Pressure Vessel Newsletter

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Serving the Pressure Vessel Community Since 2007

From The Editor's Desk:

So you have been tasked with specifying a new pressure vessel. The design pressure is less than 15 psig. Do you specify the vessel to be built to ASME code or not? Well… you choose not, because for pressure of less than 15 psig, ASME code does not require you to stamp the pressure vessel with ASME symbol.

So you specify a non-code pressure vessel and get a vessel that is just slapped together with different materials and welds, inappropriate nozzle connections and even nozzles installed on knuckle seamlines. You did save money… but was it worth it?

OK... this is an extreme example. This likely will not happen but the chances are pretty good that your pressure vessel will not be welded by the best welder in the shop, the materials will not be of best quality, and overall the pressure vessel will be inferior to the ASME code pressure vessel.

The difference between a non-code pressure vessel and a code-pressure vessel is typically about $7000. That extra investment gets you a U-stamp, a pressure test, an inspection report, calculation by a professional engineer, and material traceability. There is no reason, other than cost, not to design a pressure vessel to ASME Section VIII standards.

Also, even if ASME code doesn't seem to apply, other guidelines may. For example, OSHA may require compliance to API 620 requirements for low pressure vessels. The US-DOT may set limits on minimum design pressure allowed for cargo and portable tanks containing various lethal chemicals and may force the fabricator to follow ASME Section VIII code.

In any event, requiring a suitably robust pressure vessel will avoid potential incidents.

[Taken from "Take High Road with Low-Pressure Vessels" by Dirk Willard in Chemical Processing Magazine]

Ramesh K Tiwari

ramesh.tiwari@codesignengg.com

In this issue…

A PRIMER ON ASME SECTION VIII, DIV. 1 MATERIALS

Construction, as used in ASME Code, is an all-inclusive term comprising of materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. ASME Boiler & Pressure Vessel (BPV) Code provides rules for construction of boilers, pressure vessels and nuclear components. The primary code for pressure vessel construction is ASME BPV Section VIII (ASME Section VIII) which is divided into three divisions.

Division 1 largely contains appendices, some mandatory and some nonmandatory, that detail supplementary design criteria, nondestructive examination techniques, and inspection acceptance standards for pressure vessels. It also contains rules that apply to the use of the single ASME certification mark with the U, UM, and UV designators. Division 1 is the focus of this article.

Division 2 contains requirements for the materials, design, and nondestructive examination techniques for pressure vessels. Compared to Division 1, Division 2's standards are far more rigorous, but allow for higher stress intensity values. The rules put forth in Division 2 can also apply to human occupancy pressure vessels, primarily in the diving industry. Like Division 1, Division 2 contains guidelines that apply to the use of the single ASME certification mark as it applies to the U2 and UV designators.

Division 3 provides rules that to pressure vessels that operate at pressures, either internal or external, exceeding 10,000 psi. Division 3 does not establish maximum pressure limits for either of the preceding Section VIII divisions, nor does it establish a minimum pressure limit for itself. Like the previous two divisions, it also provides rules that dictate the use of the single ASME certification mark with the U3 and UV3 designator.

ASME SECTION VIII, DIVISION 1

ASME Section VIII, Division 1 (Division 1) contains mandatory requirements, specific prohibitions, and nonmandatory guidance for pressure vessel materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. It is divided into three Subsections, Mandatory Appendices and Nonmandatory Appendices.

- Subsection A consists of Part UG, covering general requirements applicable to all pressure vessels.
- Subsection B covers specific requirements that are applicable to various methods used in fabrication of pressure vessels. It consists of welding, forging and brazing methods.
- Subsection C covers specific requirements applicable to several classes of materials used in pressure vessel construction. It consists of carbon and low alloy steels, nonferrous metals, high alloy steels, cast iron, clad and lined material, cast ductile iron, ferritic steels with properties enhanced by heat treatment, layered construction, low temperature materials, and impregnated graphite.

  The maximum allowable stress values for these classes of materials (except for impregnated graphite) are provided in ASME Section II, Part D.
- Mandatory Appendices address specific subjects not covered elsewhere in Division 1, and their requirements are mandatory when the subject covered is included in the construction.
- Nonmandatory Appendices provide information and suggested good practices.

Pressure vessels may be designed and constructed using any combination of the methods of fabrication and the classes of materials covered by Division 1, provided the rules applying to each method and material are complied with. The materials that are subject to stress due to pressure shall conform to one of the specifications given in

ASME Section II, Part D, Subpart 1, Tables 1A, 1B and 3. Furthermore, such materials shall be limited to those that are permitted in the applicable part of Subsection C of Division 1.

Material for nonpressure parts, such as skirts, supports, baffles, lugs, clips, and extended heat transfer surfaces, need not conform to the specifications for the material to which they are attached or to a material specification permitted in Division 1, but if attached to the vessel by welding shall be of weldable quality.

We will concentrate on the materials permitted in Subsection C of Division 1, and on ASME Section II, Part D.

USE OF MATERIALS NOT PERMITTED BY DIVISION 1

Using materials other than those allowed by Division 1 is not permitted. Data for new materials may be submitted to the ASME BPV Committee on Materials for approval to use in the construction of pressure vessels. The request for Code approval will normally be for materials for which there is a recognized national or international specification. ASME BPV Committee on Materials only approves materials covered by specifications that have been issued by standards-developing organizations such as, but not limited to, American Petroleum Institute (API), American Society for Testing and Materials (ASTM), American Welding Society (AWS), Canadian Standards Association (CSA), European Committee for Standardization (CEN), Japanese Industrial Standards (JIS), Standards Association of Australia (SAA), and China Standards Committee (CSC). Requests for approval of material specifications of other than national or international organizations, such as those of material producers/ suppliers or equipment manufacturers, will not be considered for approval.

If the materials are made to a recognized national or international specification other than that of ASTM or AWS, the inquirer shall also give notice to the standards-developing organization that a request has been made to ASME for approval of the specification under the ASME Code and should request that the issuing organization grant ASME permission to at least reproduce copies of the specification for Code Committee internal use and, if possible, reprint the specification. For other materials, a request shall be made to ASTM, AWS, or a recognized national or international standardization body to include the material in a specification that can be presented to the BPV Committee on Materials.

The ASME BPV Committee on Materials considers requests to approve new materials only from boiler, pressure vessel, transport tank, nuclear facility component manufacturers, architect‐engineers, or end users. Such requests should be for materials for which there is a reasonable expectation of use in a boiler, pressure vessel, transport tank, or nuclear facility component constructed to the rules of one of the Sections of this Code. When a grade does exist in a defined wrought product form, a material producer/supplier may request the inclusion of additional wrought product forms. When a grade does exist in a defined cast product form, a material producer/supplier may request the inclusion of additional cast product forms.

The organization requesting that an ASME BPV Committee approve a “new material for use in their Code book should be aware that only the BPV Committee on Materials provides the appropriate design values for the Construction Codes, including Division 1. The design values are calculated in accordance with the appropriate mandatory Code rules. If the inquirer considers the material to be essentially identical to one that has been approved by the BPV Committee on Materials, the inquirer shall so state in its request, and the BPV Committee on Materials shall evaluate that judgment. If the material is not essentially identical to one that has been approved by the BPV Committee on Materials, the inquirer shall provide all of the data cited in this Mandatory Appendix. Based on those data, the BPV Committee on Materials will provide the appropriate design values.

RESPONSIBILITY FOR SELECTING MATERIALS

It is the responsibility of the user or his designated agent to ensure that materials used for the construction of the vessels will be suitable for the intended service with respect to retention of satisfactory mechanical properties, and resistance to corrosion, erosion, oxidation, and other deterioration during their intended service life.

Corrosion

The user or his designated agent shall specify corrosion allowances other than those required by the rules of this Division. Where corrosion allowances are not provided, this fact shall be indicated on the Data Report. Vessels or parts of vessels subject to thinning by corrosion, erosion, or mechanical abrasion shall have provision made for the desired life of the vessel by a suitable increase in the thickness of the material over that determined by the design formulas, or by using some other suitable method of protection. Material added for these purposes need not be of the same thickness for all parts of the vessel if different rates of attack are expected for the various parts. No additional thickness need be provided when previous experience in like service has shown that corrosion does not occur or is of only a superficial nature.

Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. Telltale holes shall not be used in vessels that are to contain lethal substances, except for vent holes in layered construction. When telltale holes are provided, they shall have a diameter of 1/16 in. to 3/16 in. and have a depth not less than 80% of the thickness required for a seamless shell of like dimensions. These holes shall be provided in the opposite surface to that where deterioration is expected.

Vessels subject to corrosion shall be supplied with a suitable drain opening at the lowest point practicable in the vessel; or a pipe may be used extending inward from any other location to within 1/4 in. of the lowest point.

FORGINGS

Forged material can be used in pressure vessel construction, provided the material has been worked sufficiently to remove the coarse ingot structure. Forged rod or bar may only be used within the following limitations:

- Except for flanges of all types, hollow cylindrically shaped parts [up to and including NPS 4 (DN 100)] may be machined from rod or bar, provided that the axial length of the part is approximately parallel to the metal flow lines of the stock.
- Other parts, such as heads or caps [up to and including NPS 4 (DN 100)], not including flanges, may be machined from rod or bar.
- Elbows, return bends, tees, and header tees shall not be machined directly from rod or bar.

Forgings certified to SA-105, SA-181, SA-182, SA-350, SA-403, and SA-420 may be used as tubesheets and hollow cylindrical forgings for pressure vessel.

CASTINGS

Cast material may be used in the construction of pressure vessels and vessel parts. Their allowable stress values shall be multiplied by the following casting quality factor (for all materials except cast iron):

- A factor not to exceed 80% shall be applied to static castings that are examined in accordance with the minimum requirements of the material specification. In addition to the minimum requirements of the material specification, all surfaces of centrifugal castings shall be machined after heat treatment to a finish not coarser than 250 μin. (6.3 μm) arithmetical average deviation, and a factor not to exceed 85% shall be applied.
- For nonferrous and ductile cast iron materials, a factor not to exceed 90% shall be applied if:
  - Each casting is subjected to a thorough examination of all surfaces, particularly such as are exposed by machining or drilling, without revealing any defects;
  - At least three pilot castings representing the first lot of five castings made from a new or altered design are sectioned or radiographed at all critical sections without revealing any defects;

- One additional casting taken at random from every subsequent lot of five is sectioned or radiographed at all critical sections without revealing any defects; and
- All castings other than those that have been radiographed are examined at all critical sections by the magnetic particle or liquid penetrant methods.

- For nonferrous and ductile cast iron materials, a factor not to exceed 90% may be used for a single casting that has been radiographed at all critical sections and found free of defects.
- For nonferrous and ductile cast iron materials, a factor not to exceed 90% may be used for a casting that has been machined to the extent that all critical sections are exposed for examination for the full wall thickness; as in tubesheets drilled with holes spaced no farther apart than the wall thickness of the casting.
- For carbon, low alloy, or high alloy steels, higher quality factors may be applied if in addition to the minimum requirements, additional examinations are made as follows.
  - For centrifugal castings, a factor not to exceed 90% may be applied if the castings are examined by the magnetic particle or liquid penetrant methods.
  - For static and centrifugal castings a factor not to exceed 100% may be applied if the castings are examined in accordance with all of the requirements of Mandatory Appendix 7.
- The following additional requirements apply when castings are to be used in vessels to contain lethal substances:
  - Castings of cast iron and cast ductile iron are prohibited.
  - Each casting of nonferrous material permitted by this Division shall be radiographed at all critical sections without revealing any defects. The quality factor for nonferrous castings for lethal service shall not exceed 90%.
  - Each casting of steel material permitted by this Division shall be examined per Mandatory Appendix 7 for severe service applications. The quality factor for lethal service shall not exceed 100%.

BOLTS AND STUDS

Bolts and studs are used for the attachment of removable parts.

When studs are used, they shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion, provided that the threaded portions are at least 1½ diameters in length. Studs greater than eight diameters in length may have an unthreaded portion that has the nominal diameter of the thread, provided the following requirements are met:

- The threaded portions shall be at least 1½ diameters in length;
- The stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion;
- A suitable transition shall be provided between the root diameter and the unthreaded portion; and
- Particular consideration shall be given to any dynamic loadings.

MINIMUM THICKNESS OF PRESSURE RETAINING COMPONENTS

The minimum thickness permitted for shells and heads, after forming and regardless of product form and material, shall be 1/16 in. (1.5 mm) exclusive of any corrosion allowance. Exceptions are:

1. The minimum thickness does not apply to heat transfer plates of plate - type heat exchangers.

2. This minimum thickness does not apply to the inner pipe of double pipe heat exchangers nor to pipes and tubes that are enclosed and protected from mechanical damage by a shell, casing, or ducting, where such pipes or tubes are NPS 6 (DN 150) and less. This exemption applies whether or not the outer pipe, shell, or protective element is constructed to Code rules. When the outer protective element is not provided by the Manufacturer as part of the vessel, the Manufacturer shall note this on the Manufacturer's Data Report, and the owner or his designated agent shall be responsible to assure that the required enclosures are installed prior to operation. Where pipes and tubes are fully enclosed, consideration shall be given to avoiding buildup of pressure within the protective chamber due to a tube/pipe leak. All other pressure parts of these heat exchangers that are constructed to Code rules must meet the 1/16 in. (1.5 mm) minimum thickness requirements.
3. The minimum thickness of shells and heads of unfired steam boilers shall be ¼ in. (6 mm) exclusive of any corrosion allowance.
4. The minimum thickness of shells and heads used in compressed air service, steam service, and water service, made from carbon and low alloy steel materials shall be 3/32 in. (2.5 mm) exclusive of any corrosion allowance.
5. This minimum thickness does not apply to the tubes in air cooled and cooling tower heat exchangers if all the following provisions are met:
    a. The tubes shall not be used for lethal service applications;
    b. The tubes shall be protected by fins or other mechanical means;
    c. The tube outside diameter shall be a minimum of 3/8 in. (10 mm) and a maximum of 1-1/2 in. (38 mm);
    d. The minimum thickness used shall not be less than that calculated by the code formulas for shell and in no case less than 0.022 in. (0.5 mm).

MAXIMUM ALLOWABLE STRESS VALUES

The maximum allowable stress value is the maximum unit stress permitted in a given material used in a vessel constructed under these rules. <u>The maximum allowable tensile stress values</u> permitted for different materials are given in ASME Section II, Part D, Subpart 1. A listing of these materials is given in the following tables, which are included in Subsection C of Division 1 – See Table 1.

<u>The maximum allowable longitudinal compressive stress</u> to be used in the design of cylindrical shells or tubes, either seamless or butt welded, subjected to loadings that produce longitudinal compression in the shell or tube shall be the smaller of the following values:

1. The maximum allowable tensile stress value permitted for the material.
2. The value of the factor "B" determined by the procedure in paragraph UG-23(b)(2) of Division 1.

The wall thickness of a vessel computed by these rules shall be determined such that, for any combination of loadings that induce primary stress and are expected to occur simultaneously during normal operation of the vessel, the induced maximum general primary membrane stress does not exceed the maximum allowable stress value in tension. For the combination of earthquake loading, or wind loading with other loadings, the wall thickness of a vessel shall be determined such that the general primary membrane stress shall not exceed 1.2 times the maximum allowable stress. This rule is applicable to stresses caused by internal pressure, external pressure, and axial compressive load on a cylinder. Earthquake loading and wind loading need not be considered to act simultaneously.

These loads shall not induce a combined maximum primary membrane stress plus primary bending stress across the thickness that exceeds 1-1/2 times the maximum allowable stress value in tension. It is recognized that high localized discontinuity stresses may exist in vessels designed and fabricated in accordance with the rules of Division 1. Insofar as practical, design rules for details have been written to limit such stresses to a safe level consistent with experience.

The maximum allowable stress values that are to be used in the thickness calculations are to be taken from the tables at the temperature that is expected to be maintained in the metal under the conditions of loading being considered.

Table 1: Listing of Tables of Permitted Materials for Division 1 Pressure Vessels

Table	Title
UCS-23	Carbon and Low Alloy Steel (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A for other carbon steels)
UNF-23.1 through UNF-23.5	Nonferrous Metals (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1B for other nonferrous metals)
UHA-23	High Alloy Steel (stress values in Section II, Part D, Subpart 1, Table 3 for bolting and Table 1A or Table 1B for other high alloy steels)
UCI-23	Maximum Allowable Stress Values in Tension for Cast Iron
UCD-23	Maximum Allowable Stress Values in Tension for Cast Ductile Iron
UHT-23	Ferritic Steels with Properties Enhanced by Heat Treatment (stress values in Section II, Part D, Subpart 1, Table 1A)
ULT-23	Maximum Allowable Stress Values in Tension for 5%, 8%, and 9% Nickel Steels and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction

ASME SECTION II, PART D

The properties of the materials, including allowable stresses, used in construction of Division 1 pressure vessels are provided in ASME Section II, Part D (ASME II-D). ASME II-D consists of three Subparts, Mandatory Appendices, and Nonmandatory Appendices. Subpart 1 contains the stress tables, Subpart 2 contains the physical properties tables, and Subpart 3 contains the charts and tables for determining shell thickness of components under external pressure.

Subpart 1

The guidelines to clarify which information in the stress tables provided in Subpart 1 is mandatory and which is not are given here. The information and restrictions provided in the Notes found throughout the various stress tables are mandatory. The lines of information in Tables 1A, 1B, and 3 (we will look only at Division 1 materials) frequently have essential information referenced in the Notes column. These Notes are organized as follows:

a. EXX: Defining onset of values based on successful experience in service

b. GXX: General requirements

c. HXX: Heat treatment requirements

d. SXX: Size requirements

e. TXX: Defining onset of time - dependent behavior

f. WXX: welding requirements

Let us look at the information provided in Table 1A for the most commonly used carbon steel material – SA 516 Grade 70. This information is reproduced (though not in exact form) here:

Line Number	33	P.No.	1
Nominal Composition	Carbon Steel	Group No.	2
Product Form	Plate	Min. Tensile Strength	70,000 psi
Spec. No.	SA-516	Min. Yield Strength	38,000 psi
Type/ Grade	70	Max. Temperature	1000°F
Alloy Desig./UNS No.	K02700	Ext. Pressure Chart	CS-2
Class/Condition/Temper	---	Notes	G10, S1, T2
Size/Thickness	---		

Temperature	Allowable Stress	Temperature	Allowable Stress	Temperature	Allowable Stress
100°F	20,000 psi	500°F	20,000 psi	850°F	9,300 psi
150°F	20,000 psi	600°F	19,400 psi	900°F	6,700 psi
200°F	20,000 psi	650°F	18,800 psi	950°F	4,000 psi
250°F	20,000 psi	700°F	18,100 psi	1000°F	2,500 psi
300°F	20,000 psi	750°F	14,800 psi		
400°F	20,000 psi	800°F	12,000 psi		

The specifications and grades or types, coupled with the assigned Notes for each line, provide the complete description of material in the context of the allowable stresses or design stress intensities.

In Tables 1A and 2A, the information in the Nominal Composition column is nonmandatory and is for information only. However, these nominal compositions are the primary sorting used in these three tables. The information in the Alloy Designation/UNS Number column is nonmandatory for specifications for which a grade or type is provided. This is primarily true for the non-stainless steel alloys in these tables. For specifications for which no type or grade is listed, the UNS number is mandatory. Particularly for the stainless steels, for which no type or grade is listed, the UNS number is the grade.

The only difference between Table 1A and Table 1B with regard to the mandatory/nonmandatory nature of the information, is that in Table 1B, the UNS number information is used as the basis of the sorting scheme for materials and is almost always mandatory.

Where provided, the information in the columns for Product Form, Specification Number, Type/Grade, Class/Condition/Temper, Size/Thickness, and External Pressure Chart Number is mandatory. The information in the P - Number and Group Number columns is also mandatory; however, the primary source for this information is Table QW/QB - 422 in ASME Section IX (ASME IX). When there is a conflict between the P - number and Group number information in these stress tables and that in ASME IX, the numbers in ASME IX shall govern.

The information in the Minimum Tensile Strength and Minimum Yield Strength columns is nonmandatory. These values are a primary basis for establishing the allowable stresses and design stress intensities. When there is a conflict between the tensile and yield strength values in the stress tables and those in the material specifications in Section II, Parts A and B, the values in Parts A and B shall govern.

The information in the Applicability and Maximum Temperature Limits columns is mandatory. Where a material is permitted for use in more than one Construction Code, the maximum use temperature limit in these columns is critical. The temperature to which allowable stress or design stress intensity values are listed is not necessarily the temperature to which use is permitted by a particular Construction Code. Different Construction Codes often have different use temperature limits for the same material and condition. These stress values are provided to permit interpolation to be used to determine the allowable stress or design stress intensity at temperatures between the next lowest temperatures for which stress values are listed and the maximum - use temperature limit listed in these columns.

Subpart 1 also contains mechanical property tables. Mechanical property tables include Table U for tensile strength values for ferrous and nonferrous materials, and Table Y-1 for yield strength values for ferrous and nonferrous materials.

Subpart 2

Subpart 2 contains physical property tables that include:

Table TE-1: Thermal expansion for ferrous materials

Table TE-2: Thermal expansion for aluminum materials

Table TE-3: Thermal expansion for copper materials

Table TE-4: Thermal expansion for nickel materials

Table TE-5: Thermal expansion for titanium materials

Table TCD for thermal conductivity (TC) and thermal diffusivity (TD)

Table TM-1: Modulus of elasticity *E* of ferrous materials for given temperature

Table TM-2: Modulus of elasticity *E* of aluminum and aluminum alloys for given temperature

Table TM-3: Modulus of elasticity *E* of copper and copper alloys for given temperature

Table TM-4: Modulus of elasticity *E* of high nickel alloys for given temperature

Table TM-5: Modulus of elasticity *E* of titanium and zirconium for given temperature

Table PRD for poisson's ratio and density for ferrous and nonferrous materials.

Subpart 3

Subpart 3 contains charts that are used in determining minimum required thicknesses of pressure vessel components under external pressure. Determining minimum thickness for pressure vessel components under external pressure requires use of two charts:

Figure G – Geometric chart for components under external or compressive loadings (for all materials)

Material charts -	Figures CS-1 through CS-6:	Carbon steel
	Figures HT-1 through HT-2:	Quenched and tempered low alloy steel, SA 508-4N, and SA 543 Type B and C, Class 2
	Figures HA-1 through HA-9:	Austenitic steel

Figure CI-1: Cast iron

Figure CD-1: Cast ductile iron

Figures NFA-1 through NFA-13: Aluminum alloys

Figures NFC-1 through NFC-8: Copper alloys

Figures NFN-1 through NFN-27: Nickel alloys

Figures NFT-1 through NFT-5: Titanium alloys

Figures NFZ-1 through NFZ-2: Zirconium alloys

Both Figure G and the material charts are also presented in tabular format that lend for easy programming.

References:

ASME Boiler and Pressure Vessels, Section VIII, Division 1

ASME Boiler and Pressure Vessels, Section II, Part D

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THE ART OF TANK GAUGING

WHAT IS TANK GAUGING?

Tank gauging is the measurement of liquids in large storage tanks with the purpose of quantifying the volume and mass of the product in the tanks.

The oil and gas industry generally uses static volumetric assessments of the tank content. This involves level, temperature and pressure measurements. There are different ways of measuring the liquid level and other properties of the liquid. The measurement method depends on the type of tank, the type of liquid and the way the tank is used.

Storage tanks can contain large volumes of liquid product representing a significant value. The accuracy performance of a tank gauging system is of high importance when assessing the tank content at any given time.

Tank gauging is used on large storage tanks in refineries, fuel depots, pipelines, airports, and storage terminals. Storage tanks usually come in four basic designs: Cylindrical fixed roof tanks, cylindrical floating roof tanks and pressurized tanks of either spherical or horizontal cylinder design. There are tank gauges available for all these tank types.

Besides precision level gauging, temperature measurements are essential in assessing tank contents accurately. All liquids have a thermal expansion coefficient and proper volume compensation needs to be applied when transferring volumes at different temperature conditions. A pressure measurement of the liquid head is often added to provide a current assessment of the average observed density and to calculate the product mass.

Modern tank gauging systems digitize the tank measurement and digitally transmit the tank information to a control room where the liquid volume and mass information is distributed to users of the inventory data.

TANK GAUGING IS A SYSTEM SCIENCE

The concept of tank gauging involves much more than just the precision instruments on the tank. Tank gauging requires reliable data communication over large field bus networks, often both wired and wireless. The communication solutions often need arrangement for redundancy in the field buses, the data concentrators, the network components and the network servers. Tank gauging systems must also be able to calculate product volumes and mass according to the industry standards. The tank gauging software/information system must perform many different functions spanning from operator interface, batch handling, reporting, alarm functions, connectivity to host systems and much more. It is a system engineering science across many areas of technology.

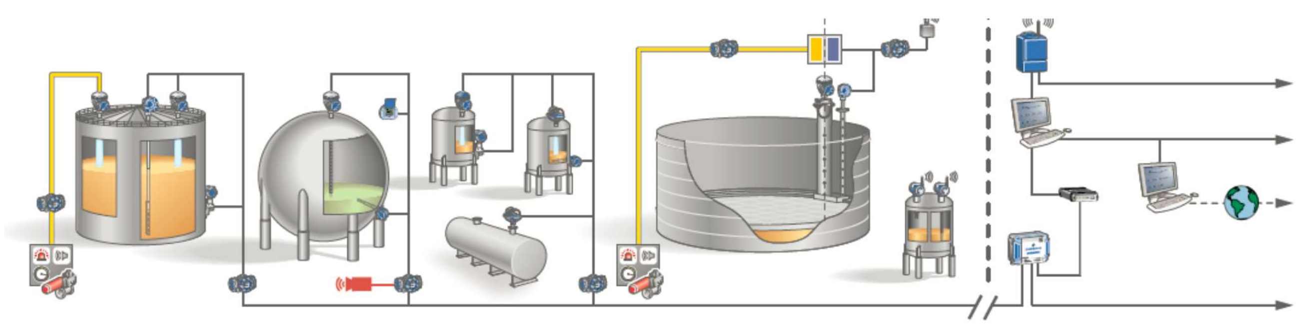

Figure 1: Tank gauging involves a substantial number of interdependent devices and functions

WHERE IS TANK GAUGING USED?

Tank gauging is needed wherever liquids are stored in large tanks. Such storage tanks are found in:

- Refineries
- Petrochemical industry
- Distribution terminals
- Pipeline terminals
- Fuel depots
- Air fueling storage at airports
- Chemical storage

Storage tanks are often placed in clusters or tank farms. The tanks are atmospheric, pressurized or cryogenic.

Atmospheric tanks are vertical cylinders with various roof designs. Most common are:

- Fixed roof tanks, either cone roof or dome roof tanks.
- Floating roof tanks with various designs.

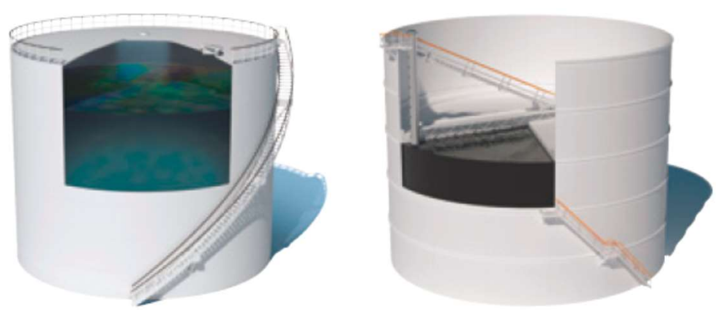

Figure 2: Fixed Roof and Floating Roof Tanks

In a fixed roof tank there is a vapor space between the liquid surface and the external roof.

In a floating roof tank the liquid surface is covered by either an internal or an external floating roof. There are many different designs of floating roofs depending on the service, the liquid and the size of the tank. It is common that floating roof tanks have one or more still-pipes that go from the bottom of the tank, through an opening in the floating roof to the top of the tank. This still-pipe is used to access the liquid for sampling, hand level gauging, hand temperature measurement and automatic tank gauging. With a good Automatic Tank Gauge (ATG) design, all these things can be performed in one still pipe.

Pressurized tanks are often of spherical or horizontal cylinder design.

Hand gauging cannot be performed on pressurized tanks. For high accuracy automatic tank gauging a still-pipe inside the tank is normally required.

In cryogenic tanks, automatic tank gauges are often of the same design as for pressurized tanks.

The methods for proper automatic tank gauging are described in various engineering standards. The most commonly applied standards are the Manual of Petroleum Measurement Standards (MPMS) issued by the American Petroleum Institute (API).

Figure 3: Pressurized tanks normally require automatic tank gauging in a still-pipe

Figure 4: Cryogenic Tank Storing LNG at -260°F

THE PURPOSE OF TANK GAUGING

The information from a tank gauging system is used for many different purposes. The most common are:

- Oil movement and operations
- Inventory control
- Custody transfer
- Loss control and mass balance
- Volume reconciliation
- Overfill prevention
- Leak detection

<u>Oil Movement and Operations</u>

The operation of a tank farm relies heavily on information regarding the situation in the tank farm. To operate the tank farm safely and efficiently it is important to know exactly what is going on inside the tanks. The tank gauging system must at any given time provide instant information about:

- How much liquid is in the tank
- How much available room is left in the tank
- At what level rate the tank is being filled/ discharged
- When the tank will reach a dangerously high level
- When the tank will become empty at a given pump rate
- How long a given batch transfer will take

The operation will also require that the tank gauging system gives alerts and alarms before any preset level or dangerous high tank level is reached.

Oil movement and operations depend on reliable and readily available tank information. A loss of tank gauging data will seriously interrupt time critical operations and product transfers which may lead to unplanned shut downs.

Inventory Control

A tank farm stores valuable assets, and owners of the assets will require very accurate assessments of their value. The tank gauging system should be able to provide high accuracy inventory reports at given intervals or instantly if so required. Automatic measurement of free water at the bottom of the tank may also be required for accurate inventory assessment. The tank inventory figures are essential for financial accounting purposes and are often used for fiscal and customs reporting. The system should be able to calculate net volumes and mass according to the rules set forth by industry standards organizations such as API and others.

Custody Transfer

When buying and selling large volumes of liquids, tank gauging data serves as the main input for establishing correct invoicing and taxation. Certified tank gauging can provide more accurate transfer assessments compared with metering when performing large transfers such as from a tanker ship to a shore tank. With a certified tank gauging system manual tank surveying can often be omitted. For legal or fiscal custody transfer, the tank gauging system must be certified by international authorities, mainly the International Organization of Legal Metrology (OIML). The system may also be required to have approvals from local metrology entities such as PTB, NMi, LNE or other national institutes. Custody transfer requires the highest possible accuracy of the tank gauging system. The OIML standard R 85:2008 defines the requirements for tank gauges used for custody transfer.

Loss Control and Mass Balance

The financial impact of refinery losses is of great importance. Achieving a high quality mass balance of a refinery is the method by which losses are estimated. It is important to distinguish between real losses and apparent losses stemming from measurement errors. The refinery loss is defined as:

$$\text{Loss} = \text{Inputs} - \text{Outputs} - \text{Current Inventory} + \text{Previous Inventory} - \text{Fuel}$$

For loss control purposes the highest possible accuracy of inventory measurement is required. Hence the quality and performance of the tank gauging system is of utmost importance in the area of loss control and mass balance.

Volume Reconciliation

Tank farm operations need to accurately manage transactions and reconcile transfers versus physical inventory. Every company is accountable; reconciliation and error reporting provide the auditing and traceability that is often required. The tank gauging system will allow the immediate data acquisition and response required for accurate daily accounting and reconciliation.

The performance of flow meters can be monitored when transfer data from the meters are compared with batch reports from the tank gauging system.

Overfill Protection

A tank overfill can have disastrous consequences. A spill can cause explosions and fire that can spread to all tanks in the tank farm and to the surrounding area. Since the tanks contain huge amounts of stored energy, a fire can have far-reaching consequences. Fires caused by overfill have rendered legal damages exceeding $1 billion. From this, and many other perspectives, preventing tank overfill is extremely important. A spill can happen when the tank operators are unaware of what's going on in the tank farm. This could take place if an undetected fault occurs in the tank gauging components. High level switches could, if not maintained and tested properly, also fail.

Tank gauging devices provide the basic process control layer in the tank farm. Independent high level indicators or level-switches form the next layer of protection. Any undetected failure of these two protection layers can cause a serious accident. This is why the reliability of the tank gauging system and the high level alarm system has to meet the requirements stated by the standards for Functional Safety.

Leak Detection

If the tank gauging system is accurate and stable enough it can be used for tank leak detection. When a tank is settled and closed, the tank gauging system can be set to detect small liquid movements. It is recommended that leak detection is based on Net Standard Volume (NSV) rather than just level. By monitoring the NSV, level movements caused by temperature changes can be canceled out. Custody transfer grade accuracy performance of the tank gauging system is required for proper leak detection.

TANK GAUGING TECHNOLOGIES

In addition to manual hand gauging using a tape measure, various automatic tank gauges have developed over time. Most mechanical devices are in contact with the liquid. Modern electronic tank gauges are non-contacting and have no moving parts.

HAND GAUGING

Hand gauging can be performed on most atmospheric tanks. A specially designed measurement tape is used for this purpose. These are normally made of stainless steel with a weight at the end of the tape graded in millimeters or fractions of inches. The tape is used to measure ullage or innage (liquid level).

The ullage is the distance from the reference point of the tank down to the liquid surface. The tank level is then calculated by taking the reference height minus the measured ullage. Ullage measurements are often used on heavier liquids like black oils and crude oil.

Figure 5: Hand Dipping Tape

Figure 6: Hand Gauging with a Dipping Tape

Direct level measurement (innage) can also be carried out with a hand tape. This method is used on clean liquids since the tape will be submerged into the full height of the tank. When gauging clean products with a tape an indication paste is used to make the surface cut visible.

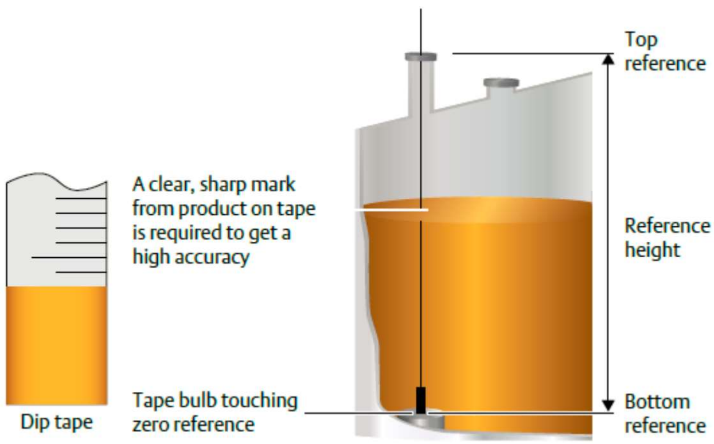

Figure 7: Manual Level Measurement Definitions

For proper and accurate hand gauging, a high quality, newly calibrated tape is required. On heated tanks it may be necessary to calculate the thermal expansion of the tape to obtain good measurement accuracy. The API standard MPMS describes how proper manual tank gauging is performed.

FLOAT GAUGES

Automatic tank gauges started to appear in the 1930's. One of the early designs of tank gauges was the float gauge. In this design, a large float inside the tank is connected to a metallic tape. The tape is connected to a spring motor and a mechanical numeric indicator at the lower end of the outside of the tank through a pulley system. No external power is required for a float gauge, the movement of the liquid level powers the whole mechanism. For remote monitoring the float gauge may be equipped with a transmitter. The transmitter sends the tank level values through signal cables to the control room.

The accuracy performance of a float gauge is often low. There are plenty of error sources such as buoyancy differences, dead-band, back-lash and hysteresis in the mechanisms. If anything goes wrong with the float, the tape or the guide wires, it is necessary to carry out service work inside the tank. No gauging can be done with the float gauge while waiting for a repair.

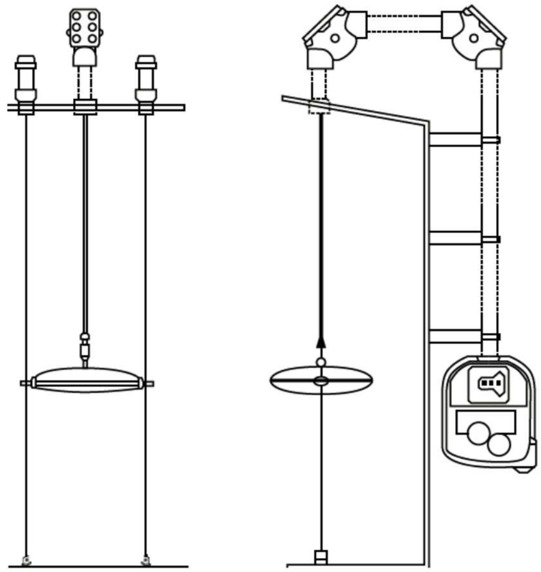

Figure 8: Float and gauge tape was introduced around 1940.

The float gauge is a relatively simple device but has many moving parts that will require maintenance and repair over its lifetime.

SERVO GAUGES

In the 1950's, development in mechanics and electronics led to the servo gauge. With this gauge type, the float is replaced by a small displacer. The displacer has buoyancy but does not float on the liquid. The displacer needs to be suspended by a thin wire which is connected to the servo gauge on top of the tank. A weighing system in the servo gauge senses the tension in the wire, signals from the weighing mechanism control an electric motor in the servo unit and make the displacer follow the liquid level movements. An electronic transmitter sends the level information over field buses to the readout in the control room.

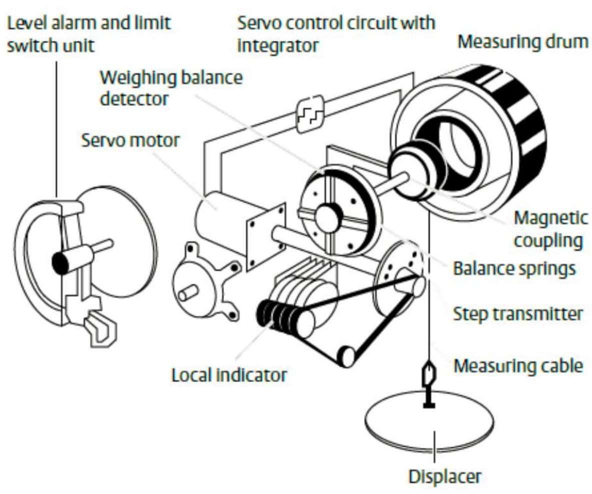

Figure 9: Servo Gauge

To keep the displacer from drifting in the tank, a still pipe is needed wherever a servo gauge is installed. This is also required in fixed roof tanks.

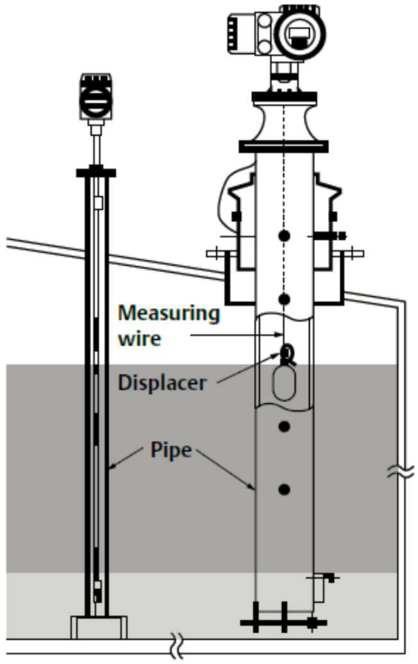

Figure 10: Servo gauge and temperature sensor measuring inside still-pipes

The servo gauge generally performs better than a float gauge. A newly calibrated servo gauge can meet custody transfer accuracy requirements. However, the servo gauge has many moving parts and the displacer and the wire are in contact with the tank liquid. Hence servo gauges need attention in the form of calibration, routine maintenance and repair.

RADAR GAUGES

The first radar tank gauges were developed in the mid 1970's (radar is also referred to as microwaves) for installations on seagoing tankers. In the early 1980's, radar tank gauges were further developed to fit shore based storage tanks. Radar technology rapidly gained market share and is today generally the first choice in any tank gauging project. Today, there is a large supply of radar instruments on the market effectively replacing mechanical, ultra sound and capacitance level sensors due to their inherent user benefits.

Figure 11: First high precision radar gauge installed in 1985 on a refinery tank

A radar level gauge has no moving parts and requires no regular maintenance. Radar devices require no direct contact with the liquid. This makes it possible to use a radar gauge on a wide variety of liquids from heated heavy asphalt to cryogenic liquefied gases like Liquefied Natural Gas (LNG). A good radar tank gauge can easily provide reliable gauging for over thirty years.

If the radar is designed correctly it requires no recalibration after the first adjustment on the tank.

Figure 12: Modern radar level gauge on a fixed roof tank

DIFFERENT TYPES OF RADAR GAUGES

There are many radar level gauges on the market. Several are made for process applications where high accuracy and stability are not the primary requirements. Unit cost and other considerations related to these applications are more important.

Process Radar Level Gauges

Process radar devices are made for many different applications in the process industry. High pressure and high temperature combined with strong tank agitation are common challenges for process radar installations. Under these conditions, high level accuracy is not the primary focus. Other qualities such as high reliability and low maintenance are more important. Pulse radar is the dominant technology in most process radar transmitters. Pulse radar provides low cost, low power and reliable gauging under tough conditions. Process radar transmitters are in general 2-wire units driven by a 4-20 mA loop bus powered, or battery powered wireless. They are either of free space propagation type or guided wave. The free space radar transmitters have a horn, a lens or parabolic antenna. The guided wave type has a solid or flexible antenna protruding into the tank.

There is a wide spectrum of process radar devices, and manufacturers in the market serve different market segments such as the chemical industry, oil and gas and the food and beverage industry.

Currently, pulse technology based radar transmitters are less accurate than FMCW based transmitters used for tank gauging applications.

Figure 13: Non-contacting radar level transmitter and guided wave radar level transmitter for process applications

Tank Gauging Radar Gauges

To meet the high performance requirements of custody transfer accuracy in tank gauging applications, radar devices typically use the Frequency Modulated Continuous Wave (FMCW) signal processing method. The FMCW method sometimes goes under the name “Synthesized Pulse”.

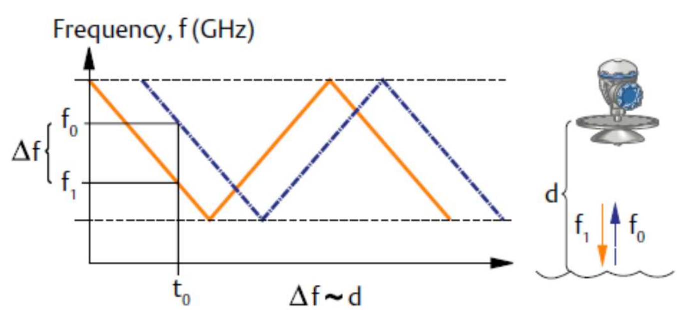

Figure 14: The FMCW Method

FMCW is capable of delivering an instrument level gauging accuracy of better than a millimeter over a 50+ meter range.

Since its birth in the 1970’s, the FMCW based radar tank gauge has developed rapidly. Several generations of radar tank gauges have been released. The latest design has been miniaturized to the extent that two radar units can share the same small enclosure and deliver reliability and accuracy never seen before. At the same time, power requirements have been reduced to the point that radar tank gauges can be made totally intrinsically safe and require only a 2 wire bus for power and communication.

FMCW is required to make a radar tank gauge accurate, but this is not enough on its own. Precision radar gauges must also have specially designed microwave antennas to be able to deliver both the instrument accuracy and installed accuracy required by custody transfer standards.

One important property of radar antennas is that they should be designed in such a way that any condensation will quickly drip off. Therefore, antennas inside tanks require sloping surfaces to avoid accumulation of condensate liquids.

Figure 15: Antenna design with no horizontal surfaces according to API standard

There are three main types of applications for radar tank gauges:

- Fixed roof tank installation
- Floating roof tank installation on a still pipe
- Installation on tanks with liquefied gases, pressurized or cryogenic

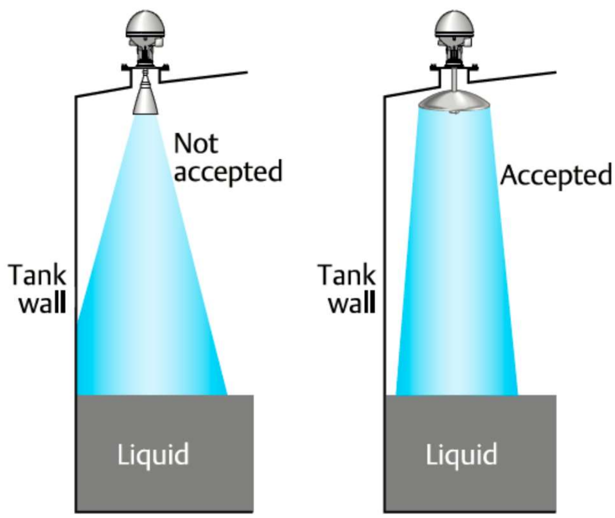

Figure 16: Radars with Wide Beam (small antenna) and Narrow Beam (large antenna)

A radar tank gauge should be able to deliver highest accuracy when mounted on existing tank openings. On a fixed roof tank, the openings suitable for tank gauging are normally found on the roof close to the tank wall. This position is ideal due to stability provided by the tank wall and a minimum of roof flexing as a result. A radar tank gauge must be able to deliver highest accuracy even when placed close to the tank wall. Antennas with a narrow microwave beam are most suitable for such tank locations in close proximity to the wall. The larger the antenna, the narrower the microwave beam becomes.

On a floating roof tank, the still-pipe is located where any liquid level gauging takes place since the rest of the liquid surface is covered by the floating roof. A radar tank gauge antenna for still-pipes must be designed so that existing still-pipes of various sizes and designs can be used. The still-pipe must have slots or holes to allow good liquid mixing between the inside and the outside of the pipe. If no holes or slots are present it is likely that the liquid level inside the pipe will be different from the rest of the tank. If the pipe is filled from the bottom, heavier product will then accumulate in the pipe. The slots or holes prevent this.

A radar tank gauge for still-pipe applications must have the ability to cope with a still pipe with large slots/holes and yet deliver high accuracy. It must also perform with the highest accuracy even if the pipe has rust and dirt build-up on the inside.

In addition, a still-pipe antenna must be made so that the still-pipe can be accessed for other tasks like sampling and hand gauging.

RADAR FREQUENCY SELECTION

For tank gauging applications, the reliability of the gauging and the accuracy performance are the primary qualities. To meet the requirements it is important to select the optimal antenna design and the right microwave frequency. When using still pipes as waveguides it turns out that frequencies in the X-band are optimal. Fixed roof storage tanks without still pipes often have tank apertures in sizes 200 to 600 mm (8 to 24 in.) in diameter. Suitable antennas for such openings are those that can handle heavy water condensation and dirt build-up. Under these conditions horn, cone or parabolic antenna design has proven to work very well, especially since they can be designed with drip-off surfaces. Such antennas at this size range have an excellent track record when used in frequency ranges between 9-10 GHz (X-band).

Higher frequencies are used in process radar gauges to be able to fit smaller antennas in narrow tank gauge openings. However small antennas and higher frequencies tend to increase sensitivity to condensation and dirt build-up.

PRESSURIZED TANKS

Figure 17: Radar gauge sensor including heavy atmosphere compensation in an LPG tank

Special properties are required for a microwave antenna used for tank gauging in pressurized tanks:

- The antenna arrangement must be able to withstand the tank pressure.
- It should have a shut-off valve for protection and to meet safety requirements.
- It should have the ability to compensate for high-density tank atmospheres and any effect this has on the microwave propagation speed.

- It should be possible to verify the performance of the gauge during normal tank operations.

There are solutions to meet all these criteria with a good gauge and antenna design.

References:

Engineer’s Guide to Tank Gauging, 2017 Edition: Emerson

HOW TO HELP YOUR BODY HEAL ITSELF

The more you know about how your body works, the better able you are to make the choices necessary to enhance both the quantity (longevity) and the quality of your life.

Hygiene is defined as the science of health. It encompasses a broad body of knowledge about the natural laws that determine health and numerous techniques that enable you to use this information to maximize your health potential. The requirements of health can be classified into four general categories:

1. Diet: a plant based diet of whole natural foods that meets your individual nutritional needs.
2. Environment: getting fresh air, pure water, and appropriate sunshine, and avoiding environmental stressors such as air and water pollution, and excess exposure to dust, pollen, chemicals and noise.
3. Activity: engaging in regular aerobic exercise and getting adequate rest and sleep.
4. Psychology: engaging in productive activity and developing the interpersonal social skills necessary for a successful life.

When the requirements of health are adequately provided, the self-healing mechanisms of the body attempt to restore and/or optimize health. Your body's ability to do this is only limited by your inherent constitution (genetics) and the amount of use and abuse that has taken place.

Health and disease are not antagonists. Disease processes such as diarrhea, fever, and inflammation are not only natural, but are necessary attempts by the body to regain optimum health. Attempts to suppress these adaptive and eliminative processes with drugs and other invasive treatment may create problems by interfering with body's self-healing mechanisms.

Your body is a self-healing organism. By bypassing its natural self-repair process and handing all your power over to a doctor, you might be ignoring the very thing you need to heal. Our body is brilliantly equipped with natural self-repair mechanisms that kill the cancer cells we produce every day, fight infectious agents, repair broken proteins, keep our coronary arteries open and naturally fight the aging process.

Our autonomic nervous system has two major operating systems – the sympathetic nervous system which produces the body's stress response, also known as "fight or flight"; and the parasympathetic nervous system which produces the body's relaxation response, also know as "rest and digest". The body's natural self-repair mechanisms only fully function when the nervous system is in relaxation mode.

Our stress response is there for a good reason: if you are getting chased by a tiger, that burst of cortisol and epinephrine it produces will refocus all your body's restorative powers to pump up your blood pressure and heart rate, activate your large muscle groups and save your life. Stress response were meant to be limited only to life-or-limb-threatening dangers, but many modern-day humans are in fight-or-flight mode all the time.

We all know that stress is bad for us, but did you realize that every stressful thought, feeling or belief – we average more than 50 such responses every day – disables the body's ability to repair itself.

We have an unhealthy relationship with the very notion of stress. We often think it means that we are too busy (and therefore we are worthy and important). But it is much more than demands on your time and energy. Sure, stress can be running around like a headless chicken, trying to check off your to-do list. But as far your nervous system is concerned, stress is also social isolation and loneliness. It's selling your soul for a paycheck. Stress is a pessimistic worldview. It's toxic relationships. Stress is money worries. It is knowing there is a song within you that has yet to be sung or feeling out of touch with your life's purpose. Stress is negative beliefs about your health. It's feeling like nobody really gets the real you. It's pretending to be something you're not. And stress is feeling disconnected from your higher power.

Your brain can't tell the difference between "I'm getting chased by a tiger!" and "Nobody loves me" or "I'm never going to get well." As far as nervous system is concerned, they all signal imminent danger, and that is what stress really is, as far as your body is concerned.

WHAT REALLY MAKES US SICK?

Did you know that lonely people have double the rate of heart disease than those who are part of a supportive community and that researchers have found that loneliness may be a greater risk factor for your health than smoking or not exercising? Did you know that optimists have a 77 percent lower risk of heart disease than pessimists, or that happy people live 7 to 10 years longer than unhappy people?

THE MEDICINE WE REALLY NEED

We need a different kind of medicine to keep the nervous system in relaxation response so that the body can heal itself. To the nervous system, "medicine" has a different meaning: it means being loved just as you are. It is helping those in need. It is expressing your creative genius. It is seeing the glass half full and laughing out loud. It is unconditional love of animals. It is speaking truth. It is communing with nature, and nourishing body with real food. It is tapping into your higher power. It is being unapologetically YOU.

When you give yourself this medicine, you turn off the stress responses, turn on your relaxation responses and allow the body to do one of the things it does best – heal. That's why you can't hand your body over to your doctor – nobody but you knows the medicine you really need. I am not suggesting you abandon Western medicine. If you are in a car accident, having a heart attack, or about to deliver a premature baby, get thee to an emergency room, STAT! But if you have tried what Western medicine has to offer and you're still sick, I encourage you to write yourself a prescription of "self-healing medicine". Maybe to finally get well, you need to quit your soul-sucking job or escape a toxic relationship. Maybe you need to meditate more or move to the country. Maybe you need to find your calling and do your part to save the world. Maybe you need to paint.

Your body is your business because nobody but you knows what triggers your stress responses or equally important, how you might activate your relaxation responses. The power lies in your hands.

So I ask you the question: "Tell me, what is it you plan to do with your one wild and precious life?

When you start to live the answer, your body's natural self-repair mechanisms will flip on and you will have done everything within your power to heal yourself.

References:

Mind Over Medicine: How to Help Your Body Heal Itself *by* Lissa Rankin, M.D.

BUILDING A BETTER TOMMORROW

It is becoming less practical for many companies to maintain in-house engineering staff. That is where we come in – whenever you need us, either for one-time projects, or for recurring engineering services. We understand the codes and standards, and can offer a range of services related to pressure vessels, tanks and heat exchangers.

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