.82}}{h_{fg}} \quad (kg/s) \qquad (1)$$

where:

F = fire exposure factor according to section 8.5 of the IGC Code
A = external surface area of type C tank (m^2)
h_{fg} = latent heat of vaporization of cargo at 1.2 x MARVS (J/kg)

Equation (2) for isenthalpic flashing mass flux of liquid through PRV orifice:

$$G_v \approx h_{fg} \cdot \rho_g \left[\frac{1}{T_o \cdot c}\right]^{1/2} \quad (kg/(m^2s)) \qquad (2)$$

where:

h_{fg} = see equation (1)
ρ_g = vapour density at 1.2 x MARVS and corresponding boiling temperature (kg/m^3)
T_o = temperature (K)[1] of cargo at 1.2 x MARVS
c = liquid specific heat at 1.2 x MARVS and T_o ($J/(kg\ K)$)

Note: This expression is valid for multicomponent mixtures whose boiling point range does not exceed 100° *K*.

Equation (3) for two-phase mass flow rate through PRV is installed:

$$W = G_v \cdot K_w \cdot A_v \quad (kg/s) \qquad (3)$$

where:

G_v = is taken from equation (2) ($kg/(m^2s)$)
K_w = PRV discharge coefficient on water (≈ 0.8 · measured K_d on air)
A_v = actual orifice area of PRV (m^2)

Equation (4) for Code PRV capacity for two-phase mass flow:

$$W' = G_v \cdot K_w \cdot A_v \frac{Q_{GCC}}{Q_{IR}} \quad (kg/s) \qquad (4)$$

where:

Q_{GCC} = Code PRV capacity of air at standard conditions in accordance with IGC Code 8.5.2 (m^3/s)
Q_{IR} = installed rated PRV capacity of air at T = 273°K and p = 1.013bar (m^3/s)

Equation (5) for the calculation of the static pressure difference in a pipe section of constant diameter in which the mass flux (G_p) is constant:

$$\Delta p = G_p^2(v_e - v_i) + 1/2 \cdot G_p^2\left(\frac{v_e + v_i}{2}\right)\left(4f\frac{L}{D} + \sum N\right) \quad (Pa) \qquad (5)$$

(10^5 Pa = 1 bar = 14.5 psi)

[1] °C + 273 = *K*

where:

G_p = $\frac{W}{\pi \cdot D^2/4}$ *or* $\frac{W'}{\pi \cdot D^2/4}$ ($kg/(m^2 s)$)
mass flux through the pipe section
v_e = two-phase specific volume at pipe section exit (m^3/kg)
v_i = two-phase specific volume at pipe section inlet (m^3/kg)
f = Fanning friction factor $f = 0.005$ for two-phase fully turbulent flow
L = length of pipe section (m)
D = diameter of pipe section (m)
ΣN = sum of dynamic loss coefficients for fittings in the pipe section $N = 4f \frac{L}{D}$ equivalent.
(Typical values of N are given in annex 2, table 2)

Equation (5.1) For contractions, the difference in stagnation pressure is defined by:

$$\Delta p = \frac{1}{2} \cdot G_{p,e}^2 \cdot v_i \cdot N \quad (Pa) \tag{5.1}$$

where:

N = dynamic loss coefficients of the contraction
$G_{p,e}$ = mass flux at the exit of the contraction ($kg/(m^2 s)$)
v_i = specific volume at the inlet of the contraction (m^3/kg)

Equation (6) for two-phase critical choking pressure at vent mast exit or at exit from any vent pipe section:

$$p_{ec} = G_p \left[\frac{p_o \cdot \omega}{\rho_o}\right]^{1/2} \quad (Pa) \tag{6}$$

where:

G_p = as defined in equation (5)
p_o = cargo vapour pressure in tank at inlet to PRV (Pa)
ρ_o = cargo liquid density in tank at inlet to PRV at p_o and T_o (kg/m^3)
ω = compressible flow parameter in tank at inlet to PRV

$$= \alpha_o + (1 - \alpha_o)\frac{\rho_o \cdot c \cdot T_o \cdot p_o \cdot (v_{go} - v_{fo})^2}{(h_{go} - h_{fo})^2}$$

where:

α_o	=	inlet void fraction or vapour volume fraction at inlet to PRV
	=	0, when assuming isenthalpic expansion of saturated liquid, at 1.2 · *MARVS*, through the PRV
c		see equation (2)
T_o		see equation (2)
$(v_{go} - v_{fo})$	=	difference in gaseous and liquid specific volume at temperature T_o at inlet to PRV (m^3/kg)
$(h_{go} - h_{fo})$	=	difference in gaseous and liquid enthalpy at temperature T_o at inlet to PRV (J/kg)

Equation (7) for exit quality, or vapour mass fraction at pipe section exit:

$$x_e = \frac{h_{fo} - h_{fe} + 1000 \cdot q \cdot \sum a/W}{h_{fg}} \qquad (7)$$

(e.g. $x_e = 0.3$ ≡ 30% quality ≡ 30% vapour + 70% liquid by mass)

where:

h_{fo}	=	liquid enthalpy in tank at inlet to PRV (*J/kg*)
h_{fe}	=	liquid enthalpy at back pressure at pipe section exit (*J/kg*)
h_{fg}	=	latent heat of vaporization at back pressure at pipe section exit (*J/kg*)
q	=	heat flux from fire exposure into vent pipe equal to 108 kW/m^2
a	=	heated external surface area of vent pipe section (m^2)
W	=	mass flow rate in vent pipe section (*kg/s*)

Equations (8), **(9)** for two-phase density (ρ) and specific volume (v):

$$\rho = \rho_g / x \qquad (kg/m^3) \qquad (8)$$

where:

ρ_g	=	saturated vapour density at pipe section inlet or exit
x	=	vapour fraction at pipe section inlet or exit

$$v = 1/\rho \qquad (m^3/kg) \qquad (9)$$

4 References

1 General

1.1 IGC-, GC- Codes 8.2.17 draft text of amendments
BCH 22/14, annex 8
Code for Existing Ships 8.2.15 draft text of amendments BCH 22/14, annex 8

1.2 BCH 20/7, annex 4, validated by BCH 21/INF.3, annex 2

1.3 IGC Code 8.2.16 draft amendment BCH 22/14, annex 9; API RP 520 Part II, Third Edition, November 1988, 2.2.2 on page 2

1.4 IGC Code 8.2.16 draft amendment BCH 22/14, annex 9; API RP 521, Third Edition, November 1990, 5.4.1.3.1 on page 45 and API RP 520, Part I, Fifth Edition, July 1990, 2.2.4.1 on page 7 and 4.3.2.1 Fig. 27 on page 30

1.5 BCH 20/7, annex 5 as referenced in 3. Equations

2.4 Frank J. Heller:
Safety relief valve sizing: API versus CGA requirements plus a new concept for tank cars: API-Proceedings 1983, Refining Department, Vol. 62, API, W.D.C, pp. 123-135

3 Equations

(1) "Some Notes on the Practical Application of the IMCO Gas Carrier Code to Pressure Vessel Type Cargo Tanks",
M. Böckenhauer, GASTECH 1981, Hamburg 1981.

(2) "Flashing Flows or: Some Practical Guidelines for Emergency Releases"
Fauske and Associates, Plant/Operations Progress, July 1985, Private communication SIGTTO/Fauske and Associates, June 1st 1994

(5) Private communication SIGTTO/Fauske and Associates, January 21, 1993. "The Discharge of Two-Phase Flashing Flow in a Horizontal Duct", Fauske and Associates, AIChE Journal, March 1987 on pages 524 (equation) and 526 (Fanning friction factor in two-phase flows).

(6) "Size Safety Relief Valves for Flashing Liquids";
J.C. Leung (Fauske and Associates), Chemical Engineering Progress, Feb. (1992), pp. 70-75

(7) BCH 20/7, annex 5

(8) BCH 20/7, annex 5

(9) BCH 20/7, annex 5

ANNEX 1

AMENDMENTS TO THE INTERNATIONAL CODE FOR THE CONSTRUCTION AND EQUIPMENT OF SHIPS CARRYING LIQUEFIED GASES IN BULK (IGC CODE) (RESOLUTION MSC.32(63))

Amendments related to application

1 Replace existing paragraphs 1.1.2 and 1.1.3 by the following:

"1.1.2 Unless expressly provided otherwise, the Code applies to ships the keels of which are laid or which are at a stage at which:

.1 construction identifiable with the ship begins; and

.2 assembly of that ship has commenced comprising at least 50 tonnes or 1% of the estimated mass of all structural material, whichever is the less;

on or after 1 July 1998. Ships constructed before 1 July 1998 are to comply with resolution MSC.5(48) adopted on 17 June 1983 subject to amendments by resolution MSC.30(61) adopted on 11 December 1992.

1.1.3 A ship, irrespective of the date of construction, which is converted to a gas carrier on or after 1 July 1998, should be treated as a gas carrier constructed on the date on which such conversion commences."

Amendments related to filling limits

2 Replace existing chapter 15 by the following:

"CHAPTER 15

FILLING LIMITS FOR CARGO TANKS

15.1 General

15.1.1 No cargo tanks should have a higher filling limit (FL) than 98% at the reference temperature, except as permitted by 15.1.3.

15.1.2 The maximum loading limit (LL) to which a cargo tank may be loaded should be determined by the following formula:

$$LL = FL \frac{\rho R}{\rho L}$$

where:

LL = loading limit expressed as a percentage, being the maximum allowable liquid volume relative to the tank volume to which the tank may be loaded;

FL = filling limit as specified in 15.1.1 or 15.1.3;

ρR = relative density of cargo at the reference temperature; and

ρL = relative density of cargo at the loading temperature and pressure.

15.1.3 The Administration may allow a higher filling limit (FL) than the limit of 98% specified in 15.1.1 at the reference temperature, taking into account the shape of the tank, arrangements of pressure relief valves, accuracy of level and temperature gauging and the difference between the loading temperature and the temperature corresponding to the vapour pressure of the cargo at the set pressure of the pressure relief valves, provided the conditions specified in 8.2.17 are maintained.

15.1.4 For the purposes of this chapter only, "reference temperature" means:

.1 the temperature corresponding to the vapour pressure of the cargo at the set pressure of the pressure relief valves when no cargo vapour pressure/temperature control as referred to in chapter 7 is provided;

.2 the temperature of the cargo upon termination of loading, during transport, or at unloading, whichever is the greatest, when a cargo vapour pressure/temperature control as referred to in chapter 7 is provided. If this reference temperature would result in the cargo tank becoming liquid full before the cargo reaches a temperature corresponding to the vapour pressure of the cargo at the set pressure of the relief valves required in 8.2, an additional pressure relieving system complying with 8.3 should be fitted.

15.1.5 The Administration may allow type C tanks to be loaded according to the following formula, provided that the tank vent system has been approved in accordance with 8.2.18:

$$LL = FL\frac{\rho R}{\rho L}$$

where:

LL = loading limit as specified in 15.1.2;

FL = filling limit as specified in 15.1.1 or 15.1.3;

ρR = relative density of cargo at the highest temperature which the cargo may reach upon termination of loading, during transport, or at unloading, under the ambient design temperature conditions described in 7.1.2; and

ρL = as specified in 15.1.2.

This paragraph does not apply to products requiring a type 1G ship.

15.2 **Information to be provided to the master**

The maximum allowable loading limits for each cargo tank should be indicated for each product which may be carried, for each loading temperature which may be applied and for the applicable maximum reference temperature, on a list to be approved by the Administration. Pressures at which the pressure relief valves, including those valves required by 8.3, have been set should also be stated on the list. A copy of the list should be kept permanently on board by the master.

15.3 Chapter 15 applies to all ships regardless of the date of construction."

3 The following words are added at the end of existing paragraph 8.2.17:

"at the maximum allowable filling limit (FL)".

4 The following new paragraph 8.2.18 is added after existing paragraph 8.2.17:

"8.2.18 The adequacy of the vent system fitted on tanks loaded in accordance with 15.1.5 is to be demonstrated using the guidelines developed by the Organization. A relevant certificate should be permanently kept on board the ship. For the purposes of this paragraph, vent system means:

.1 the tank outlet and the piping to the pressure relief valve;

.2 the pressure relief valve;

.3 the piping from the pressure relief valve to the location of discharge to the atmosphere and including any interconnections and piping which joins other tanks.

This paragraph may apply to all ships regardless of the date of construction."

Amendments related to cargo tank vent systems

5 Replace existing paragraph 8.2.3 by the following:

"8.2.3 In general, the setting of the pressure relief valves should not be higher than the vapour pressure which has been used in the design of the tank. However, where two or more pressure relief valves are fitted, valves comprising not more than 50% of the total relieving capacity may be set at a pressure up to 5% above MARVS."

6 Add the following sentences are added to existing paragraph 8.2.4:

"Valves should be constructed of materials with a melting point above 925°C. Consideration should be given to lower melting point materials for internal parts and seals if their use will yield a significant improvement in the general operation of the valve."

7 Replace existing paragraph 8.2.9 by the following:

"8.2.9 Each pressure relief valve installed on a cargo tank should be connected to a venting system, which should be so constructed that the discharge of gas will be unimpeded and directed vertically upwards at the exit; and so arranged as to minimize the possibility of water or snow entering the vent system. The height of vent exits should be not less than B/3 or 6 m, whichever is the greater, above the weather deck and 6 m above the working area, the fore and aft gangway, deck storage tanks and cargo liquid lines."

8 Add the following sentences to existing paragraph 8.2.16:

"The pressure drop in the vent line from the tank to the pressure relief valve inlet should not exceed 3% of the valve set pressure. For unbalanced pressure relief valves the back pressure in the discharge line should not exceed 10% of the gauge pressure at the relief valve inlet with the vent lines under fire exposure as referred to in 8.5.2."

ANNEX 2

WORKED EXAMPLE OF THE PROCEDURES

Procedures
Reference No.

By 2.1 Figure 1 is a simplified flow sheet of a cargo tank vent system with one vent stack connected to two tanks. The system has been divided into sections between nodes, marked by capital letters A to N, at changes in pipe diameter and at interconnections with flows from other relief valves at F and J.

Table 1 lists the vent pipe lengths and external surface areas, the fittings in the vent system and their Friction Resistance Factors. Table 2 gives some typical values for Friction Resistance Factors (N). N may vary with pipe diameter.

By 2.2 The IGC Code minimum tank relief capacity, Q_{GCC}, is calculated for the Case Study ship tank analysed in BCH 20/7, annexes 2 to 5 which has an external surface area of 747 m^2 and MARVS of 11.0 bar g.

By IGC Code 8.5.2 for propane:

for **1.2 x *MARVS* = 11.0 x 1.2 + 1.0 = 14.2 *bar a***

$$L = 308.6\ kJ/kg$$
$$T = 273 + 41 = 313° K$$
$$D = 0.635, for\ k = 1.13$$
$$Z = 1.0$$
$$M = 44$$
$$A^{0.82} = 227.05$$
$$F = 0.2$$

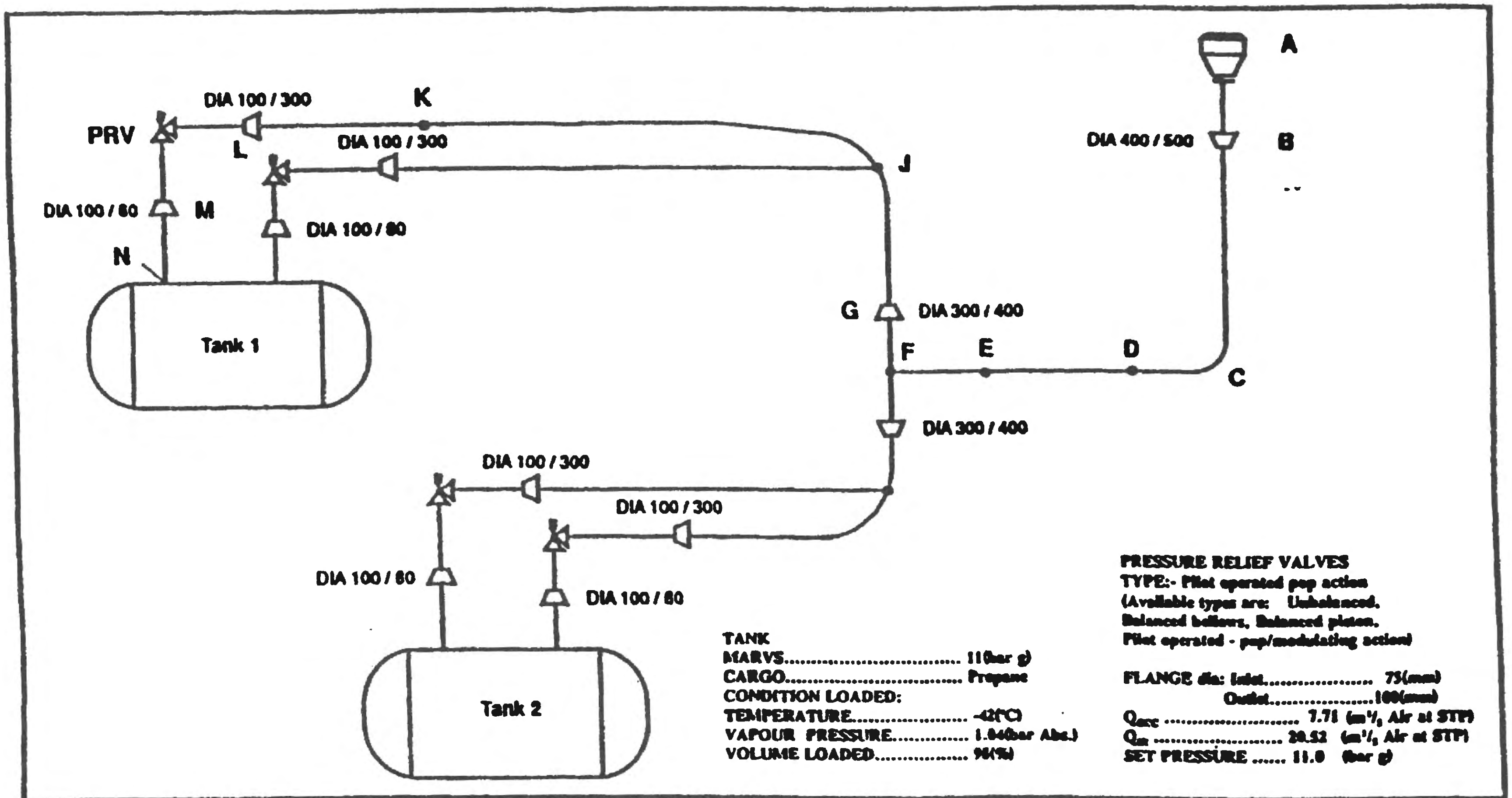
$$Q_{GCC} = 0.2 \cdot \frac{12.4}{308.6\ .\ 0.635} \cdot \sqrt{\left(\frac{1.0\ .\ 314}{44}\right)} \cdot 227.05 = 7.68\ m^3/s\ of air\ at STP$$

The Q_{GCC} for the actual case study ship tank = 7.71 m^3/s of air at standard conditions (STP) of 273°K and 1.013 bar a.

The installed rated capacity for two 75 mm x 100 mm AGCo Type 95 POPRVs

Q_{IR} = 20.52 m^3/s of air at standard conditions (STP),

or 20.52/7.71 = 2.66 times the Q_{GCC}



Simplified flow sheet of a cargo tank vent system with one vent stack connected to two tanks

Fig. 1

Pipe section	Length [mm]	Pipe diameter [mm]	Surface area [m²]	Fitting	Specification	Dynamic loss coefficients N	Pipe $4f\frac{L}{D}$	$4f\frac{L}{D} + \Sigma N$
A	1,080	500/750	2.04	A = Cowl/vent exit	—	2.25	—	2.25
A - B	1,565	500	2.46				0.063	0.063
Section total			4.50					2.313
B - C	2,650	400	3.331	B = Conical expansion	d/D = 0.8	*)	0.132	0.132
C - D	2,546	400	3.20	C = Long radius bend	90°	0.3	0.127	0.427
D - E	14,880	400	18.701	D = Bend	45°	0.2	0.744	0.944
E - F	2,093	400	2.63	E = Bend	45°	0.2	0.105	0.305
Section total			27.86					2.008
F - G	642	400	0.81	F = Hard tee	—	1.1	0.032	1.132
G - J	1,066	300	1.00	G = Conical expansion	d/D = 0.75	*)	0.071	0.071
Section total			1.81					
J - K	1,340	300	1.263	J = Soft tee	—	0.3	0.089	0.389
K - L	481	300	0.453	K = Bend	45°	0.2	0.032	0.232
Section total			1.72					0.621
L - PRV	216	300/100	—	L = Conical expansion	d/D = 0.33	*)	0.043	0.043
PRV - M	108	80	—				0.027	0.027
M	108	80	—	M = Conical reduction	d/D = 0.8	0.1	—	0.1
M - N	142	100	—	N = Square edged inlet	—	0.5	0.028	0.528

*) Ignored under procedure 2.7.

Table 1 List of vent pipe lengths and surface areas, fittings and dynamic loss coefficients

Fitting	Equivalent 4f L/D = N
Inlet pipe from tank to PRV:	
Square-edged inlet 	0.5
Protruding conical inlet 	0.15
Conical reduction 	0.1
Discharge piping from PRV to mast vent exit:	
45° bend	0.2
45° single-mitre elbow	0.45
90° long radius bend	0.3
90° short radius bend	0.5
90° double-mitre elbow	0.6
Soft-tee 	0.3
Hard-tee 	1.1
Cowl mast vent exit 	2.25
Top-hat mast vent exit 	[4.5]
Flame screen for IGC Code 17.10	1.4
References: *"Sizing Safety Valve Inlet Lines"* Chemical Engineering Progress, November 1980 *"Engineering Data Book, Figure 17-1"* Gas Processors Association, 10th Edition, 1987 *"Guide for Pressure-Relieving and Depressurising Systems"* Table 5, API RP 521 Third Edition, November 1990	

Table 2

Typical values for dynamic loss coefficient (N) for vent system fittings
"N" may vary with pipe diameter

By equation (1) for all vapour mass flow rate from tank for propane:

where h_{fg} *at* 1.2 . *MARVS* = 308600 *J/kg*

$$W_g = \frac{71000 \ . \ 0.2 \ . \ 227.05}{308600} = 10.44 \ kg/s$$

or Code PRV all vapour mass flow rate per PRV = 5.22 kg/s

and installed rated all vapour mass flow rate per PRV = 5.22 . 2.66 = 13.89 kg/s

where h_{fg} *at MARVS* = 322800 *J/kg*

$$W_g = \frac{71000 \ . \ 0.2 \ . \ 227.05}{322800} = 9.99 \ kg/s$$

or installed rated all vapour mass flow rate per PRV = 4.99 . 2.66 = 13.27 kg/s

By equation (2) for two-phase mass flux through PRV orifice for propane

At 1.2.MARVS where C = 2931 J/kg

$$G_v = 308600 \ . \ 30.3 \ . \left[\frac{1}{314 \ . \ 2931}\right]^{½} = 9727 \ kg/m^2\text{-}s$$

At MARVS where C = 2750 J/kg

$$G_v = 322800 \ . \ 25.5 \ . \left[\frac{1}{307 \ . \ 2750}\right]^{½} = 8959 \ kg/m^2\text{-}s$$

By equation (3) for two-phase mass flow rate through installed rated PRV orifice area

$A_v = 0.004032 \ m^2$; $K_w = 0.72$

At 1.2.MARVS:

$W = 9727 \ . \ 0.72 \ . \ 0.004032 = 28.25 \ kg/s$

At MARVS:

$W = 8959 \ . \ 0.72 \ . \ 0.004032 = 26.01 \ kg/s$

By equation (4) for two-phase mass flow rate through Code PRV

At 1.2 MARVS:

$$W' = 28.25 \cdot \frac{7.71}{20.52} = 10.6 \ kg/s$$

By 2.3 **The all vapour capacity and two-phase pressure drops in the pipe from the cargo tank to the PRV inlet are calculated as the difference in stagnation pressures by using the second term of equation (5) for pipe sections of constant diameter and by using equation (5.1) for conical reduction fittings (contractions).**

For Code PRV all vapour capacity at 1.2 . MARVS

Section N to M and from table 1:

where $G_p = 5.22/\pi \cdot 0.1^2/4 = 665$ kg/m²-s; $v = 0.0330$ m^3/kg *with incompressible flow assumed.*

$\Delta P = 0.5 \cdot 665^2 \cdot 0.0330 \cdot 0.528 = 3900$ *Pa* (0.039 *bar*)

Conical reduction fitting M:

where $G_p = 5.22/\pi \cdot 0.08^2/4 = 1038$ kg/m^2-s; $N = 0.1$

$\Delta P = 0.5 \cdot 1038^2 \cdot 0.0330 \cdot 0.1 = 1800$ *Pa* (0.018 *bar*)

Section M to PRV and from table 1:

where $G_p = 1038$ kg/m^2-s; $4f\,L/D + \Sigma N = 0.027$

$\Delta P = 0.5 \cdot 1038^2 \cdot 0.0330 \cdot 0.027 = 500$ *Pa* (0.005 *bar*)

Section N to PRV total $\Delta P = 0.039 + 0.018 + 0.005 = 0.06$ *bar*

For installed rated all vapour capacity at MARVS

Section N to M:

where $G_p = 13.27/\pi \cdot 0.1^2/4 = 1689$ kg/m^2-s; $v = 0.0392$ m^3/kg *with incompressible flow assumed*

$\Delta P = 0.5 \cdot 1689^2 \cdot 0.0392 \cdot 0.528 = 29500$ *Pa* (0.295 *bar*)

Conical reduction fitting M:

where $G_p = 13.27/\pi \cdot 0.08^2/4 = 2640$ kg/m^2-s

$\Delta P = 0.5 \cdot 2640^2 \cdot 0.0392 \cdot 0.1 = 13700$ *Pa* (0.137 *bar*)

Section M to PRV:

where $G_p = 2640$ *kg/m²-s*

$\Delta P = 0.5 \,.\, 2640^2 \,.\, 0.0392 \,.\, 0.027 = 3700$ *Pa* (0.037 *bar*)

Section N to PRV total $\mathbf{\Delta P = 0.295 + 0.137 + 0.037 = 0.47}$ ***bar***

For Code PRV two-phase capacity at 1.2 . MARVS

Section N to M:

where $G_p = 10.6/\pi \,.\, 0.1^2/4 = 1349$ *kg/m²-s;* $v = 0.002145$ *m³/kg with saturated liquid flow assumed*

$\Delta P = 0.5 \,.\, 1349^2 \,.\, 0.002145 \,.\, 0.528 = 1000$ *Pa* (0.01 *bar*)

Conical reduction fitting M:

where $G_p = 10.6/\pi \,.\, 0.08^2/4 = 2109$ *kg/m²-s*

$\Delta P = 0.5 \,.\, 2109^2 \,.\, 0.002145 \,.\, 0.1 = 500$ *Pa* (0.005 *bar*)

Section M to PRV:

where $G_p = 2109$ *kg/m²-s*

$\Delta P = 0.5 \,.\, 2109^2 \,.\, 0.002145 \,.\, 0.027 = 100$ *Pa* (0,001 *bar*)

Section N to PRV total $\mathbf{\Delta P = 0.01 + 0.005 + 0.001 = 0.016}$ ***bar***

For installed rated two-phase capacity at MARVS

Section N to M:

where $G_p = 26.01/\pi \,.\, 0.1^2/4 = 3311$ *kg/m²-s;* $v = 0.002088$ *m³/kg with saturated liquid flow assumed*

$\Delta P = 0.5 \,.\, 3311^2 \,.\, 0.002088 \,.\, 0.528 = 6000$ *Pa* (0.06 *bar*)

Conical reduction fitting M:

where $G_p = 26.01/\pi \,.\, 0.08^2/4 = 5174$ *kg/m²-s*

$\Delta P = 0.5 \,.\, 5174^2 \,.\, 0.002088 \,.\, 0.1 = 2800$ *Pa* (0.028 *bar*)

Section M to PRV:

where $G_p = 5174\ kg/m^2\text{-}s$

$\Delta P = 0.5\ .\ 5174^2\ .\ 0.002088\ .\ 0.027 = 800\ Pa\ (0.008\ bar)$

Section N to PRV total $\Delta P = 0.06 + 0.028 + 0.008 = 0.10$ *bar*

By 2.4 Check system compliance with requirements of section General, ref. 1.3

1.3.1 At Code PRV all vapour capacity at 1.2 . MARVS

$\Delta P\ .\ 100/P_{MARVS} = 0.06\ .\ 100/11.0 = 0.55\%$
Guidelines 1.3 = 3% *maximum*

At Code PRV two-phase capacity at 1.2 . MARVS

$= 0.016\ .\ 100/11.0 = 0.15\%$

1.3.2 At installed rated all vapour capacity at MARVS

$= 0.47\ .\ 100/11.0 = 4.27\%$*

At installed rated two-phase capacity at MARVS

$= 0.10\ .\ 100/11.0 = 0.91\%$

$\Delta P_{close} > 0.02\ .\ P_{MARVS} + \Delta P_{inlet}$

$> 0.02\ .\ 11.0 + 0.47 > 0.69\ bar$

For stable operation of the PRV, closing pressure should be less than:

$11.0 - 0.69 \leq 10.31$ *bar g* for a pop-action POPRV

*Acceptable because pilot senses at a point that is not affected by the inlet pipe pressure drop. If a protruding conical inlet (N = 0.15) had been added to the square-edged inlet (N = 0.5), the pressure drop would have been reduced, by 0.15/0.5 . 29500 = 8900 *Pa*, to 38000 *Pa* which is 3.5% of set pressure.

By 2.5 The two-phase critical exit choking pressure is estimated, using saturated propane properties at 1.2 x MARVS (14.2 bar a)

By equation (6)

$$where\ w = 0 + (1-0)\frac{466.2\ .\ 2931\ .\ 314\ .\ 1420000\ .\ (0.0330-0.0021)^2}{(832800-524200)^2}$$

= 6.09

and where W' for Code discharge from four PRVs

$$= 10.6\ .\ 4 = 42.4\ kg/s;\ D_{exit} = 0.5\ m;\ G_p = \frac{42.4}{\pi\ .\ 0.5^2/4} = 215.9\ kg/m^2\text{-}s$$

$$P_{ec} = 215.9\ .\left[\frac{1420000\ .\ 6.09}{466.2}\right]^{1/2} = 215.9\ .\ 136.2 = 29400\ Pa\ (0.29\ bar\ a)$$

Thus the exit flow is not choked and the vent pipe exit pressure is 100000 Pa (1 bar a)

By 2.6 The exit vapour fraction, x_e, assuming a fire exposure heat flux of 108 kW/m² into uninsulated vent discharge piping at the Code rated two-phase flow rate, is estimated.

By equation (7) and from table 1:

$$where\ \Sigma\frac{a}{W} = \frac{27.86 + 4.50}{42.4} + \frac{1.81}{21.2} + \frac{1.72}{10.6} = 1.011\ m^2\text{-}s/kg$$

$$and\ x_e = \frac{524200 - 320300 + 108000\ .\ 1.011}{425200}$$

= 0.74

By equations (8) and (9)

$$\rho_e = \frac{2.32}{0.74} = 3.14\ kg/m^3\ and\ v_e = 0.319\ m^3/kg$$

By 2.7 The pressure drops between the vent discharge piping nodes are estimated by equation (5), with iteration until the upstream node absolute pressure, vapour fraction and specific volume are justified, and working section by section back up the pipe to the PRV.

Section B to A and from table 1:

$where\ G_p = 4\ .\ 10.6/\pi\ .\ 0.5^2/4 = 215.9\ kg/m^2\text{-}s$

By first approximation ΔP = 0.5 215.9² 0.319 2.313
= 17200 Pa (0.17 bar)

Try $P_B = 1.18\ bar\ a$

By equation (7) and from table 1:

where $\Sigma a/W = 27.86/42.4 + 1.81/21.2 + 1.72/10.6 = 0.9048\ m^2\text{-}s/kg$

$$\text{and } x_B = \frac{524200 - 328700 + 108000 \,.\, 0.9048}{421600}$$

= 0.70

By equations (8) and (9)

$\rho_B = 2.73/0.70 = 3.90\ kg/m^3;\ v_B = 0.256\ m^3/kg$

By equation (5)

$\Delta P \quad = \quad 215.9^2 \,.\, (0.319\text{-}0.256) + 0.5 \,.\, 215.9^2 \,.\, (0.319 + 0.256)/2 \,.\, 2.313$

$\quad\quad = \quad 2900 + 15500 = 18400\ Pa$ (0.18 bar)

and $P_B \quad = \quad 1.18$ *bar a*

By 2.8 *and* P_{ec} *at B* = 337.3 . 136.2 = 46000 *Pa* (0.46 *bar a*) *using mass flux at exit from section F to B*

Section F to B and from table 1:

where $G_p = 4 \,.\, 10.6/\pi\ 0.4^2/4 = 337.3\ kg/m^2\text{-}s$

By first approximation $\quad \Delta P \quad = \quad 0.5 \,.\, 337.3^2 \,.\, 0.256 \,.\, 1.808$
$\quad\quad = \quad$ 26300 Pa (0.26 *bar*)

$P_F \quad = \quad 1.18 + 0.26 = 1.44$, *Try* 1.51 *bar a*

By equation (7) and from table 1:

where $\Sigma a/W = 1.81/21.2 + 1.72/10.6 = 0.2477\ m^2\text{-}s/kg$

$$\text{and } x_F = \frac{524200 - 343300 + 108000 \,.\, 0.2477}{412600}$$

= *0.50*

By equations (8) and (9)

$$\rho_F = \frac{3.45}{0.50} = 6.90\ kg/m^3;\ v_F = 0.145\ m^3/kg$$

By equation (5)

ΔP = 337.3^2 (0.256-0.145) + 0.5 . 337.3^2 (0.256 + 0.145)/2 . 1.808

= 12600 + 20600 = 33200 *Pa* (0.33 bar)

and P_F = 1.18 +0.33 = 1.51 *bar a*

By 2.8 *and* P_{ec} *at F* = 168.7 . 136.2 = 23000 *Pa* (0.23 *bar a*)

Section G to F and from table 1:

where G_p = 2 x 10.6/π 0.4^2/4 = 168.7 kg/m^2-s

By first approximation ΔP = 0.5 . 168.7^2 . 0.145 . 1.132
= 2300 *Pa* (0.02 *bar*)

This pressure drop is too small to justify a more accurate estimation. For the purposes of this calculation, we can assume the specific volume remains constant from G to L.

Section J to G and from table 1:

where G_p = 2 . 10.6/π 0.3^2/4 = 299.9 kg/m^2-s

By first approximation ΔP = 0.5 . 299.9^2 . 0.145 . 0.071
= 500 *Pa* (0.01 *bar*)

Section L to J and from table 1:

where G_p = 10.6/π 0.3^2/4 = 149.9 kg/m^2-s

By first approximation ΔP = 0.5 . 149.9^2 . 0.145 . 0.621
= 1000 *Pa* (0.01 *bar*)

P_L = 1.51 + 0.02 + 0.01 + 0.01 = 1.55 *bar a* at exit from conical expansion fitting

By equation (7)

$$x_L = \frac{524200 - 344600 + 0}{415800} = 0.432$$

By equations (8) and (9)

$$\rho_L = \frac{3.54}{0.432} = 8.19 \ kg/m^3 ; v = 0.122 \ m^3/kg$$

Conical expansion fitting at L:

In accordance with procedure 2.7 last paragraph, the static inlet pressure to this fitting is assumed to be 1.55 bar a.

Section PRV and from table 1:

where $G_p = 10.6/\pi\ 0.1^2/4 = 1349.9$ kg/m²-s

By 2.8 and P_{ec} at exit of pipe section from PRV to L = 1349 . 136.2 = 184000 *Pa* (1.84 bar a)

Therefore, the exit of the 100 mm diameter pipe section PRV to L is choked and the exit pressure at L is 1.84 bar a.

By equation (7) at 1.84 bar a

$$x_L = \frac{524200 - 355100 + 0}{411600} = 0.411$$

By equations (8) and (9)

$$\rho_L = \frac{4.18}{0.411} = 10.17\ kg/m^3; v_L = 0.098\ m^3/kg$$

By first approximation $\Delta P = 0.5 \cdot 1349^2 \cdot 0.098 \cdot 0.043 = 3800\ Pa\ (0.04\ bar)$

$P_{PRV} = 1.84 + 0.04 = 1.88\ bar\ a$; *Try* 2.42 *bar a*

By equation (7)

$$x_{PRV} = \frac{524200 - 371800}{403600} = 0.378$$

By equations (8) and (9)

$$\rho_{PRV} = \frac{5.49}{0.378} = 14.52\ kg/m^3; v_{PRV} = 0.069\ m^3/kg$$

By equation (5)

$$\Delta P = 1349^2\ (0.098 - 0.069) + 0.5\ .\ 1349^2 \left(\frac{0.098 + 0.069}{2}\right)\ .\ 0.043$$

$$= 52800 + 3300 = 56100\ Pa\ (0.56\ bar)$$

and $P_{PRV} = 1.84 + 0.56 = 2.40\ bar\ a\ (1.40\ bar\ g)$

By 2.9 **Back pressure at Code PRV two-phase flow at 14.2 bar a is 1.40 x 100/11.0 = 12.7% of set pressure (gauge) which assures adequate relief capacity for POPRVs.**

By 2.10 **Procedure for unbalanced PRVs only. The procedures 2.5 to 2.8 are repeated in this worked example using the installed rated mass flow for information only.**

By 2.5 **At the installed rated two-phase mass flow W = 28.25 x 4 = 113.0 kg/s.**

By equation (6)

$$P_{ec} = \frac{113.0}{\pi\ 0.5^2/4}\left[\frac{1420000\ .\ 6.09}{466.2}\right]^{1/2} = 78400\ Pa\ (0.78\ bar\ a)$$

Thus exit flow is not choked and vent pipe exit pressure is 100000 *Pa* (1 *bar a*)

By 2.6 The exit vapour fraction is estimated by **equation (7)** x_e **= 0.58** and the two-phase exit density and specific volume by **equations (8) and (9).**

ρ_e = 4.00 kg/m^3; $v_e = 0.250\ m^3/kg$

By 2.7 **Section B to A:**

where
G_p = 575 kg/m^2-s; $\Sigma a/W = 0.339\ m^2\text{-}s/kg$
x_B = 0.48; $\rho_B = 10.31\ kg/m^3$; $v_B = 0.097\ m^3/kg$
ΔP = 116900 *Pa* (1.17 *bar*)
P_B = 2.17 bar a
P_{ec} = 899 . 136.2 = 122000 *Pa* (1.22 *bar a*)

Section F to B:

where
G_p = 899 kg/m^2-s; $\Sigma a/W = 0.0929\ m^2\text{-}s/kg$
x_F = 0.37; $\rho_F = 18.17\ kg/m^3$; $v_F = 0.055\ m^3/kg$
ΔP = 89500 *Pa* (0.89 *bar*)
P_F = 2.17 + 0.89 = 3.06 bar a
P_{ec} = 449 . 136.2 = 61000 *Pa* (0.61 *bar a*)

Section G to F:

where
G_p = 449 kg/m^2-s
ΔP = 6300 *Pa* (0.06 *bar*)

Section J to G:

where
G_p = 799 kg/m^2-s
ΔP = 1200 *Pa* (0.01 *bar*)

Section L to J:

where G_p = 400 kg/m²-s
ΔP = 2600 *Pa* (0.03 *bar*)
P_L = 3.06+ 0.06 + 0.01 + 0.03 = 3.16 bar a
x_L = 0.34; $\rho_L = 20.44\ kg/m^3$; $v_L = 0.049\ m^3/kg$
P_{ec} = 400 . 136.2 = 54000 *Pa* (0.54 *bar a*)

Conical expansion fitting at L:

By procedure 2.7, static inlet pressure is 3.16 bar a.

Section PRV to L:

where G_p = 3596 kg/m²-s
P_{ec} = 3596 . 136.2 = 490,000 *Pa* (4.9 *bar a*)

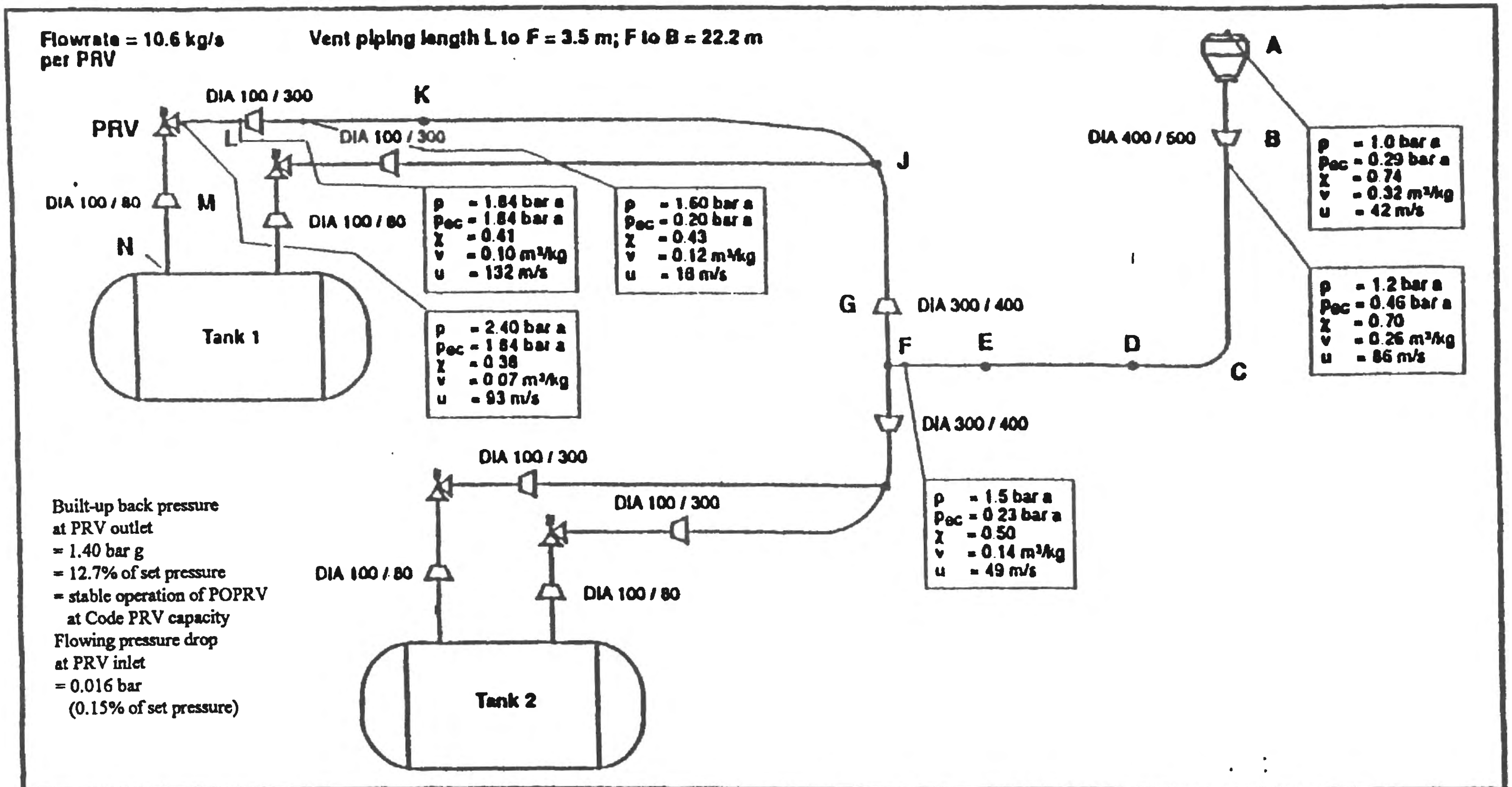
Thus, P_L = 4.90 *bar a*
x_L = 0.270
x_{PRV} = 0.241
ΔP = 83700 *Pa* (0.84 *bar*)
P_{PRV} = 4.90+ 0.84 = 5.74 *bar a* or 4.74 *bar g*

By 2.9 Back pressure at installed rated two-phase flow at 14.2 *bar a is* 4.74 . 100/11.0 = 43.1% of set pressure (gauge) which assures normal full capacity operation of the POPRVs.

Summary of predictions

The predicted two-phase propane properties are shown at five node points in the PRV discharge vent piping, in figure 2 at the Code PRV flow-rate, and in figure 3 at the installed rated flow-rate. The flowing pressure drop in the piping to the PRV inlet is less than Guideline 1.3 requires. The built-up back pressure at the PRV outlet is also less than Guideline 1.4 requires for the pilot-operated PRVs installed.

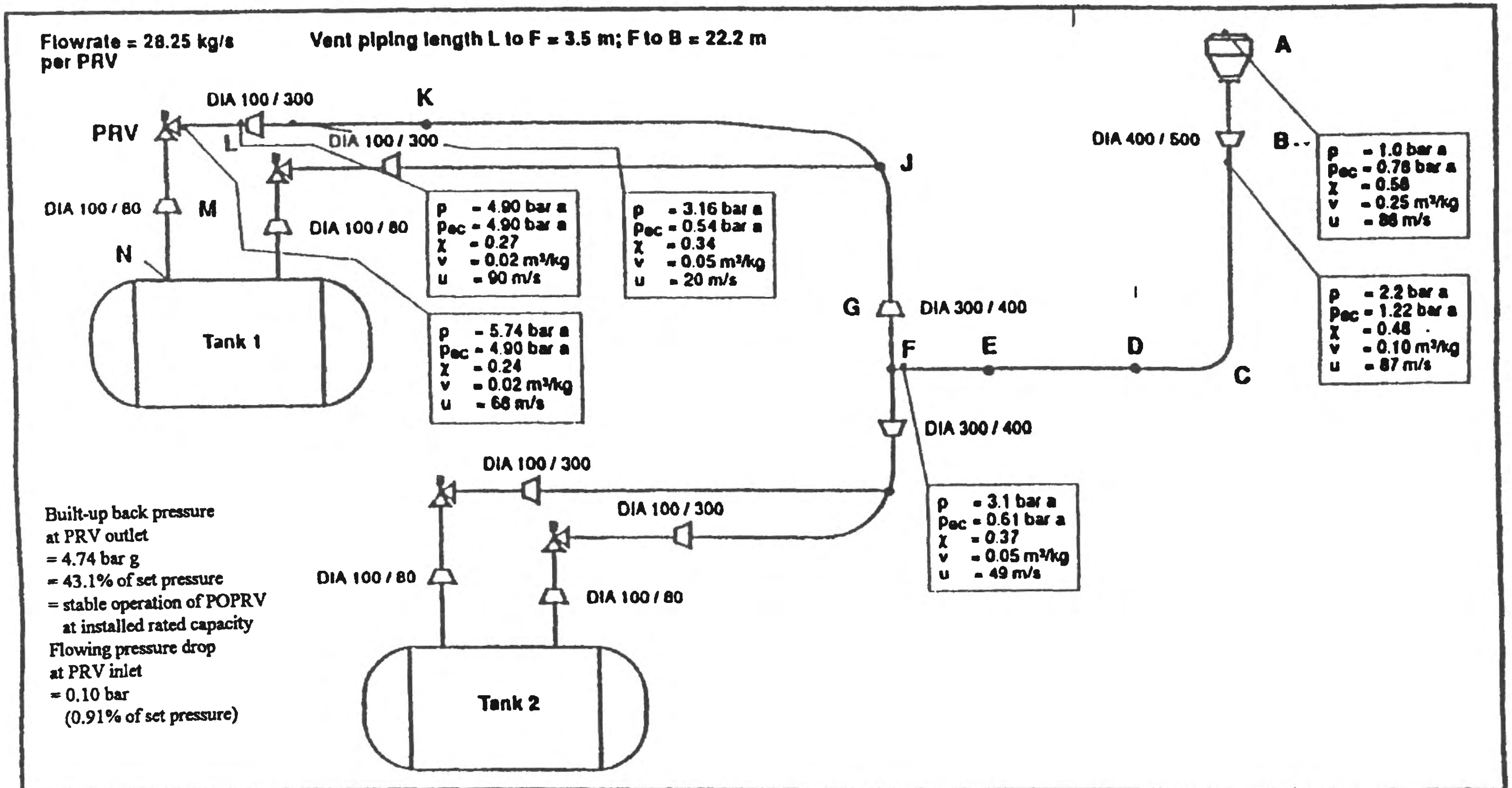
The flowing pressure drop in the PRV inlet piping is well within Guideline 1.3 for the Code PRV all vapour flow-rate but exceeds the requirement for the installed rated all vapour flow-rate. However, the pressure drop is acceptable for reasons explained in the footnote to paragraph 1.3.2 above. The blowdown and closing pressure should be set to assure stable operation when both PRVs are open.



Two-phase propane properties at Code PRV relief flowrate

- Simplified flow sheet of a cargo tank vent system with one vent stack connected to two tanks -

Fig. 2



Two-phase propane properties at installed rated flowrate

- Simplified flow sheet of a cargo tank vent system with one vent stack connected to two tanks -

Fig. 3

These procedures are now applied to example case 3B in Dow Chemical Company's Report to CTAC using their RELief DESign program, February 25, 1992 (BCH 22/INF.6). Per RELDES RESULTS on page 9, the last two-phase flow of 106 lbs/sec (48.1 kg/s) occurs at a tank pressure of 169 psig (12.66 bar a), Quality (percent vapour by mass) is stated to be 0.10% and Vessel Inventory is 76.2% liquid propane. The PRV discharge vent pipe is assumed to be 10 ft long by 8 inches diameter (3.04 m length x 0.203 m dia) and PRV Orifice Area is 12.3 sq. in. ($7.935 \times 10^{-3}\ m^2$), $K_d = 0.953$.

By equation (2)

$$G_v = 318600 \ . \ 26.9 \ . \left[\frac{1}{309.3 \quad 2722}\right]^{1/2} = 9341 \ kg/m^2\text{-}s$$

By equation (3), assuming $K_w = 0.8 \times 0.953 = 0.76$

W = 0.76 . 0.007935 . 9341 = 56.3 *kg/s*
RELDES prediction = 48.1 *kg/s*

Thus equations (2) and (3) predict a flow rate 17% higher than RELDES.

By equation (6)

where α_o = *vapour fraction by volume in tank*
= 0.238 *from Vessel Inventory*

$$w = 0.238 + 0.762 \ . \ 475.0 \ . \ 2722 \ . \ 309.3 \ . \ 1266000 \ \frac{(0.0372 - 0.002106)^2}{318600^2}$$

$$= 4.92$$

and

$$P_{ec} = \frac{48.1}{0.03237}\left[\frac{1266000 \ . \ 4.92}{475.0}\right]^{1/2} = 170200 \ Pa \ (1.70 \ bar \ a)$$

At 12.66 bar a, vapour fraction by mass at PRV inlet.

Vapour mass per cubic metre	=	0.238 . 26.9	=	6.402 *kg*
Liquid mass per cubic metre	=	0.762 . 475.0	=	361.95 *kg*
Total mass per cubic metre			=	368.35 *kg*

and vapour fraction = 6.4/368 = 0.017

or Quality = 1.7% compared to RELDES 0.10%

At vent piping exit back pressure = 1.70 bar a

$$x_e = 0.0017 + 0.983 \cdot \left[\frac{510400 - 350500}{413700}\right] = 0.40$$

and

$$\rho_e = \frac{3.88}{0.40} = 9.70 \ kg/m^3; v_e = 0.103 \ m^3/kg$$

$$G_p = \frac{48.1}{0.03237} = 1486 \ kg/m^2\text{-}s$$

say at inlet to vent discharge pipe back pressure = 3.31 bar a:

$$x_i = 0.017 + 0.983 \left[\frac{510400 - 392300}{393600}\right] = 0.31$$

and

$$\rho_i = \frac{7.33}{0.31} = 23.6 \ kg/m^3; v_i = 0.042 \ m^3/kg$$

By equation (5), where 4f L/D = 4 . 0.005 . 3.04/0.203 = 0.30

ΔP = $1486^2 . (0.103-0.042) + 0.5 . 1486^2 . (0.103 + 0.042)/2 . 0.3$
= 134700 + 24000 = 158700 *Pa* (1.59 *bar*)

Thus back pressure at PRV discharge flange:

= 1.70 + 1.59 = 3.29 *bar a* or = 2.29 *bar g* (33.2 *psig*) for comparison with RELDES prediction 32.8 psig

= Thus, **equations (6), (7), (8), (9) and (5)** predict a back pressure 1% higher than RELDES.