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Revision Memo

12/04	Highlights of this revision are as follows:
Par. 2.2	Updated references to Global Practices
Par. 8.4	Additional liquid overfill calculatin guidance provided
Par. 9.7	Updated guidance on prevention of failure of reactor outlet collector design
Par. 14.4	Updated flange rating tables to most current standard of ASME B16.5

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1. SCOPE

This Design Practice provides guidelines for establishing the **design temperature, design pressure, CET**, and other parameters that are necessary for the mechanical design of **pressure vessels, piping**, storage tanks, and other equipment. The pressure-temperature ratings of steel pipe flanges and flanged fittings are also included. Good engineering judgment must be applied when using these guidelines since every situation that may be encountered in process design cannot be covered in a document of this type.

Refer to [Design Practice DPs VIII, X and XI](#) for guidance on establishing the **design temperature, design pressure**, and **CET** for fired heaters, pumps, and compressors.

Note also that these guidelines are intended for new installations. Application to existing equipment should be done considering past practices and current guidelines, as well as experience with the specific installation.

2. REFERENCES

2.1 DESIGN PRACTICES

- a. [DP VII](#) Fixed-Bed Reactors
- b. [DP VIII](#) Fired Heaters
- c. [DP X](#) Pumps
- d. [DP XI](#) Compressors
- e. [DP XIV](#) Fluid Flow
- f. [DP XV](#) Safety in Plant Design
- g. [Offsite Design Practices](#)

2.2 GLOBAL PRACTICES

- a. GP 03-02-04 Pressure Relieving Systems
- b. GP 03-07-01 Piping Layout, Supports, and Flexibility
- c. GP 03-10-01 Piping Selection and Design Criteria
- d. GP 03-15-01 Pressure Relief Valves
- e. GP 03-16-01 Flanged Joints, Gaskets, and Bolting
- f. GP 05-01-01 Pressure Vessels
- g. GP 05-03-01 Pressure Testing of Unfired Pressure Vessels
- h. GP 06-01-01 TEMA Type Shell and Tube Heat Exchangers
- i. GP 09-02-01 Additional Requirements for Pressure Storage Spheres
- j. GP 09-04-01 Atmospheric Storage Tanks
- k. GP 09-06-01 Refrigerated Storage Tanks
- l. GP 14-01-01 External Insulation
- m. GP 18-04-01 Postweld Heat Treatment of Equipment Handling Alkaline Solutions
- n. GP 18-10-01 Additional Requirements for Materials

2.3 OTHER REFERENCES

- b. *Refinery Construction Materials Manual*, EMRE Manual No. EETD 028
- c. *Chemicals Construction Materials Manual*, EMRE Manual No. CED 009
- d. *Exxon Engineering Materials Data Book*, Volumes I and II
- e. *Exxon Piping Vibration Evaluation Guide*, ER&E Report No. EE.21E.89
- f. *Determination of Pressure Transients in Piping Caused by Pump Startup*, ER&E Report No. EE.5E.80

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- g. *Analysis of Transient Pressures and Flows in Liquid-Filled Pipelines*, ER&E Report No. EE.137E.81
- h. *Use of High Integrity Protection Systems (HIPS) to Reduce Loads to Existing Flare Systems*, ER&E Report No. EE.137E.96
- i. *Surge Relief Devices for Liquid-Filled Piping Systems*, ER&E Report No. EE.126E.82
- j. *Surge Relief Devices for Liquid-Filled Piping Systems*, ER&E Report No. EE.74E.83
- k. *Evaluating Surge Pressures in Piping Systems*, ER&E Report No. EE105E.84
- l. *Improved Analysis Method for Use in Pipe Pressure Surge Evaluations*, ER&E Report No. EE.62E.86
- m. *Reducing Pressure Relief Valve Chatter Induced by Hydraulic Surge*, ER&E Report No. EE.86E.95
- n. *Exxon Blue Book*, EMRE Manual Nos. 012 and 011
- o. *Exxon Fitness for Service Guide*, EMRE Manual No. TMEE17
- p. *API 620, Recommended Rules for the Design and Construction of Large, Welded, Low-Pressure Storage Tanks*
- q. *API 650, Welded Steel Tanks for Oil Storage*
- r. *ASME B16.1, Cast Iron Pipe Flanges and Flanged Fittings*
- s. *ASME B16.5, Pipe Flanges and Flanged Fittings*
- t. *ASME B16.34, Valves, Flanged, Threaded, and Welding End*
- u. *ASME B16.47, Large Diameter Steel Flanges, NPS 26 through NPS 60*
- v. *ASME B31.1, Power Piping*
- w. *ASME B31.3, Process Piping*
- y. *ASME Boiler and Pressure Vessel Code, [DP VIII](#), Rules for Construction of Pressure Vessels*
 - Division 1
 - Division 2, *Alternative Rules*
 - Division 3, *Alternative Rules for High Pressure Vessels*

3. INTRODUCTION

Design conditions should be set such that they are adequate to cover all foreseeable **normal and alternative operating conditions**, such as startup, shutdown, process upsets, planned increases in operating severity, different feedstocks or products, reactivation, decoking, and regeneration. Note that **design conditions** include parameters such as liquid level and pressure drop through the equipment in addition to pressure and temperature. **Design contingencies** and **remote contingencies**, as defined in this Design Practice, should also be considered. In most cases, it is necessary to add an increment to the **maximum operating pressure** to obtain the **design pressure**. In addition, it is often desirable to add an increment to the **maximum operating temperature** to obtain the **design temperature**. Design conditions should be specified to also cover minimum temperature (CET) and pressure (vacuum) requirements.

For each piece of equipment and piping, it is necessary to determine the **design contingencies** and **remote contingencies** to be considered in establishing the design conditions vs. those that should be handled by providing overpressure and/or overtemperature protective devices, or by using operating procedures and controls.

It should also be recognized that the occurrence of some events (e.g., **double contingencies**) is practically impossible, so they should not be considered in establishing **design conditions**. Also, there are other contingencies that must be handled by operating procedures and controls, since it is not practical to set design conditions high enough to cover them. In addition, there are certain short-time **remote contingency** events for which it is acceptable to allow the pressure to exceed the **design conditions** by a limited amount, as described in this Design Practice.

For equipment that can contain a liquid (including fluidized or bulk solids), the level of the contents coincident with each pressure/temperature combination must be considered in the design calculations. See **Par. 5** for additional guidance.

It is also necessary to specify other design considerations for equipment design as described in **Par. 12** of this Design Practice.

The development of contingency scenarios, and their categorization as design, remote, or not considered requires experience and judgment since all situations are not covered in this practice. In addition, local codes may have requirements that must be followed.

Terms in bold face are defined in **Par. 4** below.

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4. DEFINITIONS

Alternative Operations

Expected equipment operating modes that differ from **normal operation**.

ASME B16.5

Pipe Flanges and Flanged Fittings. Contains pressure/temperature ratings as well as dimensional and materials requirements for flanges up to NPS 24.

ASME B16.47

Large Diameter Steel Flanges, NPS 26 through NPS 60.

ASME B31.1

Power Piping.

ASME B31.3

Process Piping.

ASME Code

ASME Boiler and Pressure Vessel Code, [DP VIII](#), *Rules for the Construction of Pressure Vessels*.

Division 1 covers minimum construction requirements for the design, fabrication, inspection, testing, and certification of **pressure vessels**.

Division 2 provides an alternative set of rules that require a more detailed design by analysis but permit higher design stress intensity values (i.e., allowable stresses). In addition, some of the fabrication and examination requirements in Division 2 are more restrictive than those contained in Division 1.

Division 3 provides rules for the design, construction, and inspection of pressure vessels with design pressures generally above 10,000 psi (69,000 kPa).

Auto-refrigeration

Cooling of a fluid caused by reduction in pressure, or of a liquid by evaporation, usually associated with a reduction in pressure.

Category M Fluid Service

ASME B31.3 defines a fluid service as **Category M** when the potential for personnel exposure to the fluid is judged to be significant, and a single exposure to a very small quantity of a toxic fluid, caused by leakage, can produce serious irreversible harm to persons on breathing or bodily contact, even when prompt restorative measures are taken. An extremely small percentage of process plant **piping** covered by **ASME B31.3** will be classified as **Category M Fluid Service**. Consultation with the Safety/Risk Section of EMRE is recommended before deciding to classify a service as **Category M**.

Piping in Category M Fluid Service usually would be connected to vessels in **lethal service**.

Common Cause Failure Mode

A coincident failure in two or more similar elements of a system caused by a single event. An example of a common cause failure mode is the simultaneous failure of two independent level instruments due to freezing of the process fluid in the instrument leads when exposed to low ambient temperatures.

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Critical Exposure Temperature (CET)

The **Critical Exposure Temperature (CET)** is defined as the lowest metal temperature for which the equipment must be designed. The CET is derived from either the operating, upset or atmospheric conditions. The CET may initially be determined as either the lowest metal temperature at which a component will be subject to a pressure greater than 25% of the design pressure, or the **lowest one-day mean ambient temperature, whichever is less**. See **Par. 11.5** for additional information related to CET determination. The CET may be a single temperature at an operating pressure or an envelope of temperatures and pressures. The **CET** is used as one of the criteria for selecting the materials of construction and toughness requirements.

No knowledge of the equipment design details, including materials of construction, is required to determine the **CET** as defined above. However, when the equipment details and design codes are known, or when the fitness for service of existing equipment is being evaluated, a less conservative value of CET may be specified according to the following criteria:

- a. **Pressure Vessels** (including heat exchangers and pressure storage spheres): The CET is defined as the lowest metal temperature at which a component will be subjected to a general primary membrane tensile stress greater than 8000 psi (55.2 MPa). The CET may also be defined according to the following options:
 1. The minimum metal temperature at which a component could be subjected to a pressure greater than 40% of the design pressure for vessels constructed to the ASME Code [DP VIII Division 1](#), with a 4.0 safety factor as required by the Code prior to the 1999 addenda.
 2. The minimum metal temperature at which a component could be subjected to a pressure greater than 35% of the design pressure for vessels constructed to the ASME Code [DP VIII Division 1](#), with a 3.5 safety factor as recognized in the 1999 addenda to the ASME Code.
 3. The minimum metal temperature at which a component could be subjected to a pressure greater than 30% of the design pressure for vessels constructed to the ASME Code [DP VIII Division 2](#).
 4. For pressure vessels designed to a higher allowable stress than that permitted in these codes, or when the applicable code is unknown, the CET may be taken as the lowest metal temperature at which the vessel will be subjected to a pressure greater than 25% of the design pressure or a membrane stress greater than 8000 psi (55.2 Mpa).

The CET for pressure vessels is determined from the anticipated process and atmospheric conditions.

- b. **Piping**: The CET for systems constructed to the ASME B31.3 Piping Code is defined as the lowest metal temperature at which a component will be subject to either a pressure greater than 30% of the design pressure or a combined total longitudinal stress due to pressure, weight effects and displacement strains exceeding 8000 psi (55.2 MPa). The CET for piping is determined from the anticipated process and atmospheric conditions.
- c. **Machinery**: The CET for Machinery pressure containing components is specified by the process designer, consistent with the considerations in **Par. 11.5.4**. Consult with the local Machinery Engineering contact or the Machinery Engineering Section of EMRE for more details.
- d. **Atmospheric storage tanks**, the **CET** is defined as the lower of either the lowest one-day mean atmospheric temperature plus 15°F (8°C), or the hydrostatic test temperature.

Cryogenic Service

A service with a **CET** colder than -150°F (-101°C).

Cyclic Service

Equipment, excluding **piping**, is in **cyclic service** if the number of startups and shutdowns plus other significant pressure or temperature cycles may exceed 1000 during the life of the unit.

Piping is in **cyclic service** if the number of startups and shutdowns plus other significant pressure or temperature cycles may exceed 7000 during the life of the unit.

Design Conditions

The **design pressure, design temperature, CET**, liquid level (including fluidized or bulk solids), and **vessel pressure drop** specified for equipment and **piping**. An equipment item may have more than one set of **design conditions**, and different sections of a vessel can have different design conditions.

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Design Contingency

An abnormal condition including mal-operation, equipment malfunction, or other event that is not planned, but is foreseen to the extent that the situations involved are considered in establishing equipment **design conditions**.

Design Minimum Temperature

For **piping** designed to **ASME B31.3**, this term is the lowest component temperature expected in service. This temperature may establish special design and material qualification requirements. Components considered should include pipes, valves, flanges, gaskets and bolting. The **design minimum temperature** should be equal to or colder than the **CET**.

DESIGN PRESSURE

Design pressure is the pressure in the equipment or **piping** under consideration at the most severe combination of coincident temperature, liquid level (including fluidized or bulk solids), and **vessel pressure drop** expected during service, that results in the greatest required component thickness and the highest component rating (e.g., highest **ASME B16.5** flange class). More than one set of design conditions should be specified if the most severe pressure, temperature, liquid level, and **vessel pressure drop** will not occur at the same time.

For **pressure vessels**, the design pressure refers to the pressure at the top of the vessel. Maximum liquid level and **vessel pressure drop** (if appropriate) should also be specified. **Design pressure** is equal to or less than the **Maximum Allowable Working Pressure (MAWP)**.

Design Temperature

The mean metal temperature in the component under consideration at the most severe condition of coincident pressure, liquid level (including fluidized or bulk solids), and **vessel pressure drop** expected during operation. More than one set of design conditions should be specified if the most severe pressure, temperature, liquid level, and **vessel pressure drop** will not occur at the same time. This is usually, but not necessarily, the warmest temperature for equipment with only one set of design conditions.

Double or Multiple Contingency

Two or more independent, unrelated, abnormal events that, if they occurred simultaneously or within a restricted short time interval, could result in an **emergency**. Multiple contingencies are normally not considered in the setting of design conditions or the design of overpressure protection facilities. However, it is the responsibility of the designer to consider the vulnerability of the control and protective system to **common cause failure modes** which might reasonably apply. Examples of common cause failure modes might relate to potentially fouling conditions, low winter temperatures or off normal operations, that might cause simultaneous failure of process control and protection systems. In such circumstances, the designer may need to provide designated "safety critical" protection, such as instrument purge or heating, safety valve inlet / outlet line tracing, independent types of instrument sensors, etc.

Emergency

An interruption from **normal operation** in which personnel, equipment, or the environment may be endangered or adversely affected.

Intermediate-Time Pressure Allowance (for Piping Only)

ASME B31.3 permits an increase of not more than 20% above the **design pressure** at the temperature of the increased condition for a maximum of 50 hours at any one time and for less than 500 hours per year, provided the restrictions in **Par. 11.3.4** are met.

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Lethal Service

Service in which the equipment contains toxic gases or liquids of such a nature that a very small amount of the gas or of the vapor or the liquid mixed or unmixed with air is dangerous to life when inhaled. This class includes substances of this nature that are stored under pressure or may generate a pressure if stored in a closed vessel. An extremely small percentage of **pressure vessels** covered by the **ASME Code** will be in **lethal service**. Consultation with the Safety/Risk Section of EMRE is recommended before deciding to classify a service as **lethal**.

Vessels in **lethal service** usually would be connected to **piping** in **Category M Fluid Service**.

Lowest One-Day Mean Ambient Temperature

The lowest 24-hour average air temperature recorded at the site for the last 50 years.

Low Temperature Service

Service in which the fluid temperature during normal or contingency operation is below the **lowest one-day mean ambient temperature** for a particular location.

Maximum Allowable Working Pressure (MAWP)

For pumps and compressors, see [DP X-A](#) and [DP XI-A](#), respectively.

For **pressure vessels**, per the **ASME Code**, **MAWP** is the maximum (gauge) pressure permissible at the top of a vessel in its normal operating position at the designated coincident temperature and liquid level specified for that pressure. **MAWP** does not apply to piping. The **MAWP**:

1. May be determined for more than one designated operating temperature and coincident liquid level, using for each temperature the applicable allowable stress value.
2. Is the least of the values for the internal or external pressure for any of the pressure boundary components.
3. Is based on calculations using nominal thickness minus the allowances for corrosion, and minus the thickness required for loading other than pressure for every element of a vessel.
4. Is assumed to be equal to the **design pressure** for all cases in which calculations were not made to determine the value of the **MAWP**.
5. May, in final vessel construction, be higher than the **design pressure**, due to the selection of commercially available plate with a nominal thickness greater than that required for pressure and other loading.

Maximum Operating Pressure

The maximum internal pressure, under the coincident temperature, predicted for **normal operation, alternative operations**, and applicable **design contingencies**. Different **maximum operating pressures** may be specified for each section of a vessel or **piping** system if the fluid pressures will be different.

Maximum Operating Temperature

The maximum process fluid temperature, under the coincident pressure, predicted for **normal operation, alternative operations**, and applicable **design contingencies**. Different **maximum operating temperatures** may be specified for each section of a vessel or **piping** system if the fluid temperatures will be different.

Minimum Design Metal Temperature (MDMT)

For **pressure vessels**, the term used by the **ASME Code** to describe the lowest metal temperature expected in service, except when lower temperatures are permitted by **Paragraph UCS-66** of the **ASME Code**, Division 1. It is used in the **ASME Code**, Division 1 to specify the minimum temperature for use in mechanical design, and after completion of vessel fabrication to define the "as built" minimum vessel temperature based on the warmest of the **MDMTs** determined for each component of the vessel. The equipment designer specifies the **MDMT** based on the **CET** that had been specified by the process designer. The **MDMT** should be equal to or colder than the **CET**.

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Minimum Operating Pressure

The minimum internal pressure (for vacuum conditions), under the coincident temperature, predicted for **normal operation**, **alternative operations**, and applicable **design contingencies**.

Minimum Operating Temperature

For **pressure vessels** and **piping**, the minimum process fluid temperature expected for **normal operation**, **alternative operations**, and applicable **design contingencies** regardless of pressure.

Minimum Test Temperature

The **minimum test temperature** is the lowest metal temperature that should be permitted during a pressure test.

Normal Operation

Operation in equipment or **piping** processing or handling the material it was designed to process or handle.

Operating Conditions

A particular combination of pressure, temperature, liquid level and **vessel pressure drop**.

Piping

An assembly of pipes, fittings, flanges, bolting, gaskets, valves, strainers, pipe supporting elements, expansion joints, and other components used to convey, distribute, mix, separate, discharge, meter, control, or snub fluid flows.

Piping Code

ASME B31.3 Process Piping, **ASME B31.1 Power Piping**, or other code that may apply at a particular location.

Pressure Vessel

A container for the containment of pressure, either internal or external, that does not meet the definition of piping or storage tank and falls within the scope of the **ASME Code** or other applicable pressure vessel code. The pressure may be obtained from an external source, or by the application of heat or cold from a direct or indirect source, or any combination thereof.

Pressure Relief Device (PRD)

A safety valve, relief valve, safety relief valve, pressure relief valve, vacuum relief valve, rupture disk, buckling pin device, etc., that actuates at a pre-set level to limit pressure or vacuum in equipment.

Remote Contingency

An abnormal condition that could result in exceeding the **design pressure** at the coincident temperature, but whose probability of occurrence is so low that it is not considered as a **design contingency**. Note that temperatures above the design temperature may also be permitted under remote contingency conditions.

Set Pressure and Burst Pressure

The **set pressure** or **burst pressure** is the gage pressure at which a **PRD** is adjusted to open under service conditions. For a relief or safety relief valve in liquid service, the **set pressure** is the inlet pressure at which the valve starts to discharge with a significant volume under service conditions. For a safety or safety relief valve in gas or vapor service, including two phase and supercritical conditions, the **set pressure** is the inlet pressure at which the valve pops open under service conditions. Note that in both cases, leakage may occur at pressures above 90% of the **set pressure**. For rupture disks or buckling pin valves, the **burst pressure** is the gage pressure at which the disk is expected to burst or the buckling pin is expected to buckle.

Short-Time Pressure Allowance (for Piping Only)

Per **ASME B31.3**, an intrinsically limited increase of not more than 33% above the **design pressure** (including accumulation - see **DP XV-C**) at the temperature of the increased condition. It is permitted for a maximum of 10 hours at any one time and for less than 100 hours per year, provided the restrictions in **Par. 11.3.4** are met.

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Storage Tank

Per **API 650, Welded Steel Tanks for Oil Storage**, a vertical, cylindrical, aboveground, closed or open top tank in various sizes and capacities for storing petroleum, petroleum products, and other liquid products at internal pressures approximating atmospheric. It includes only tanks whose entire bottom is uniformly supported and to tanks in nonrefrigerated service that have a **maximum operating temperature** of 500°F (260°C).

Vessel Pressure Drop

The maximum (positive) difference in pressure between the bottom of a vessel and the top, caused by losses due to flow. The liquid static head is not included and should be specified separately. Pressure drop need not be considered in down flow vessels.

5. ECONOMIC CONSIDERATIONS IN PROCESS DESIGN

The purpose of this section of the Design Practice is to ensure that **design conditions** for all pressurized equipment are set appropriately, based on the requirements of the process. Detailed economic considerations are outside of the scope of this section. However, some general guidance in the specification of equipment and **piping** is provided as follows:

- a. Economics should be based on project "life cycle cost" and not just initial investment.
- b. Carbon and low alloy steel vessels can be designed in accordance with the **1998 ASME Code** Division 1 for temperatures up to 500°F (260°C) with very little or no additional cost for the vessel, as the allowable stresses for these materials are essentially constant in this temperature range. Note, however, that this may require the use of a higher flange rating and that the connecting piping must also be designed for a higher temperature so that adequate wall thicknesses and piping flexibility are provided. For vessels designed to **ASME Code**, Division 2 or most codes of other nations, however, the allowable stress is reduced from the ambient value at temperatures below 500°F (260°C); so, there may be some additional cost associated with the specification of temperatures between ambient and 500°F (260°C). From 500°F (260°C) to 750°F (400°C), the allowable stress decreases slightly. At temperatures above 750°F (400°C), the allowable stress decreases sharply in most codes, resulting in significant increases in vessel costs. Economic alternatives of internally lined or alloy steel equipment should therefore be considered for temperatures above 750°F (400°C). The cost of carbon steel and low alloy equipment may be minimized by careful selection of the **design conditions**.
- c. For **pressure vessels** that are expected to weigh over 100 tons (91 tonnes), or with wall thickness over 2 in. (50 mm), or with a **design pressure** above 1,500 psi (10,000 kPa), construction to the **ASME Code**, Division 2 rather than Division 1 may result in a significantly lower total erected cost. Consult with the local mechanical engineering contact or the Mechanical Engineering Section of EMRE for more details.
- d. The pressure / temperature ratings of most process **piping** systems are usually governed by the flange ratings provided in **ASME B16.5**. Ratings for some common flange materials are shown in **Par. 14**. For other materials, refer to **ASME B16.5**. **Piping** system cost will increase in steps when the **design pressure/temperature** conditions are increased to the point where they require use of the next higher flange rating class. An increase in the pipe schedule (i.e., wall thickness) may also be required at higher pressures.
- e. In the case of some large diameter, low pressure **piping**, commonly available pipe schedules (e.g., Sch. 10 or 20) are not used; so, the pipe wall thickness and cost may increase proportionally with **design pressure**. Examples are flue gas lines in fluid catalytic cracking and fluid coker units, and flare headers.
- f. If the equipment is not in **low temperature service**, it is usually economically acceptable to use the **lowest one-day mean ambient temperature** as the **CET**. In the past, there were cases in which preheating the material prior to pressurization was specified to reduce costs. However, carbon steel material availability currently permits specification of **CETs** as low as -55°F (-48°C) without significant additional cost. Therefore, specification of preheat should be done only in unusual cases or when preheat is economically justified to avoid a change to a more expensive low-temperature material. Consult with the local materials engineering contact or the Materials Engineering Section of EMRE for more details.
- g. It may be economical to increase the **design pressure** for vessels tied to a closed flare system to reduce the size of the **PRD** and associated **piping**.

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- h. The design of the bottom section of a tower may be governed by conditions other than process conditions. Often, wind or hydrostatic test loads (and, occasionally, earthquake loads) will govern the shell thickness at the bottom section of tall towers [generally over 100 ft (30 m)]. Therefore, the thickness required for pressure only should not be used for economic studies if towers are over 100 ft (30 m) high. The Mechanical Engineering Section of EMRE may be contacted for additional guidance.
- i. The mean metal temperature, which is used for design, is normally assumed to be equal to the fluid temperature unless the equipment is refractory lined. If the maximum fluid temperature exists for only a short time (i.e., transient condition), or in the case of heavy wall uninsulated equipment, a transient thermal (heat transfer) analysis may be conducted to determine the mean metal temperature expected if there is an economic incentive to reduce the **design temperature**. This mean metal temperature may then be specified as the **design temperature**. Contact the Mechanical Engineering Section of EMRE for assistance.
- j. For heat exchangers, drums, or other **pressure vessels** in liquid service, and with a vertical dimension of less than about 20 ft (6 m), it is usually economically feasible to design for the "liquid full" condition, since the increase in pressure at the bottom of the vessel is small. Consideration should be given to the design of overhead lines in this condition. See **Par. 8.4**.

The design calculations for all **pressure vessels** (including heat exchangers) shall be performed using design pressure, design liquid level (including fluidized and bulk solids), specific gravity, and/or design pressure at various elevations.

Note that if the **design pressure** of a vessel has been established based on the **ASME B16.5** flange pressure/temperature ratings, the additional liquid head may require the next higher flange class rating for nozzles toward the bottom of the vessel. It is important to specify the liquid head in addition to the **design pressures and temperatures**.

The **GP 05-01-01** requirement that all vessels be designed for a field hydrotest does not eliminate the need to consider the liquid head at each design condition. The stress during hydrotest is permitted to be as high as 90% of the material's yield strength, but is typically less than 50% of yield at **design conditions**.

6. DETERMINING DESIGN CONDITIONS - OVERVIEW

For each item of equipment and **piping** system segment, the following steps are recommended to determine the **design conditions**:

- a. Determine the most severe sets of **normal and alternative operating conditions** using the guidelines in **Par. 7**. These sets of **operating conditions** should include as a minimum:
 1. The highest fluid temperature expected, together with the other coincident **operating conditions**.
 2. The highest fluid pressure expected, together with the other coincident **operating conditions**.
 3. The highest liquid level (including fluidized and bulk solids) expected, together with the other coincident operating conditions. Note that it is not necessary to specify liquid level if it is economically acceptable to design the equipment or piping to be full of a 1.0 specific gravity liquid at each design and contingency condition.
 4. The lowest fluid temperature expected regardless of pressure.
 5. The lowest fluid temperature expected when the fluid pressure is at the value determined in **Par. 6.a.2** above.
 6. For heat exchangers, use the worst case differentials based on the design conditions. Alternatively, the maximum expected differential pressures and temperatures may be used.

Vessel pressure drop should be included where applicable.

Other sets of **operating conditions** should be included if there is a possibility that they could be the limiting condition for design. Different sections of a single vessel or **piping** system may have different **operating conditions**.

- b. Determine what **design contingencies** and **remote contingencies** should be considered in determining the **design conditions** using the guidelines in **Pars. 8** and **9**. Normally these contingencies will be handled with **PRDs**. However, in some cases it may be economical to raise the **design pressure and temperature** to eliminate or reduce the size of the **PRD**. These pressure / temperature combinations should be combined with those determined in **Par. 6.a**. Note that **PRDs** limit only pressure and not temperature.
- c. Apply an adjustment, per **Par. 11**, to each operating condition and to each **design** and **remote contingency** condition identified to obtain **design conditions**.

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- d. For equipment other than **piping**, select the sets of **design conditions** to be specified. Multiple sets of **design conditions** may be provided as necessary so that the equipment designer can determine which condition will govern the design thickness for each component.
- e. A single value for the **CET** or an envelope of pressure and temperature should be provided for mechanical design. When a pressure-temperature envelope is specified, the designer must specify the lowest expected temperature for the process.
- f. For **piping**, all credible sets of **design conditions** for each segment of the system should be identified to ensure that they are considered in the **piping** flexibility analysis. Sufficient information should be provided so the analysis can be performed during detailed engineering (see **Par. 13**).
- g. Review the other considerations for equipment design specifications in **Par. 12**.

7. CONSIDERATIONS IN ESTABLISHING OPERATING CONDITIONS

7.1 GENERAL

The first step in establishing **design conditions** for an equipment item is to list the conditions of temperature, pressure, liquid level (including fluidized and bulk solids), and **vessel pressure drop** that the equipment will be exposed to during **normal operation**, and **alternative operations**. This paragraph provides guidelines for developing this list.

The following conditions are usually considered to be either normal or alternative operating modes. These conditions should be considered when specifying **maximum and minimum operating temperatures, pressures**, liquid level, and **vessel pressure drop**.

7.2 COOLING DUE TO AUTO-REFRIGERATION

The cooling of gases and liquids due to **auto-refrigeration** when the pressure is reduced should be considered in determining the **minimum operating temperature** of the equipment.

7.3 FLASHING OF LIQUIDS THROUGH CONTROL VALVES AND PRESSURE RELIEF DEVICES

The cooling of gases and liquids due to **auto-refrigeration** as they expand through control valves and **pressure relief devices** should be considered in determining the **minimum operating temperature** of the valve or device as well as for the downstream **piping** and equipment. It may not be necessary to design an entire vent system or downstream **piping** system for the low temperature if the fluid will mix with a warmer stream or will otherwise increase in temperature.

7.4 STEAMOUT OPERATIONS

Startup and shutdown often utilize steam. Where this is anticipated, the steam temperature and pressure in the equipment during the steamout operation should be listed for consideration in establishing **design conditions**. When equipment is vented during steamout, the pressure is typically very low; therefore, the possibility of developing a vacuum in the vessel after steamout should be considered.

7.5 STARTUP AND SHUTDOWN OPERATIONS

Startup and shutdown often involve sequences of heating and cooling that could impose temperature differentials on **piping** and heat exchangers greater than those for **normal operation**. These should be identified to ensure that they are considered in the **piping** flexibility analysis and heat exchanger design. For example, circulating hot oil to heat up a tower via selected circuits while other circuits remain cold causes the cold circuit **piping** to be stretched by the growth of the tower. In addition, pressure surges that may result from starting and stopping pumps or sudden valve closure or opening on long lines in liquid service should be considered. The Exxon Piping Vibration Evaluation Guide (EE.21E.89), Chapter VIII, contains guidelines for estimating hydraulic surge pressures. The Mechanical Engineering Section of EMRE should be consulted if there are special concerns.