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Guidance on Practice for Temperature Instruments

GP 30-01

BP GROUP
ENGINEERING TECHNICAL PRACTICES

Foreword

This is the first issue of Engineering Technical Practice (ETP) BP GP 30-01. This Guidance on Practice (GP) is based on parts of documents from the merged BP companies as follows:

Amoco

A PC-TI-00-G	Process Control—Temperature Instruments—Guide
A PC-TI-00-E	Process Control—Temperature Instruments—Selection, Specification, and System Design Specification

Arco

Standard 301	Temperature Elements
Standard 302	Temperature Instruments

BP (Pre-1999)

RP 30-1	Instrumentation and Control, Design and Practice
RP 30-2	Instrumentation and Control, Selection and Use of Measurement Instrumentation

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1. Scope

This GP provides guidance on practice for selection and application of temperature instrumentation. For guidance on practice for storage tank temperature instrumentation refer to **BP GP 58-XX**.

2. Normative references

The following normative documents contain requirements that, through reference in this text, constitute requirements of this technical practice. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this technical practice are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

BP

DS 30-01.1	Temperature Gages.
DS 30-01.2	RTDs, Thermocouples, Transmitters and Thermowells.
DS 30-01.3	Temperature Instruments.
GP 12-15	Guidance on Practice for Wire and Cable.
GP 12-60	Guidance on Practice for Hazardous Area Electrical Installations.
GP 30-25	Guidance on Practice for Common Field Instrument Issues.
GP 30-80	Guidance on Practice for Safety Instrumented Systems (SIS)—Implementation of the Process Requirements Specification.
GP 30-90	Guidance on Practice for Commissioning of Instruments and Control Systems.

American Petroleum Institute (API)

API RP 551	Process Measurement Instrumentation (Section 5, Temperature).
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American Society of Mechanical Engineers (ASME)

ASME PTC 19.3	Temperature Measurement Instruments and Apparatus.
ASME BPVC, Section VIII	Boiler and Pressure Vessel Code, Rules for Construction of Pressure Vessels, Division 1.

British Standards Institute (BSI)

BS 6739	Code of practice for Instrumentation in process control systems: installation design and practice.
BS EN 10204	Metallic products — Types of inspection documents.

Institute of Electrical and Electronics Engineers (IEEE)

IEEE Standard 518	Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources.
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Instrumentation Society of America (ISA)

ISA 20-1981	Specification Forms for Process Measurement and Control Instruments, Primary Elements, and Control Valves.
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International Electrotechnical Commission (IEC)

IEC 60529	Degrees of protection provided by enclosures (IP Code).
IEC 60584	Thermocouples.
IEC 60751	Industrial platinum resistance thermometer sensors.
IEC 61520	Metal thermowells for thermometer sensors – Functional dimensions.

National Electrical Manufacturers Association (NEMA)

NEMA 250	Enclosures for Electrical Equipment (1000 Volts Maximum).
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3. Symbols and abbreviations

For the purpose of this GP (GIS), the following symbols and abbreviations apply:

AWG American Wire Gauge.

EMI Electromagnetic interference.

IS Intrinsically safe.

I/O Input/output.

NPS Nominal pipe size.

NPT National pipe taper thread.

OAL Overall length.

OD Outer diameter.

PAS Process automation system.

PID Proportional integral derivative.

PT Platinum.

PVC Polyvinyl chloride.

RFI Radio frequency interference.

RTD Resistance temperature detector.

SS Stainless steel.

4. Temperature measurement**4.1. General**

- a. Temperature instruments shall comply with GP 30-25. Additional guidance on temperature instruments is contained in API RP 551, Section 5.
- b. Elements should be removable during normal plant operations, with the following exceptions:
 1. If embedded mineral insulated sensors are used to measure bearing or motor/generator winding temperatures.



2. On air conditioning systems, if removal and subsequent reinsertion of sensors can be performed without undue problems.
3. If skin temperatures of heater or boiler tubes are measured by direct contact sensors.

In the listed cases (1), (2), and (3), thermowells are not commonly used. There is, however, a requirement to seal the process from the environment. The common method is with a compression fitting. In certain applications (for example, reactor bed temperature), it may be necessary to pass the sensor through a special isolating shear valve so that if a compression fitting fails, process isolation can be achieved. In such cases, the design should ensure the temperature sensor does not drop into the process. This may require the use of a special probe with a reduced diameter tip.

- c. If sensors are installed without a thermowell and the process fluid is potentially hazardous, the circuit shall be intrinsically safe (IS).

IS sensor circuits should be avoided. Galvanic isolators degrade the measurement uncertainty of the loop. Even leakage currents in "low leakage" Zener barriers degrade the measurement.

- d. Instrument's electronic housing for outdoor use shall comply with IEC IP 66 in accordance with IEC 60529 (NEMA 4X in accordance with NEMA 250).

In aggressively corrosive environments, SS enclosures may be required.

- e. Instruments in hazardous (classified) areas shall comply with GP 12-60.
- f. Protection required for radio frequency interference (RFI) shall be discussed and agreed upon with Vendor.

The effect of RFI may need to be considered as part of the overall installation.

- g. Temperature instrumentation may be specified using the following BP data sheets:

1. DS 30-01.1 Temperature Gages.
2. DS 30-01.2 RTDs, Thermocouples, Transmitters and Thermowells.
3. DS 30-01.3 Temperature Instruments.

4.2. Selection

- a. Resistance temperature detectors (RTDs) should be used for the following applications:
 1. Control.
 2. Alarm.
 3. Shutdown.
- b. The use of head mounted RTD transmitters should be considered to eliminate problems of unbalanced resistance element extension leads. (See 10.1)
- c. RTDs or thermocouples may be used for remote temperature indication.

RTDs are the preferred sensor type.

For temperatures ranging from cryogenic to about 450°C (850°F), an RTD is preferable over a thermocouple. Though RTDs were once more expensive, today the cost difference between the two is negligible.

RTDs provide greater accuracy, stability, and life span. Over its useable range, a standard grade RTD provides more than twice the accuracy of a thermocouple.

RTDs drift just fractions of a degree per year and are accurate for many years when used at temperatures below 450°C (850°F). Thermocouples, however, are not as accurate and require frequent replacement.



- d. If RTDs are not suitable, thermocouples should be used.

RTDs may not be suitable for applications that suffer from vibration. The manufacturer should be consulted in such cases.

- e. Use of bimetallic and filled systems for control, alarm, and shutdown applications shall be subject to BP approval.

Filled systems have an inherent failure mode that indicates low temperature (the unsafe condition for many applications). Bimetallic and filled systems are difficult to check locally and are susceptible to mechanical damage. In addition, failures are not self-revealing.

Because of the above, the use of bimetallic and filled systems on control, alarm, and shutdown service is not recommended. However, for some applications, such as local control on noncritical service or on pneumatic systems (for example, tank heating and electrical tracing), their use may be considered. Also, such systems are often supplied as part of a packaged plant. In this case, if such criteria as contractual guarantees are involved, the use of these systems should be individually assessed.

4.3. Design considerations

- a. Temperature elements (RTDs or thermocouples) shall have only one receiving instrument.
- b. Instrument scales shall be specified to ensure average service operating temperature is approximately 50% of full scale temperature, and maximum expected temperature is less than 90% of full scale temperature.
- c. Temperature sensing elements should be totally immersed into the process fluid.

Total immersion provides the highest accuracy temperature measurement.

- d. Thermocouple devices should be supplied with burnout protection as follows:

1. Burnout protection actions should include upscale, downscale, and hold.
2. Actions should be selectable.
3. Designs should include detection of sensor failures and measurement circuit wiring faults.

Diagnostic features within "smart" transmitters may provide fault detection.

4. Sensor failures should be alarmed.
- e. Safety and operability shall be considered in selection of burnout protection action.
 1. In services that are for operator monitoring only and do not affect plant operation (for example, indications, recordings, or alarms), burnout protection should drive measured variable readings to plant fault condition.
 2. For shutdown and control duties, each application should be individually assessed to ensure sensor, transmitter, or wiring failure modes inherently drives the plant to safe condition or that burnout protection initiates action to protect the plant (for example, switching a controller to "Manual").
 3. In services that affect plant operation (for example, control loops and trip functions), the plant should not be tripped nor any control malfunction be caused by thermocouple burnout. However, safety systems shall not be compromised by thermocouple burnout.

A two from three voting system may be required to achieve this.

4. For each system, an alarm on the thermocouple burnout should be included to alert the operator when important functions trip controls to "Manual".



Failure detection of an RTD is more clearly defined than failure detection of a thermocouple.

- f. For safety functions, separate sensors and transmitters shall be used. Refer to GP 30-80.
- g. Temperature instruments installed in hazardous areas shall comply with GP 12-60.
- h. For control applications the use of dual element sensors is strongly recommended.

Use of dual elements allows the user to switch connecting wires from one element to the second element without removing the sensor assembly from service, should the first element fail or require verification.

Dual elements are preferred as they cost less to install and minimise the impact on operations in the event of an element failure.

- i. If dual elements are used for IS measurements, isolation between elements should be checked to ensure it meets IS requirements.

5. Thermowells

5.1. General

- a. With the exception of embedded devices in machines, boilers, and special duty devices, thermowells shall be provided for:

1. RTD or thermocouple assemblies.
2. Filled temperature systems.
3. Dial thermometers.
4. Temperature test locations.

Test wells are supplied if a measuring element is not provided.

Temperature elements are installed in a thermowell to protect temperature sensing elements and to allow online maintenance.

- b. Standard thermowell dimensions should be used.

Cost is reduced if thermowells comply with process industry standards.

A standard bore size that permits a thermowell to accommodate an RTD, a thermocouple, a bimetallic thermometer, or a test thermometer provides design and operating flexibility as well as cost reduction.

- c. Filled thermal systems and some special test thermometers may require the use of non-standard thermowell bore.

Test thermometers are used for mass balances, for heat transfer analysis and/or where a permanent temperature monitoring is not required for normal operations. Special test thermometers for accuracy requirements may require a specific sensor bulb size that may not fit in a standard dimension thermowell. Furthermore, vapour or gas filled bulbs are usually 17,5 mm (11/16 in) diameter, which is not a standard dimension.

5.2. Design considerations

- a. Thermowell design shall comply with Annex B and IEC 61520.
- b. Thermowell pressure/temperature ratings, testing and certification requirements shall be compatible with applicable piping or vessel specifications.
- c. Material certification shall comply with 3.1B of BS EN 10204, as a minimum.



- d. Unless specified otherwise by BP, thermowells shall undergo internal hydrostatic testing with a pressure of 138 bar(g) (2 000 psig).
- e. Except in environments where process compatible alloys or welding are required, thermowells shall be series 316 SS.

Stainless steel is not acceptable in environments where the chloride ion content exceeds 100 ppm.

Sour service requires at least 316 SS.

Corrosive services may require thermowells made of other materials. Thermowells are available in special grades of stainless steel, chrome-moly steel, Hastelloy B and C, nickel, titanium, monel, and many other materials.

For hot amine service, monel thermowells are recommended.

- f. Except in environments where process compatible alloys are required, for fabricated flanged or weld-in thermowells, 316 L SS shall be specified.

316 SS is not acceptable for welding construction or application due to carbon content. Low carbon (316 L) is required.

- g. Thermowells shall be bored from solid barstock. Flanges may be attached by a full penetration weld. N.D.T. on flange weld shall be dye penetrant.

- h. If feasible, thermowells should be tapered rather than stepped or straight.

For high line velocities that approach maximum stream velocity limits, shorter tapered thermowells with greater wall thickness increase the natural frequency of the thermowell.

Generally, a tapered thermowell does not cost more than a stepped or straight thermowell, unless the supplier is not set up to make tapered thermowells.

Calculations for tapered thermowells can be done more easily than for straight or stepped thermowells.

- i. If feasible, thermowell overall length (OAL) for use with RTDs or thermocouples should match the OAL used for standard dial thermometers.
- j. Thermowells shall withstand stream velocity stresses. As per ASME PTC 19.3, the ratio of wake frequency or Strouhal frequency to natural frequency of a thermowell shall be less than 0,8.

$$f_w = 220 (2,64) V/B \quad \text{where:}$$

f_w = wake frequency, cycles per second

V = fluid velocity, m/s (fps)

B = thermowell diameter at tip, mm (in)

Fluid flow past a thermowell causes vortices to be shed from the well at a frequency, termed the wake frequency, proportional to the fluid velocity. If the wake frequency is at or near the natural frequency of a given thermowell, a resonance condition may occur where a massive amount of energy is absorbed by the thermowell, resulting in very high stresses and possible failure. Even if the thermowell does not fail, the sensor capsule inside the thermowell may be subjected to severe levels of shock and vibration, resulting in erroneous readings or total sensor failure.

- k. If the ratio of wake frequency to natural frequency of a thermowell is greater than 0,8 the following should be considered:



1. Decrease the wake frequency by reducing the flow velocity or use a larger diameter thermowell, or
 2. Increase the natural frequency of the thermowell by using a stiffer thermowell configuration, i.e. a different thermowell type or material, or a shorter length thermowell.
1. Except in tank or reactor installations, thermowells shall be assessed for resonance if:
 1. Thermowells are special design.
 2. BP standard wells are used with velocities that exceed Table 1.

Table 1 – Maximum velocity for BP standard wells

Thermowell length	Maximum gas or liquid velocity
250 mm (9 in)	18 m/s (60 ft/s)
300 mm (12 in)	11 m/s (36 ft/s)
500 mm (18 in)	5 m/s (16 ft/s)

3. Excessive mechanical vibration or organ pipe effect is expected.
Thermowells are subject to vibration transmitted from adjacent machinery or vortex shedding from high fluid flow rates.
- m. The maximum permissible thermowell length shall be computed in accordance with ASME PTC 19.3 or equivalent method approved by BP.
The maximum permissible length is dependent upon both vibratory and steady state stress. The requirement for keeping the frequency ratio at 0.8 or less (see 5.2.j) imposes one limitation on maximum length. The other limitation is one of steady state stress considerations.
- n. If short thermowells are required in small diameter pipe work, a thinner wall thermowell should be considered.
Thinner wall thermowells improve response time and reduce measurement errors.
- o. The element sensitive length and thermowell shall match and provide adequate immersion depth into the line or vessel to achieve accurate measurement.
- p. Exposed tip thermowells shall only be specified if control requirements dictate a more rapid response time than can be achieved with conventional thermowells. Use of exposed tip thermowells shall be subject to BP approval.
- q. Fabricated thermowells may be used for RTDs and thermocouples installed in tanks or reactors. Such thermowells usually need to withstand only pressure and temperature conditions, not appreciable flowing fluid forces.
Typically, fabricated thermowells are much longer than standard wells and have a larger bore since they may house multiple elements.
- r. If special thermowells are required, their design shall be subject to BP approval. Special design may be needed for:
 1. Fast response.
 2. High fluid velocities
 3. Measurement of reactor bed temperatures.
 4. Installation in lines smaller than DN 80 (NPS 3).
 5. Analyser installations.



6. Corrosive or erosive service.

For highly corrosive or erosive processes, it may be necessary to coat thermowells. In such cases, advice from manufacturers on various coatings should be obtained.

- s. Refer to Table 2 for guidance on special thermowells.

Table 2 – Factors that influence strength and measurement (ASME PTC 19.3)

Factor	Ideal for Measurement	Ideal for Strength
Length	Long Conductivity errors reduced. Active porting of sensor must be in flow stream.	Short Impingement force reduced. Higher natural frequency.
Thickness	Thin Reduced conductivity loss. Faster response.	Thick Greater moment of inertia, less stress. Higher natural frequency.
Mass Velocity	High Increase heat transfer. Faster response.	Low Reduces impingement forces. Lower Karman trail vortex frequency.

5.3. Installation

- a. Unless otherwise approved by BP, temperature sensors shall be installed in thermowells.

The most common application of sensors fitted without thermowells are skin thermocouples on heater tubes, bearing temperatures, and fast response measurements on gas turbines, etc. In other applications, temperature devices should be installed with thermowells except in special circumstances. Such exceptions are usually for reasons that relate to response speed or severe space limitations.

- b. For installations without thermowells and exposed tip thermowells:
- Design shall prevent accidental removal of temperature sensor.
 - Installation shall be clearly labelled. A permanently affixed label shall indicate to maintenance personnel that no thermowell has been installed. Labels shall also warn of need to depressurise line or vessel before removing temperature device. See Annex B.
 - An effective secondary seal shall be used to ensure process fluid under pressure does not enter transmission cables.
- c. Unless measurement would be adversely affected, thermowells should be mounted into pipes, rather than process vessels.
- d. Threaded thermowells shall be limited to locations where threaded piping connections are allowed.
- e. Pipe diameter for thermowell installations should be at least DN 80 (NPS 3).
- f. Thermowell nozzles in piping should be installed in accordance with Annex A.
- g. Unless measurement is otherwise calculated (refer to 5.2.m, thermowell installations shall allow immersion between 1/3 and 2/3 the internal diameter of pipe, elbow, or tee.
- h. If the thermowell has a weep hole, it should be installed with weep hole in downward position.



Weep holes allow moisture to drain out of the well for protection against freeze, damage, or rupture.

- i. In vessels, thermowells:
 1. Shall have nozzles installed in accordance with ASME BPVC, Section VIII.
 2. Should have an insertion length of 440 mm (16 in).
- j. In columns, thermowells shall be immersed into liquid. Other methods shall be subject to BP approval.
- k. Thermowells requiring replacement under pressure shall be retractable and should be specified and installed in accordance with Annex I. Retractable thermowells shall:
 1. Have sufficient clearance for withdrawal and replacement. Distance for withdrawal shall be approximately thermowell length plus at least 300 mm (12 in).
 2. Be inserted until thermowell thrust collar is approximately 12,5 mm (1/2 in) from packing assembly. (Refer to Annex I.)
 3. Have an immersion depth of at least 50 mm (2 in) for liquids, and 75 mm (3 in) for gases.
 4. Have assemblies braced to resist external forces applied during withdrawal.
- l. Test thermowells shall be fitted with brass or stainless steel plugs that are secured by chain or wire of corrosion resistant material per Figure 1.

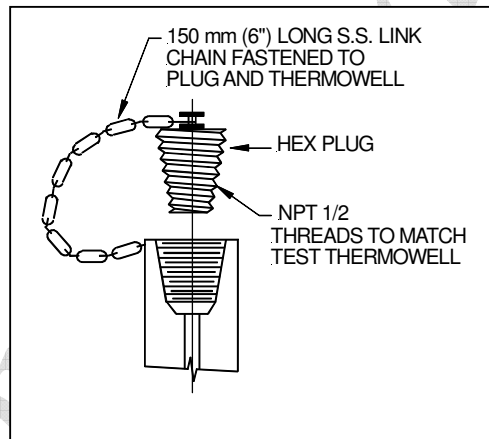


Figure 1 – Test thermowell plug

- m. If installed in insulated lines and vessels, thermowells should be examined to ensure lagging extensions match insulation thickness.

6. Resistance temperature detectors

6.1. General

- a. Nominal 100 ohm at 0°C (32°F), platinum, metal sheathed, mineral insulated RTDs are the preferred temperature sensing device.

For Class 1 Fiscal/Custody Transfer measurement systems IEC 60751 Class A RTD elements shall be used, as a minimum, and consideration given to using higher accuracy elements.

- b. Standard RTDs should be limited to a temperature range from –200°C to 450°C (–300°F to 850°F), provided this falls within the manufacturer's recommended range.

