8.1 Limiti di infiammabilità di miscele a più componenti.

Quando il combustibile non è un composto singolo ma una miscela di più solventi e quindi non si trovano dati sperimentali sui limiti di infiammabilità, si può ricorrere a calcoli che si basano su criteri di additività, partendo dai limiti dei singoli composti. Una regola molto usata è quella di **Le Chatelier**, nota come **legge delle miscele**. L'equazione è la seguente:

$$L_i = \frac{100}{\sum_j \frac{\chi_j}{L_{i,j}}} \tag{12}$$

Applicando, per esempio, la regola di Le Chatelier a un gas naturale della seguente composizione:

metano	80%	(L_i = 5,0%)
etano	15%	(L_i = 2,9%)
propano	4%	(L_i = 2,1%)
butano	1%	(L_i = 1,8%)

il limite inferiore della miscela risulta:

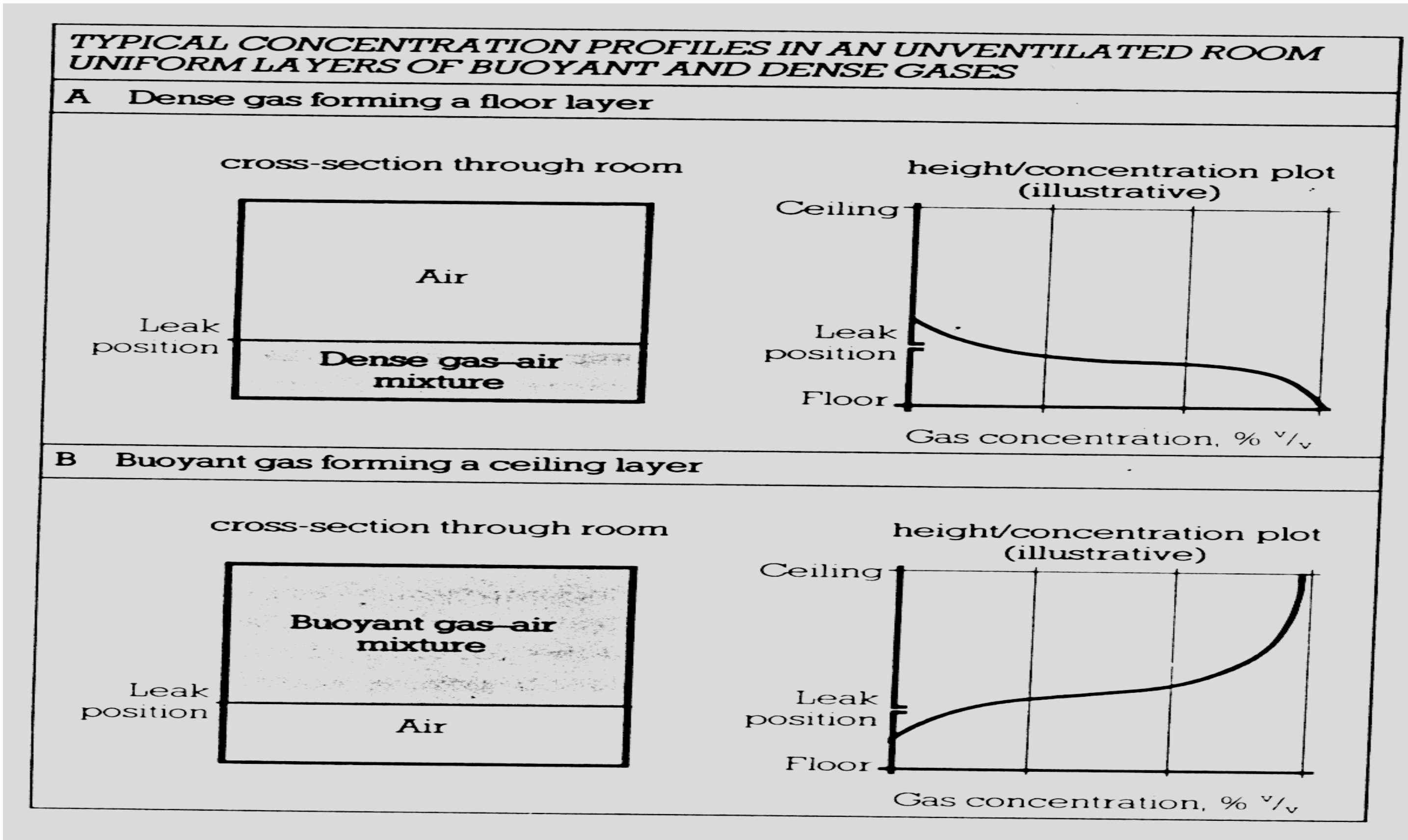
$$L_i = \frac{100}{80/5{,}0 + 15/2{,}9 + 4{,}0/2{,}1 + 1{,}0/1{,}8} = 4{,}2\%$$

ACCUMULAZIONE DI GAS

FATTORI CHE INFLUENZANO LA CRESCITA DELLA CONCENTRAZIONE DI GAS NEGLI EDIFICI

- ***DENSITA' DEI GAS***
- ***CARATTERISTICHE DELLA SORGENTE DI PERDITA DI GAS***
- ***VENTILAZIONE***

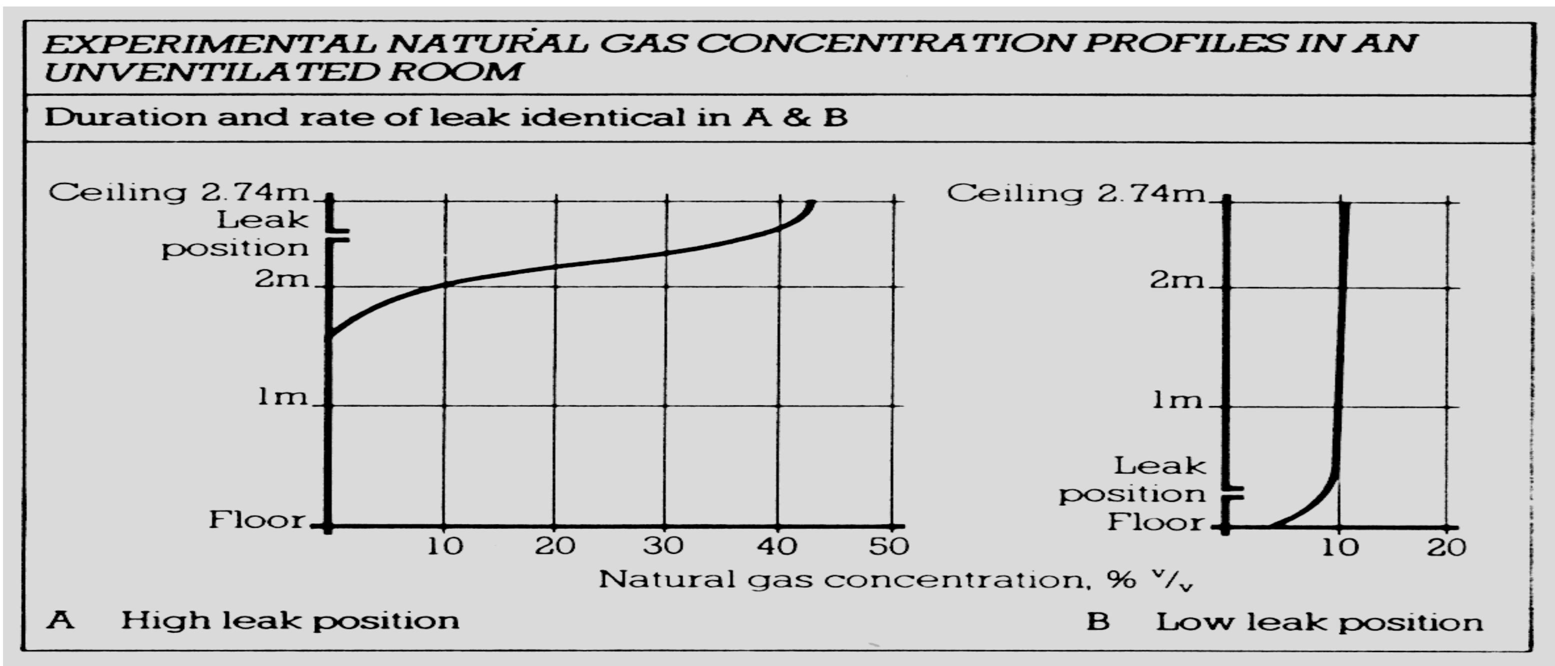
DENSITA'



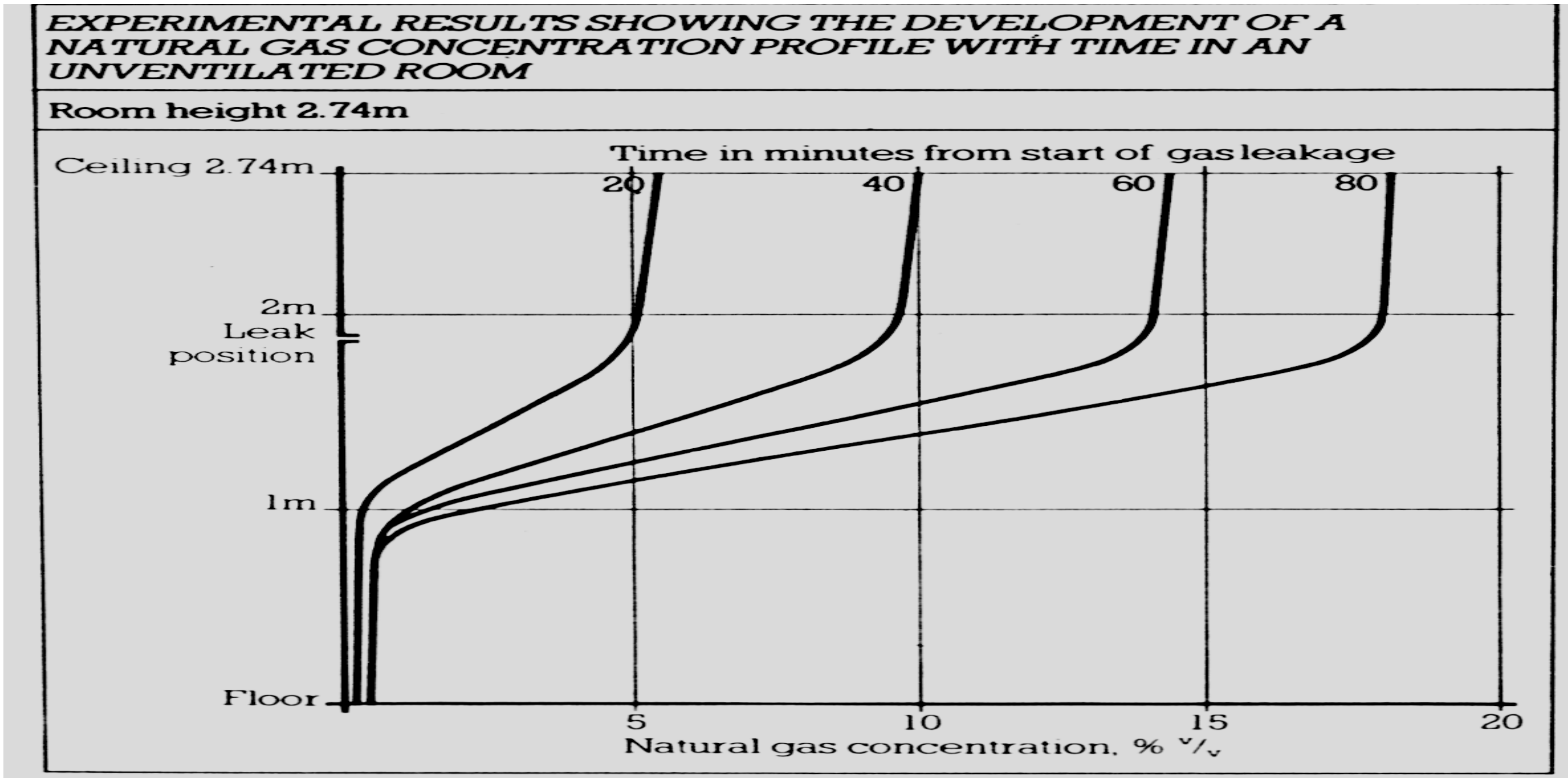
TYPICAL CONCENTRATION PROFILES IN AN UNVENTILATED ROOM
UNIFORM LAYERS OF BUOYANT AND DENSE GASES
A Dense gas forming a floor layer
cross-section through room
Air
Leak position
Dense gas–air mixture
height/concentration plot (illustrative)
Ceiling
Leak position
Floor
Gas concentration, % v/v
B Buoyant gas forming a ceiling layer
cross-section through room
Buoyant gas–air mixture
Leak position
Air
height/concentration plot (illustrative)
Ceiling
Leak position
Floor
Gas concentration, % v/v

SORGENTE DI PERDITA

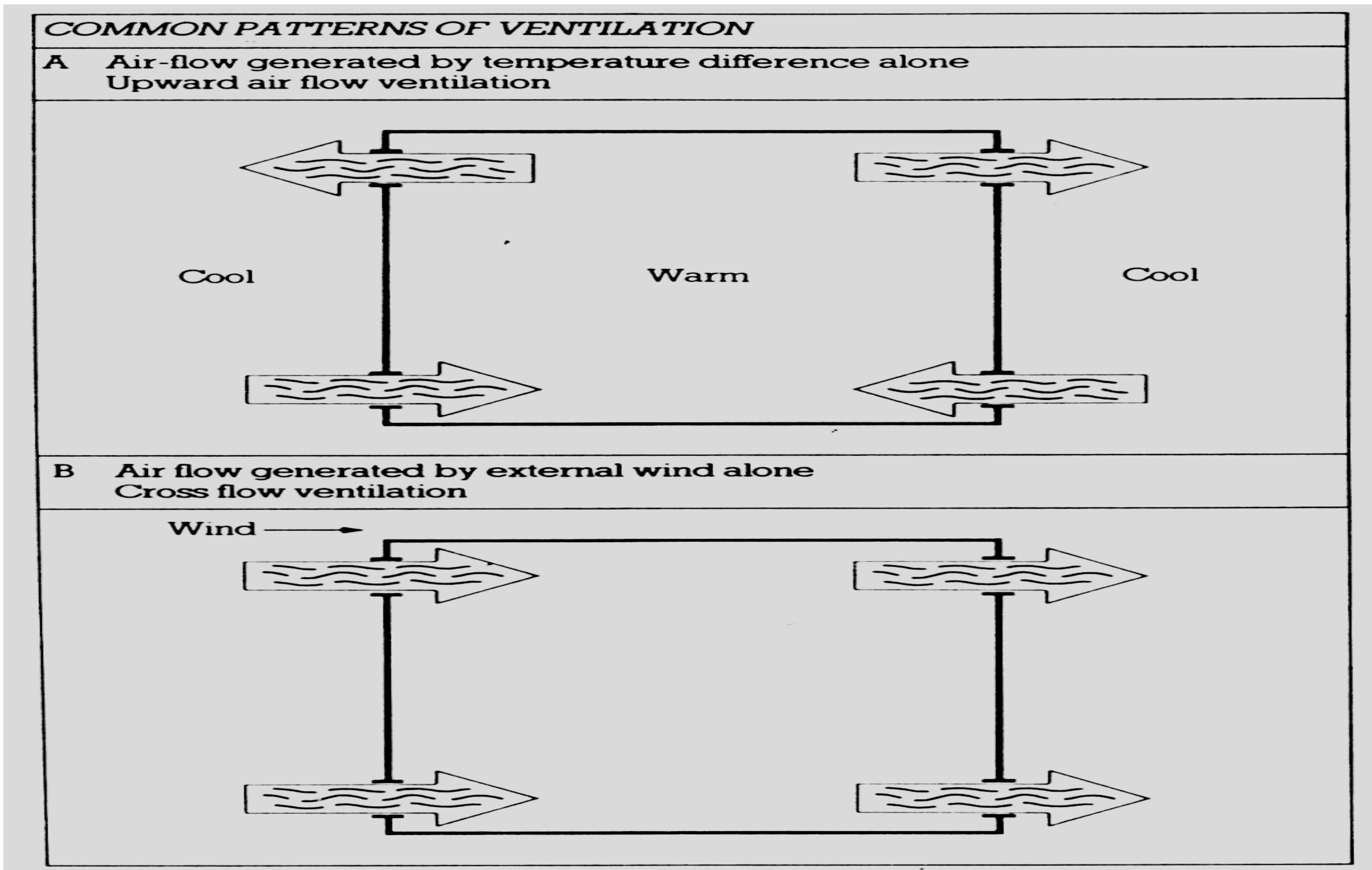
- ***CARATTERISTICHE DELLA SORGENTE CHE INFLUENZANO L'ACCUMULO DI GAS***
  - ***POSIZIONE ED ORIENTAZIONE***
  - ***PORTATA DI GAS***
  - ***VELOCITA' DEL GAS***



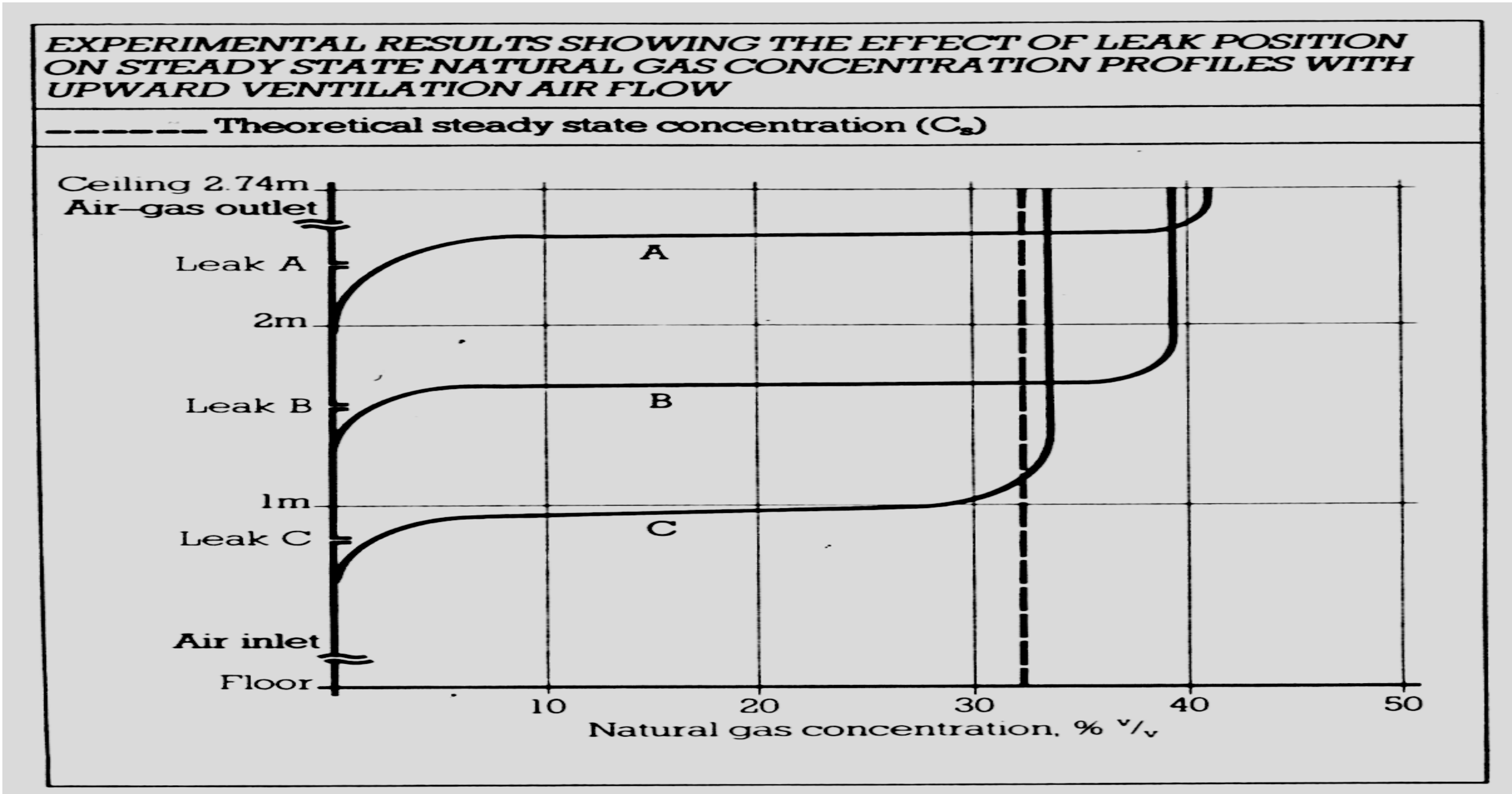
SORGENTE DI PERDITA



VENTILAZIONE



VENTILAZIONE (cont.)



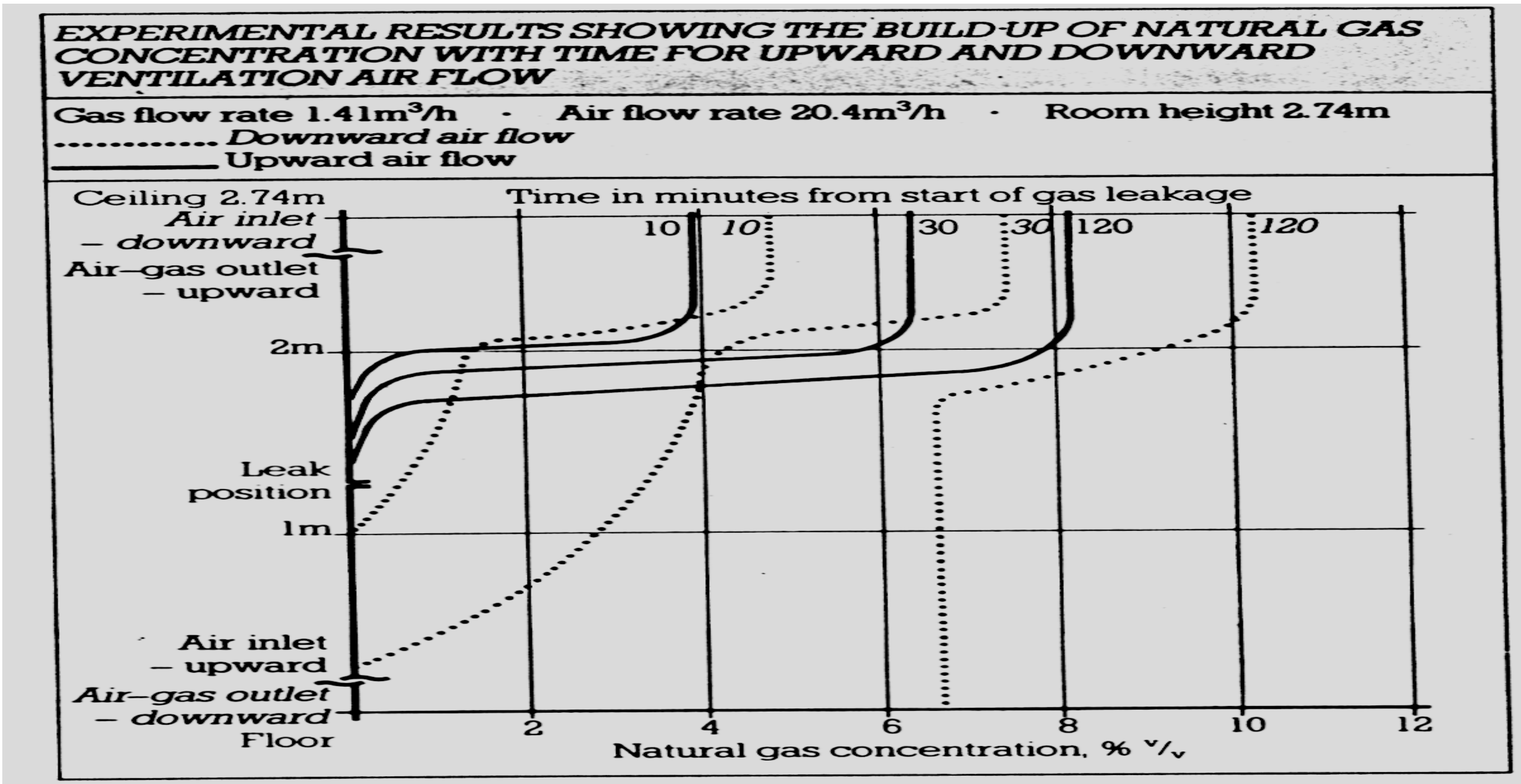
CONCENTRAZIONE STAZIONARIA

$$C_s = 100Q_g/(Q_a+Q_g)$$

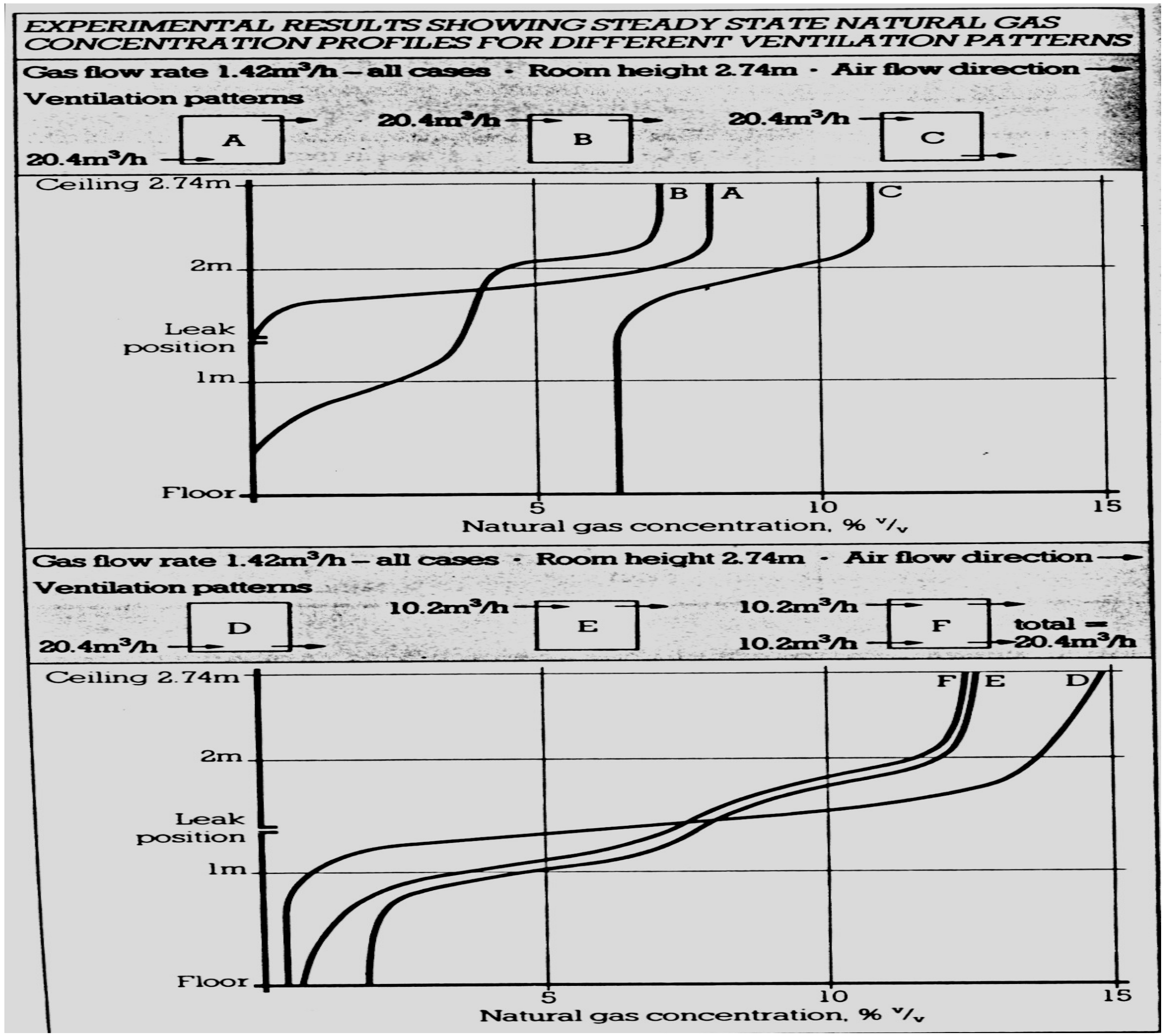
Q_g= PORTATA VOLUMETRICA DI GAS

Q_a = PORTATA VOLUMETRICA DI ARIA

VENTILAZIONE (cont.)



VENTILAZIONE (cont.)



STIMA CONCENTRAZIONE

STIMA DELLA CONCENTRAZIONE DEL GAS CON L'IPOTESI DEL PERFETTO MISCELAMENTO

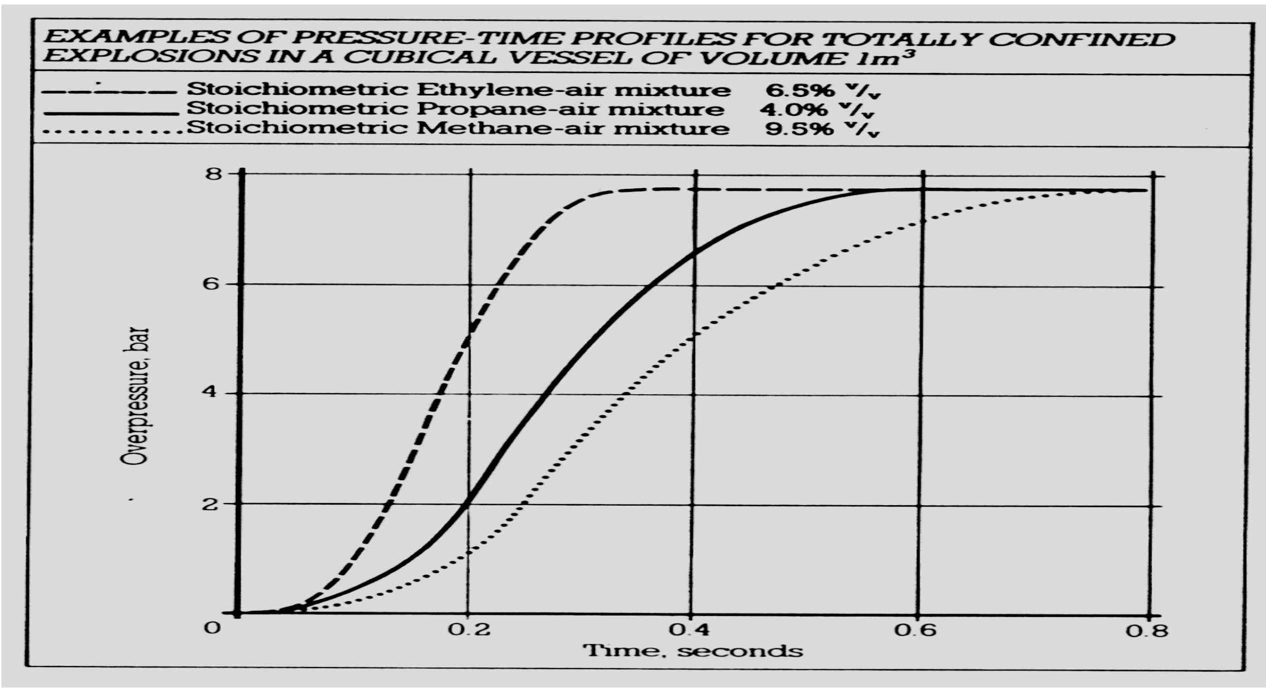
$$C=[100Qg/(Qg+Qa)]\{1-\exp[-(Qg+Qa)t/V]\}$$

C= CONCENTRAZIONE DEL GAS	**[%]**
Qg=PORTATA GAS ENTRANTE (cost)	**[Kg/h]**
Qa=PORTATA ARIA ENTRANTE (cost)	**[Kg/h]**
t= TEMPO	**[s]**
V=VOLUME	**[m^3]**

ESPLOSIONI CONFINATE

<u>TIPI DI ESPLOSIONI</u>

- ***ESPLOSIONE TOTALMENTE CONFINATA***
- ***ESPLOSIONE CONFINATA CON APERTURA DI UNO SFIATO DURANTE L'ESPLOSIONE***



ESPLOSIONE TOTALMENTE CONFINATA

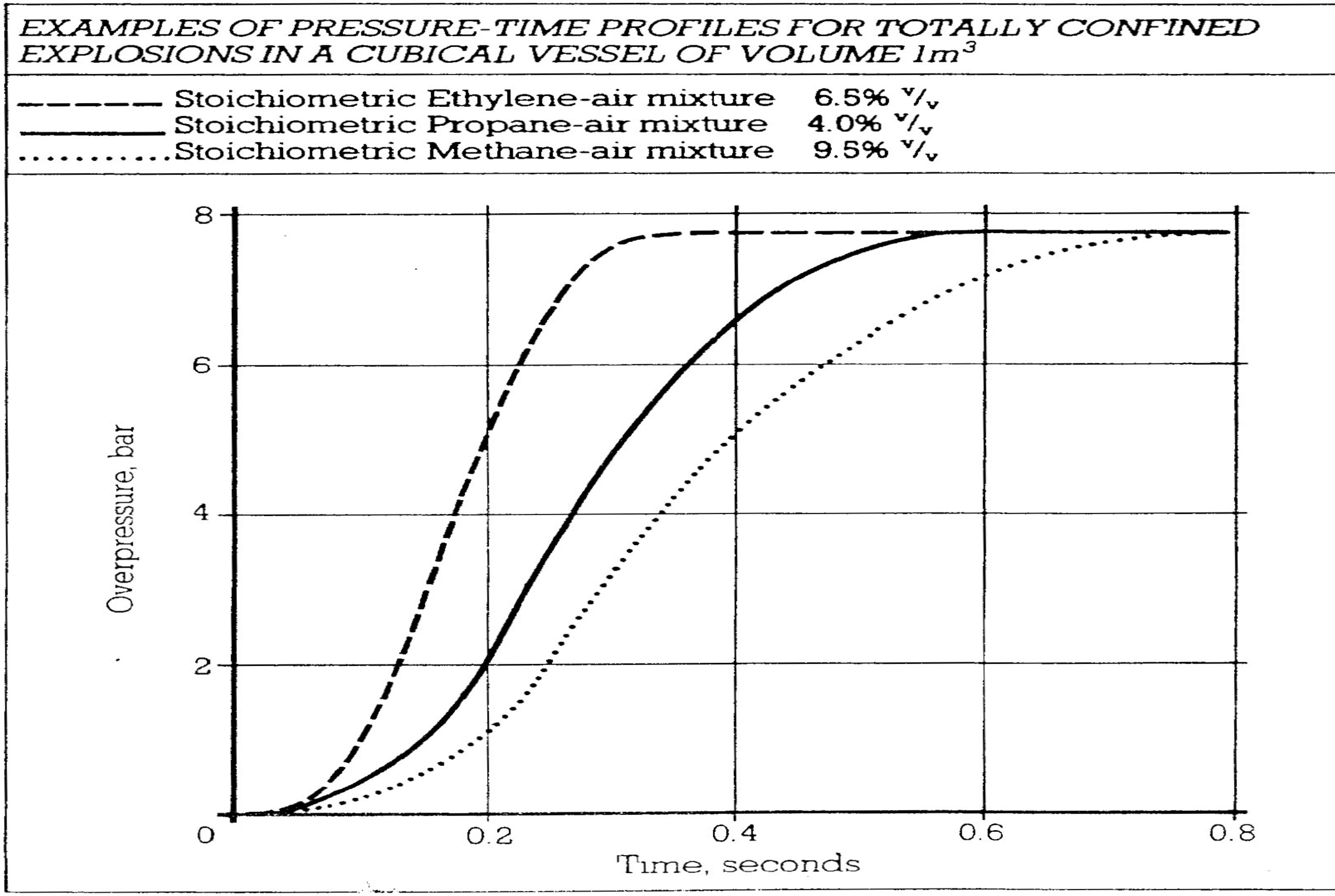


table 1.3 — *TYPICAL COMBUSTION PROPERTIES OF SOME HYDROCARBON GASES AND HYDROGEN IN AIR*

Fuel	Molecular weight	A Flammability limits % v/v gas Lower	Upper	% Gas at stoichio-metric ratio	B % Gas at maximum burning velocity	B Maximum laminar burning velocity S_o (m/s)
Hydrogen H_2	2	4	75	30	54	3.5
Methane CH_4	16	5	15	9.5	10	0.45
Ethane C_2H_6	30	3	12.5	5.6	6.3	0.53
Propane C_3H_8	44	2.2	9.5	4.0	4.5	0.52
Butane C_4H_{10}	58	1.9	8.5	3.1	3.5	0.50
Pentane C_5H_{12}	72	1.5	7.8	2.6	2.9	0.52
Hexane C_6H_{14}	86	1.2	7.5	2.2	2.5	0.52
Heptane C_7H_{16}	100	1.2	6.7	1.9	2.3	0.52
Acetylene C_2H_2	26	2.5	80	7.7	9.3	1.58
Ethylene C_2H_4	28	3.1	32	6.5	7.4	0.83
Propylene C_3H_6	42	2.4	10.3	4.4	5.0	0.66
Butylene C_4H_8	56	1.7	9.5	3.4	3.9	0.57
Benzene C_6H_6	78	1.4	7.1	2.7	3.3	0.62
Cyclohexane C_6H_{12}	84	1.3	8.0	2.3	2.7	0.52

C Adiabatic flame temperature T_f K	Expansion ratio T_f/T_i (T_i = 288K)	D Maximum laminar flame speed (m/s)	E Auto-ignition temperature K	F Minimum ignition energy, millijoules	G Net calorific value (288K, 1 atmos) MJ/m³	Fuel
2318*	8.0	28.0	847	0.02	10.2	Hydrogen H_2
2148*	7.4	3.5	813	0.29	34	Methane CH_4
2168*	7.5	4.0	788	0.24	60.5	Ethane C_2H_6
2198*	7.6	4.0	723	0.25	86.4	Propane C_3H_8
2168*	7.5	3.7	678	0.25	112.4	Butane C_4H_{10}
2232	7.7	4.0	533	0.25	138.1	Pentane C_5H_{12}
2221	7.7	4.0	498	0.25	164.4	Hexane C_6H_{14}
2196	7.6	4.0	488	0.25	190.4	Heptane C_7H_{16}
2598*	9.0	14.2	578	0.02	51	Acetylene C_2H_2
2248*	7.8	6.5	763	0.12	56	Ethylene C_2H_4
2208*	7.7	5.1	733	0.28	81.5	Propylene C_3H_6
2203*	7.6	4.3	658	0.28	107.1	Butylene C_4H_8
2287	7.9	4.9	833	0.22	134	Benzene C_6H_6
2232	7.8	4.1	518	0.24	167.3	Cyclohexane C_6H_{12}

A From Coward and Jones[5]

B Value for H_2 from Rose and Cooper[3]. Value for C_2H_2 as recommended by Andrews and Bradley[6]. Other values based on comparative data from Gerstein *et al*[7] which have been corrected in line with a currently accepted value of 0.45 m/s for methane-air – See Andrews and Bradley[6]

C Values marked by * from Lewis and Von Elbe[1], other values from Perry and Chilton[8]

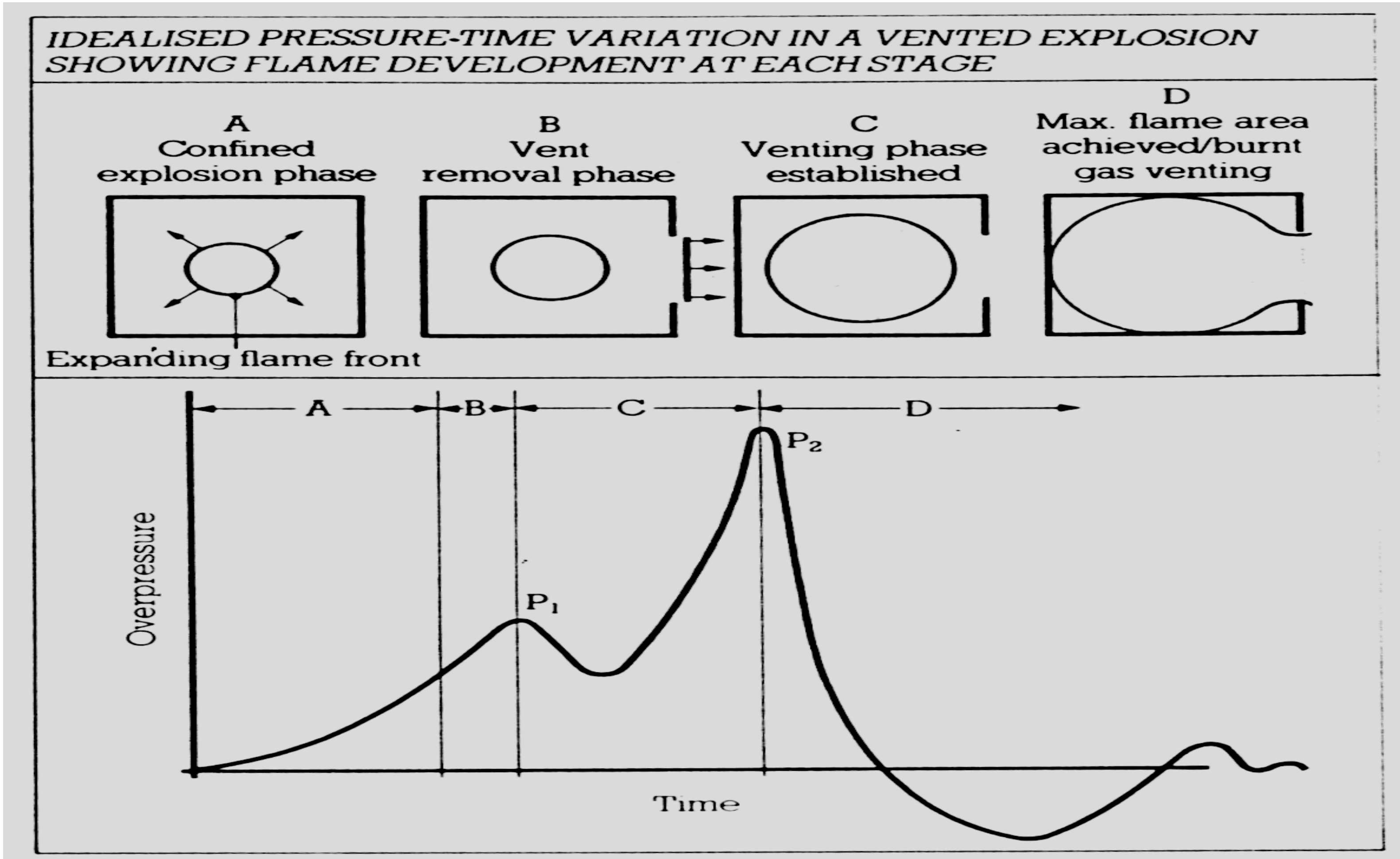
D Assumes $S_f = S_o (T_f/T_i)$ – See Section 1.3.3

E Value for Hydrogen from Perry and Chilton[8] – all others from Zabetakis[9]

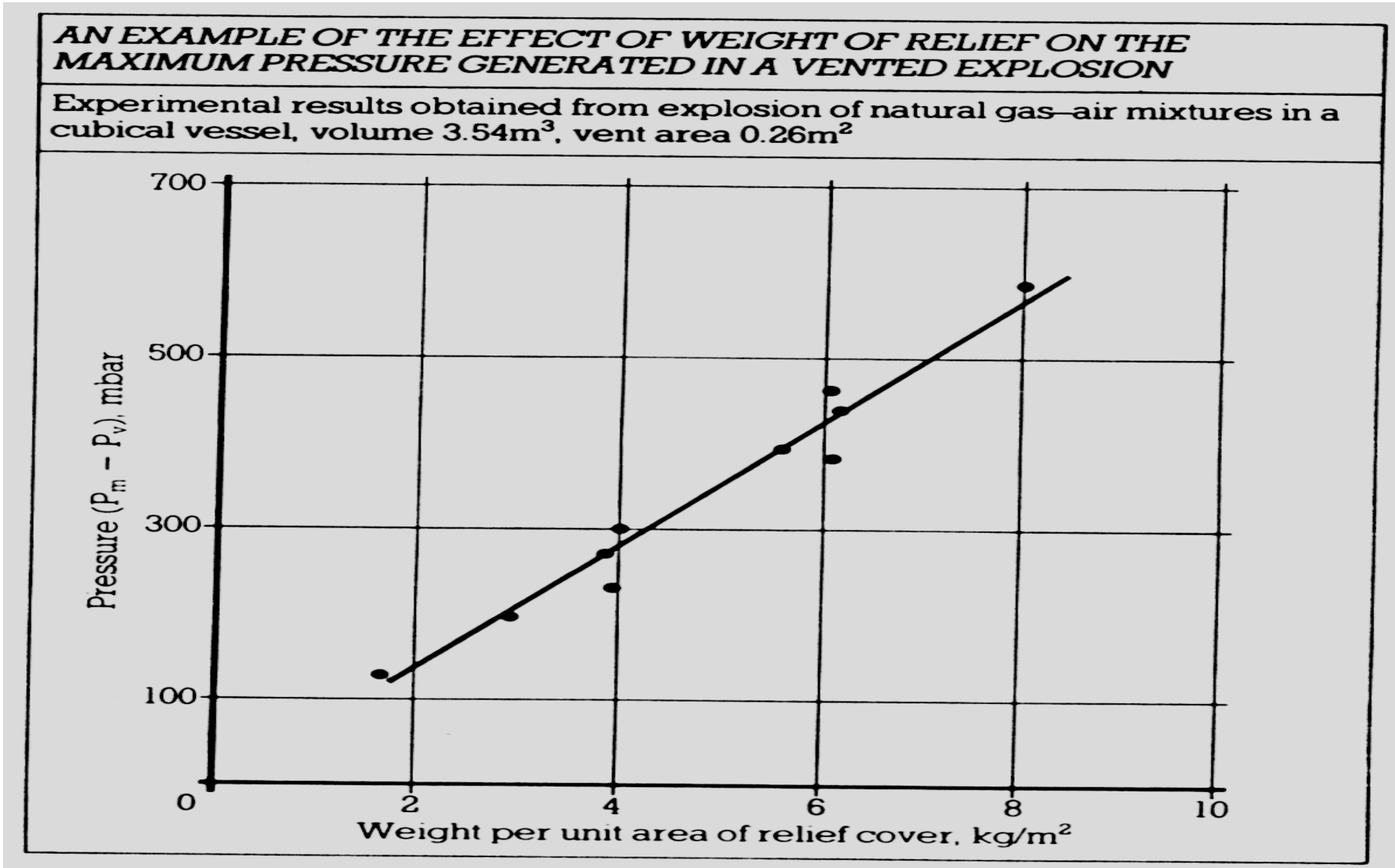
F Values from Lewis and Von Elbe[1]. Values represent minimum energy stored in test circuit prior to spark discharge

G Values from Rose and Cooper[3].

ESPLOSIONI VENTATE

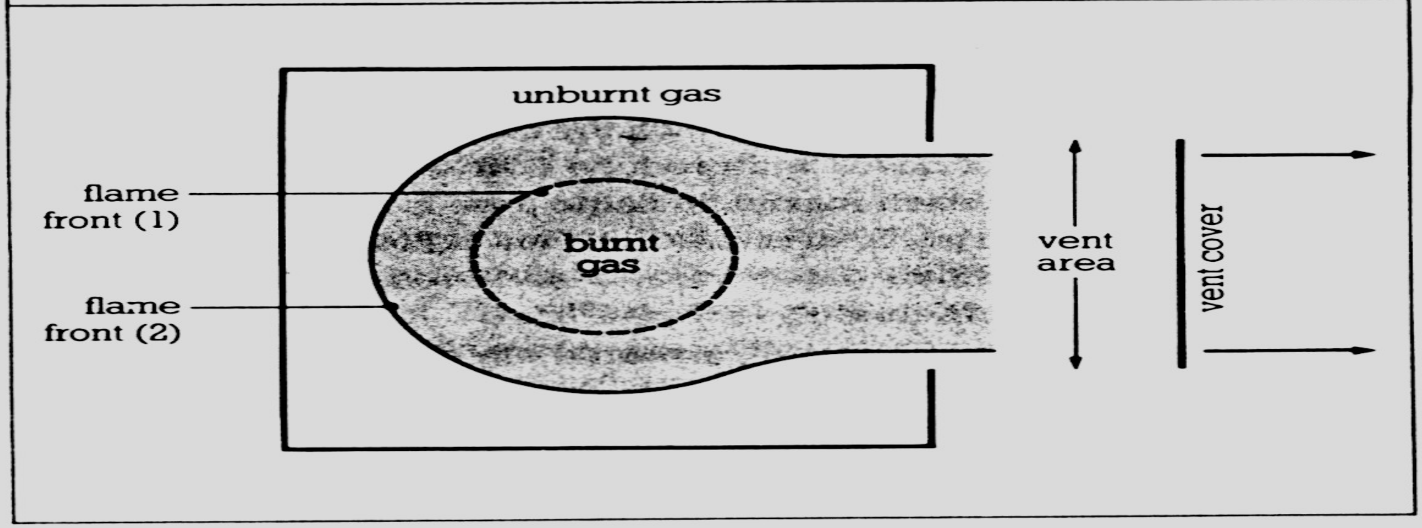


ESPLOSIONI VENTATE



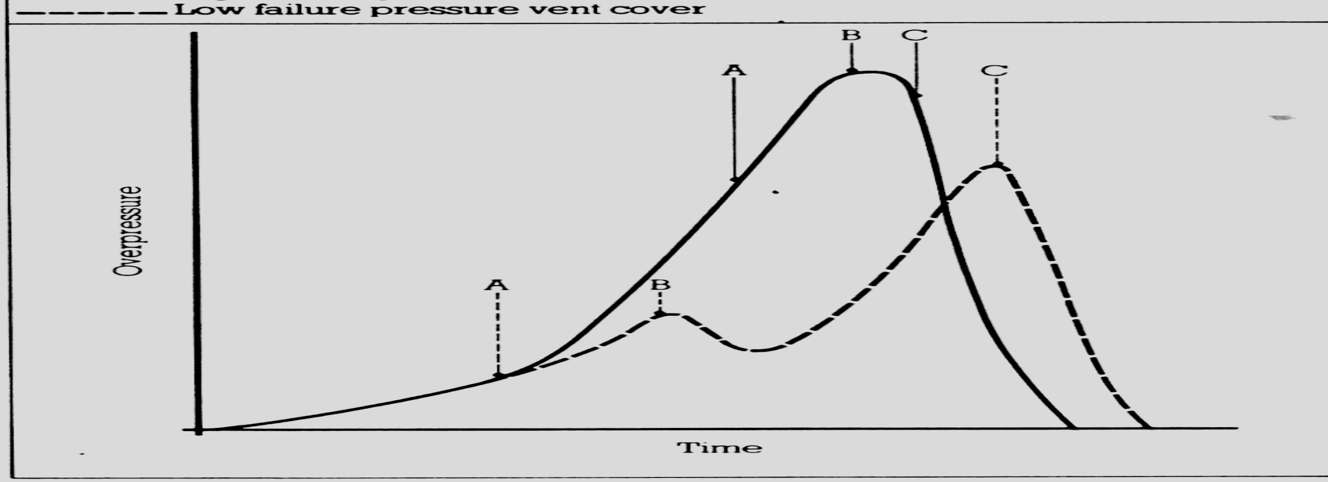
ESPLOSIONI VENTATE

CHANGE IN FLAME SHAPE FROM (1) SPHERICAL TO (2) PEAR SHAPE AFTER VENT REMOVAL



SCHEMATIC PRESSURE-TIME PROFILES FOR VENTED EXPLOSIONS

A: Vent failure
B: Outflow of gases established
C: Onset of burnt gas venting
——— High failure pressure vent cover
– – – – Low failure pressure vent cover



ESPLOSIONI VENTATE

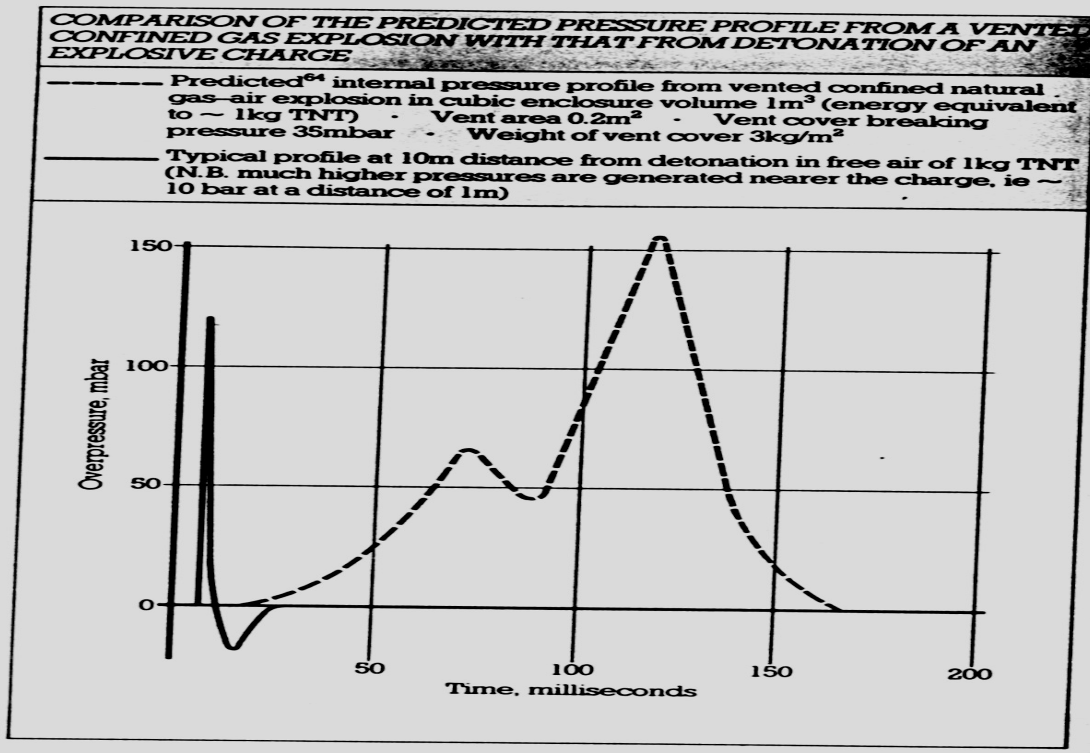
SCOSTAMENTI DAL COMPORTAMENTO IDEALE SFERICO

- ***DISTRIBUZIONE DEL GAS NON UNIFORME NELL'AMBIENTE***
- ***GEOMETRIA DEL VOLUME***
- ***PUNTO DI IGNIZIONE***
- ***IGNIZIONI MULTIPLE***
- ***PRESENZA DI MECCANISMI CHE ACCELLERANO LA FIAMMA***
  - ***TURBOLENZA***
  - ***INSTABILITA' DELLA FIAMMA***

FORMULE EMPIRICHE

***A SUMMARY OF COMMONLY USED EMPIRICAL FORMULAE AND THEIR RANGES OF APPLICATION** all pressures in mbar*		
Formula $P_1 = S_o (4.3\ KW + 28)/V^{1/3}$ $P_2 = 58\ S_o K$	*Author* Cubbage and Simmonds,[49,50]	*Range of application* $L_{max} : L_{min} \leq 3:1$ $K \leq 5$ $W \leq 24\ kg/m^2$
Comments Vent cladding can be of any material provided that no restraining force (other than the minimum of friction) is used to maintain the vent in position.		
Formula $P_m = P_v + 23 (S_o^2 KW/V^{1/3}) (\ldots$ $\ldots [f(\lambda, \lambda_o)])$	*Author* Cubbage and Marshall,[34]	*Range of application* $L_{max} : L_{min} \leq 3:1$ $K \leq 4$ $2.4 kg/m^2 \leq W \leq 24 kg/m^2$ $P_v \leq 490$ mbar
Comments Predicts maximum pressure generated, irrespective of whether this is P_1 or P_2. For $\lambda \leq 750 kJ/m^3$, and $P_v < 350$ mbar, use $f(\lambda, \lambda_o) = 1 - \exp[-(\lambda - \lambda_o)/(\lambda + \lambda_o)]$. For $\lambda \leq 750 kJ/m^3$, and $P_v > 350$ mbar, use $f(\lambda, \lambda_o) = (\lambda - \lambda_o)/\lambda$. For hazard assessment use $f(\lambda, \lambda_o) = 1$ to calculate maximum possible pressure rise. Vent cladding can be any material (preferably friable), provided it is held in place by a positive force.		
Formula $P_m = 1.5 P_v + 77.7\ S_o K$	*Author* Rasbash,[51]	*Range of application* $L_{max} : L_{min} \leq 3:1$ $K \leq 5$ $W \leq 24\ kg/m^2$ $P_v \leq 70$ mbar
Comments Formula essentially predicts the second peak pressure, P_2. Vent cladding can be any material held in place by a positive force.		
Formula $P_m = 1.5\ P_v + \ldots$ $S_o \{ [(4.3 KW + 28)/V^{1/3}] + 77.7 K \}$	*Author* Rasbash *et al,* [52]	*Range of application* $L_{max} : L_{min} \leq 3:1$ $K \leq 5$ $W \leq 24\ kg/m^2$ $P_v \leq 70$ mbar
Comments Predicts maximum pressure generated, irrespective of whether this is P_1 or P_2		

IMPULSO



On first thought it might

TIPI DI CARICHI

t_d = DURATA DELL'IMPULSO

T_N=PERIODO NATIRALE DI OSCILLAZIONE

- ***$t_d > T_N$ CARICHI STATICI***
- ***$t_d = T_N$ CARICHI STATICI***
- ***$t_d < T_N$ CARICHI DINAMICI***

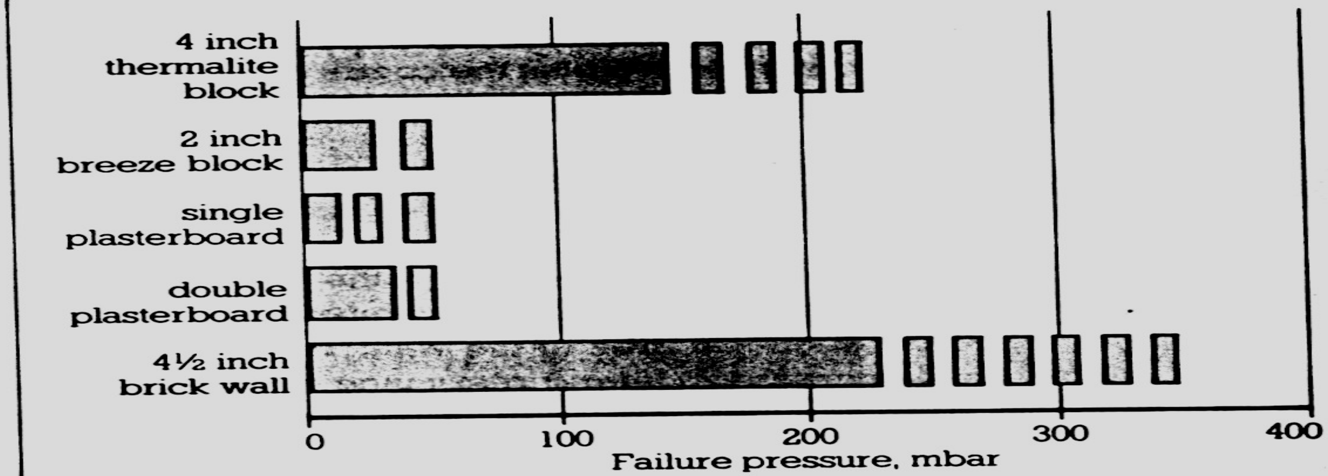
TYPICAL PERIODS OF VIBRATION OF STRUCTURAL ELEMENTS AND DURATION OF PRESSURE PULSES

	Period/Duration (milliseconds)
Concrete floors	10–30
Concrete walls	10–15
Brick walls	20–40
Confined gas explosion	100–300
Pressure wave from detonation of an explosive charge	1–10

RESISTENZA

COMPARISON OF FAILURE PRESSURES OF DIFFERENT WALL CONSTRUCTIONS

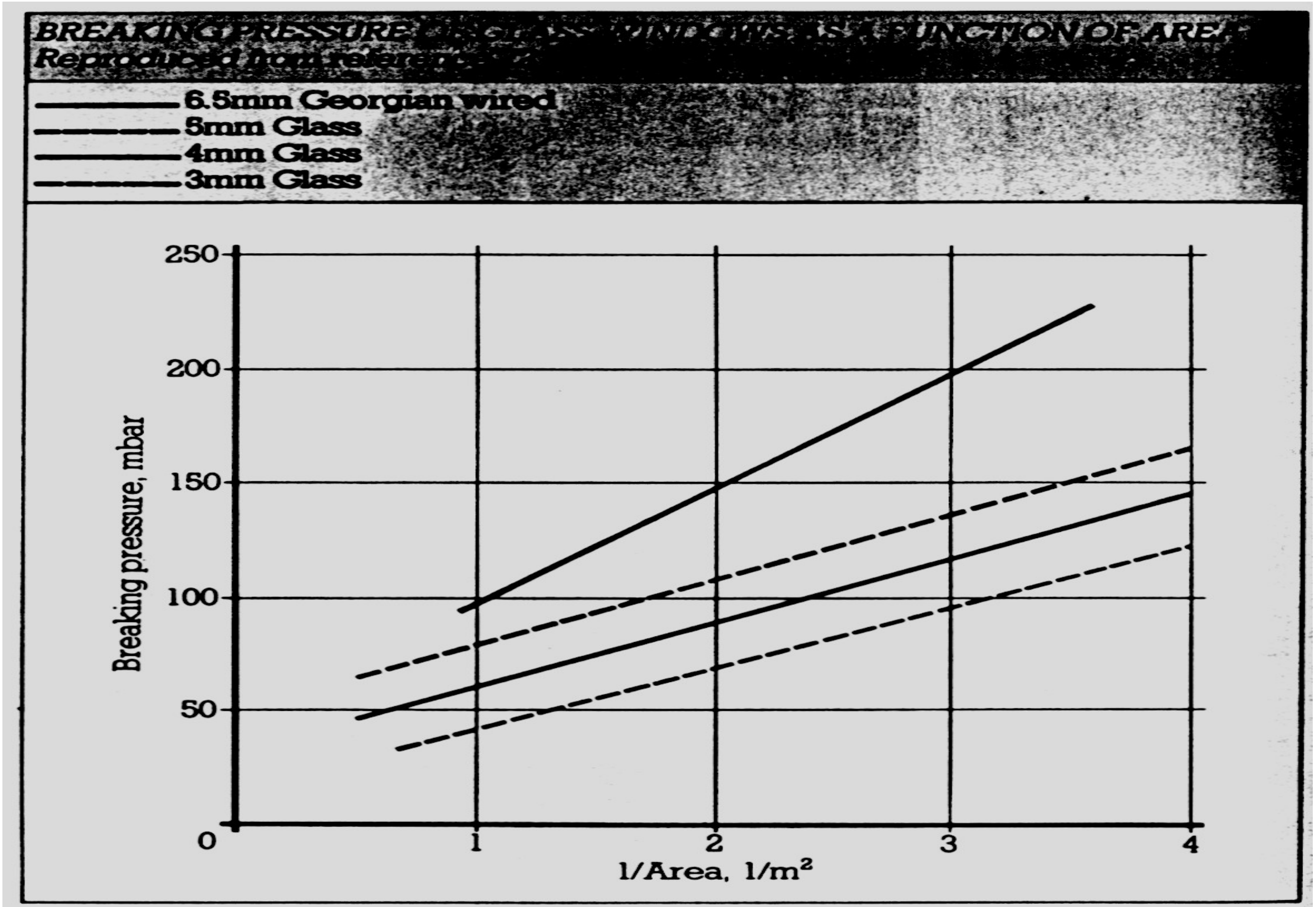
All walls have area 5.1m²
Unbroken line represents no damage
Broken line represents possible cracking
End of broken line represents failure



TYPICAL FAILURE PRESSURES OF SOME STRUCTURAL BUILDING ELEMENTS UNDER GAS EXPLOSION CONDITIONS

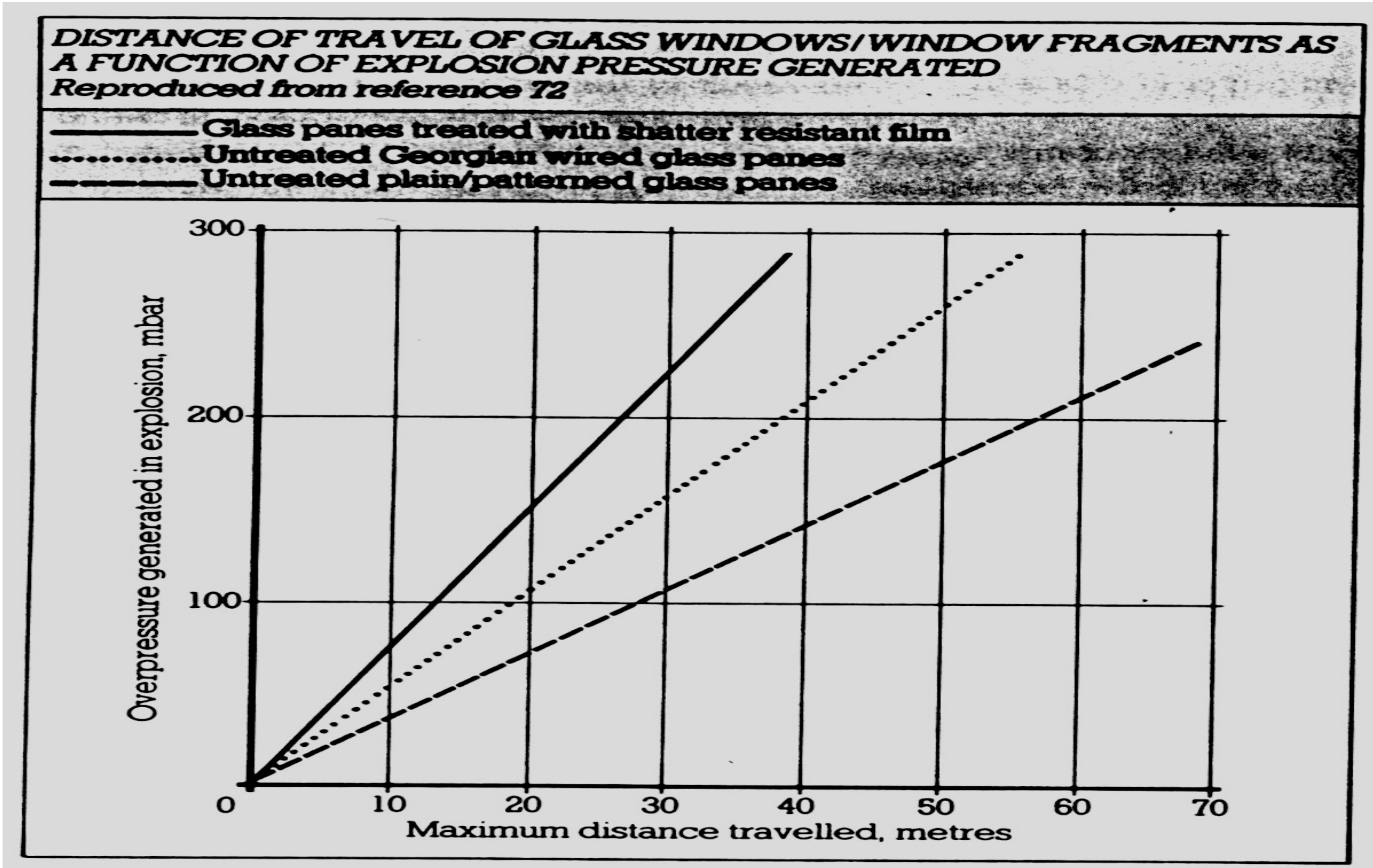
Structural element	*Typical failure pressure (mbar)*
Glass windows	20–70
Room doors	20–30
Light partition walls (eg. plasterboard on wooden studding)	20–50
50mm thick breeze block walls	40–50
Unrestrained brick walls	70–150

VETRI



BREAKING PRESSURE
6.5mm Georgian wired
5mm Glass
4mm Glass
3mm Glass
250
200
150
100
50
0
1
2
3
4
Breaking pressure, mbar
1/Area, 1/m²

VETRI



DISTANCE OF TRAVEL OF GLASS WINDOWS/WINDOW FRAGMENTS AS A FUNCTION OF EXPLOSION PRESSURE GENERATED
Reproduced from reference 72
Glass panes treated with shatter resistant film
Untreated Georgian wired glass panes
Untreated plain/patterned glass panes
300
200
100
0
10
20
30
40
50
60
70
Overpressure generated in explosion, mbar
Maximum distance travelled, metres

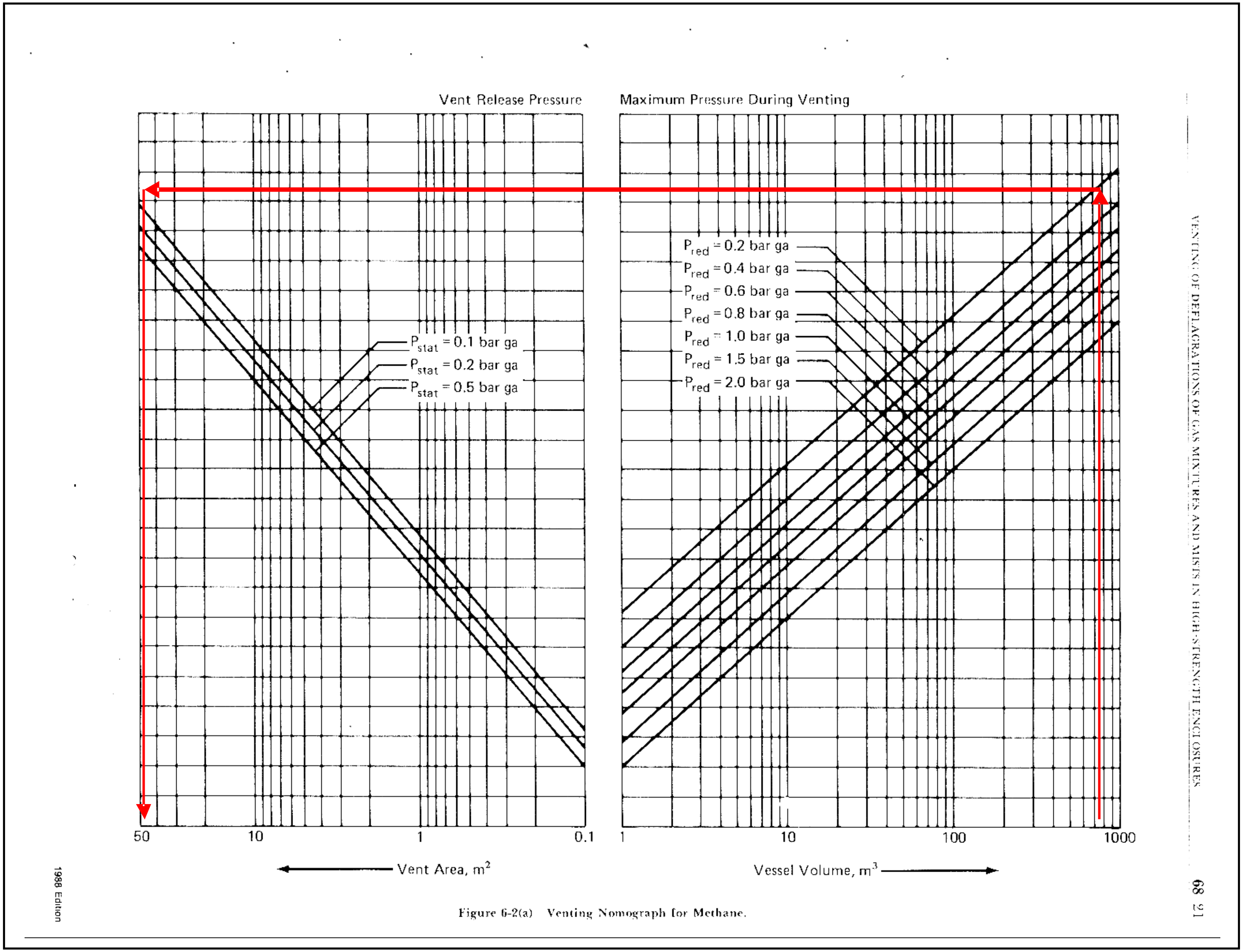
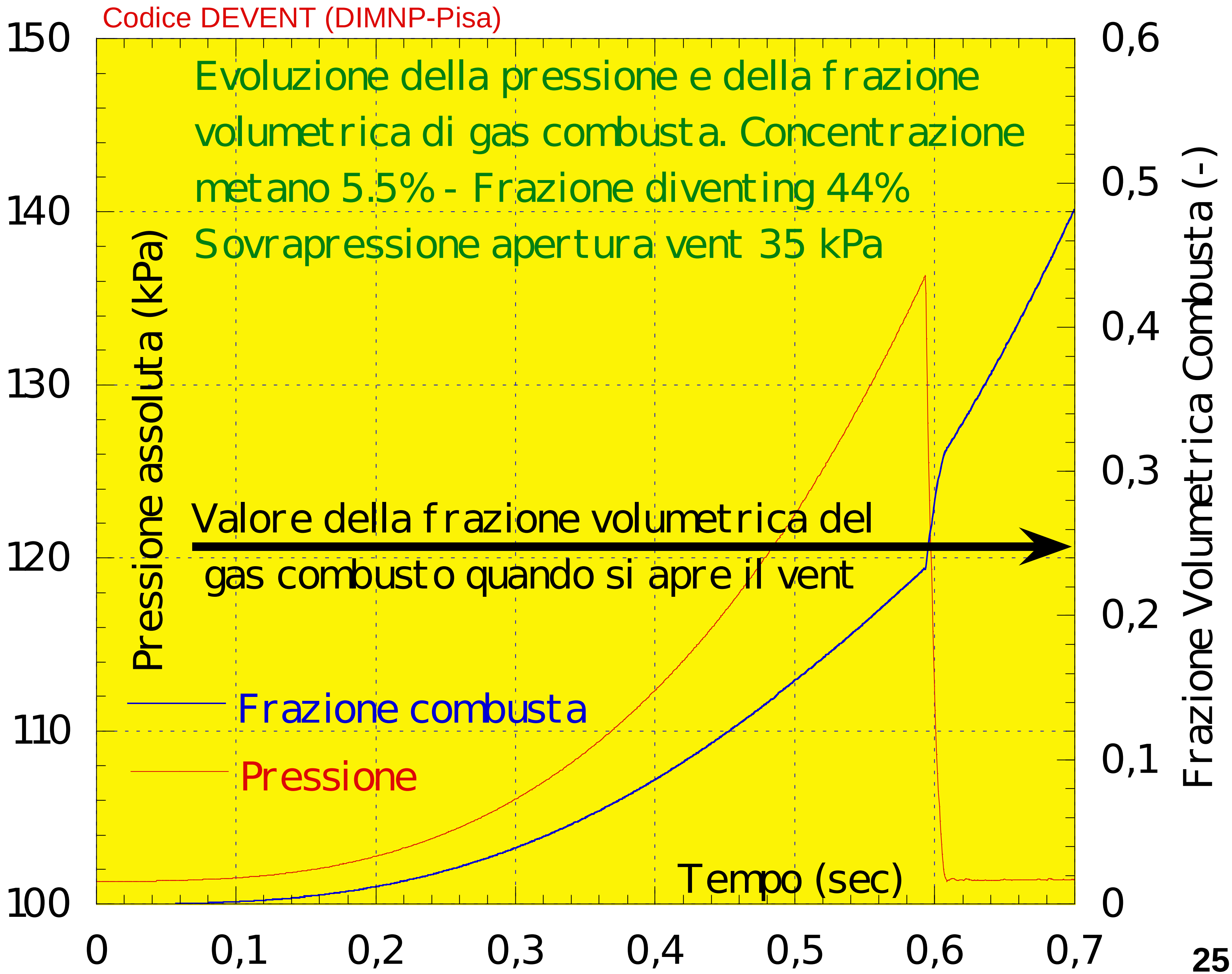


Figure 6-2(a) Venting Nomograph for Methane.

Figura 5 – Normogramma NFPA per Metano


Codice DEVENT (DIMNP-Pisa)
Evoluzione della pressione e della frazione volumetrica di gas combusta. Concentrazione metano 5.5% - Frazione diventing 44%
Sovrapressione apertura vent 35 kPa
Valore della frazione volumetrica del gas combusto quando si apre il vent
Frazione combusta
Pressione
Pressione assoluta (kPa)
Frazione Volumetrica Combusta (-)
Tempo (sec)
150
140
130
120
110
100
0,6
0,5
0,4
0,3
0,2
0,1
0
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7