INSTRUMENTATION HANDOOK
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The handbook is dedicated in particular to operators involved in the design and use of measurement and control systems for industrial processes in chemical, petrochemical, iron and steel, energy and similar plants, with the aim of being a reference and consultation manual regarding the topical aspects of instrumentation and industrial automation, such as:

- the basic foundational concepts of measurement and control instrumentation related to power supplies, standardized analogue signals and digital communication protocols;

- the symbology of the analogical and digital instrumentation, of the primary measurement elements and of the final regulation and safety elements, as well as of the connections to the process;

- the terminology concerning the static and dynamic characteristics of the instrumentation, as well as the initial calibration and periodic verification of the instrumentation;

- the operating conditions of the instrumentation in normal and extreme operating conditions in process atmospheres with danger of explosion and fire;

- the instruments and measurement systems of the main physical and chemical parameters relating to the different industrial processes with selection and selection criteria in the various applications;

- control, regulation and safety valves with selection and sizing criteria and installation and verification applications;

- simple regulation techniques in feedback and coordinates in feedforward, ratio, cascade, auto-selection and self-adaptive;

- the control systems of continuous and discontinuous industrial processes with particular emphasis on the safety aspects of design and operation.

The handbook is divided into two Volumes including three main Parts:

- **Volume I: Introduction and Measurement**

    Part 1, which first illustrates the general concepts on industrial instrumentation, the symbology, the terminology and calibration of the measurement instrumentation, the functional and applicative conditions of the instrumentation in normal applications and with danger of explosion, as well as the main directives (ATEX , EMC, LVD, MID and PED);

    - Part 2, which subsequently deals with the instrumentation for measuring physical quantities: pressure, level, flow rate, temperature, humidity, viscosity, mass density, force and vibration, and chemical quantities: pH, redox, conductivity, turbidity, explosiveness, gas chromatography and spectrography, treating the measurement principles, the reference standard, the practical executions and the application advantages and disadvantages for each size,.

- **Volume II: Control and Safety (2019)**

    - Part 3, which first illustrates the control, regulation and safety valves and then and simple regulation techniques in feedback and coordinates in feedforward, ratio, cascade, override, splitrange, gapcontrol, variable decoupling, and then the Systems of Distributed Control (DCS) for continuous processes, Programmable Logic Controllers (PLC) for discontinuous processes and Communication Protocols (BUS), and finally the aspects relating to System Safety Systems, from Operational Alarms, to Fire & Gas systems, to systems of ESD stop and finally to the Instrumented Safety Systems (SIS) with graphic and analytical determinations of the Safety Integrity Levels (SIL) with some practical examples.

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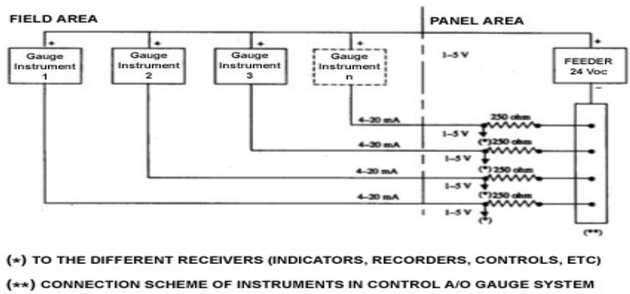
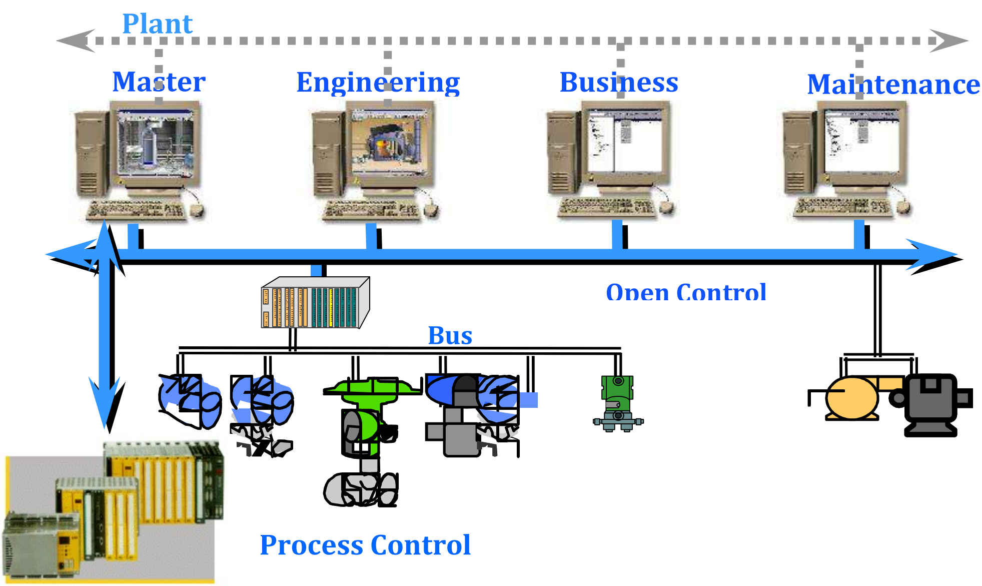
1. INSTRUMENTATION GENERAL

This first point deals with the power supplies and the normalized analogical (4-20 mA), hybrid (Hart) and digital (Fieldbus) instrumentation signals and the serial and parallel wire connection systems:



as well the typical instrumentation fieldbus integration in the actual process control systems:

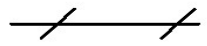
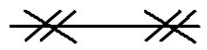
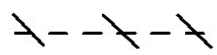
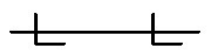


2. INSTRUMENTATION SYMBOLOGY

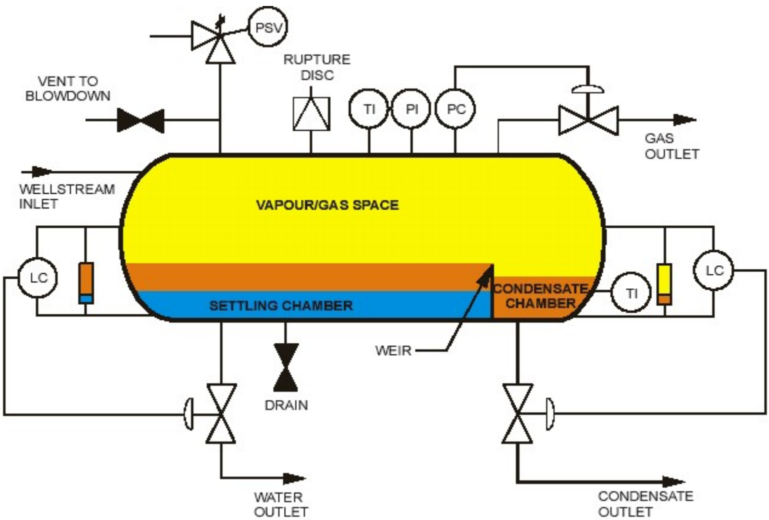
The symbology for the identification of the measurement and control instrumentation on flow and process diagrams and on P & IDs (Piping & Instrument Diagram), commonly called P&I (Piping & Instrumentation), is generally compliant with the ISA Standard ISA S.5, that foresee this identification table:

	PRIMA LETTERA *FIRST-LETTER*		LETTERE SUCCESSIVE *SUCCEEDING-LETTERS*		
	VARIABILE MISURATA/ INIZIATRICE *MEASURED OR INITIATING VARIABLE*	MODIFICATORE *MODIFIER*	LETTURA O FUNZIONE PASSIVA *READOUT OR PASSIVE FUNCTION*	FUNZIONE IN USCITA *OUTPUT FUNCTION*	MODIFICATORE *MODIFIER*
A	Analisi *Analysis*		Allarme *Alarm*		
B	Rivelaz.fiamma *Burner, Combustion*				
C				Controllo *Control*	
D		Differenziale *Differential*			
E	Tensione *Voltage*		Sensore *Sensor (Primary Elem.)*		
F	Portata *Flow rate*	Rapporto *Ratio (Fraction)*			
G			Vetro *Glass, Viewing Device*		
H	Manuale *Hand*				Alto *High*
I	Corrente *Current (Electrical)*		Indicazione *Indicate*		
J	Potenza *Power*	Scansione *Scan*			
K	Tempo *Time, Time Schedule*	*Time Rate of Change*		*Control Station*	
L	Livello *Level*		Luce/segnalaz. *Light*		Basso *Low*
M	Umidita' *Moisture*	*Momentary*			*Middle, Intermediate*
N					
O			Orifizio *Office, Restriction*		
P	Pressione *Pressure, Vacuum*		Presa campione *Point (Test) Connection*		
Q	Quantita' *Quantity*	Integraz./totaliz. *Integrate, Totalize*			
R	*Radiation*		Registrazione *Record*		
S	Velocita'/freq. *Speed, Frequency*	Sicurezza *Safety*		Interruttore *Switch*	
T	Temperatura *Temperature*			Trasmettitore *Transmit*	
U	Multivariabile *Multivariable*		Multifunzione *Multifunction*	Multifunzione *Multifunction*	Multifunzione *Multifunction*
V	Vibrazione *Vibration*			Valvola/serranda *Valve, Damper, Louver*	
W	Peso, forza *Weight, Force*		Pozzetto *Well*		
X	Stato di pericolo *Danger*	Asse X *X Axis*	*Unclassified*	*Unclassified*	Avaria *Fault*
Y	Evento/stato *Event, State or Presence*	Asse Y *Y Axis*		Operatore (non defin.) *Relay, Compute, Convert*	
Z	Posizione/dimens. *Position, Dimension*	Asse Z *Z Axis*		Elemento finale *Driver, Actuator, Unclassified Final Control Element*	-

The typical connection instrument it is following in table:

SYM. REF. No.	SIMBOLO *SYMBOL*	DESCRIZIONE *DESCRIPTION*	STD CODE	STD REF. No.
3201		Connessione al processo o tubazione di alimentazione strumenti (nota 1) *Process connection or instrument supply pipe (note 1)*	ISA S51	6.2.1
3202		Segnale non definito *Undefined signal*	ISA S5.1	6.2.1
3203		Segnale pneumatico (puo' essere usato per ogni tipo di gas) *Pneumatic signal (may be used for any gas type)*	ISA.S5	6.2.1
3204		Alternativa (nota 2) segnale pneumatico binario (puo' essere usato per ogni tipo di gas) *ON-OFF pneumatic binary signal (may be used for any gas type)*	ISA S5.1 CEI	6.2.1 30-04-06
3205		Segnale elettrico *Electric signal*	ISA S5.1	6.2.1
3206		Alternativa (nota 2) segnale elettrico binario *Electric binary signal (ON-OFF)*	ISA S5.1	6.2.1
3207		Segnale idraulico *Hydraulic signal*	ISA S5.1 CEI	6.2.1 30-04-07

while a typical graphical P&I representation is shown below:



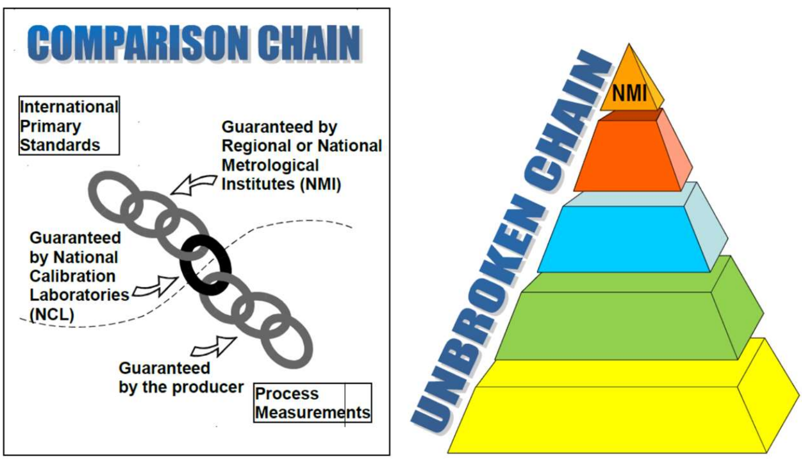
3. INSTRUMENTATION TERMINOLOGY

To circulate the measures in the National and International context, the measures must be traceable or referable to the same universally recognized measurement standards and so consequently they will become comparable in the worldwide.

The metrological traceability it is in accordance with the VIM: International Vocabulary in Metrology according ISO Guide 99 is defined as:
Property of measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to measurement uncertainty"

as represented in figure

(a) The chain of comparisons between measurements on the product and the International Primary Standards guaranteed by National Calibration Laboratories (NCL) accredited to the National Calibration System adhering to the Regional or International accreditation system
(b) The pyramid of traceability through the unbroken chain from Process, Measuring Instrument, Reference Standard and National Calibration Laboratories (NCL) and finally to the National Metrological Institutes (NMI)



(a) (b)

4. INSTRUMENTATION CALIBRATION

The control of measuring instruments, namely:

- measuring equipment in the Quality Management System ISO 9001
- surveillance equipment in the Environmental Management System ISO 14001

provide, where necessary to ensure valid results, that the measuring instruments are:

a) calibrated and verified at specified intervals or prior to use, against measurement standards traceable to international or national measurement standards; where no such standards exist, they must be registered with the criteria used for calibration or verification;
b) adjusted or regulated again, when necessary;
therefore, all management systems provide the initial calibration and any periodic "adjustment or metrological confirmation" (according to ISO 10012 Measurement Management System) of the measuring instruments to validate the various measurement processes to ensure proper traceability of measurements to the International System SI.

To correctly perform a calibration must have infrastructure, means, methods and procedures, and appropriate staff, or possess the four fundamental pillars:

1) Ambient conditions

If the measurement ambient is to industrial, it is appropriate that the measures are carried out within the maximum limits set out below:

- **Temperature** : 20 ± 5 °C (or 25 ± 10 °C)
- **Relative humidity** : 50 ± 25 %

to contain the drift of standard and calibration instruments.

If, however, the measurement is made in the laboratory,

- **Temperature** : 20 ± 2 °C for mech. measures
  23 ± 3°C for electr. measures
- **Relative humidity** : 50 ± 10 % (or ± 20 %)

to get a better uncertainty and traceability meas. process.

2) Measurement equipment

appropriate equipment to the measuring ranges and the desired levels of uncertainty, traceable to the International System of SI units (see point 1) by:

- ***National Calibration Laboratories (NCL):***
  - **EA** : European cooperation for Accreditation
  - **ILAC** : International Laboratory Accreditation Coop.
- ***Or National Metrological Institutes (NMI).***

The reference standard instrument should still have a measurement uncertainty of typically better than 1/3 of the nominal uncertainty of the calibrated instrument.

3) Technical Personnel

Specifically trained and operating under the procedures:

- technical
- management

regarding the Quality Manual of the Organization.

4) Operating procedures

The operating calibration procedures should be specifically drawn up:

- for each type of provided measurement;
- for each type of instrumentation with ref. normatives.

In the absence of a specific reference normatives, it is good practice to follow the generic operating procedures reported below.

The general index of operational procedures should be:

1. Scope and purpose
2. Identification and classification
3. Normative references
4. Ambient conditions
5. Initial checks
6. Calibration method
7. Calibration verification
8. Calibration results
9. Metrological confirmation

5. OPERATIONAL CONDITIONS

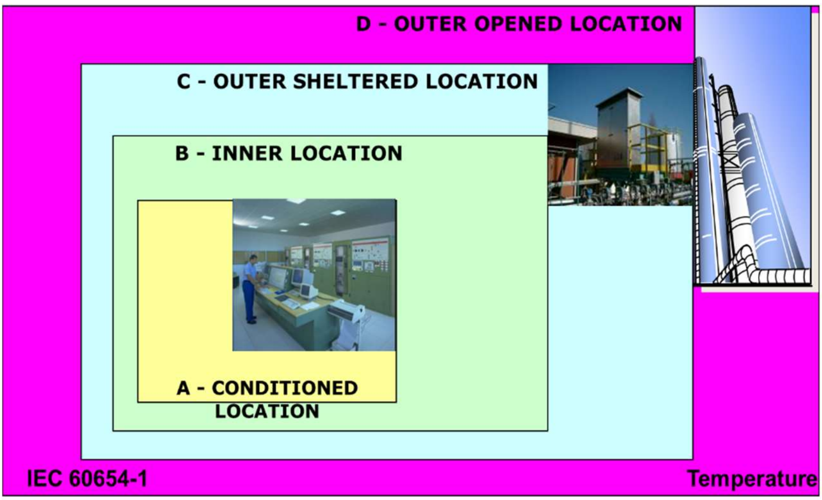
The foreseen climatic conditions for instrumentation location are the following (see Figure):

PLACE OF AIR CONDITIONING (Class A)
A place where both temperature and air humidity are regulated within specified limits.

PLACE AT CLOSED WITH HEATING/COOLING (Class B)
A place where only the air temperature is regulated within specified limits.

PLACE AT THE COVER (Class C)
A place where neither temperature nor air humidity is regulated. The equipment is protected from direct exposure to climatic elements, such as direct solar radiation, falling rain or other precipitation and full wind pressure.

PLACE AT OUTDOOR SITE (Class D)
A place where neither temperature nor air humidity is regulated. The equipment is exposed to various weather conditions, such as direct solar radiation, rain, hail, sleet, snow, ice and wind.



6. ENCLOSURE PROTECTION

The instrument or equipment installed in the field in uncovered or covered areas, or with a panel or back-panel, must have a total or at least a minimum protection against atmospheric agents, mechanical random impacts, as well as towards the incidental penetration of tools or human parts of the operators.

For this purpose, the international classifications in the sector are described briefly for:

- Against penetration of foreign bodies:
  IP classification against the penetration of solid, liquid bodies and the protection of people against contact with dangerous parts inside the case according to International Standard IEC 60529:

Code element	Number or letter	Protection against solids	Protection against liquids	Protection for personal	Protection special case
First letter characteristic	0 1 2 3 4 5 6	Not protected >50,0 mm of diameter >12,5 mm of diameter > 2,5 mm of diameter > 1,0 mm of diameter Dust partially protected Dust totally protected			
Second letter characteristic	0 1 2 3 4 5 6 7 8		Not protected Vertical water drops ± 15 ° water drops ± 60° water rain ± 180° water sprinkles Normal water jets Potent water jets Temporary immersion Continue immersion		
Additional Letter (optional)	A B C D			Hand Finger Tool Wire	
Supplementary letter (optional)	H M S W				High voltage equipment Motored equipment Stopped equipment Special weather conditions

- Against mechanical impacts:
  IK classification against mechanical impacts according to the International Standard IEC 62262:

CODE (IK)	00	01	02	03	04	05	06	07	08	09	10
Energy (J)	0	0,1	0,2	0,3	0,5	0.7	1	2	5	10	20

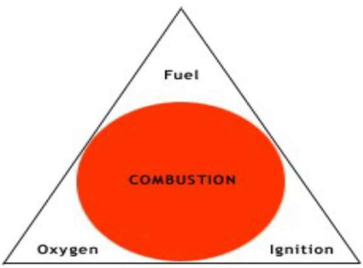
7. EXPLOSION-PROOF SYSTEMS

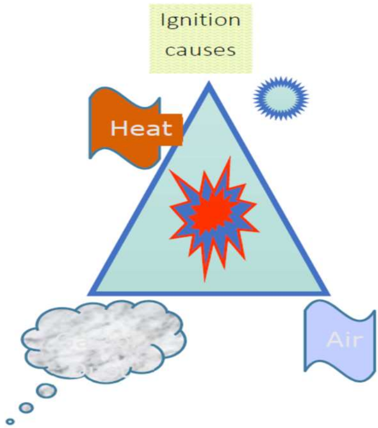
The equipment to be installed in places with danger of explosion due to the presence of flammable gases or vapors and / or combustible dusts must have a safe electrical construction, that is incapable of triggering an explosive atmosphere, both in normal operating conditions and in certain fault or overload conditions.

The electrical constructions so constructed, and suitable for use in places with danger of explosion, are commonly referred to as Ex safety equipment.

The explosion phenomenon (ignition and relative combustion) is an exothermic reaction that occurs due to the simultaneous presence, and in the necessary proportions, of three fundamental components:

• Fuel in the form of gas, steam or dust
• Oxidising, usually air or oxygen
• Electric, thermal or ignition energy

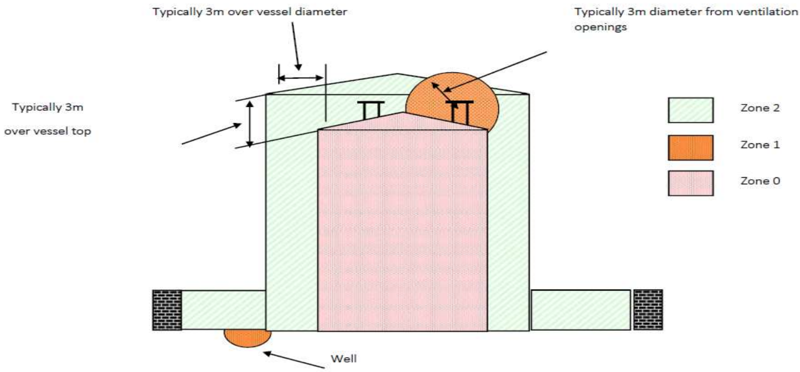




Dangerous Zone Classification:

CLASS	CODE	TYPE & EXAMPLE (1)
Class 0	C0	Explosive materials: Trinitrotoluene, nitroglycerin, ...
Class 1	C1	Flammable gas/vapor: Hydrogen, acetylene, methane, ...
Class 2	C2	Flammable dust: fiber, grain, carbon, ...
(1) IEC Standard Classification		

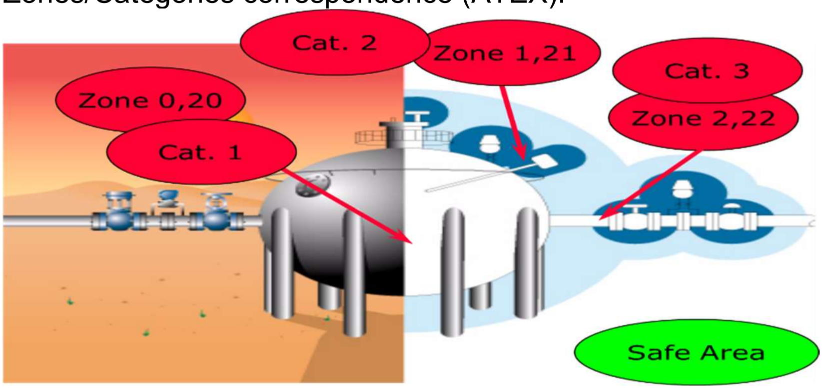
Example of Zone Classification:



European Category Classification (ATEX Directive):

GROUP	CATEGORY	EXPLOSIVE SUBSTANCE PRESENCE	SUBSTANCE	PROTECTION LEVEL	FAILURE OR MEANS OF PROTECTION
I Mines	M1	Present	Grisou or Flammable dust	Very high	Two means independents even in case of exceptional failure
	M2	Probable presence	Grisou or Flammable dust	High	One means even in case of normal failure
II Surface Industry Codified G for Gas D for Dust	1 (1)	Elevate probability or per long period	Gas, vapor, fog or air/dust	Very high	Two means independents even in case of exceptional failure
	2 (2)	Probable presence	Gas, vapor, fog or air/dust	High	One means even in case of normal failure
	3 (3)	Scarce probability or For short period	Gas, vapor, fog or air/dust	Normal	Protection level in normal working conditions
(1) Corresponds to Zone 0					
(2) Corresponds to Zone 1					
(3) Corresponds to Zone 2					

Zones/Categories correspondence (ATEX):



ATEX marking:

The ATEX Directive requires that the devices and components for which the EC Examination Certificate is required must contain at least the following data:

- standard marking for compliance with the European Directive
- number of the Notified Body (NB) charged with supervising production:
- specific abbreviation of the □x explosion protection inscribed in a hexagon
- appliance unit (I for mines and connection parts, II for surface industries)
- appl. category (1 for Zone 0 or 20, 2 for Zone 1 or 21, 3 for Zone 2 or 22)
- type of dangerous substances (G for gases and vapors, D for dusts)

Example of ATEX marking:

CE xxxx Ex II 1G (xxxx = identification of the NB)

MEANS:
II for surface industries, 1 category for Zone 0, G for Gas

New International IEC Ex Classification against ATEX Classific.

ATEX	EPL: IEC	
	GAS	DUST
Cat 1	Ga	Da
Cat 2	Gb	Db
Cat 3	Gc	Dc

EPL means:
Equipment Protection Level

IEC IECEx

8. PRESSURE EQUIPMENT DIRECTIVE (PED)

To classify a Pressure Equipment or Instrument is mandatory that have been satisfied the:

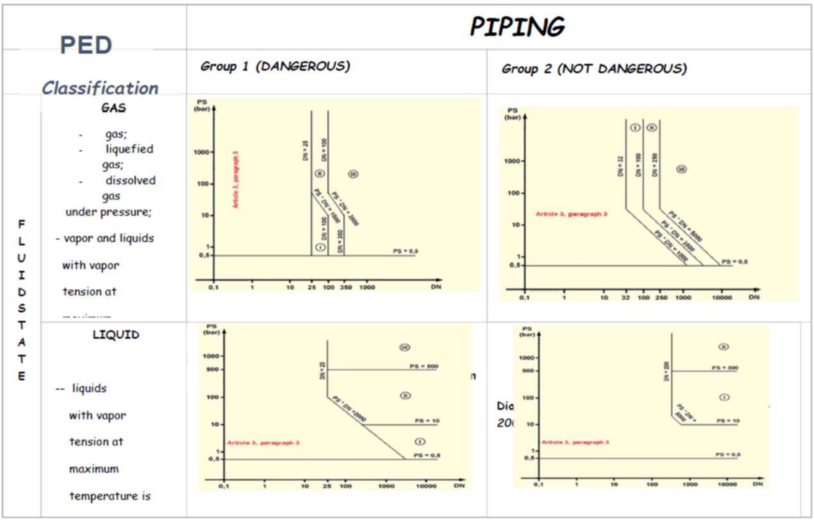
ESR :
Essential Safety Requirements specified by the European Directive 97/23/CEE named:

PED :
Pressure Equipment Directive

The PED need to know at least the following project design factors:

PS: Safety Pressure rating
DN: Diameter Nominal
V : Volume of equipment
G : Group of danger fluid

Example to PED classification for Piping:



PED classification not required for these applications:

- if piping DN is lower 25 as: pneumatic connections, on line valves and flow measurement, etc.
- if the nominal pressure of vessel (or instrument) is lower 200 bar with volume (capacity) lower 1 litre
- if the instrument haven't proper volume, as in case of: thermowell, vibrating or sonic level switches, etc.

9. PHYSICAL MEASUREMENT

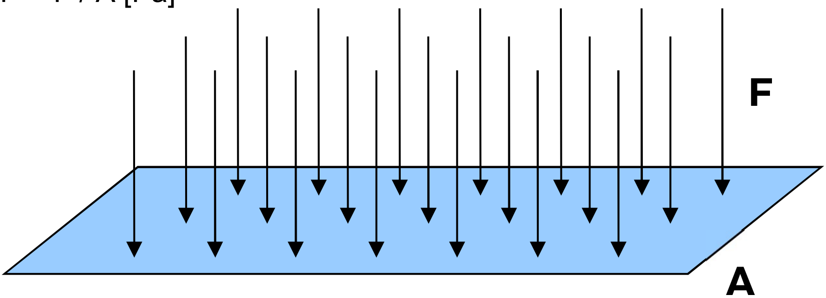
This chapter describes the main physical measurement and they related indicator and transmitters for:

- Pressure
- Flow
- Level
- Temperature
- Humidity
- Viscosity
- Density
- Mass

9.1. PRESSURE

The pressure P is defined by the ratio between the force F acting orthogonally on a surface and the area A of the surface itself, through the following relation:

P = F / A [Pa]

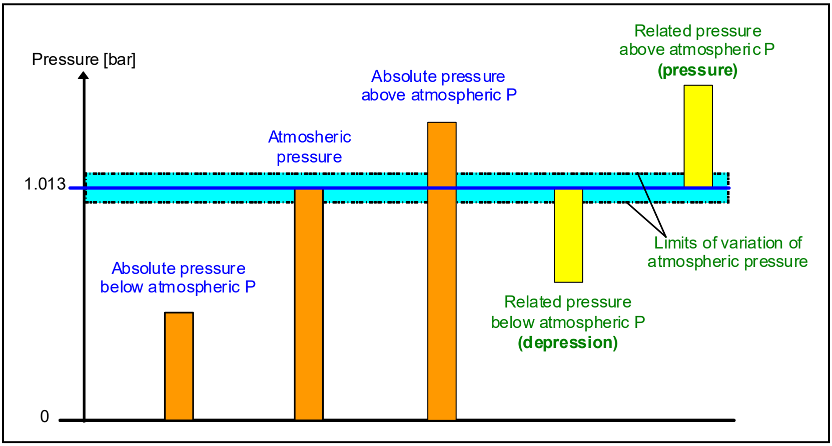


Measurement Conversion Table

Unità SI e derivate — Altre unità

bar	mbar	N/m² Pa	kN/m² kPa	mmHg (0 °C) Torr	mH_2O (4 °C)	kg/cm² at (*)	Inch Hg (0 °C)	Inch H_2O (4 °C)	psi lbf/in² (**)	atm (standard)
1	1000	$1 \cdot 10^{5}$	100	750,062	10,1972	1,01972	29,530	401,463	14,5038	0,986923
$1 \cdot 10^{-3}$	1	100	0,100	0,750062	$1{,}01972 \cdot 10^{-2}$	$1{,}01972 \cdot 10^{-3}$	0,029530	0,401463	0,014504	$9{,}86923 \cdot 10^{-4}$
$1 \cdot 10^{-5}$	$1 \cdot 10^{-2}$	1	$1 \cdot 10^{-3}$	$7{,}501 \cdot 10^{-3}$	$1{,}01972 \cdot 10^{-4}$	$1{,}01972 \cdot 10^{-5}$	$2{,}953 \cdot 10^{-4}$	$4{,}015 \cdot 10^{-3}$	$1{,}45038 \cdot 10^{-4}$	$9{,}86923 \cdot 10^{-6}$
$1 \cdot 10^{-2}$	10	1000	1	7,501	0,10197	0,010197	0,2953	4,015	0,145038	$9{,}86923 \cdot 10^{-3}$
$1{,}33322 \; 10^{-3}$	1,33322	133,322	0,133322	1	$1{,}35951 \cdot 10^{-2}$	$1{,}35951 \cdot 10^{-3}$	0,039370	0,535240	0,019337	$1{,}31579 \cdot 10^{-3}$
0,098067	98,0665	$9{,}80665 \cdot 10^{3}$	9,80665	73,5559	1	0,1	2,8959	39,3701	1,42233	0,096784
0,980665	980,665	$9{,}80665 \cdot 10^{4}$	98,0665	735,559	10	1	28,959	393,701	14,2233	0,967841
0,033864	33,8639	3386,39	3,38639	25,4	0,345316	0,034532	1	13,5951	0,491154	0,033421
$2{,}49089 \cdot 10^{-3}$	2,49089	249,089	0,249089	1,86832	$2{,}540 \cdot 10^{-2}$	$2{,}540 \cdot 10^{-3}$	0,073556	1	0,03613	$2{,}458 \cdot 10^{-3}$
0,06895	68,9476	6894,76	6,89476	51,7149	0,70307	0,070307	2,03602	27,68	1	0,068046
1,01325	1013,25	$1{,}01325 \cdot 10^{5}$	$1{,}01325 \cdot 10^{2}$	760	10,3323	1,03323	29,921	406,78	14,6959	1

Concept related to the pressure measurement



Measuring range for dial manometer (EN 837)

INSTRUMENT	MEASURING RANGES (1)			
Manometers or Pressure gauges	Measuring ranges in bar (2)			
	0 ÷ 0,6			
	0 ÷ 1	0 ÷ 10	0 ÷ 100	0 ÷ 1000
	0 ÷ 1,6	0 ÷ 16	0 ÷ 160	0 ÷ 1600
	0 ÷ 2,5	0 ÷ 25	0 ÷ 250	
	0 ÷ 4	0 ÷ 40	0 ÷ 400	
	0 ÷ 6	0 ÷ 60	0 ÷ 600	
	Measuring ranger in mbar (3)			
	0 ÷ 1	0 ÷ 10	0 ÷ 100	
	0 ÷ 1,6	0 ÷ 16	0 ÷ 160	
	0 ÷ 2,5	0 ÷ 25	0 ÷ 250	
	0 ÷ 4	0 ÷ 40	0 ÷ 400	
	0 ÷ 6	0 ÷ 60	0 ÷ 600	
Vacuum gauges	Measuring ranges in bar			
	-0,6 ÷ 0	-1 ÷ 0		
	Measuring ranges in mbar (3)			
	-1 ÷ 0	-10 ÷ 0	-100 ÷ 0	
	-1,6 ÷ 0	-16 ÷ 0	-160 ÷ 0	
	-2,5 ÷ 0	-25 ÷ 0	-250 ÷ 0	
	-4 ÷ 0	-40 ÷ 0	-400 ÷ 0	
	-6 ÷ 0	-60 ÷ 0	-600 ÷ 0	
Pressure and vacuum gauges	Measuring ranges in bar			
	-1 ÷ +0,6	-1 ÷ +3	-1 ÷ + 9	-1 ÷ +24
	-1 ÷ +1,5	-1 ÷ +5	-1 ÷ +15	

9.2. FLOW

Units of Measurement and Definitions

The flow rate expresses the quantity of fluid (liquid or gas or steam) passing through a section (closed or opened) in the unit time. It can be expressed in terms of volume (by volume) or in terms of weight (by mass).

Volumic Flow (Qv):

$Qv = A \cdot V$ [m^3/s]

where

A = area of the flowing section [m^2]

V = average velocity of the flowing fluid [m/s]

Mass Flow (Qm):

$Qm = A \cdot V \cdot \rho$ [kg/s]

where

ρ = volumic mass of the flowing fluid (or density) [kg/m^3]

Table 1. Conversions per Unit of Measurement for Volumic Flow

	Liters per second l/s	Liters per minute l/min	Cubic meter per hour m^3/h	Cubic feet per hour ft^3/h	Cubic feet per minute ft^3/min	U.K. gallons per minute U.K. gal/min	U.S. gallons per minute U.S. gal/min	U.S. barrels per day U.S. barrel/d
l/s	1	60	3.6	127.1	2.119	13.2	15.85	543.4
l/min	0.0166	1	0.06	2.119	0.03532	0.22	0.2642	9.057
m^3/h	0.2778	16.66	1	35.31	0.5886	3.666	4.403	150.9
ft^3/h	0.007865	0.4719	0.02832	1	0.01666	0.1038	0.1247	4.275
ft^3/min	0.4719	28.32	1.699	60	1	6.229	7.481	256.5
U.K. gal/min	0.07577	4.546	0.2727	9.633	0.1606	1	1.201	41.17
U.S. gal/min	0.06309	3.785	0.2271	8.021	0.1337	0.8327	1	34.29
U.S. barrel/d	0.00184	0.1104	0.006624	0.2339	0.003899	0.02428	0.02971	1

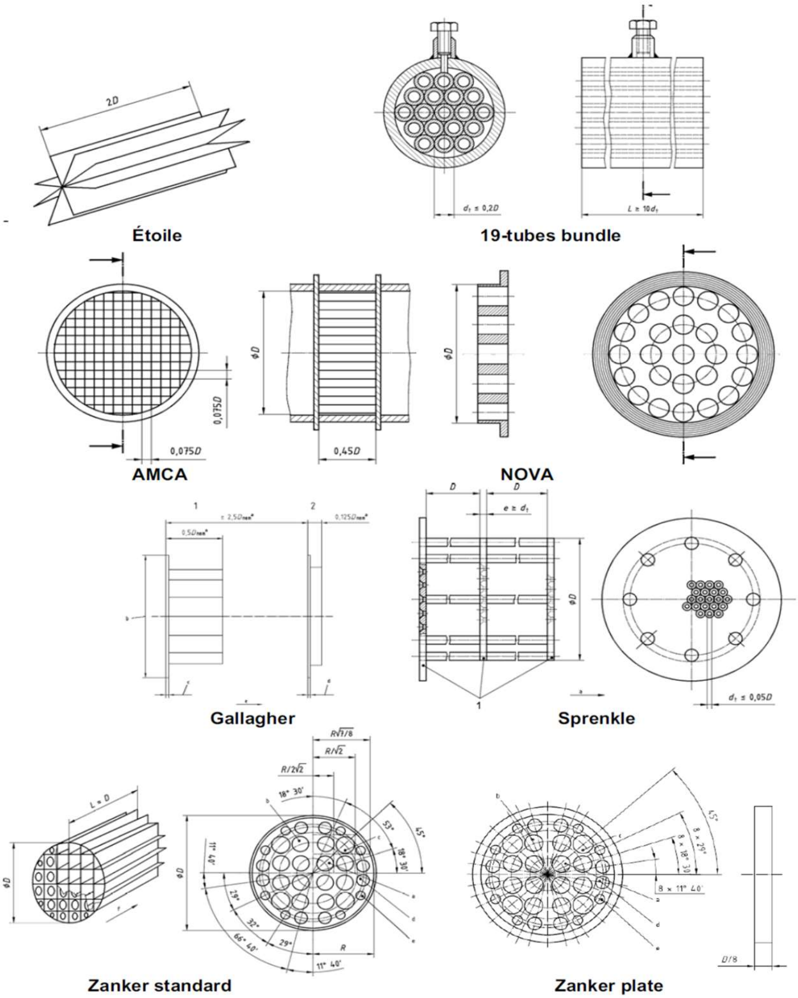
Table 2. Conversions per Unit of Measurement for Mass Flow

	Kilograms per second kg/s	Kilograms per minute kg/min	Kilograms per hour kg/h	Pounds per second lb/s	Pounds per minute lb/min	Pounds per hour lb/h	Short ton per hour S ton/h	Long ton per hour L ton/h
kg/s	1	60	3600	2.205	132.3	7937	3.968	3.543
kg/min	0.01666	1	60	0.03675	2.205	132.3	0.06613	0.05905
kg/h	0.0002778	0.01666	1	0.0006124	0.03674	2.205	0.001102	0.0009842
lb/s	0.4536	27.22	1633	1	60	3600	1.8	1.607
lb/min	0.00756	0.4536	27.22	0.01666	1	60	0.03	0.02679
lb/h	0.000126	0.00756	0.4536	0.0002778	0.01666	1	0.0005197	0.0004464
S ton/h	0.252	15.12	907.1	0.5555	33.33	2000	1	0.8929
L ton/h	0.2822	16.93	1016	0.6222	37.33	2240	1.12	1

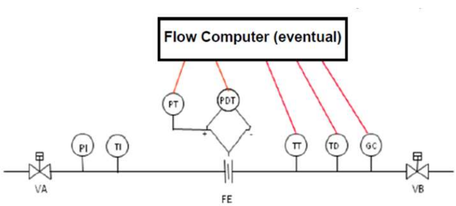
The main flowmeter and related standard are the following:

- Orifice : ISO 5167
- Magnetic :ISO 7817
- Vortex :ISO 12764
- Turbines :ISO 9951
- Volumics :EN 12480
- Sonics :ISO 17089
- Massics :ISO 10790
- Thermal :ISO14511

Main flow straightener for fiscal measurement



Typical fiscal measurement with Orifice plate

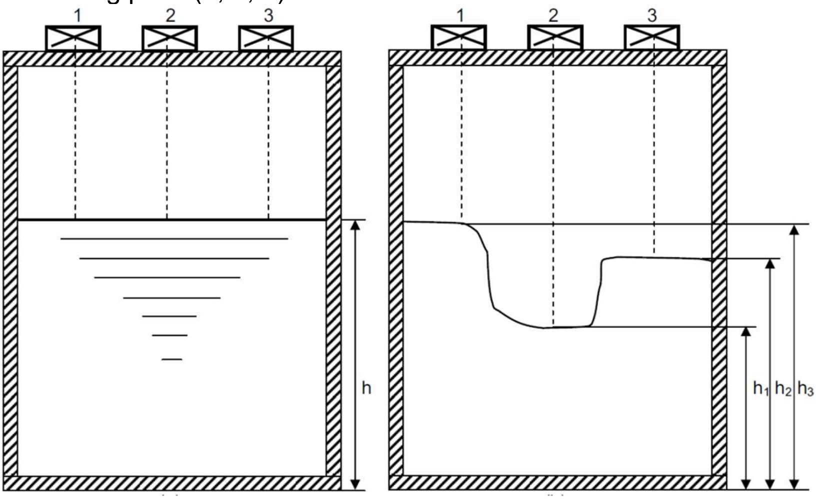


FC	: Flow Computer (eventual)
FE	: Flow Element (orifice plate)
GC	: Gas Chromatograph (eventual)
PT	: Pressure Transmitter
PDT(FT)	: Pressure Differential Transmitter
TD	: Densimeter (eventual)
TT	: Temperature Transmitter
PI, TI	: Pressure and Temperature Indicators
VA, VB	: Shut Valve, upstream & downstream

9.3. LEVEL

The level of liquid and solid products (such as: powders, mixtures, granules, etc.), in containers (such as tanks, silos, vessels, etc.), is measured in height in meters.

In the case of liquids, the level or height measurements is always the effective real average height of the liquid content, while in the case of solids, the level or height measured, is the punctual real actual height of the solid content, height which is a function substantially of the measuring point (1, 2, 3).



The main levelmeter are the following:

- Visual
- Mechanical
- Floating
- Taste
- Pressure
- Resistance
- Capacitance
- Conductance
- Sonic
- Optical
- Radar
- Nuclear
- Rotation
- Vibrating
- Etc.

9.4. TEMPERATURE

Units of Measurement and Definitions

The kelvin is the fraction 1/273.16 of the temperature interval from the triple point of water to absolute zero, and can be formulated as follows:

1 K = 1/273.16 Thermodynamic temperature of the triple point of water

For conversion to other units still in use and for the evolution of the temperature scale, see table 1 and table 2. (Please note that for temperature intervals, the kelvin K corresponds to the °C.)

Table 1. Conversion for Temperature Measurement Units

Temperature	t_C	t_K	t_F	t_R
t_C	1	$t_K - 273.15$	$5/9\ (t_F - 32)$	$5/9\ t_R - 273.15$
t_K	$t_C + 273.15$	1	$5/9\ t_F + 255.37$	$5/9\ t_R$
t_F	$9/5\ t_C + 32$	$9/5\ t_K - 459.67$	1	$t_R - 459.67$
t_R	$9/5\ t_C + 491.67$	$9/5\ t_K$	$t_F + 459.67$	1

Table 2. Fixed Points of the International Temperature Scales

Substance		Fixed Points (@ 101325 Pa)	IPTS 68		ITS 90	
Element	Symbol		(K)	(°C)	(K)	(°C)
Hydrogen	H_2	Triple point	13.81	-259.34	13.803	-259.347
Hydrogen	H_2	Liquefaction point	17.042	-256.108	17.036	-256.114
Hydrogen	H_2	Boiling point	20.282	-252.868	20.271	-252.879
Neon	Ne	Triple point	(1)	(1)	24.556	-248.594
Neon	Ne	Boiling point	27.102	-246.048	(1)	(1)
Oxygen	O_2	Triple point	54.361	-218.789	54.358	-218.792
Oxygen	O_2	Boiling point	90.188	-182.962	(1)	(1)
Argon	Ar	Triple point	(1)	(1)	83.806	-189.344
Mercury	Hg	Triple point	(1)	(1)	234.316	-38.834
Water	H_2O	Fusion point	273.15	0	273.15	0
Water	H_2O	Triple point	273.16	0.01	273.16	0.01
Gallium	Ga	Fusion point	(1)	(1)	302.915	29.765
Water (2)	H_2O	Boiling point	373,15	100	373.124	99.974
Indium	In	Fusion point	(1)	(1)	426.749	156.599
Tin	Sn	Solidification point	505.118	231.968	505.078	231.928
Zinc	Zn	Solidification point	692.73	419.58	692.677	419.527
Antimony (2)	Sb	Solidification point	903.89	630.74	(1)	(1)
Aluminum	Al	Solidification point	(1)	(1)	933.473	660.323
Silver	Ag	Solidification point	1235.93	961.93	1234.93	961.78
Gold	Au	Solidification point	1337.58	1064.43	1337.33	1064.18
Copper	Cu	Solidification point	(1)	(1)	1357.77	1084.62

Table 3. Temperature Limits and Interpolating Polynomials for Normalized Resistance Thermometers

Material Type	Temperature Limits (°C)	Temperature Coefficient (/°C)	Interpolating Polynomial (3) $Rt = Ro\ (1 + A{*}t + B{*}t^2 + C{*}t^3)$ (Ω)
Platinum (1)	– 200 / +850	$3.85 * 10^{-3}$	$A = 3.9083 \cdot 10^{-3}$ $B = -5.7750 \cdot 10^{-7}$ $C = -4.1830 \cdot 10^{-12}$ (4)
Nickel (2)	– 60 / +180	$6.17 * 10^{-3}$	$A = 5.485 \cdot 10^{-3}$ $B = 6.650 \cdot 10^{-6}$ $C = 2.805 \cdot 10^{-11}$
Copper (2)	– 180 / +200	$4.26 * 10^{-3}$	$A = 4.260 \cdot 10^{-3}$

Table 4. Temperature Ranges and Tolerance Classes of Standardized Resistance Thermometers (Thermoresistances)

Thermoresistance Type (0)	Commercial Denomination (4)	Tolerance Classes	Temperature Ranges (°C)	Tolerance Values (°C)
Platinum – Pt (1)	PRT	AA A B C	– 50 / + 250 – 100 / + 450 – 200 / + 600 – 200 / + 600	$\pm (0.10°C + 1.7 \cdot 10^{-3}\ \|t\|)$ (3) $\pm (0.15°C + 2.0 \cdot 10^{-3}\ \|t\|)$ (3) $\pm (0.30°C + 5.0 \cdot 10^{-3}\ \|t\|)$ (3) $\pm (0.60°C + 10.0 \cdot 10^{-3}\ \|t\|)$ (3)
Nickel – Ni (2)	NRT	C C	0 / + 180 – 60 / 0	$\pm (0.20°C + 8.0 \cdot 10^{-3}\ \|t\|)$ (3) $\pm (0.20°C + 16.5 \cdot 10^{-3}\ \|t\|)$ (3)
Copper – Cu (2)	CRT	B C	–50 / + 200 –50 / + 200	$\pm (0.25°C + 3.5 \cdot 10^{-3}\ \|t\|)$ (3) $\pm (0.50°C + 6.5 \cdot 10^{-3}\ \|t\|)$ (3)

Table 6. Temperature Limits of Standardized Thermocouples (IEC 60584-1)

Thermocouple Type (1)	Thermocouple Materials		Temperature Range	Commercial Denomination (2)
	Positive Conductor	Negative Conductor		
T	Copper	Copper – Nickel	– 270 / 400	Copper Constantan
E	Nickel – Chromium	Copper – Nickel	– 270 / 1000	Chromel Constantan
J	Iron	Copper – Nickel	– 210 / 1200	Iron Constantan
K	Nickel – Chromium	Nickel – Aluminum	– 270 / 1300	Chromel Alumel
N	Nickel – Cr – Si	Nickel – Silicon	– 270 / 1300	Nicrosil Nisil
S	Platinum – 10% Rh	Platinum	– 50 / 1760	
R	Platinum – 13% Rh	Platinum	– 50 / 1760	
B	Platinum – 30% Rh	Platinum – 6% Rhodium	0 / 1820	
C	Tungsten – 5% Re	Tungsten – 26% Rhenium	0 / 2315	
A	Tungsten – 5% Re	Tungsten – 20% Rhenium	0 / 2500	

(1) Thermocouples in pure metals (IEC 62460) have no identifying letter, but rather the component metals symbols
(2) The Copper-Nickel alloy is commonly called Constantan

Table 7. Tolerance Classes of Standardized Thermocouples (IEC 60584-2)

Thermocouple Type	Thermocouple Materials		Tolerance Classes (1)	
	Positive Conductor	Negative Conductor	1	2
T	Copper	Copper – Nickel	0.5°C or 0.4%	1.0°C or 0.75%
E	Nickel – Chromium	Copper – Nickel	1.5°C or 0.4%	2.5°C or 0.75%
J	Iron	Copper – Nickel	1.5°C or 0.4%	2.5°C or 0.75%
K	Nickel – Chromium	Nickel – Aluminum	1.5°C or 0.4%	2.5°C or 0.75%
N	Nickel – Cr – Si	Nickel – Silicon	1.5°C or 0.4%	2.5°C or 0.75%
S	Platinum – 10% Rh	Platinum	1.0°C or 0.2%	1.5°C or 0.25%
R	Platinum – 13% Rh	Platinum	1.0°C or 0.2%	1.5°C or 0.25%
B	Platinum – 30% Rh	Platinum – 6% Rhodium	(2)	1[illegible] or 0.25%
C	Tungsten – 5% Re	Tungsten – 26% Rhenium	(2)	1.0% > 425°C
A	Tungsten – 5% Re	Tungsten – 20% Rhenium	(2)	1.0% > 1000°C

(1) Tolerance values are always worth the greater value.
(2) For types A, B, C, the Tolerance Class 1 is not foreseen.

Table 8. Tolerance Classes of Extension (X) and Compensation (C) Cables for Thermocouples (IEC 60584-3)

Cable Type	Cable Symbol	Tolerance Classes		Cable Temperature Range	Measure Junction Temperature
		1	2		
EXTENSION (1)	TX	± 30 µV (0.5°C)	± 60 µV(1.0°C)	– 25°C / +100°C	300°C
	EX	± 120µV (1.5°C)	± 200 µV(2.5°C)	– 25°C / +200°C	500°C
	JX	± 85µV (1.5°C)	± 140 µV(2.5°C)	– 25°C / +200°C	500°C
	KX	± 60µV (1.5°C)	± 100 µV(2.5°C)	– 25°C / +200°C	900°C
	NX	± 60µV (1.5°C)	± 100 µV(2.5°C)	– 25°C / +200°C	900°C
COMPENSATION (2)	NC	–	± 100 µV(2.5°C)	0°C / +150°C	900°C
	KCA	–	± 100 µV(2.5°C)	0°C / +150°C	900°C
	KCB	–	± 100 µV(2.5°C)	0°C / +100°C	900°C
	RCA/SCA	–	± 30 µV (2.5°C)	0°C / +100°C	1000°C
	RCB/SCB	–	± 60 µV (5.0°C)	0°C / +200°C	1000°C

(1) The extension cable is of the same constituents as the thermocouple materials, used for common thermocouples: T, E, J, K, N.
(2) The compensation cable is made of other materials than those constituting the thermocouple, used for precious thermocouples: R, S, B (for the latter, they are usually used for normal copper cables with typical maximum error of 3.5° C).

9.5. HUMIDITY

Units of Measurement and Definitions

The humidity is a quantity generated by the presence of water vapor in the atmosphere, or in gases, liquids, and solids. Among the various definitions relating to humidity, the following are generally used:

Relative Humidity (RH):

The relative humidity is defined by the percentage ratio between the humidity present in a fluid (e.g., air) and what there would be if it were saturated in the same conditions of pressure and temperature.

The relative humidity is therefore the ratio between the water vapor pressure (pv) present in the fluid under normal conditions and what it would be if it were in the saturation conditions (ps). It is given by the following relationship:

RH = pv / ps

Absolute Humidity (AH):

The absolute humidity is defined by the percentage ratio between the quantity of water present in a substance (solid, liquid, or gaseous) and the same amount of dry substance. It can be expressed in different ways:

For large concentrations:

- g/m^3
- g/kg

For small concentrations:

- Parts per million by volume (PPMv)
- Parts per million by mass (PPMm)

Table 2. Comparative Table of Different Humidity Measuring Units in the Air with Approximate Relationships

Frost Point (°C)	Vapor Pressure (mbar)	PPM Volume (PPMv)	PPM Mass (PPMm)	Relative Humidity @ 20°C (%)
0	6.105	6020	3742	26.1
– 2	5.173	5100	3170	22.1
– 4	4.373	4320	2685	18.7
– 6	3.686	3640	2262	15.8
– 8	3.101	3060	1902	13.3
– 10	2.600	2570	1597	11.1
– 12	2.176	2140	1330	9.3
– 14	1.815	1790	1113	7.8
– 16	1.510	1490	926	6.4
– 18	1.252	1230	765	5.3
– 20	1.035	1020	634	4.4
– 22	0.8533	841	523	3.6
– 24	0.7013	691	429	3.0
– 26	0.5733	566	352	2.5
– 28	0.4680	462	287	2.0
– 30	0.3812	376	234	1.6
– 32	0.3090	340	211	1.3
– 34	0.2497	246	153	1.1
– 36	0.2009	198	123	0.8
– 38	0.1612	159	98.8	0.6
– 40	0.1288	127	78.9	0.5
– 42	0.1024	101	62.8	0.4
– 44	0.08919	80.1	49.8	0.3
– 46	0.06413	63.2	39.3	0.3
– 48	0.05040	49.7	30.9	0.2
– 50	0.03933	39.4	24.5	0.2
– 52	0.03066	31.1	19.3	0.1
– 54	0.02373	23.4	14.5	0.1
– 56	0.01840	18.3	11.4	0.08
– 58	0.01413	14.1	8.76	0.06
– 60	0.01077	10.6	6.59	0.04
– 62	0.008186	8.07	5.02	0.03
– 64	0.006186	6.11	3.80	0.02
– 66	0.004653	4.61	2.87	0.02
– 68	0.003479	3.44	2.14	0.01
– 70	0.002586	2.55	1.58	0.01
– 72	0.001907	1.88	1.17	0.008
– 74	0.001399	1.38	0.858	0.006
– 76	0.001027	1.01	0.628	0.004
– 78	0.000747	0.747	0.464	0.003
– 80	0.000533	0.526	0.327	0.002
– 82	0.000387	0.382	0.237	0.002
– 84	0.000267	0.263	0.163	0.001
– 86	0.000187	0.184	0.114	0.0008
– 88	0.000133	0.134	0.0833	0.0006
– 90	0.000093	0.0923	0.0574	0.0004
– 92	0.000064	0.0632	0.0393	0.0003
– 94	0.000044	0.0434	0.0270	0.0002
– 96	0.000029	0.0291	0.0181	0.0001
– 98	0.000021	0.0197	0.0122	0.00008
– 100	0.000013	0.0131	0.0081	0.00005

9.6. VISCOSITY

Units of Measurement and Definitions

The units of measurement used in the International System (SI) for liquids and gases are the following:

For the Kinematic Viscosity ν:

The unit is the square millimeter per second (mm^2/s), equivalent to centistokes (cSt) of the centimeter – gram – second (CGS) measuring system:

1 mm^2/s = 1 cSt (for other correspondences, see table 1)

For the Dynamic Viscosity η:

The unit is millipascal per second (mPa · s), equivalent to centipoise (cP) of the measuring system CGS:

1 mPa · s = 1 cP (for other correspondences see table 2)

Table 1. Correspondence of Units of Measurement of Kinematic Viscosity

	m^2/s	mm^2/s	St	cSt	ft^2/s
m^2/s	1	10^6	10^4	10^6	10.76
mm^2/s	10^{-6}	1	10^{-2}	1	0.00001076
St	10^{-4}	10^2	1	10^2	0.001076
cSt	10^{-6}	1	10^{-2}	1	0.00001076
ft^2/s	0.0929	92900	929	92900	1

Table 2. Correspondence of Units of Measurement of Dynamic Viscosity

	Pa · s	mPa · s	P	cP	lb / ft · s
Pa · s	1	10^3	10^1	10^3	0.672
mP · s	10^{-3}	1	10^{-2}	1	0.000672
P	10^{-1}	10^2	1	10^2	0.0672
cP	10^{-3}	1	10^{-2}	1	0.000672
lb / ft · s	1.488	1488	14.88	1488	1

The viscosity of water at 20°C has the following singularities:

- Kinematic viscosity at 20°C ≡ 1 mm^2/s (or 1 cSt)
- Dynamic viscosity at 20°C ≡ 1 mPa · s (or 1 cP)

This is given that the density of water in these conditions is typically equivalent to 1000 kg/m^3.

The viscosity of the liquids can be detected by a viscometer's calibrated orifice, such as:

- Engler viscometer: The relationship between the time taken by 200 cm^3 of the measured liquid at the temperature 20°C to flow from a calibrated hole, and the time taken by an equal volume of water at the same temperature. The viscosity is expressed in degrees Engler (°E) of measured liquid.
- Saybolt viscometer: It measures the time in seconds until 60 cm^3 of the measured liquid flows from a calibrated orifice, and the resulting viscosity is expressed in Seconds Saybolt Universal (SSU), or in Seconds Saybolt Furol (SSF), as a function of the select orifice.
- Redwood viscometer: It measures the time in seconds it takes for 50 cm^3 of the measured liquid to flow from a calibrated orifice, and the resulting viscosity is expressed in Seconds Redwood Number 1 (SR N. 1), or in Seconds Redwood Number 2 (SR N. 2), as a function of the orifice used.

9.7. DENSITY

Units of Measurement and Definitions

The units of measurement of density, or volumic mass, used in the International System (SI) is kg/m^3. For the relationship with other units, see table 0.

Table 0. Conversion for Density or Volumic Mass Measurement Units (*)

	kg/l (*)	kg/m^3	lb/ft^3	lb/in^3
kg/l (*)	1	1000	62.43	0.03613
kg/m^3	0.001	1	0.06243	0.00003613
lb/ft^3	0.01602	16.02	1	0.0005787
lb/in^3	27.68	27680	1728	1

(*) kg/l ≡ g/ml ≡ g/cm^3 ≡ kg/dm^3 ≡ Mg/m^3 ≡ t/m^3

The density, which is more properly called *volumic mass*, is indicated as ρ if it is absolute or ρr if it is relative to water for liquid or air for the gas. It is commonly determined or calculated on the following conditions:

- Normal at 0°C and 101325 Pa
- Standard at 15°C and 101325 *Pa*

The standard terms in the English system of units are slightly different, namely:

- Standard at 60°F (15.6°C) and 14.69565 psia (101325 *Pa*)

Or with a slightly higher temperature, the resulting values of densities are then a slightly lower reference (given the expansion in temperature of liquids and gases).

Before reporting the calibration procedures of density meters, otherwise called densimeters, first the following topics will be presented:

- measures of liquids (water and other common)
- measures of gases (air and other common gases)

Table 6. Air Density in kg/m^3 as a Function of Temperature *t* (°C) and Relative Humidity (%)

t	Relative Humidity (%)											t
(°C)	0	10	20	30	40	50	60	70	80	90	100	(°C)
0	1.293	1.293	1.293	1.292	1.292	1.292	1.292	1.292	1.291	1.291	1.291	0
5	1.270	1.270	1.269	1.269	1.269	1.268	1.268	1.268	1.268	1.267	1.267	5
10	1.248	1.247	1.247	1.246	1.246	1.245	1.244	1.244	1.243	1.243	1.242	10
15	1.226	1.225	1.225	1.224	1.223	1.222	1.222	1.221	1.220	1.220	1.219	15
20	1.205	1.204	1.203	1.202	1.201	1.199	1.198	1.197	1.196	1.195	1.194	20
25	1.185	1.184	1.182	1.181	1.179	1.178	1.177	1.175	1.174	1.172	1.171	25
30	1.165	1.163	1.161	1.160	1.158	1.156	1.154	1.152	1.151	1.149	1.147	30
35	1.146	1.143	1.141	1.138	1.136	1.133	1.131	1.128	1.126	1.123	1.121	35
40	1.128	1.125	1.122	1.119	1.116	1.113	1.110	1.107	1.104	1.101	1.098	40
45	1.110	1.106	1.102	1.098	1.094	1.090	1.086	1.082	1.078	1.074	1.070	45
50	1.093	1.088	1.083	1.078	1.073	1.068	1.063	1.058	1.053	1.048	1.043	50
55	1.076	1.070	1.064	1.058	1.052	1.045	1.039	1.033	1.027	1.021	1.015	55
60	1.060	1.052	1.044	1.037	1.029	1.021	1.013	1.005	0.998	0.990	0.982	60
65	1.044	1.034	1.025	1.015	1.006	0.996	0.986	0.977	0.967	0.958	0.948	65
70	1.029	1.017	1.005	0.994	0.982	0.970	0.958	0.946	0.935	0.923	0.911	70
75	1.014	1.000	0.985	0.971	0.957	0.942	0.928	0.914	0.900	0.885	0.871	75
80	1.000	0.983	0.965	0.948	0.930	0.913	0.896	0.878	0.861	0.843	0.826	80
85	0.986	0.965	0.944	0.923	0.903	0.882	0.861	0.840	0.820	0.799	0.778	85
90	0.973	0.948	0.923	0.898	0.873	0.848	0.824	0.799	0.774	0.749	0.724	90
95	0.959	0.929	0.900	0.870	0.841	0.811	0.782	0.752	0.723	0.693	0.664	95
100	0.947	0.912	0.878	0.843	0.808	0.773	0.738	0.703	0.669	0.634	0.599	100

9.8. MASS

Units of Measurement and Definitions

The unit of mass in the International System of units is the kg, which is equivalent to the mass of 1 dm^3 of distilled water at 4°C. For the correspondence with other units, see table 1.

Table 1. Conversions of Mass Units

	Ounce oz	Pound lb	Short Ton S ton	Long Ton L ton	Kilogram kg	Tonne t (*)
oz	1	0.0625	0.00003125	0.0000279	0.02835	0.00002835
lb	16	1	0.0005	0.0004464	0.4536	0.0004536
S ton	32000	2000	1	0.8929	907.2	0.9072
L ton	35840	2240	1.12	1	1.016	1.016
kg	35.27	2.205	0.001102	0.0009842	1	0.001
t (*)	35270	2205	1.102	0.9842	1000	1

(*) Tonne (t) = Megagram (Mg)

The mass may sometimes also be detected as a weight force, by means of the following relationship:

$F = m \cdot a$

where

F	=	weight force (gravitational) exerted by the mass	[N]
m	=	mass	[kg]
a	=	local gravitational acceleration	[m/s^2]

The weight force (gravitational) is thus directly proportional to the mass of the body or of the product, but also depends on local gravitational acceleration, whose value may differ from the standard gravitational acceleration gs, equivalent to:

$gs = 9.80665\ m/s^2$

Table 2. Acceleration of Gravity (m/s^2) as a Function of Latitude (in °) at Sea Level

Latitude (°)	0	1	2	3	4	5	6	7	8	9
0	9.78033	9.78037	9.78042	9.78050	9.78061	9.78075	9.78092	9.78112	9.78135	9.78162
10	9.78191	9.78223	9.78258	9.78296	9.78337	9.78381	9.78428	9.78476	9.78528	9.78582
20	9.78638	9.78697	9.78759	9.78822	9.78888	9.78956	9.79026	9.79098	9.79172	9.79247
30	9.79324	9.79403	9.79483	9.79565	9.78648	9.79732	9.79817	9.79904	9.79991	9.80079
40	9.80167	9.80256	9.80346	9.80436	9.80526	9.80616	9.80706	9.80796	9.80886	9.80976
50	9.81065	9.81154	9.81242	9.81329	9.81416	9.81501	9.81586	9.81669	9.81751	9.81831
60	9.81911	9.81988	9.82064	9.82138	9.82210	9.82281	9.82349	9.82415	9.82479	9.82541
70	9.82601	9.82658	9.82712	9.82764	9.82813	9.82860	9.82904	9.82945	9.82983	9.93019
80	9.83051	9.83081	9.83107	9.83131	9.83151	9.83168	9.83183	9.83194	9.83202	9.83206
90	9.83208	.								

Table 3. Classification of the Standards' Nominal Values and Their Tolerances (OIML R 111)

Nominal Value	Tolerance According to Accuracy Class (mg)								
	E_1	E_2	F_1	F_2	M_1	M_{1-2}	M_2	M_{2-3}	M_3
5000 kg			25 000	80 000	250 000	500 000	800 000	1 600 000	2 500 000
2000 kg			10 000	30 000	100 000	200 000	300 000	600 000	1 000 000
1000 kg		1 600	5 000	16 000	50 000	100 000	160 000	300 000	500 000
500 kg		800	2 500	8 000	25 000	50 000	80 000	160 000	250 000
200 kg		300	1 000	3 000	10 000	20 000	30 000	60 000	100 000
100 kg		160	500	1 600	5 000	10 000	16 000	30 000	50 000
50 kg	25	80	250	800	2 500	5 000	8 000	16 000	25 000
20 kg	10	30	100	300	1 000		3 000		10 000
10 kg	5.0	16	50	160	500		1 600		5 000
5 kg	2.5	8.0	25	80	250		800		2 500
2 kg	1.0	3.0	10	30	100		300		1 000
1 kg	0.5	1.6	5.0	16	50		160		500
500 g	0.25	0.8	2.5	8.0	25		80		250
200 g	0.10	0.3	1.0	3.0	10		30		100
100 g	0.05	0.16	0.5	1.6	5.0		16		50
50 g	0.030	0.10	0.30	1.0	3.0		10		30
20 g	0.025	0.080	0.25	0.8	2.5		8.0		25
10 g	0.020	0.060	0.20	0.6	2.0		6.0		20
5 g	0.016	0.050	0.16	0.5	1.6		5.0		16
2 g	0.012	0.040	0.12	0.4	1.2		4.0		12
1 g	0.010	0.030	0.10	0.3	1.0		3.0		10
500 mg	0.008	0.025	0.08	0.25	0.8		2.5		
200 mg	0.006	0.020	0.06	0.20	0.6		2.0		
100 mg	0.005	0.016	0.05	0.16	0.5		1.6		
50 mg	0.004	0.012	0.04	0.12	0.4				
20 mg	0.003	0.010	0.03	0.10	0.3				
10 mg	0.003	0.008	0.025	0.08	0.25				
5 mg	0.003	0.006	0.020	0.06	0.20				
2 mg	0.003	0.006	0.020	0.06	0.20				
1 mg	0.003	0.006	0.020	0.06	0.20				

10. CHEMICAL MEASUREMENTS

This chapter deals with the following chemical measures and their detection:

10.1 Chemical measurements for liquids

10.1.1 pH and Redox

10.1.2 Conductivity

10.1.3 Turbidity

10.1.4 Colorimetry

10.1.5 Dissolved oxygen

10.2 Chemical measurements for gases

10.2.1 Infrared

10.2.2 Ultraviolet

10.2.3 Oxygen

10.2.4 Fuels

10.2.5 Chromatographs

10.2.6 Spectrometers

10.3 Sampling systems

10.3.1 General information

10.3.2 Terminology

10.3.3 Source and sample fluid

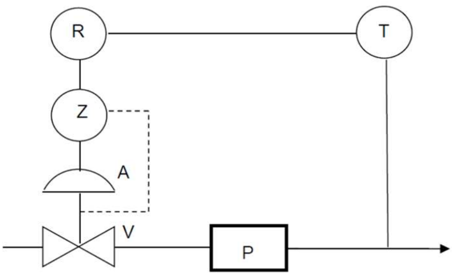
10.3.4 Sampling system

10.2.5 Sampling probes

10.2.6 Application examples

11. CONTROL VALVES

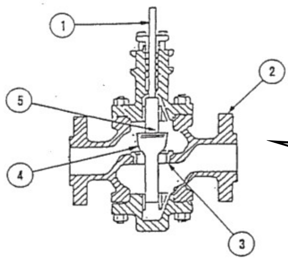
This chapter covers the following topics related to control valves:
11.1 General information
11.2 Terminology
11.3 Construction aspects
11.4 Sizing
11.5 Choice of valves
11.6 Installation of the valves
11.7 Actuators
11.8 Positioners
11.9 Final selection of regulation/control valves
The control valve is a device that changes the flow rate of fluid in a process control system and is operated by an actuator which moves the valve closing member (shutter) in response to a signal of the control system and almost always it is provided with a positioner to guarantee the correct correspondence between the control signal and the valve opening / closing position.



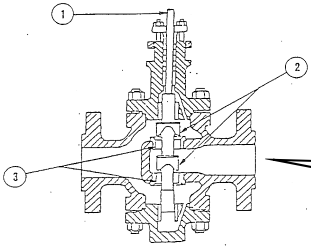
LEGENDA

A Actuator
P Process
R Reg./Controller
T Transmitter
V Valve

Valve Typologies

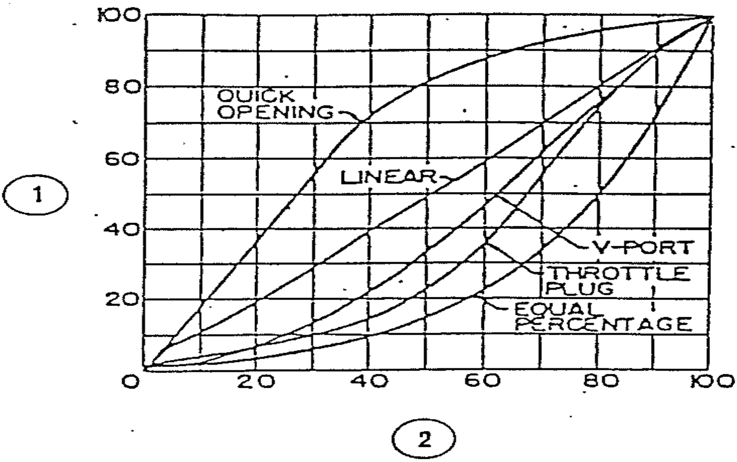


Single seat valve
1 - Stem
2 - Flange
3 - Seat ring
4 - Plug
5 - Guide system



Double seat valve
1 - Stem
2 - Plugs
3 - Seat ring

Flow valve characteristics



Control valve standards

NUMBER	TITLE
IEC 60534	INDUSTRIAL PROCESS CONTROL VALVES
IEC 60534-1	Part 1: Terminology and general considerations
IEC 60534-2	Part 2: Flow capacity
IEC 60534-3	Part 3: Dimensions
IEC 60534-4	Part 4: Inspection and routine testing
IEC 60534-5	Part 5: Marking
IEC 60534-6	Part 6: Mounting of positioners
IEC 60534-7	Part 7: Control valves data sheet
IEC 60534-8	Part 8: Noise considerations

Control valve leakages

Leak Class (1)	Test Fluid	Test Procedure (2)	Leak Maximum	Applicability
I	Liquid or Gas	(3)	(3)	Valves on purchaser specification
II	Liquid or Gas	A	5.10^{-3} Q_{nom}	Valves with double seat
III	Liquid or Gas	A	1.10^{-3} Q_{nom}	Valves butterfly
IV-S1	Liquid or Gas	A o B	1.10^{-4} Q_{nom}	Valves with single seat
IV-S2	Gas	A	2.10^{-2} .ΔP.D (l/h)	As above with more seating force
V	Liquid	B	$1{,}8.10^{-5}$. ΔP.D (l/h)	As above with teflon insert
VI	Gas	A	0,3.ΔP.F (l/h) (4)	As above with soft insert

12. SAFETY DEVICES

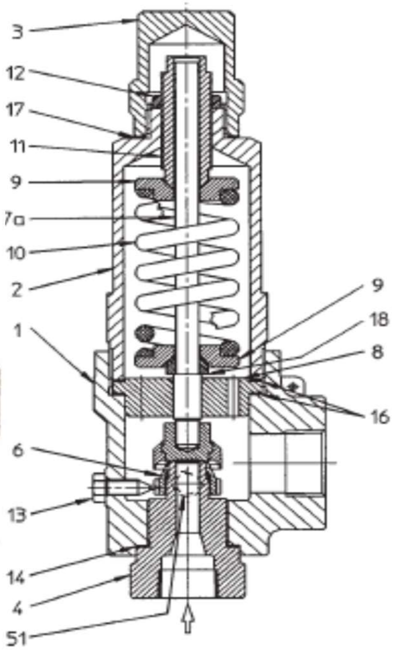
This chapter covers the following security devices:

12.1 Safety valves

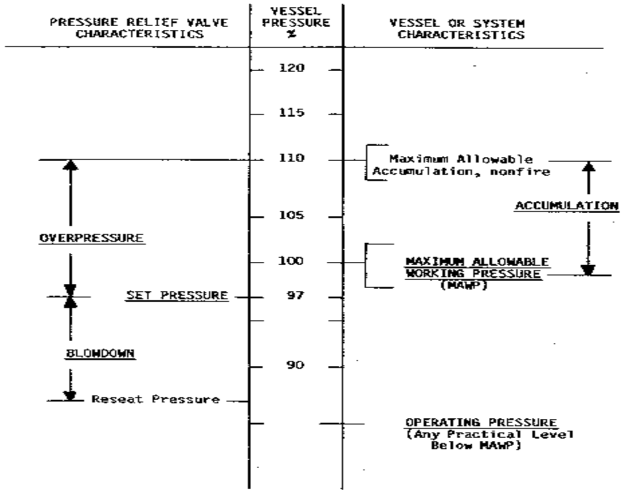
The safety valve is therefore one of the main safety devices used to protect systems and equipment under pressure from excess pressure and / or vacuum.

Its main characteristic is that an auto mechanical device operated by the pressure of the process to be protected that intervenes due to the differential pressure to which it is subjected and then it is self-reclosable when the process pressure falls within its normal operating limits (unlike instead of the rupture disks and venting membranes, which once in place must be substitutes in order to be able to proceed in the normal exercise of the process under consideration).

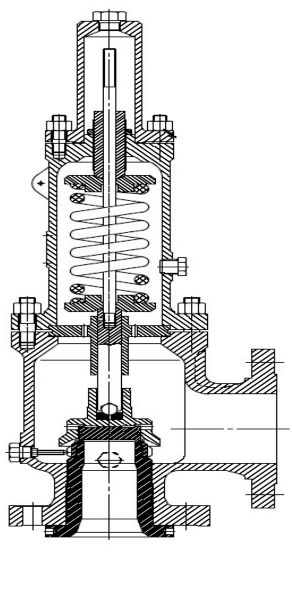
Typically, the safety valve is a device consisting of a process connection, a closing / opening trim, an antagonist closing spring and a discharge connection normally of equal or greater dimensions than the process connection:

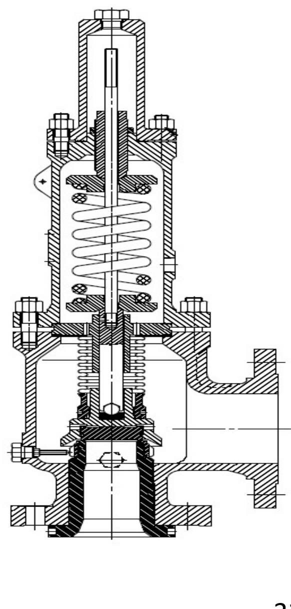


La figure illustrates the normal operating pressure and the maximum allowable working pressure with the possible pressure accumulation before the valve become completely open.



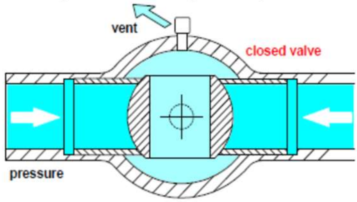
Valves typologies, without bellow and with below, to discharge the fluid respectively in atmosphere and in pressure piping collectors

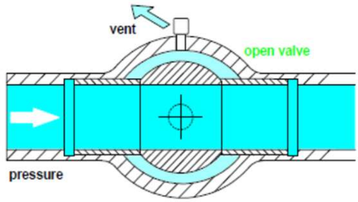




12.2 Blocking valves

Typically used to bring the process in safety conditions, as:
BDV Blow Down Valves
SDV Shut Down Valves





12.3 Controlled systems

Standardized by international Standard ISO 4126-5.

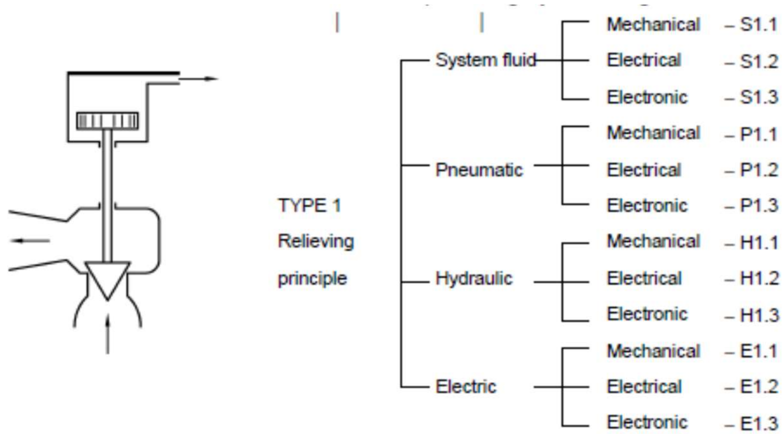


Figure 2 a) — Type 1 : Relieving principle

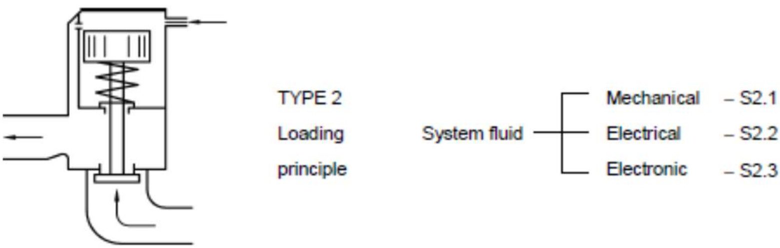


Figure 2 b) — Type 2 : Loading principle

12.4 Rupture discs

Standardized by international Standard ISO 4126-2.

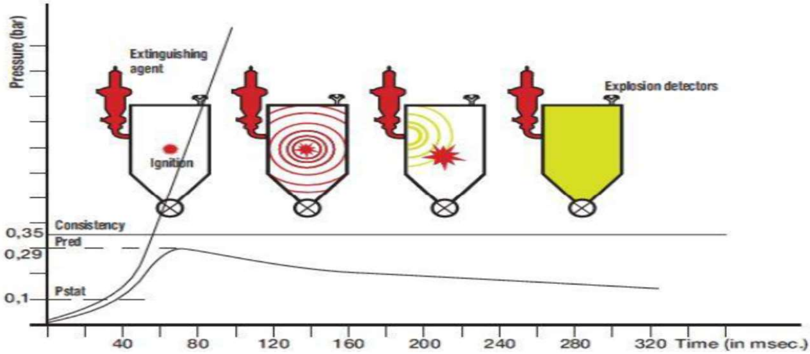
12.5 Venting devices

This point deals with the following arguments concerning the explosion relief devices and the explosion protection systems.

There are different types of reactions that are commonly defined as "explosion" and that create a "deflagration", that is, an explosion that propagates at subsonic speed:

The type of fuel that can ignite in a deflagration includes a wide range of gases, powders or hybrid mixtures that, when triggered in a confined volume, can reach in a few thousandths of a second a dozen or more bars.

Compared to the venting systems, the suppression has the advantage that it can also be adopted for the equipment placed inside buildings since there are no external effects and it must also be considered that, with the suppression of an explosion, the combustion is not total and therefore the internal damages to the equipment are lower and its new start up faster.



13. CONTROL TECNIQUES

This chapter deals with the following control techniques:

13.1 Feedback control

This point deals with the following arguments related to Feedback:
13.1.1 General information
13.1.2 Control loop
13.1.3 Process dynamics
13.1.4 Recognition of processes
13.1.5 Stabilization of processes
13.1.6 The PID controller
13.1.7 Tuning PID controllers
13.1.8 Self-tuning of controllers
13.1.9 Selection of industrial controllers
13.1.10 Examples of industrial controllers

The standard PID control algorithm:

$$o(t) = K_p \left[e(t) + \frac{1}{T_i} \int e(t)dt + T_d \frac{de(t)}{dt} \right]$$

Where:
o   output signal from the controller
e   inut error to the controller
t   time
Kp proportional gain
Ti   interval time
Td derivative time

PID action improve:

ACTION	RAPIDITY	ACCURACY	STABILITY
P	++	+	-
I	-	++	-
D	+	+	++

PID tuning with Ziegler& Nichols rules:

CONTROLLER	Proportional Gain Kp	Integral Time Ti	Derivative Time Td
P	**0.50 Kc**	**-**	**-**
P+I	**0.45 Kc**	**Tc/1.25**	**-**
P+I+D	**0,60 Kc**	**Tc/2**	**Tc/8**

Where:

- Kc is the critical gain
- Tc is the critical time

that are obtained on the process to be checked excluding the I and D actions and increasing the proportional gain until the process reaches the critical conditions of persistent oscillations.

PID selection related to the process:

The primary element to consider in the selection of controller is the variation of the process load which is not always of the linear type:

- If these variations are quite relevant and if you want to achieve a high readiness and stability of the controlled variable, it is advisable to use a self tuning controller.
- In any case, the selection of the controller and related actions, is strictly dependent on the control dynamics of the system being controlled and therefore with the characteristics of the process to be controlled.

The table guides the controller choice of in various applications.

PROCESS CONTROL CHARACTERISTICS	FLOW or Liquid Pressure	Pressure of Gas	Level	Temper.	Reaction or composition
Dead time Constant time Oscillation time Noise presence	negligible little 1 ÷ 10 s often	negligible single 1 ÷ 10 s seldom	negligible single 1 ÷ 30 s often	variable multiple min÷hour seldom	constant multiple min÷hour often
CONTROLLER CHARACTERISTICS					
Proportional Action Kp Integral Action Ti Derivative Action Td	0,1 ÷ 1 necessary inadvisable	10 ÷ 100 unnecessary unnecessary	1 ÷ 10 sometimes inadvisable	1 ÷ 10 necessary necessary	0,1 ÷ 1 necessary possibly

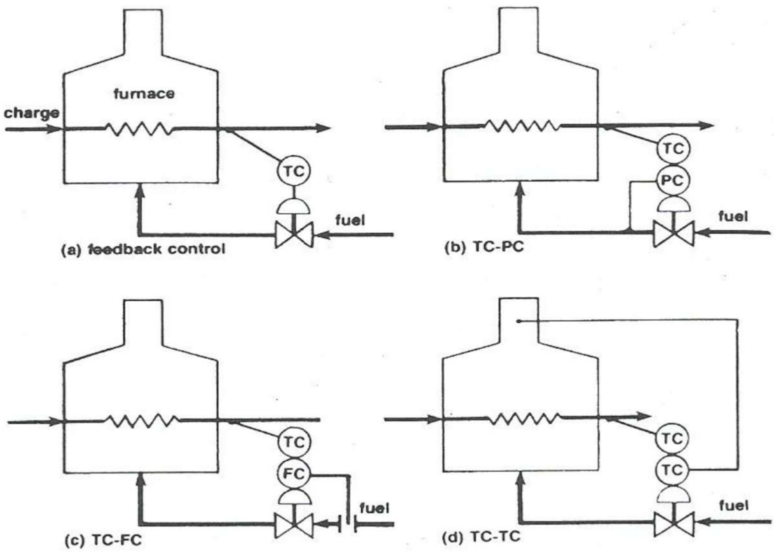
13.2 Special controls

This point deals with the following arguments concerning the special control techniques:

13.2.1 General information
13.2.2 On-Off
13.2.3 Feedforward
13.2.4 Ratio
13.2.5 Cascade
13.2.6 Over_ride
13.2.7 Split_range
13.2.8 Gap_control)
13.2.9 Dead time compensation
13.2.10 Multi variables decoupling

The figure illustrates for example the various types of controls that can be implemented in general on a preheating oven (furnace) in which the charge temperature (charge) at the outlet is controlled by acting on the combustion gas (fuel), through a temperature regulator (TC) and a possible secondary flow, pressure and temperature regulator (respectively FC, PC, TC), that is:

- o Simple feedback adjustment (feedback control):
  Control very susceptible to pressure and fuel flow variations
- o Coordinated cascade adjustment (TC on PC):
  improved control that compensates for variations in fuel pressure
- o Coordinated cascade regulation (TC on FC):
  improvement control that compensates for variations in fuel flow
- o Coordinated cascade regulation (TC on TC):
  improvement that compensates temperature variations of the heater chimney



14. CONTROL SYSTEMS

This chapter covers the following topics related to control systems:

14.1 Distributed Control Systems (DCS)
14.2 Programmable Logic Controllers (PLC)
14.3 Communication Protocols (BUS)

In the context of automation, Distributed Control System (DCS) represent the most adopted solution for large continuous plants: Refineries, energy production plants, paper mills, glassworks, chemical plants, etc.

They perform both functions normally implemented on:

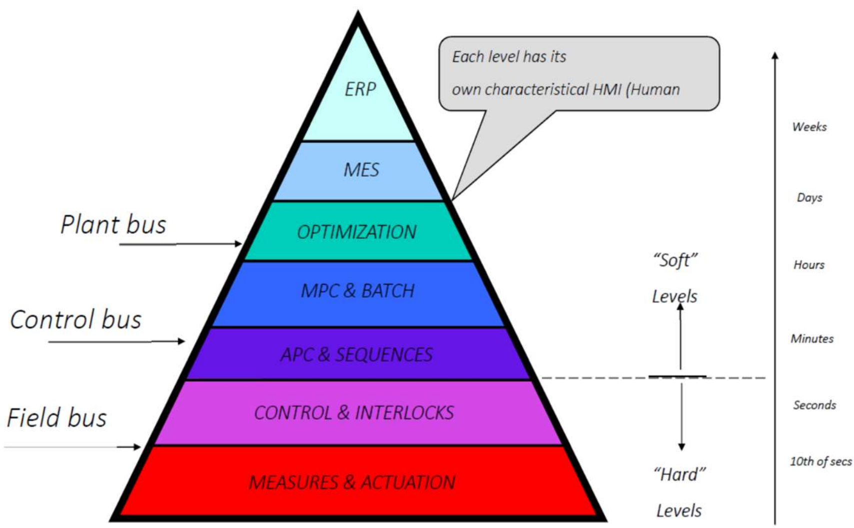
- PLC: Programmable Logic Controller
- SCADA: Supervision Control And Data Acquisition

for this reason they can be placed as shown in figure within the pyramid of the integrated control system:

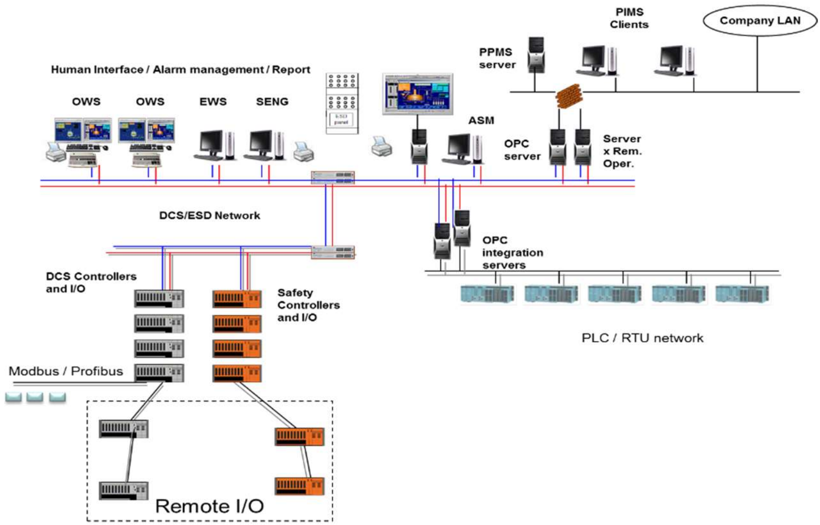
- CIM: Computer Integrated Manufacturing,

who presents production policies at the top:

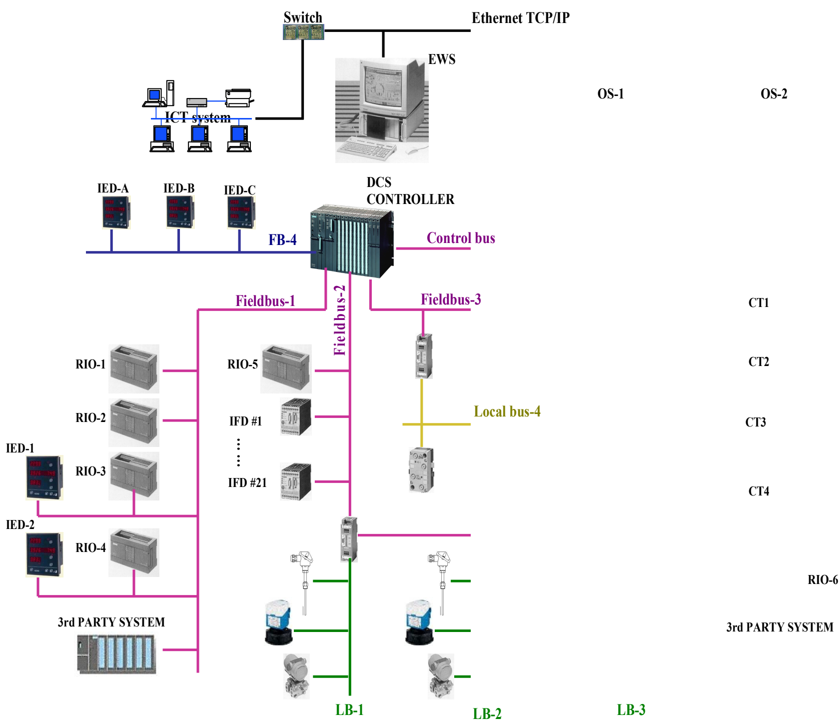
- ERP: Enterprise Resource Planning
- MES: Manufacturing Execution System



Typical DCS Architecture



New DCS Architecture based in Fieldbus and Internet



15. SAFETY SYSTEMS

This last chapter covers the following topics related to security systems:
15.1 Alarm Systems
15.2 Fire & Gas Systems (FGS)
15.3 Emergency Stop Systems (ESD)
15.4 Instrumented Safety Systems (SIS)

The safety in industrial plants is obtained with the subsequent stratification of prevention and protection systems that guarantee in this way, the potential dangers that intervene in case of failure of the systems of the underlying layers (figure):

The prevention systems it based upon these elements:
- Basic Process Control System (BPCS)
- Alarms Operators in case the process escapes the BPCS
- Safety Instrumented System (SIS) in the event that operators are unable to bring the system under control by

The protection systems are typically the following:
- mechanical type, discharge protection (safety valves and others)
- containment type, containment protection (basins and channels)
- organizational type for emergency and evacuation personnel and with Fire & Gas prevention and protection System: FGS).