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.
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GENERAL INFORMATION ON THE INSTRUMENTATION</td>
<td>General information on process measurement and control (standard power supplies, signals and protocols)</td>
</tr>
<tr>
<td>2</td>
<td>SYMBOLOGY OF THE INSTRUMENTATION</td>
<td>Process and instrumentation identification (P&amp;I)</td>
</tr>
<tr>
<td>3</td>
<td>TERMINOLOGY OF THE INSTRUMENTATION</td>
<td>Terms relating to static and dynamic characteristics</td>
</tr>
<tr>
<td>4</td>
<td>CALIBRATION OF INSTRUMENTATION</td>
<td>Measurement uncertainty, calibration and periodic metrological confirmation</td>
</tr>
<tr>
<td>5</td>
<td>OPERATING CONDITIONS</td>
<td>Power supply, temperature, humidity, pressure, electromagnetic interference</td>
</tr>
<tr>
<td>6</td>
<td>PROTECTION OF HOUSINGS</td>
<td>Protection codes against penetration of solid and liquid bodies (IP) and mechanical impacts (IK)</td>
</tr>
<tr>
<td>7</td>
<td>EXPLOSION-PROOF SYSTEMS</td>
<td>Protection modes and security systems (Exd, Exe, Exi, Em, En, Eo; Ep, Eq; Es, etc.)</td>
</tr>
<tr>
<td>8</td>
<td>INSTRUMENTS EUROPEAN DIRECTIVES</td>
<td>ATEX, EMC, LVD, MID, PED</td>
</tr>
</tbody>
</table>
Parte 2^ MEASUREMENT

9  PHYSICAL MEASUREMENT
Pressure, flow, level, temperature, humidity, viscosity, density, mass, etc.

10  CHEMICAL MEASUREMENT
For liquids (pH, conductivity, etc.) and gas (IR, UV, chromatography, spectrography, etc.)

Volume II: CONTROL AND SAFETY

Parte 3^ CONTROLLO E SICUREZZA

11  CONTROL VALVES
Construction features, selection and sizing criteria, actuators and positioners

12  SAFETY DEVICES
Construction features, selection and sizing criteria of safety valves, rupture discs, etc.

13  CONTROL TECHNIQUES
Feedback, feedforward and others special controls; selection criteria and tuning of PID controller (Proportional + Integral + Derivative)

14  CONTROL SYSTEMS
Distributed Control Systems (DCS), Programmable Logic Controllers (PLC) e Fieldbus Communications

15  SAFETY SYSTEMS
Alarm Systems, Fire&Gas Systems, Emergency Systems, Safety Instrumented Systems
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:

![Diagram of instrumentation fieldbus integration]

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

![Diagram of process control systems integration]
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:

<table>
<thead>
<tr>
<th>PRIMA LETTERA</th>
<th>LETTERE SUCCESSIVE</th>
<th>MODIFICATORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>VARIABLE MISURATA/INIZIATRICE</td>
<td>FUNZIONE PASSIVA</td>
<td>FUNZIONE IN USCITA</td>
</tr>
<tr>
<td>MEASURED OR INITIATING VARIABLE</td>
<td>READOUT OR PASSIVE FUNCTION</td>
<td>OUTPUT FUNCTION</td>
</tr>
</tbody>
</table>

| A | Analisi | Analys | Allarme | Alarm |
| B | Rivellaz. Fiamma | Burner, Combustion | Controllo | Control |
| C | Differenziale | Differential | Sensore | Sensor (Primary Elem.) |
| D | Tensione | Voltage | | |
| E | Potenza | Power | Rapporto | Ratio (Fraction) |
| F | Portata | Flow rate | | |
| G | Vetro | Glass, Viewing | | |
| H | Manuale | Hand | | |
| I | Corrente (Elettrica) | Current (Electrical) | Indicazione | Indicate |
| J | Potenza | Power | Scansione | Scan |
| K | Tempo | Time, Time Schedule | Tempi di Cambio | Control Station |
| L | Livello | Level | Luci/Sperimentazioni | Light |
| M | Umidità | Moisture | Momentary | |
| N | | | | |
| O | | | | |
| P | Pressione | Pressure, Vacuum | Pressa campione | Point (Test) |
| Q | Quantità | Quantity | Integraz./Totale | Integrate/Totize |
| R | Radiazione | Radiation | Registrazione | Record |
| S | Velocità/Frequenza | Speed, Frequency | Sicurezza | Safety |
| T | Temperatura | Temperature | Interruttore | Switch |
| U | Multivariable | Multivariable | Multifunzione | Multifunction |
| V | Vibrazione | Vibration | Valvola/serranda | Valve, Damper, Lever |
| W | Peso, forza | Weight, Force | Pozzetto | Well |
| X | Stato di pericolo | Danger | Asse X | X Axis |
| Y | Evento/istato | Event, State or Presence | Asse Y | Y Axis |
| Z | Posizione/dimensioni | Position, Dimension | Asse Z | Z Axis |

| A | Analisi | Analys | Allarme | Alarm |
| B | Rivellaz. Fiamma | Burner, Combustion | Controllo | Control |
| C | Differenziale | Differential | Sensore | Sensor (Primary Elem.) |
| D | Tensione | Voltage | | |
| E | Potenza | Power | Rapporto | Ratio (Fraction) |
| F | Portata | Flow rate | | |
| G | Vetro | Glass, Viewing | | |
| H | Manuale | Hand | | |
| I | Corrente (Elettrica) | Current (Electrical) | Indicazione | Indicate |
| J | Potenza | Power | Scansione | Scan |
| K | Tempo | Time, Time Schedule | Tempi di Cambio | Control Station |
| L | Livello | Level | Luci/Sperimentazioni | Light |
| M | Umidità | Moisture | Momentary | |
| N | | | | |
| O | | | | |
| P | Pressione | Pressure, Vacuum | Pressa campione | Point (Test) |
| Q | Quantità | Quantity | Integraz./Totale | Integrate/Totize |
| R | Radiazione | Radiation | Registrazione | Record |
| S | Velocità/Frequenza | Speed, Frequency | Sicurezza | Safety |
| T | Temperatura | Temperature | Interruttore | Switch |
| U | Multivariable | Multivariable | Multifunzione | Multifunction |
| V | Vibrazione | Vibration | Valvola/serranda | Valve, Damper, Lever |
| W | Peso, forza | Weight, Force | Pozzetto | Well |
| X | Stato di pericolo | Danger | Asse X | X Axis |
| Y | Evento/istato | Event, State or Presence | Asse Y | Y Axis |
| Z | Posizione/dimensioni | Position, Dimension | Asse Z | Z Axis |
The typical connection instrument it is following in table:

<table>
<thead>
<tr>
<th>SYM. REF. No.</th>
<th>SIMBOLo SYMBOL</th>
<th>DESCRIZIONE DESCRIPTION</th>
<th>STD. CODE</th>
<th>STD. REF. No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3201</td>
<td></td>
<td>Connessione al processo o tubazione di alimentazione strumenti (nota 1)</td>
<td>ISA 551</td>
<td>6.2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Process connection or instrument supply pipe (note 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3202</td>
<td></td>
<td>Segnale non definito</td>
<td>ISA S5.1</td>
<td>6.2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Undefined signal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3203</td>
<td></td>
<td>Segnale pneumatico (può essere usato per ogni tipo di gas)</td>
<td>ISA S5.5</td>
<td>6.2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pneumatic signal (may be used for any gas type)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3204</td>
<td></td>
<td>Alternativa (nota 2) segnale pneumatico binario (può essere usato per ogni tipo di gas)</td>
<td>ISA S5.1</td>
<td>6.2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ON-OFF pneumatic binary signal (may be used for any gas type)</td>
<td>CEI</td>
<td>30-04-06</td>
</tr>
<tr>
<td>3205</td>
<td></td>
<td>Segnale elettrico</td>
<td>ISA S5.1</td>
<td>6.2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electric signal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3206</td>
<td></td>
<td>Alternativa (nota 2) segnale elettrico binario</td>
<td>ISA S5.1</td>
<td>6.2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electric binary signal (ON-OFF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3207</td>
<td></td>
<td>Segnale idraulico</td>
<td>ISA S5.1</td>
<td>6.2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydraulic signal</td>
<td>CEI</td>
<td>30-04-07</td>
</tr>
</tbody>
</table>

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)
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:

<table>
<thead>
<tr>
<th>Code element</th>
<th>Number or letter</th>
<th>Protection against solids</th>
<th>Protection against liquids</th>
<th>Protection for personal</th>
<th>Protection special case</th>
</tr>
</thead>
<tbody>
<tr>
<td>First letter characteristic</td>
<td>0</td>
<td>Not protected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>&gt;50,0 mm of diameter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>&gt;12,5 mm of diameter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>&gt; 2,5 mm of diameter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>&gt; 1,0 mm of diameter</td>
<td>Dust partially protected</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td>Dust totally protected</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second letter characteristic</td>
<td>0</td>
<td>Not protected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Vertical water drops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>± 15° water drops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>± 60° water rain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>± 180° water sprinkles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Normal water jets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Potent water jets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Temporary immersion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Continue immersion</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>CODE (IK)</th>
<th>00</th>
<th>01</th>
<th>02</th>
<th>03</th>
<th>04</th>
<th>05</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (J)</td>
<td>0</td>
<td>0,1</td>
<td>0,2</td>
<td>0,3</td>
<td>0,5</td>
<td>0,7</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>
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:**

<table>
<thead>
<tr>
<th>CLASS</th>
<th>CODE</th>
<th>TYPE &amp; EXAMPLE (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 0</td>
<td>C0</td>
<td>Explosive materials: Trinitrotoluene, nitroglycerin, ...</td>
</tr>
<tr>
<td>Class 1</td>
<td>C1</td>
<td>Flammable gas/vapor: Hydrogen, acetylene, methane, ...</td>
</tr>
<tr>
<td>Class 2</td>
<td>C2</td>
<td>Flammable dust: fiber, grain, carbon, ...</td>
</tr>
</tbody>
</table>

(1) **IEC Standard Classification**
Example of Zone Classification:

European Category Classification (ATEX Directive):

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

(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 \( \text{Ex} \) 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:

\[ \text{CE} \ xxxx \ \text{Ex} \ II \ 1G \ (xxxx = \text{identification of the NB}) \]

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

New International IEC Ex Classification against ATEX Classific.

<table>
<thead>
<tr>
<th>ATEX</th>
<th>EPL: IEC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GAS</td>
</tr>
<tr>
<td>Cat 1</td>
<td>Ga</td>
</tr>
<tr>
<td>Cat 2</td>
<td>Gb</td>
</tr>
<tr>
<td>Cat 3</td>
<td>Gc</td>
</tr>
</tbody>
</table>

EPL means:
Equipment Protection Level
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:

$$P = \frac{F}{A} \text{ [Pa]}$$

Measurement Conversion Table

<table>
<thead>
<tr>
<th>Unit</th>
<th>bar</th>
<th>mbar</th>
<th>N/m²</th>
<th>kN/m²</th>
<th>torr</th>
<th>mmH₂O (4 °C)</th>
<th>kg/cm²</th>
<th>in Hg (0 °C)</th>
<th>in H₂O (4 °C)</th>
<th>psi</th>
<th>lb/in² (**)</th>
<th>atm (standard)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.986923</td>
<td>98,065</td>
<td>98,065</td>
<td>10³</td>
<td>1,01972</td>
<td>29,530</td>
<td>1.01972</td>
<td>0.029530</td>
<td>0.0401463</td>
<td>14,5038</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.10⁻⁵</td>
<td>9.86923</td>
<td>0.98065</td>
<td>9.8065</td>
<td>10³</td>
<td>1.01972</td>
<td>0.029530</td>
<td>0.0401463</td>
<td>1.045038</td>
<td>14.5038</td>
<td>0.014504</td>
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<td></td>
</tr>
<tr>
<td>1.10⁻⁵</td>
<td>0.98065</td>
<td>98,065</td>
<td>98,065</td>
<td>10³</td>
<td>1.01972</td>
<td>0.029530</td>
<td>0.0401463</td>
<td>1.045038</td>
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<td>0.014504</td>
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<td>9.8065</td>
<td>9.8065</td>
<td>10³</td>
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<td>0.029530</td>
<td>0.0401463</td>
<td>1.045038</td>
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<td>0.014504</td>
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</tr>
<tr>
<td>1.10⁻³</td>
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<td>98,065</td>
<td>98,065</td>
<td>10³</td>
<td>1.01972</td>
<td>0.029530</td>
<td>0.0401463</td>
<td>1.045038</td>
<td>14.5038</td>
<td>0.014504</td>
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<td></td>
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<tr>
<td>1.10⁻²</td>
<td>98,065</td>
<td>98,065</td>
<td>98,065</td>
<td>10³</td>
<td>1.01972</td>
<td>0.029530</td>
<td>0.0401463</td>
<td>1.045038</td>
<td>14.5038</td>
<td>0.014504</td>
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<tr>
<td>1.10⁻¹</td>
<td>98,065</td>
<td>98,065</td>
<td>98,065</td>
<td>10³</td>
<td>1.01972</td>
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<td>0.0401463</td>
<td>1.045038</td>
<td>14.5038</td>
<td>0.014504</td>
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<tr>
<td>1.10⁰</td>
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<td>98,065</td>
<td>98,065</td>
<td>10³</td>
<td>1.01972</td>
<td>0.029530</td>
<td>0.0401463</td>
<td>1.045038</td>
<td>14.5038</td>
<td>0.014504</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Concept related to the pressure measurement
Measuring range for dial manometer (EN 837)

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>MEASURING RANGES (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manometers or pressure</td>
<td>Measuring ranges in bar (2)</td>
</tr>
<tr>
<td>gauges</td>
<td>0 ± 0,6</td>
</tr>
<tr>
<td></td>
<td>0 ± 1 0 ± 10 0 ± 100 0 ± 1000</td>
</tr>
<tr>
<td></td>
<td>0 ± 1,6 0 ± 16 0 ± 160 0 ± 1600</td>
</tr>
<tr>
<td></td>
<td>0 ± 2,5 0 ± 25 0 ± 250 0 ± 2500</td>
</tr>
<tr>
<td></td>
<td>0 ± 4 0 ± 40 0 ± 400 0 ± 400</td>
</tr>
<tr>
<td></td>
<td>0 ± 6 0 ± 60 0 ± 600 0 ± 600</td>
</tr>
<tr>
<td>Measuring range in mbar</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td>0 ± 1 0 ± 10 0 ± 100</td>
</tr>
<tr>
<td></td>
<td>0 ± 1,6 0 ± 16 0 ± 160</td>
</tr>
<tr>
<td></td>
<td>0 ± 2,5 0 ± 25 0 ± 250</td>
</tr>
<tr>
<td></td>
<td>0 ± 4 0 ± 40 0 ± 400</td>
</tr>
<tr>
<td></td>
<td>0 ± 6 0 ± 60 0 ± 600</td>
</tr>
<tr>
<td>Vacuum gauges</td>
<td>Measuring ranges in mbar (3)</td>
</tr>
<tr>
<td></td>
<td>-1 ± 0 -10 ± 0 -100 ± 0</td>
</tr>
<tr>
<td></td>
<td>-1,6 ± 0 -16 ± 0 -160 ± 0</td>
</tr>
<tr>
<td></td>
<td>-2,5 ± 0 -25 ± 0 -250 ± 0</td>
</tr>
<tr>
<td></td>
<td>-4 ± 0 -40 ± 0 -400 ± 0</td>
</tr>
<tr>
<td></td>
<td>-6 ± 0 -60 ± 0 -600 ± 0</td>
</tr>
<tr>
<td>Pressure and vacuum</td>
<td>Measuring ranges in bar</td>
</tr>
<tr>
<td>gauges</td>
<td>-1 ± +0,6 -1 ± +3 -1 ± +9 -1 ± +24</td>
</tr>
<tr>
<td></td>
<td>-1 ± +1,5 -1 ± +5 -1 ± +15</td>
</tr>
</tbody>
</table>
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):
\[ Qv = A \cdot V \quad \text{[m}^3/\text{s}] \]
where
\[ A = \text{area of the flowing section} \quad [\text{m}^2] \]
\[ V = \text{average velocity of the flowing fluid} \quad [\text{m/s}] \]

Mass Flow (Qm):
\[ Qm = A \cdot V \cdot \rho \quad \text{[kg/s]} \]
where
\[ \rho = \text{volumic mass of the flowing fluid (or density)} \quad [\text{kg/m}^3] \]

Table 1. Conversions per Unit of Measurement for Volumic Flow

<table>
<thead>
<tr>
<th></th>
<th>Liters per second l/s</th>
<th>Liters per minute l/min</th>
<th>Cubic meter per hour m³/h</th>
<th>Cubic feet per hour ft³/h</th>
<th>Cubic feet per minute ft³/min</th>
<th>U.K. gallons per minute U.K. gal/min</th>
<th>U.S. gallons per minute U.S. gal/min</th>
<th>U.S. barrels per day U.S. barrel/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>l/s</td>
<td>1</td>
<td>60</td>
<td>3.6</td>
<td>127.1</td>
<td>2.119</td>
<td>13.2</td>
<td>15.85</td>
<td>543.4</td>
</tr>
<tr>
<td>l/min</td>
<td>0.0166</td>
<td>1</td>
<td>0.06</td>
<td>2.119</td>
<td>0.03532</td>
<td>0.22</td>
<td>0.2642</td>
<td>9.057</td>
</tr>
<tr>
<td>m³/h</td>
<td>0.2778</td>
<td>16.66</td>
<td>1</td>
<td>35.31</td>
<td>0.5886</td>
<td>3.666</td>
<td>4.403</td>
<td>150.9</td>
</tr>
<tr>
<td>ft³/h</td>
<td>0.007865</td>
<td>0.4719</td>
<td>0.02832</td>
<td>1</td>
<td>0.01666</td>
<td>0.1038</td>
<td>0.1247</td>
<td>4.275</td>
</tr>
<tr>
<td>ft³/min</td>
<td>0.4719</td>
<td>28.32</td>
<td>1.699</td>
<td>60</td>
<td>1</td>
<td>6.229</td>
<td>7.481</td>
<td>256.5</td>
</tr>
<tr>
<td>U.K. gal/min</td>
<td>0.07577</td>
<td>4.546</td>
<td>0.2727</td>
<td>9.633</td>
<td>0.1606</td>
<td>1</td>
<td>1.201</td>
<td>41.17</td>
</tr>
<tr>
<td>U.S. gal/min</td>
<td>0.06309</td>
<td>3.785</td>
<td>0.2271</td>
<td>8.021</td>
<td>0.1337</td>
<td>0.8327</td>
<td>1</td>
<td>34.29</td>
</tr>
<tr>
<td>U.S. barrel/d</td>
<td>0.00184</td>
<td>0.1104</td>
<td>0.006624</td>
<td>0.2339</td>
<td>0.003899</td>
<td>0.02428</td>
<td>0.02971</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. Conversions per Unit of Measurement for Mass Flow

<table>
<thead>
<tr>
<th></th>
<th>Kilograms per second kg/s</th>
<th>Kilograms per minute kg/min</th>
<th>Kilograms per hour kg/h</th>
<th>Pounds per second lb/s</th>
<th>Pounds per minute lb/min</th>
<th>Pounds per hour lb/h</th>
<th>Short ton per hour S ton/h</th>
<th>Long ton per hour L ton/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/s</td>
<td>1</td>
<td>60</td>
<td>3600</td>
<td>2.052</td>
<td>132.3</td>
<td>7937</td>
<td>3.968</td>
<td>3.543</td>
</tr>
<tr>
<td>kg/min</td>
<td>0.01666</td>
<td>1</td>
<td>60</td>
<td>0.03675</td>
<td>2.052</td>
<td>132.3</td>
<td>0.06613</td>
<td>0.05905</td>
</tr>
<tr>
<td>kg/h</td>
<td>0.0002778</td>
<td>0.01666</td>
<td>1</td>
<td>0.0006124</td>
<td>0.03674</td>
<td>2.052</td>
<td>0.011102</td>
<td>0.009842</td>
</tr>
<tr>
<td>lb/s</td>
<td>0.4536</td>
<td>27.22</td>
<td>1633</td>
<td>1</td>
<td>60</td>
<td>3600</td>
<td>1.8</td>
<td>1.607</td>
</tr>
<tr>
<td>lb/min</td>
<td>0.00756</td>
<td>0.4536</td>
<td>27.22</td>
<td>1</td>
<td>60</td>
<td>3600</td>
<td>0.63</td>
<td>0.52679</td>
</tr>
<tr>
<td>lb/h</td>
<td>0.000126</td>
<td>0.00756</td>
<td>0.4536</td>
<td>0.0002778</td>
<td>0.01666</td>
<td>1</td>
<td>0.0005197</td>
<td>0.0004464</td>
</tr>
<tr>
<td>S ton/h</td>
<td>0.252</td>
<td>15.12</td>
<td>907.1</td>
<td>0.5555</td>
<td>33.33</td>
<td>2000</td>
<td>1</td>
<td>0.8929</td>
</tr>
<tr>
<td>L ton/h</td>
<td>0.2822</td>
<td>16.93</td>
<td>1016</td>
<td>0.6222</td>
<td>37.33</td>
<td>2240</td>
<td>1.12</td>
<td>1</td>
</tr>
</tbody>
</table>

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 : ISO 14511
Main flow straightener for fiscal measurement

Typical fiscal measurement with Orifice plate
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 levelmeters 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:

\[ 1 \ \text{K} = 1/273.16 \]  

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

<table>
<thead>
<tr>
<th>Temperature</th>
<th>( t_C )</th>
<th>( t_K )</th>
<th>( t_F )</th>
<th>( t_R )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_C )</td>
<td>1</td>
<td>( t_K - 273.15 )</td>
<td>5/9 ( t_F - 32 )</td>
<td>5/9 ( t_R - 273.15 )</td>
</tr>
<tr>
<td>( t_K )</td>
<td>( t_C + 273.15 )</td>
<td>1</td>
<td>5/9 ( t_F + 255.37 )</td>
<td>5/9 ( t_R )</td>
</tr>
<tr>
<td>( t_F )</td>
<td>9/5 ( t_C + 32 )</td>
<td>9/5 ( t_K - 459.67 )</td>
<td>1</td>
<td>( t_R - 459.67 )</td>
</tr>
<tr>
<td>( t_R )</td>
<td>9/5 ( t_C + 491.67 )</td>
<td>9/5 ( t_K )</td>
<td>1</td>
<td>( t_F + 459.67 )</td>
</tr>
</tbody>
</table>

Table 2. Fixed Points of the International Temperature Scales

<table>
<thead>
<tr>
<th>Substance</th>
<th>Symbol</th>
<th>IPTS 68 (K)</th>
<th>IPTS 68 (°C)</th>
<th>ITS 90 (K)</th>
<th>ITS 90 (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>Triple point</td>
<td>13.81</td>
<td>-256.34</td>
<td>15.303</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>Liquefaction point</td>
<td>17.042</td>
<td>-256.108</td>
<td>17.036</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>Boiling point</td>
<td>20.832</td>
<td>-252.686</td>
<td>20.727</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>Triple point</td>
<td>(1)</td>
<td>(1)</td>
<td>24.556</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>Boiling point</td>
<td>27.102</td>
<td>-248.048</td>
<td>(1)</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O2</td>
<td>Triple point</td>
<td>54.361</td>
<td>-218.789</td>
<td>54.358</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O2</td>
<td>Boiling point</td>
<td>90.188</td>
<td>-182.962</td>
<td>(1)</td>
</tr>
<tr>
<td>Argon</td>
<td>Ar</td>
<td>Triple point</td>
<td>(1)</td>
<td>(1)</td>
<td>83.806</td>
</tr>
<tr>
<td>Mercury</td>
<td>Hg</td>
<td>Triple point</td>
<td>(1)</td>
<td>(1)</td>
<td>234.316</td>
</tr>
<tr>
<td>Water</td>
<td>H2O</td>
<td>Fusion point</td>
<td>273.15</td>
<td>0</td>
<td>273.15</td>
</tr>
<tr>
<td>Water</td>
<td>H2O</td>
<td>Triple point</td>
<td>273.16</td>
<td>0</td>
<td>273.16</td>
</tr>
<tr>
<td>Gallium</td>
<td>Ga</td>
<td>Fusion point</td>
<td>(1)</td>
<td>(1)</td>
<td>302.915</td>
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<tr>
<td>Water (2)</td>
<td>H2O</td>
<td>Boiling point</td>
<td>373.15</td>
<td>100</td>
<td>373.124</td>
</tr>
<tr>
<td>Indium</td>
<td>In</td>
<td>Fusion point</td>
<td>(1)</td>
<td>(1)</td>
<td>426.749</td>
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<tr>
<td>Tin</td>
<td>Sn</td>
<td>Solidification point</td>
<td>505.118</td>
<td>231.968</td>
<td>505.078</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
<td>Solidification point</td>
<td>692.73</td>
<td>419.56</td>
<td>692.677</td>
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<tr>
<td>Antimony</td>
<td>Sb</td>
<td>Solidification point</td>
<td>903.69</td>
<td>630.74</td>
<td>(1)</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Al</td>
<td>Solidification point</td>
<td>(1)</td>
<td>(1)</td>
<td>933.473</td>
</tr>
<tr>
<td>Silver</td>
<td>Ag</td>
<td>Solidification point</td>
<td>1235.93</td>
<td>961.93</td>
<td>1234.93</td>
</tr>
<tr>
<td>Gold</td>
<td>Au</td>
<td>Solidification point</td>
<td>1337.58</td>
<td>1064.43</td>
<td>1337.33</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>Solidification point</td>
<td>(1)</td>
<td>(1)</td>
<td>1357.77</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Temperature Limits (°C)</th>
<th>Temperature Coefficient ( (\times 10^{-3}) )</th>
<th>Interpolating Polynomial (3) ( R_t = R_0 (1 + A^* + B^*t + C^*t^2) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platinum (1)</td>
<td>-200 / +850</td>
<td>3.85 * 10^-3</td>
<td>( A = 3.9083 \times 10^{-3} ) ( B = -5.757 \times 10^{-7} ) ( C = -4.1830 \times 10^{-12} ) (4)</td>
</tr>
<tr>
<td>Nickel (2)</td>
<td>-60 / +180</td>
<td>6.17 * 10^-3</td>
<td>( A = 5.485 \times 10^{-3} ) ( B = 6.650 \times 10^{-6} ) ( C = 2.805 \times 10^{-11} ) (1)</td>
</tr>
<tr>
<td>Copper (2)</td>
<td>-180 / +200</td>
<td>4.26 * 10^-3</td>
<td>( A = 4.260 \times 10^{-3} )</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Thermoresistance Type</th>
<th>Commercial Denomination</th>
<th>Tolerance Classes</th>
<th>Temperature Ranges (°C)</th>
<th>Tolerance Values (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platinum - Pt (1)</td>
<td>PRT</td>
<td>AA</td>
<td>-50 / +250</td>
<td>± 0.10°C ± 1.7°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>-100 / +450</td>
<td>± 0.15°C ± 2.0°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>-200 / +600</td>
<td>± 0.30°C ± 5.0°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>-200 / +600</td>
<td>± 0.60°C ± 10.0°C</td>
</tr>
<tr>
<td>Nickel - Ni (2)</td>
<td>NRT</td>
<td>C</td>
<td>0 / +180</td>
<td>± 0.20°C ± 16.5°C</td>
</tr>
<tr>
<td>Copper - Cu (2)</td>
<td>CRT</td>
<td>B</td>
<td>-50 / +200</td>
<td>± 0.25°C ± 3.5°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>-50 / +200</td>
<td>± 0.50°C ± 6.5°C</td>
</tr>
</tbody>
</table>
Table 6. Temperature Limits of Standardized Thermocouples (IEC 60584-1)

<table>
<thead>
<tr>
<th>Thermocouple Type (1)</th>
<th>Thermocouple Materials</th>
<th>Temperature Range</th>
<th>Commercial Denomination (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>Copper</td>
<td>Copper – Nickel</td>
<td>−270 / 400</td>
</tr>
<tr>
<td>E</td>
<td>Nickel – Chromium</td>
<td>Copper – Nickel</td>
<td>−270 / 1000</td>
</tr>
<tr>
<td>J</td>
<td>Iron</td>
<td>Copper – Nickel</td>
<td>−210 / 1200</td>
</tr>
<tr>
<td>K</td>
<td>Nickel – Chromium</td>
<td>Nickel – Aluminum</td>
<td>−270 / 1300</td>
</tr>
<tr>
<td>N</td>
<td>Nickel – Cr – Si</td>
<td>Nickel – Silicon</td>
<td>−270 / 1300</td>
</tr>
<tr>
<td>S</td>
<td>Platinum – 10% Rh</td>
<td>Platinum</td>
<td>−50 / 1670</td>
</tr>
<tr>
<td>R</td>
<td>Platinum – 13% Rh</td>
<td>Platinum</td>
<td>−50 / 1670</td>
</tr>
<tr>
<td>B</td>
<td>Platinum – 30% Rh</td>
<td>Platinum – 6% Rhodium</td>
<td>0 / 1820</td>
</tr>
<tr>
<td>C</td>
<td>Tungsten – 5% Re</td>
<td>Tungsten – 26% Rhenium</td>
<td>0 / 2315</td>
</tr>
<tr>
<td>A</td>
<td>Tungsten – 5% Re</td>
<td>Tungsten – 20% Rhenium</td>
<td>0 / 2500</td>
</tr>
</tbody>
</table>

(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)

<table>
<thead>
<tr>
<th>Thermocouple Type</th>
<th>Thermocouple Materials</th>
<th>Tolerance Classes (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>T</td>
<td>Copper</td>
<td>0.5°C or 0.4%</td>
</tr>
<tr>
<td>E</td>
<td>Nickel – Chromium</td>
<td>1.5°C or 0.4%</td>
</tr>
<tr>
<td>J</td>
<td>Iron</td>
<td>1.5°C or 0.4%</td>
</tr>
<tr>
<td>K</td>
<td>Nickel – Chromium</td>
<td>1.5°C or 0.4%</td>
</tr>
<tr>
<td>N</td>
<td>Nickel – Cr – Si</td>
<td>1.5°C or 0.4%</td>
</tr>
<tr>
<td>S</td>
<td>Platinum – 10% Rh</td>
<td>1.0°C or 0.2%</td>
</tr>
<tr>
<td>R</td>
<td>Platinum – 13% Rh</td>
<td>1.0°C or 0.2%</td>
</tr>
<tr>
<td>B</td>
<td>Platinum – 30% Rh</td>
<td>(2)</td>
</tr>
<tr>
<td>C</td>
<td>Tungsten – 5% Re</td>
<td>(2)</td>
</tr>
<tr>
<td>A</td>
<td>Tungsten – 5% Re</td>
<td>(2)</td>
</tr>
</tbody>
</table>

(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)

<table>
<thead>
<tr>
<th>Cable Type</th>
<th>Cable Symbol</th>
<th>Tolerance Classes</th>
<th>Cable Temperature Range</th>
<th>Measure Junction Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>EXTENSION</td>
<td>TX</td>
<td>± 30 μV (0.5°C)</td>
<td>± 60 μV (1.0°C)</td>
<td>−25°C/+100°C</td>
</tr>
<tr>
<td></td>
<td>EX</td>
<td>± 120 μV (1.5°C)</td>
<td>± 200 μV (2.5°C)</td>
<td>−25°C/+200°C</td>
</tr>
<tr>
<td></td>
<td>JX</td>
<td>± 85 μV (1.5°C)</td>
<td>± 140 μV (2.5°C)</td>
<td>−25°C/+200°C</td>
</tr>
<tr>
<td></td>
<td>KX</td>
<td>± 60 μV (1.5°C)</td>
<td>± 100 μV (2.5°C)</td>
<td>−25°C/+200°C</td>
</tr>
<tr>
<td></td>
<td>NX</td>
<td>± 60 μV (1.5°C)</td>
<td>± 100 μV (2.5°C)</td>
<td>−25°C/+200°C</td>
</tr>
<tr>
<td>COMPENSATION</td>
<td>NC</td>
<td>–</td>
<td>± 100 μV (2.5°C)</td>
<td>0°C+/150°C</td>
</tr>
<tr>
<td></td>
<td>KCA</td>
<td>–</td>
<td>± 100 μV (2.5°C)</td>
<td>0°C+/150°C</td>
</tr>
<tr>
<td></td>
<td>KCB</td>
<td>–</td>
<td>± 100 μV (2.5°C)</td>
<td>0°C+/100°C</td>
</tr>
<tr>
<td></td>
<td>RCA/SCA</td>
<td>–</td>
<td>± 30 μV (2.5°C)</td>
<td>0°C+/100°C</td>
</tr>
<tr>
<td></td>
<td>RCA/SCB</td>
<td>–</td>
<td>± 60 μV (5.0°C)</td>
<td>0°C+/200°C</td>
</tr>
</tbody>
</table>

(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 (p) 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:

\[ RH = \frac{p}{ps} \]

**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/m³
- 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

<table>
<thead>
<tr>
<th>Frost Point (°C)</th>
<th>Vapor Pressure (mbar)</th>
<th>PPM Volume (PPMv)</th>
<th>PPM Mass (PPMm)</th>
<th>Relative Humidity @ 20°C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.105</td>
<td>6020</td>
<td>3742</td>
<td>26.1</td>
</tr>
<tr>
<td>-2</td>
<td>5.173</td>
<td>5100</td>
<td>3170</td>
<td>22.1</td>
</tr>
<tr>
<td>-4</td>
<td>4.373</td>
<td>4320</td>
<td>2685</td>
<td>18.7</td>
</tr>
<tr>
<td>-6</td>
<td>3.686</td>
<td>3640</td>
<td>2262</td>
<td>15.8</td>
</tr>
<tr>
<td>-8</td>
<td>3.101</td>
<td>3080</td>
<td>1902</td>
<td>13.3</td>
</tr>
<tr>
<td>-10</td>
<td>2.600</td>
<td>2570</td>
<td>1597</td>
<td>11.1</td>
</tr>
<tr>
<td>-12</td>
<td>2.176</td>
<td>2140</td>
<td>1330</td>
<td>9.3</td>
</tr>
<tr>
<td>-14</td>
<td>1.815</td>
<td>1790</td>
<td>1113</td>
<td>7.8</td>
</tr>
<tr>
<td>-16</td>
<td>1.510</td>
<td>1490</td>
<td>826</td>
<td>6.4</td>
</tr>
<tr>
<td>-18</td>
<td>1.252</td>
<td>1230</td>
<td>705</td>
<td>5.3</td>
</tr>
<tr>
<td>-20</td>
<td>1.035</td>
<td>1020</td>
<td>634</td>
<td>4.4</td>
</tr>
<tr>
<td>-22</td>
<td>0.8533</td>
<td>841</td>
<td>523</td>
<td>3.6</td>
</tr>
<tr>
<td>-24</td>
<td>0.7013</td>
<td>691</td>
<td>429</td>
<td>3.0</td>
</tr>
<tr>
<td>-26</td>
<td>0.5733</td>
<td>566</td>
<td>352</td>
<td>2.5</td>
</tr>
<tr>
<td>-28</td>
<td>0.4680</td>
<td>462</td>
<td>287</td>
<td>2.0</td>
</tr>
<tr>
<td>-30</td>
<td>0.3812</td>
<td>376</td>
<td>234</td>
<td>1.6</td>
</tr>
<tr>
<td>-32</td>
<td>0.3090</td>
<td>340</td>
<td>211</td>
<td>1.3</td>
</tr>
<tr>
<td>-34</td>
<td>0.2497</td>
<td>246</td>
<td>153</td>
<td>1.1</td>
</tr>
<tr>
<td>-36</td>
<td>0.2009</td>
<td>198</td>
<td>123</td>
<td>0.8</td>
</tr>
<tr>
<td>-38</td>
<td>0.1612</td>
<td>159</td>
<td>98.8</td>
<td>0.6</td>
</tr>
<tr>
<td>-40</td>
<td>0.1288</td>
<td>127</td>
<td>78.9</td>
<td>0.5</td>
</tr>
<tr>
<td>-42</td>
<td>0.1024</td>
<td>101</td>
<td>62.8</td>
<td>0.4</td>
</tr>
<tr>
<td>-44</td>
<td>0.0891</td>
<td>80.1</td>
<td>49.8</td>
<td>0.3</td>
</tr>
<tr>
<td>-46</td>
<td>0.0641</td>
<td>63.2</td>
<td>33.3</td>
<td>0.3</td>
</tr>
<tr>
<td>-48</td>
<td>0.0504</td>
<td>46.7</td>
<td>30.9</td>
<td>0.2</td>
</tr>
<tr>
<td>-50</td>
<td>0.0393</td>
<td>36.4</td>
<td>24.5</td>
<td>0.2</td>
</tr>
<tr>
<td>-52</td>
<td>0.0306</td>
<td>31.1</td>
<td>19.3</td>
<td>0.1</td>
</tr>
<tr>
<td>-54</td>
<td>0.0237</td>
<td>23.4</td>
<td>14.5</td>
<td>0.1</td>
</tr>
<tr>
<td>-56</td>
<td>0.0184</td>
<td>18.3</td>
<td>11.4</td>
<td>0.08</td>
</tr>
<tr>
<td>-58</td>
<td>0.0141</td>
<td>14.1</td>
<td>8.76</td>
<td>0.06</td>
</tr>
<tr>
<td>-60</td>
<td>0.0107</td>
<td>10.6</td>
<td>6.59</td>
<td>0.04</td>
</tr>
<tr>
<td>-62</td>
<td>0.0081</td>
<td>8.07</td>
<td>5.02</td>
<td>0.03</td>
</tr>
<tr>
<td>-64</td>
<td>0.0061</td>
<td>6.11</td>
<td>3.80</td>
<td>0.02</td>
</tr>
<tr>
<td>-66</td>
<td>0.0046</td>
<td>4.61</td>
<td>2.87</td>
<td>0.02</td>
</tr>
<tr>
<td>-68</td>
<td>0.0034</td>
<td>3.44</td>
<td>2.14</td>
<td>0.01</td>
</tr>
<tr>
<td>-70</td>
<td>0.0026</td>
<td>2.55</td>
<td>1.58</td>
<td>0.01</td>
</tr>
<tr>
<td>-72</td>
<td>0.0019</td>
<td>1.88</td>
<td>1.17</td>
<td>0.008</td>
</tr>
<tr>
<td>-74</td>
<td>0.0013</td>
<td>1.38</td>
<td>0.858</td>
<td>0.006</td>
</tr>
<tr>
<td>-76</td>
<td>0.0010</td>
<td>1.01</td>
<td>0.528</td>
<td>0.004</td>
</tr>
<tr>
<td>-78</td>
<td>0.0008</td>
<td>0.747</td>
<td>0.464</td>
<td>0.003</td>
</tr>
<tr>
<td>-80</td>
<td>0.0005</td>
<td>0.526</td>
<td>0.327</td>
<td>0.002</td>
</tr>
<tr>
<td>-82</td>
<td>0.0003</td>
<td>0.382</td>
<td>0.237</td>
<td>0.002</td>
</tr>
<tr>
<td>-84</td>
<td>0.0002</td>
<td>0.263</td>
<td>0.163</td>
<td>0.001</td>
</tr>
<tr>
<td>-86</td>
<td>0.0001</td>
<td>0.184</td>
<td>0.114</td>
<td>0.0008</td>
</tr>
<tr>
<td>-88</td>
<td>0.0001</td>
<td>0.134</td>
<td>0.0833</td>
<td>0.0006</td>
</tr>
<tr>
<td>-90</td>
<td>0.0000</td>
<td>0.0923</td>
<td>0.0574</td>
<td>0.0004</td>
</tr>
<tr>
<td>-92</td>
<td>0.0000</td>
<td>0.0632</td>
<td>0.0393</td>
<td>0.0003</td>
</tr>
<tr>
<td>-94</td>
<td>0.0000</td>
<td>0.0434</td>
<td>0.0270</td>
<td>0.0002</td>
</tr>
<tr>
<td>-96</td>
<td>0.0000</td>
<td>0.0291</td>
<td>0.0181</td>
<td>0.0001</td>
</tr>
<tr>
<td>-98</td>
<td>0.0000</td>
<td>0.0197</td>
<td>0.0122</td>
<td>0.00008</td>
</tr>
<tr>
<td>-100</td>
<td>0.0000</td>
<td>0.0131</td>
<td>0.0081</td>
<td>0.0005</td>
</tr>
</tbody>
</table>
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 $\nu$:
The unit is the square millimeter per second (mm$^2$/s), equivalent to centistokes (cSt) of the centimeter – gram – second (CGS) measuring system:

$1 \text{ mm}^2/\text{s} = 1 \text{ cSt}$ (for other correspondences, see table 1)

For the Dynamic Viscosity $\eta$:
The unit is millipascal per second (mPa · s), equivalent to centipoise (cP) of the measuring system CGS:

$1 \text{ mPa} \cdot \text{s} = 1 \text{ cP}$ (for other correspondences see table 2)

| Table 1. Correspondence of Units of Measurement of Kinematic Viscosity |
|--------------------|--------|--------|-------|--------|-------|
| m$^2$/s            | 1      | 10$^6$ | 10$^4$ | 10$^5$ | 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             | 1      | 10$^3$ | 10$^1$ | 10$^3$ | 0.672 |
| mPa · 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 (*)

<table>
<thead>
<tr>
<th></th>
<th>kg/l (*)</th>
<th>kg/m$^3$</th>
<th>lb/ft$^3$</th>
<th>lb/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/l (*)</td>
<td>1</td>
<td>1000</td>
<td>62.43</td>
<td>0.03613</td>
</tr>
<tr>
<td>kg/m$^3$</td>
<td>0.001</td>
<td>1</td>
<td>0.06243</td>
<td>0.00003613</td>
</tr>
<tr>
<td>lb/ft$^3$</td>
<td>0.01602</td>
<td>16.02</td>
<td>1</td>
<td>0.0005787</td>
</tr>
<tr>
<td>lb/m$^3$</td>
<td>27.68</td>
<td>27680</td>
<td>1728</td>
<td>1</td>
</tr>
</tbody>
</table>

(*) 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 $\rho$ if it is absolute or $\rho_r$ 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 (%)

<table>
<thead>
<tr>
<th>t  (°C)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.025</td>
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<td>0.996</td>
<td>0.986</td>
<td>0.977</td>
<td>0.967</td>
<td>0.958</td>
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<td>70</td>
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<td>1.017</td>
<td>1.005</td>
<td>0.994</td>
<td>0.982</td>
<td>0.970</td>
<td>0.958</td>
<td>0.946</td>
<td>0.935</td>
<td>0.923</td>
<td>0.911</td>
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<td>75</td>
<td>1.014</td>
<td>1.000</td>
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<td>0.971</td>
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<td>0.928</td>
<td>0.914</td>
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<td>80</td>
<td>1.000</td>
<td>0.983</td>
<td>0.965</td>
<td>0.948</td>
<td>0.930</td>
<td>0.913</td>
<td>0.896</td>
<td>0.878</td>
<td>0.861</td>
<td>0.843</td>
<td>0.826</td>
</tr>
<tr>
<td>85</td>
<td>0.986</td>
<td>0.965</td>
<td>0.944</td>
<td>0.923</td>
<td>0.903</td>
<td>0.882</td>
<td>0.861</td>
<td>0.840</td>
<td>0.820</td>
<td>0.799</td>
<td>0.778</td>
</tr>
<tr>
<td>90</td>
<td>0.973</td>
<td>0.948</td>
<td>0.923</td>
<td>0.898</td>
<td>0.873</td>
<td>0.848</td>
<td>0.824</td>
<td>0.799</td>
<td>0.774</td>
<td>0.749</td>
<td>0.724</td>
</tr>
<tr>
<td>95</td>
<td>0.959</td>
<td>0.929</td>
<td>0.900</td>
<td>0.870</td>
<td>0.841</td>
<td>0.811</td>
<td>0.782</td>
<td>0.752</td>
<td>0.723</td>
<td>0.693</td>
<td>0.664</td>
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<tr>
<td>100</td>
<td>0.947</td>
<td>0.912</td>
<td>0.878</td>
<td>0.843</td>
<td>0.808</td>
<td>0.773</td>
<td>0.738</td>
<td>0.703</td>
<td>0.668</td>
<td>0.634</td>
<td>0.596</td>
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</table>
### 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 dm³ of distilled water at 4°C. For the correspondence with other units, see table 1.

#### Table 1. Conversions of Mass Units

<table>
<thead>
<tr>
<th></th>
<th>Oz 1</th>
<th>Pound 1 lb</th>
<th>Short Ton 1 s ton</th>
<th>Long Ton 1 l ton</th>
<th>Kilogram 1 kg</th>
<th>Tonne 1 t (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oz</td>
<td>1</td>
<td>0.0625</td>
<td>0.00023125</td>
<td>0.000279</td>
<td>0.02835</td>
<td>0.00032835</td>
</tr>
<tr>
<td>Lb</td>
<td>16</td>
<td>1</td>
<td>0.005</td>
<td>0.004646</td>
<td>0.4562</td>
<td>0.004536</td>
</tr>
<tr>
<td>S Ton</td>
<td>32000</td>
<td>2000</td>
<td>1</td>
<td>0.8929</td>
<td>907.2</td>
<td>0.9072</td>
</tr>
<tr>
<td>L Ton</td>
<td>35840</td>
<td>2240</td>
<td>1.12</td>
<td>1</td>
<td>1.016</td>
<td>1.016</td>
</tr>
<tr>
<td>Kg</td>
<td>35.27</td>
<td>2.205</td>
<td>0.001102</td>
<td>0.0009842</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td>T</td>
<td>35270</td>
<td>2205</td>
<td>1.102</td>
<td>0.9842</td>
<td>1000</td>
<td>1</td>
</tr>
</tbody>
</table>

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

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

\[ F = ma \]

where

- \( F \) = weight force (gravitational) exerted by the mass
- \( m \) = mass of the body or product
- \( a \) = local gravitational acceleration

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

\[ g_s = 9.80665 \text{ m/s}^2 \]

#### Table 2. Acceleration of Gravity (m/s²) as a Function of Latitude (in °) at Sea Level

<table>
<thead>
<tr>
<th>Latitude (°)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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#### Table 3. Classification of the Standards' Nominal Values and Their Tolerances (OIML R 111)

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<thead>
<tr>
<th>Nominal Value</th>
<th>E₁</th>
<th>E₂</th>
<th>E₃</th>
<th>F₁</th>
<th>F₂</th>
<th>M₁</th>
<th>M₁-₂</th>
<th>M₂</th>
<th>M₂-₃</th>
<th>M₃</th>
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<tbody>
<tr>
<td>5000 kg</td>
<td>25000</td>
<td>80000</td>
<td>250000</td>
<td>500000</td>
<td>800000</td>
<td>1600000</td>
<td>2500000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000 kg</td>
<td>10000</td>
<td>30000</td>
<td>100000</td>
<td>200000</td>
<td>300000</td>
<td>6000000</td>
<td>10000000</td>
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<td>1000 kg</td>
<td>1000</td>
<td>5000</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>500 kg</td>
<td>500</td>
<td>250</td>
<td>5000</td>
<td>10000</td>
<td>20000</td>
<td>40000</td>
<td>80000</td>
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<td></td>
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<td>200 kg</td>
<td>100</td>
<td>50</td>
<td>1000</td>
<td>2000</td>
<td>4000</td>
<td>8000</td>
<td>16000</td>
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<tr>
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<td>10</td>
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<td>100</td>
<td>200</td>
<td>400</td>
<td>800</td>
<td>1600</td>
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<tr>
<td>10 kg</td>
<td>5</td>
<td>2.5</td>
<td>50</td>
<td>100</td>
<td>200</td>
<td>400</td>
<td>800</td>
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<tr>
<td>Kg</td>
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<td>25</td>
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<tr>
<td>1 kg</td>
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<td>10</td>
<td>20</td>
<td>40</td>
<td>80</td>
<td>160</td>
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<tr>
<td>0.5 kg</td>
<td>0.5</td>
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<td>5</td>
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<td>2</td>
<td>4</td>
<td>8</td>
<td>16</td>
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<td>2</td>
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<td>8</td>
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<td>0.01</td>
<td>0.005</td>
<td>0.1</td>
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<td>0.4</td>
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<td>1.6</td>
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<tr>
<td>0.005 kg</td>
<td>0.005</td>
<td>0.0025</td>
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<td>0.2</td>
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<tr>
<td>0.001 kg</td>
<td>0.001</td>
<td>0.0005</td>
<td>0.01</td>
<td>0.02</td>
<td>0.04</td>
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<td>0.0005</td>
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<td>0.02</td>
<td>0.04</td>
<td>0.08</td>
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<td></td>
</tr>
<tr>
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<td>0.0001</td>
<td>0.00005</td>
<td>0.001</td>
<td>0.002</td>
<td>0.004</td>
<td>0.008</td>
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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.

![Diagram of control valve system]

**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

<table>
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<th>NUMBER</th>
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<td>IEC 60534</td>
<td>INDUSTRIAL PROCESS CONTROL VALVES</td>
</tr>
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<td>IEC 60534-1</td>
<td>Part 1: Terminology and general considerations</td>
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<td>IEC 60534-2</td>
<td>Part 2: Flow capacity</td>
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<td>IEC 60534-3</td>
<td>Part 3: Dimensions</td>
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<td>Part 4: Inspection and routine testing</td>
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<td>Part 5: Marking</td>
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<td>Part 6: Mounting of positioners</td>
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<td>IEC 60534-7</td>
<td>Part 7: Control valves data sheet</td>
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<td>IEC 60534-8</td>
<td>Part 8: Noise considerations</td>
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Control valve leakages

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<tr>
<th>Leak Class (1)</th>
<th>Test Fluid</th>
<th>Test Procedure (2)</th>
<th>Leak Maximum</th>
<th>Applicability</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>Liquid or Gas</td>
<td>(3)</td>
<td>(3)</td>
<td>Valves on purchaser specification</td>
</tr>
<tr>
<td>II</td>
<td>Liquid or Gas</td>
<td>A</td>
<td>$5 \times 10^{-3} Q_{nom}$</td>
<td>Valves with double seat</td>
</tr>
<tr>
<td>III</td>
<td>Liquid or Gas</td>
<td>A</td>
<td>$1 \times 10^{-3} Q_{nom}$</td>
<td>Valves butterfly</td>
</tr>
<tr>
<td>IV-S1</td>
<td>Liquid or Gas</td>
<td>A or B</td>
<td>$1 \times 10^{-7} Q_{nom}$</td>
<td>Valves with single seat</td>
</tr>
<tr>
<td>IV-S2</td>
<td>Gas</td>
<td>A</td>
<td>$2 \times 10^{-7} \Delta P \times D$ (l/h)</td>
<td>As above with more seating force</td>
</tr>
<tr>
<td>V</td>
<td>Liquid</td>
<td>B</td>
<td>$1,8 \times 10^{-5} \Delta P \times D$ (l/h)</td>
<td>As above with teflon insert</td>
</tr>
<tr>
<td>VI</td>
<td>Gas</td>
<td>A</td>
<td>$0,3 \Delta P \times F$ (l/h) (4)</td>
<td>As above with soft insert</td>
</tr>
</tbody>
</table>
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.
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:

\[ \alpha(t) = K_p e(t) + \frac{1}{T_i} \int e(t) dt + T_d \frac{de(t)}{dt} \]

Where:
- \(o\) output signal from the controller
- \(e\) input error to the controller
- \(t\) time
- \(K_p\) proportional gain
- \(T_i\) interval time
- \(T_d\) derivative time

PID action improve:
PID tuning with Ziegler & Nichols rules:

<table>
<thead>
<tr>
<th>CONTROLLER</th>
<th>Proportional Gain Kp</th>
<th>Integral Time Ti</th>
<th>Derivative Time Td</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>0.50 Kc</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P+I</td>
<td>0.45 Kc</td>
<td>Tc/1.25</td>
<td>-</td>
</tr>
<tr>
<td>P+I+D</td>
<td>0.60 Kc</td>
<td>Tc/2</td>
<td>Tc/8</td>
</tr>
</tbody>
</table>

Where:
- \( K_c \) is the critical gain
- \( T_c \) 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.
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:
- Simple feedback adjustment (feedback control): Control very susceptible to pressure and fuel flow variations
- Coordinated cascade adjustment (TC on PC): improved control that compensates for variations in fuel pressure
- Coordinated cascade regulation (TC on FC): improvement control that compensates for variations in fuel flow
- Coordinated cascade regulation (TC on TC): improvement that compensates temperature variations of the heater chimney

![Diagram of control systems](image-url)
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).