

# Pressure Vessel-Tank Sizing

## Introduction

This module is divided into two sections: mechanical design and process design. The mechanical design portion deals mainly with the thickness calculations for vessels and heads, while the process design portion deals with the sizing of process vessels and storage tanks. Selection of the Pressure Vessel/Tank Sizing option brings up the mechanical design screen (default screen), and selection of the *Process Design* option in the **Mode** menu, brings up the process design screen. Details of both sections are given below.

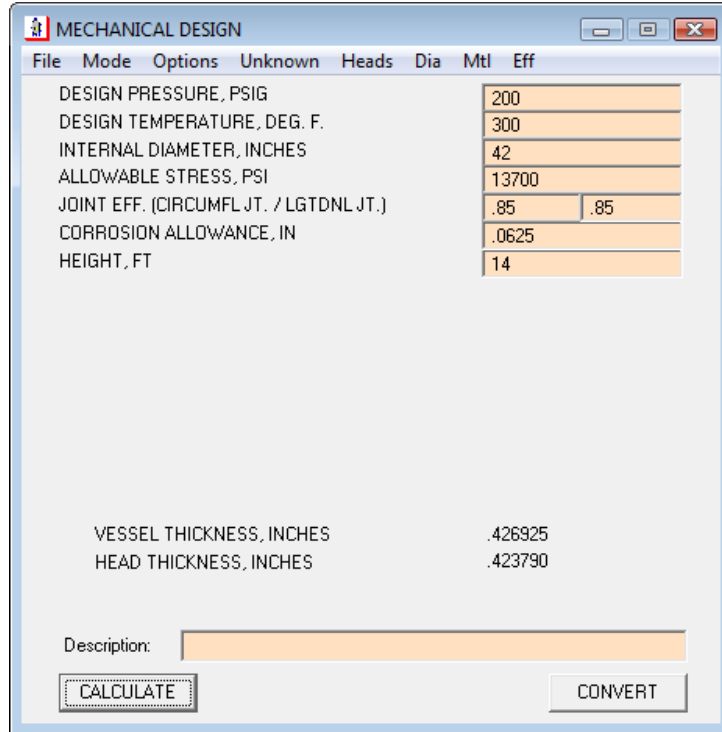
## Mechanical Design

### Overview

This program determines the shell/wall thickness or the maximum operating pressure in vertical, horizontal and spherical pressure vessels. It allows the user to study the effect of variations of temperature, pressure, joint efficiency, etc. on vessel design. It has a built-in database of material properties, and allowable stress values are continually updated on the screen with changes in temperature. All calculations are based on the ASME Boiler and Pressure Vessel Code (Section VIII) and recommendations of experienced personnel in this field.

## Window Description

The figure below shows the user interface for the mechanical design of pressure vessels. The required inputs appear in red and vary a little with the unknown variable, maximum pressure or wall thickness, that the user wants to determine. The input fields may be filled by manually entering the values or by selecting the values from the menus. Clicking the **Calculate** button displays the calculated results in blue at the bottom of the screen, while clicking the **Convert** button opens up the conversion calculator. The menus are described in the following sections



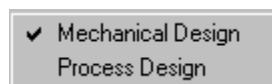
*Mechanical Design Screen for Pressure Vessel/Tank Sizing*

## Menu Item Description

This section will assist you in familiarizing yourself with the various options available on the screen. Each menu item is dealt with in turn and the various options available are then discussed in detail. The figure below shows the Mechanical Design screen with the available menu options, input and output fields.

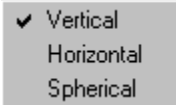
The file menu is similar to the one in other modules. The other modules are described below.

### Mode



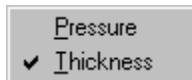
This menu allows the user to switch between the mechanical design and process design screens.

### ***Options***



This menu allows the user to select the type of vessel to be designed.

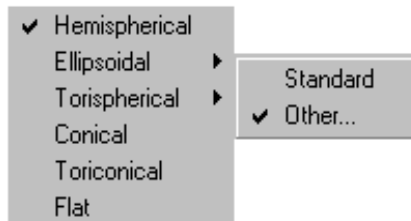
### ***Unknown***



This menu enables the user to select the unknown that is to be solved for, i.e. either:

- Pressure: When thickness is known
- Thickness: When pressure is known

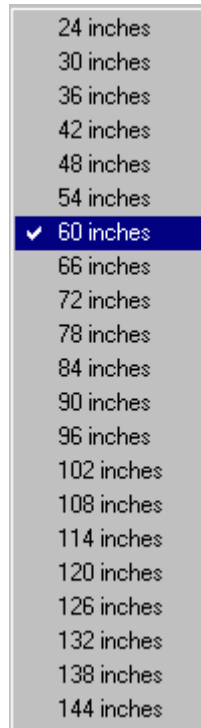
### ***Heads***



The desired head type can be selected from this menu. Some of these options are further divided into:

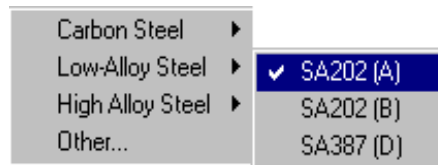
1. *Standard* - Uses standard dimensions for that particular head type, e.g., major to minor axis ratio for a standard ellipsoidal head is two and so on.
2. *Other* - Allows the user to specify the head dimensions.

### **Diameter (Dia.)**



This menu item lists the standard shell diameters, which vary from 24 -144 inches. Selection of any of these diameters would automatically place the chosen value in the corresponding input field.

### **Material (Mtl.)**



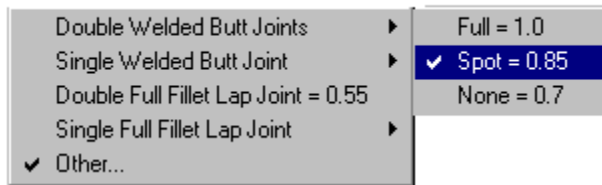
The figure above shows the materials menu with sub-options for low-alloy steel. The menu allows the user to select the material and grade of the vessel. Clicking on the desired material type retrieves the material's allowable stress value in the appropriate input field. The allowable stress value may be altered according to one's requirements. Various grades of carbon steel, low alloy steel and high alloy steel are available for selection. If the desired material is unavailable on the menu, then the user may select the *Other* option and enter the allowable stress value for the material, at the specified design temperature.

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**Note:** A warning message pops up if the input temperature exceeds the maximum allowable recommended temperature for a given material.

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## Joint Efficiency (Eff.)



This menu allows the user to select the circumferential joint efficiency. The user may either click on the desired efficiency from the menu or enter it directly in the input field. The required longitudinal joint efficiency needs to be entered manually into the input field. The figure above shows the categories of circumferential joints available for selection with the sub-menu for double-welded butt joints.

## Details about Sizing

The *vessel thickness* that is calculated by the program is the wall thickness required for rigidity. This is a function of the vessel diameter. For vessels under 42 in. diameter, the minimum thickness is 25 in., for vessels between 42 and 60 inches diameter, it is .32 in. and for over 60 in. diameters, it is .38 in.

The *design pressure* is 10% or 10-25 psi over the maximum operating pressure, whichever is greater. The maximum operating pressure is taken as 25 psi over the normal operating temperature.

A design using a head other than the hemispherical head and the standard ellipsoidal head requires additional input, such as major to minor axis ratio for ellipsoidal heads, crown and knuckle radius for torispherical heads, half apex angle for conical heads, crown radius, knuckle radius and half apex angle for toriconical heads and attachment factor for flat unstayed circular heads, covers and blind flanges (without attachment bolts). Details regarding the attachment factor to be used (if not known) are given in the ASME code (Section VIII). A default value of 0.13 is used for the attachment factor.

The *inside diameter* for pipes is determined by subtracting twice the nominal wall thickness from the nominal outside diameter.

The program calculates the design pressure for the vessel only when the thickness is known. As such calculations are normally done only for an existing vessel, the head attached to that vessel would normally withstand the pressure calculated for the latter. In case a head does need to be designed separately (pressure being unknown), select thickness as the unknown and keep varying the design pressure until the required head thickness is obtained.

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**Note:** The thickness and pressure referred to throughout this program and manual are the minimum thickness and internal design pressure, respectively.

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It is recommended that the user work through the example problems provided below.

## Example Problems

### Example 1

Obtain the thickness of a vertical vessel with an internal pressure of 200 psig, operating at a temperature of 300°F. The vessel has a height of 14 ft. and an internal diameter of 40 inches. The longitudinal and circumferential joint efficiencies are both 0.85. Also calculate the thickness of an ellipsoidal head with a major axis to minor axis ratio of 2. The vessel and head are both made of SA515(55) carbon steel with a 0.0625 in. corrosion allowance.

### Step by Step Solution Procedure

1. From the **Options** menu select *Vertical*.
2. From the **Heads** menu select *Ellipsoidal* and then *Other* to verify visually that the program is actually using an ellipsoidal head with a major to minor axis ratio of 2.
3. Key in the pressure, temperature, diameter, joint efficiencies, corrosion allowance and height.
4. Click on the **Calculate** button to obtain the head and vessel thickness.

The results obtained in this problem are as shown in figure below.

The screenshot shows a software window titled "MECHANICAL DESIGN" with a menu bar (File, Mode, Options, Unknown, Heads, Dia, Mtl, Eff) and a data entry table. The table contains input values for design pressure, temperature, diameter, allowable stress, joint efficiencies, corrosion allowance, and height. Below the table, the calculated vessel and head thicknesses are displayed. At the bottom, there are "CALCULATE" and "CONVERT" buttons and a description field.

| File  | Mode | Options | Unknown | Heads | Dia | Mtl | Eff                                    |
|---|------|---------|---------|-------|-----|-----|--|
| DESIGN PRESSURE, PSIG                                 |      |         |         |       |     |     | 200                                    |
| DESIGN TEMPERATURE, DEG. F.                           |      |         |         |       |     |     | 300                                    |
| INTERNAL DIAMETER, INCHES                             |      |         |         |       |     |     | 42                                     |
| ALLOWABLE STRESS, PSI                                 |      |         |         |       |     |     | 13700                                  |
| JOINT EFF. (CIRCUMFL JT. / LGTDNL JT.)                |      |         |         |       |     |     | .85   .85                              |
| CORROSION ALLOWANCE, IN                               |      |         |         |       |     |     | .0625                                  |
| HEIGHT, FT  |      |         |         |       |     |     | 14                                     |
|   |      |         |         |       |     |     |  |
| VESSEL THICKNESS, INCHES                              |      |         |         |       |     |     | .426925                                |
| HEAD THICKNESS, INCHES                                |      |         |         |       |     |     | .423790                                |
| Description: <input style="width: 80%;" type="text"/> |      |         |         |       |     |     |  |
| <input type="button" value="CALCULATE"/>              |      |         |         |       |     |     | <input type="button" value="CONVERT"/> |

*Example Problem 1 for Mechanical Design*

### **Example 2**

A 20 ft. tall vessel with an internal diameter of 60 inches and 0.325 inches thick wall is available for use. The vessel has a hemispherical head made of SA202(B) low alloy steel. It is to be used at a design temperature of 600°F and a design pressure of 175 psig. The vessel has double welded butt joints that are spot radiographed. The head is attached to the vessel with a Type No. 1 butt joint. Can the vessel be used for this new application if a corrosion allowance of 0.0625 in. is to be maintained? If not, can any feasible alterations be made to meet the requirements?

### **Step by Step Solution Procedure**

1. Select the *Vertical* vessel option from the **Options** menu, the *Hemispherical* head option from the **Heads** menu, the correct material from the menu titled **Mtl.** and the correct joint efficiency from the **Eff.** menu. Enter the input data in the appropriate fields selecting pressure as the unknown variable.
2. Enter the thickness, temperature, corrosion allowance and height in their appropriate input fields. Note that the stress value has been automatically filled in.
3. Click **Calculate** to obtain the design pressure. A pressure of 156.851 psig. is obtained. Since this is less than the specified operating pressure (175 psig.) this vessel can not be used, as is, for this new application.
4. A feasible alternative in this case is to check whether fully radiographing the longitudinal joints would help. Changing the longitudinal joint efficiency to 1, redo the calculation (i.e. click **Calculate**). A design pressure of 184.531 psig. is obtained which is greater than the required design pressure. Hence if the longitudinal joints are fully radiographed, the vessel could be used for the new application.

The figures below show the input and output fields for this example.

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**Note:** If the circumferential joint efficiency is greater than half the longitudinal joint efficiency use the latter efficiency for calculation purposes. Also, if supplementary loading does not cause longitudinal bending or tension in conjunction with internal pressure being investigated, the circumferential stress caused by longitudinal joints is used for calculation purposes. Therefore, in such a case the circumferential joints would not need to be altered.

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MECHANICAL DESIGN

File Mode Options Unknown Heads Dia Mtl Eff

|  |         |
|--|---------|
| VESSEL THICKNESS, INCHES               | .325    |
| DESIGN TEMPERATURE, DEG. F.            | 600     |
| INTERNAL DIAMETER, INCHES              | 60      |
| ALLOWABLE STRESS, PSI                  | 21200   |
| JOINT EFF. (CIRCUMFL JT. / LGTDNL JT.) | .85 .85 |
| CORROSION ALLOWANCE, IN                | .0625   |
| LENGTH, FT                             | 20      |

DESIGN PRESSURE, PSIG 156.851

Description:

CALCULATE CONVERT

Example Problem 2 (part 1) for Mechanical Design

MECHANICAL DESIGN

File Mode Options Unknown Heads Dia Mtl Eff

|  |       |
|--|-------|
| VESSEL THICKNESS, INCHES               | .325  |
| DESIGN TEMPERATURE, DEG. F.            | 600   |
| INTERNAL DIAMETER, INCHES              | 60    |
| ALLOWABLE STRESS, PSI                  | 21200 |
| JOINT EFF. (CIRCUMFL JT. / LGTDNL JT.) | .85 1 |
| CORROSION ALLOWANCE, IN                | .0625 |
| LENGTH, FT                             | 20    |

DESIGN PRESSURE, PSIG 184.531

Description:

CALCULATE CONVERT

Example Problem 2 (part 2) for Mechanical Design



# Process Design

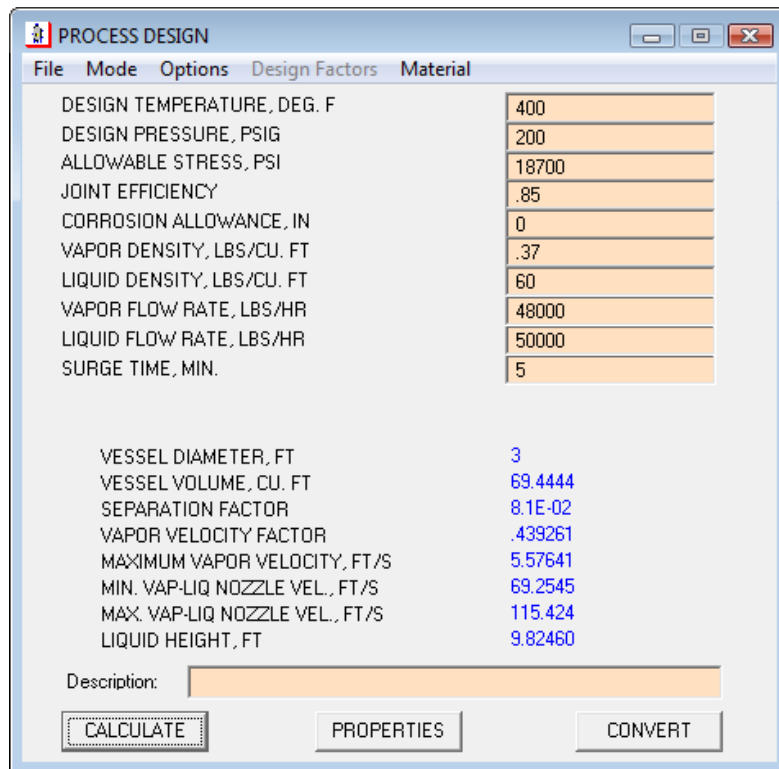
## Overview

The process design programs allows the user to size/simulate the operations of vapor-liquid separators, settling drums and reflux drums, as well as, calculate the course thicknesses of storage tanks. Variations in size with changing flows and pressure can be studied almost instantaneously. Pop-up messages warn the user of unreasonable values that could perhaps lead to process failure. This program uses minimal input data to provide a very good estimate of design parameters for preliminary sizing calculations.

Vessels in the chemical processing industry are basically of two types - those with internals, and those that are substantially without internals. This program deals with the sizing of process vessels of the latter type, generally referred to as drums or tanks. These vessels provide intermediate storage or surge for a process stream, or enable phase separation by settling. The sizing of these vessels has been primarily based on the methods developed by R. N. Watkins and B. Sigales.

## Window Description

The process design window shown below has the inputs in red and the results displayed in blue. The process design requires fluid properties, which may be already filled in if the user had calculated them in the fluid properties window



*Process Design Screen*

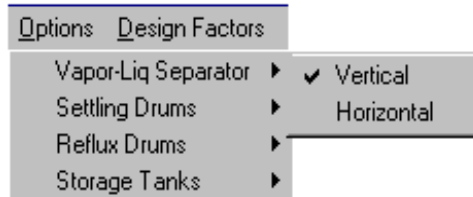
accessible from the Smartdraw screen. Alternatively, the user may manually input them or click the **Properties** button and import the properties from a saved file. The **Calculate** and **Convert** buttons perform the same functions as in other modules, viz., generate results and enter the Conversion Calculator program.

## Menu Item Description

This section will assist the user in familiarizing himself with the various options available on the screen. Each menu is dealt with in turn and the various options available are then discussed in detail. The figure above shows the *Process Design* screen with the available menus.

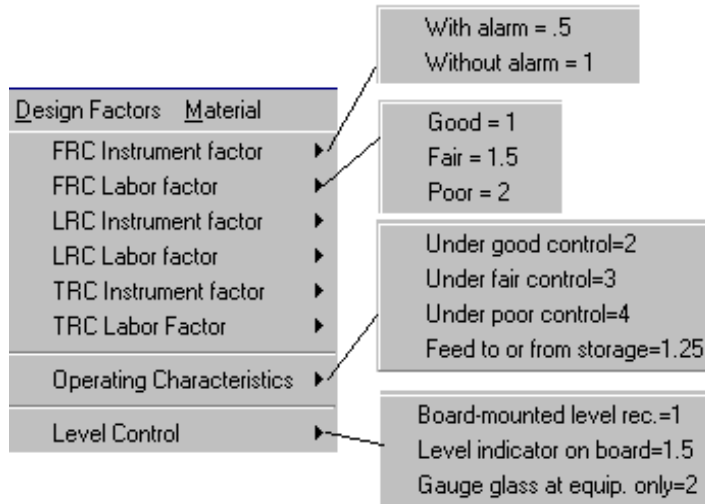
The file, mode, materials and joint efficiency menus are the same as those on mechanical design screen. Please refer to the mechanical design section for details regarding these menu items.

### Options



This menu allows the user to select the type of process vessel he desires to size. The sub-menus under these options are dealt with in their appropriate sections.

### Design Factors



This menu helps the user in deciding the surge time if the value is not known and is especially useful for reflux drum sizing. It is divided into three sections. The first section deals with the kind of controllers one has on the system, i.e. flow recorder controller (FRC), level recorder control (LRC) or temperature recorder controller (TRC). The instrument factor and labor factor of any one of these controllers must be specified, i.e. the user may specify that the flow recorder and controller is say, without an alarm and is under fair control. The user must then select its operating characteristic (section 2) and also select the

type of level control (section 3) used. If the surge time is known beforehand, then its value may be entered directly in the input field. Please refer to the reflux drum section for other details.

## Details about Sizing

Details regarding the sizing of various process vessels are given below along with example problems for each type. The length to diameter (L/D) ratio is usually in the range of 3 - 5 (diameters being smaller at higher pressures and for liquid-liquid settling). A rough dependence on pressure is shown in Table 1:

*Table 1 An approximate variation of L/D ratio with pressure*

| P (Psig) | 0 - 250 | 251 - 500 | 500 + |
|----------|---------|-----------|-------|
| L/D      | 3       | 4         | 5     |

## Vapor - Liquid Separators

This program sizes both vertical and horizontal separators. Vapor-liquid separators usually accomplish two functions. Their primary purpose is to separate vapor and liquid, but they may also serve as liquid surge drums. The basic idea of design is to provide a sufficiently low velocity so that vapor and liquid will separate. The surge volume must also be designed properly. A vertical vessel is generally preferred as its efficiency does not vary much with liquid level and is usually used when the volume of liquid is small compared with the vapor volume. As a general rule, a vessel which is to provide a large surge volume such as an atmospheric tower accumulator, should be a horizontal drum. A vessel that provides only a small surge volume, such as a compressor inter-stage knockout drum should be a vertical drum. This program sizes separators taking economics into consideration and this sometimes results in L/D ratios that are a little less than 3. According to the API code (Spec 12 J: Oil and Gas Separators), the L/D ratio for separators, should normally never be less than 2 or greater than 6. For small volumes of liquid, it may be necessary to provide more liquid surge than is necessary to satisfy the  $L/D > 2$  condition. If the required liquid surge volume is greater than that possible in a vessel having  $L/D < 5$ , a horizontal drum must be used.

The dimensions of the vertical vapor-liquid separator are calculated using the figure shown on page 105. The shell length is generally expanded in 2.5 foot increments measured from head seam to head seam and is typically 5 feet, 7.5 feet, etc. Vessel diameter is generally expanded in 6 inch increments. Example problems are given below.

## Example Problems for Vapor-Liquid Separators

### **Example 3**

It is required to size a separator that would separate a liquid with a mass flow of 50,000 LB/hr and a density of 60 lb/ft<sup>3</sup>, from a vapor, 48,000 LB/hr with a density of 0.37 lb/ft<sup>3</sup>, at 400°F and 200 psig. The surge time is 5 minutes. The

separator is to be constructed of SA202(A) low alloy steel and no corrosion allowance is to be provided. Joint efficiency = .85.

The screenshot shows a software window titled "PROCESS DESIGN" with a menu bar (File, Mode, Options, Design Factors, Material) and a list of parameters. The input parameters are on the left, and the calculated results are on the right. The results are color-coded: blue for calculated values and orange for input values.

|                                |         |
|--------------------------------|---------|
| DESIGN TEMPERATURE, DEG. F     | 400     |
| DESIGN PRESSURE, PSIG          | 200     |
| ALLOWABLE STRESS, PSI          | 18700   |
| JOINT EFFICIENCY               | .85     |
| CORROSION ALLOWANCE, IN        | 0       |
| VAPOR DENSITY, LBS/CU. FT      | .37     |
| LIQUID DENSITY, LBS/CU. FT     | 60      |
| VAPOR FLOW RATE, LBS/HR        | 48000   |
| LIQUID FLOW RATE, LBS/HR       | 50000   |
| SURGE TIME, MIN.               | 5       |
|                                |         |
| VESSEL DIAMETER, FT            | 3       |
| VESSEL VOLUME, CU. FT          | 69.4444 |
| SEPARATION FACTOR              | 8.1E-02 |
| VAPOR VELOCITY FACTOR          | .439261 |
| MAXIMUM VAPOR VELOCITY, FT/S   | 5.57641 |
| MIN. VAP-LIQ NOZZLE VEL., FT/S | 69.2545 |
| MAX. VAP-LIQ NOZZLE VEL., FT/S | 115.424 |
| LIQUID HEIGHT, FT              | 9.82460 |

Description:

Buttons: CALCULATE, PROPERTIES, CONVERT

*Example 3, Vapor-Liquid Separators*

## Step by Step Solution Procedure

1. Obtain density values in the properties window accessible from the Smartdraw screen. **Note that vapor and liquid densities have to be obtained separately.** Please save the vapor and liquid properties as separate files. Alternatively, liquid and vapor densities may be entered manually if known.
2. Select the *Vertical* separator option from the **Options** menu.
3. Select the *SA202(A) Low Alloy Steel* grade from the **Material** menu.
4. Enter the input data for the separator.
5. Click **Calculate** to obtain the results.
6. Use the figure shown on the next page to fix the height of the drum.

The input data with the results for this example are shown in the figure above.

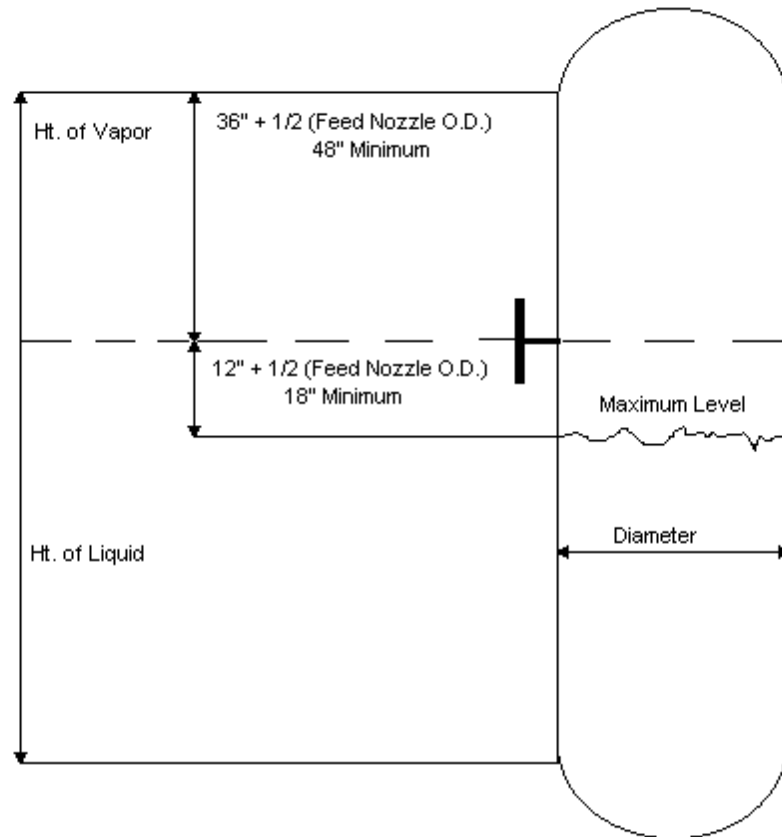


Figure for fixing the Vertical Separator Dimensions

### Example 4

**Size** a horizontal separator constructed of SA202(B) low alloy steel for the following conditions:

Flow rate of liquid = 56,000 LB/hr

Flow rate of vapor = 40,000 LB/hr

Density of liquid = 60 lb/ft<sup>3</sup>

Density of vapor = 1.47 lb/ft<sup>3</sup>

L/D ratio = 3

Corrosion allowance = .0625 in.

Joint Efficiency = .85

Temperature = 200 F

Pressure = 100 psig

### Step by Step Solution Procedure

1. Select the *Horizontal Vapor-Liquid Separator* option from the **Options** menu.
2. Select the *SA202(B)* grade of *Low Alloy Steel* from the **Materials** menu.
3. Type in the input data for the horizontal separator.
4. Click on calculate to obtain the results.

The screenshot shows a software window titled "PROCESS DESIGN" with a menu bar (File, Mode, Options, Design Factors, Material). The main area contains a list of input and output parameters. The input parameters are listed on the left, and their values are entered in text boxes on the right. The output parameters are listed on the left, and their calculated values are shown on the right. At the bottom, there is a "Description:" field and three buttons: "CALCULATE", "PROPERTIES", and "CONVERT".

|                              |         |
|------------------------------|---------|
| DESIGN TEMPERATURE, DEG. F   | 200     |
| DESIGN PRESSURE, PSIG        | 100     |
| ALLOWABLE STRESS, PSI        | 21200   |
| JOINT EFFICIENCY             | .85     |
| CORROSION ALLOWANCE, IN      | .0625   |
| VAPOR DENSITY, LBS/CU. FT.   | 1.47    |
| LIQUID DENSITY, LBS/CU. FT.  | 60      |
| VAPOR FLOW RATE, LBS/HR      | 40000   |
| LIQUID FLOW RATE, LBS/HR     | 56000   |
| L/D RATIO                    | 3       |
|                              |         |
| VESSEL LENGTH, FT.           | 9       |
| VESSEL DIAMETER, FT.         | 3       |
| VESSEL VOLUME, CU. FT.       | 120.380 |
| SEPARATION FACTOR            | .219134 |
| VAPOR VELOCITY FACTOR        | .447782 |
| MAXIMUM VAPOR VELOCITY, FT/S | 2.82551 |
| SURGE TIME, MIN              | 6.19097 |

Description:

CALCULATE      PROPERTIES      CONVERT

*Example Problem for Horizontal Vapor-Liquid Separator*

## Settling Drums

Separation of a liquid phase from a mixture of two immiscible liquids under the influence of gravity, or induced by other means is known as settling. Horizontal drums are usually used for this purpose and generally operate under full capacity. Vertical liquid-liquid separators with an overflow weir for the lighter phase are sometimes used for low rate operations or particularly large flows at, or near atmospheric pressure. The separation occurs due to the density difference between the two liquids and the rate of settling is influenced by viscosity and drop size.

As the rise or fall of droplets is interfered with by lateral flow of the liquid, the diameter of the drum should be made large enough to minimize this adverse effect. Hooper and Jacobs (1979) proposed a rule based on the Reynolds number of the phase through which the movement of the liquid occurs. The rules are shown in Table 2.

*Table 2 Separation effectiveness based on Reynolds Number*

| <b>N<sub>Re</sub></b> | <b>Effect</b>           |
|-----------------------|-------------------------|
| Less than 5,000       | little problem          |
| 5,000 - 20,000        | some hindrance          |
| 20,000 - 50,000       | major problem may exist |
| <i>Above 50,000</i>   | expect poor separation  |

The dispersed phase can be identified using the factor :

$$\Psi = Q_R * \rho_R * u_R * r^{0.3}$$

Where,

$N_{Re} = D_h * u * \rho / \mu$  is the Reynolds No. and

$D_h =$  The hydraulic diameter

$Q_R = Q_H / Q_L$  (ratio of heavy and light volumetric flows)

$\rho_R = \rho_H / \rho_L$  (ratio of heavy and light densities)

$u_R = u_H / u_L$  (ratio of heavy and light linear velocities)

$u = 2.415 * (\rho_h - \rho_L) / \mu$  ( $\mu$  being the viscosity of the corresponding liquid.)

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**Note:** All units must be consistent.

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Table 3 shows the significance of this factor.

Table 3 Ascertaining the dispersed phase

| $\psi$    | Result  |
|-----------|---|
| < 0.3     | light phase always dispersed                    |
| 0.3 - 0.5 | light phase probably dispersed                  |
| 0.5 - 2.0 | phase inversion probable, design for worst case |
| 2.0 - 3.3 | heavy phase probably dispersed                  |
| > 3.3     | heavy phase always dispersed                    |

Drum sizing is based on the settling rate and the flow rate. The drum volume should provide enough holdup time for a drop to move from the top or bottom of the drum to the interface of the two liquid phases. Often horizontal baffles or packing is provided to accelerate separation and thus reduce the drum volume. The design consists of determining the drum dimensions and also the high and low levels of the interface (needed to fix instrument connections).

## Example Problems for Settling Drums

### **Example 5**

A light hydrocarbon is to be separated from a caustic solution that is being re-circulated. Data for the settler at 70°F, at atmospheric pressure and constructed of high alloy SA240 (316) steel (joint eff. = .85, corrosion allowance = 0) is as under:

Design Pressure = 200 psig

Caustic solution, re-circulated = 14,500 lb/hr

Caustic solution, density = 68.67 lb/ft<sup>3</sup>

Light hydrocarbon load = 25,000 lb/hr

Light hydrocarbon density = 32.46 lb/ft<sup>3</sup>

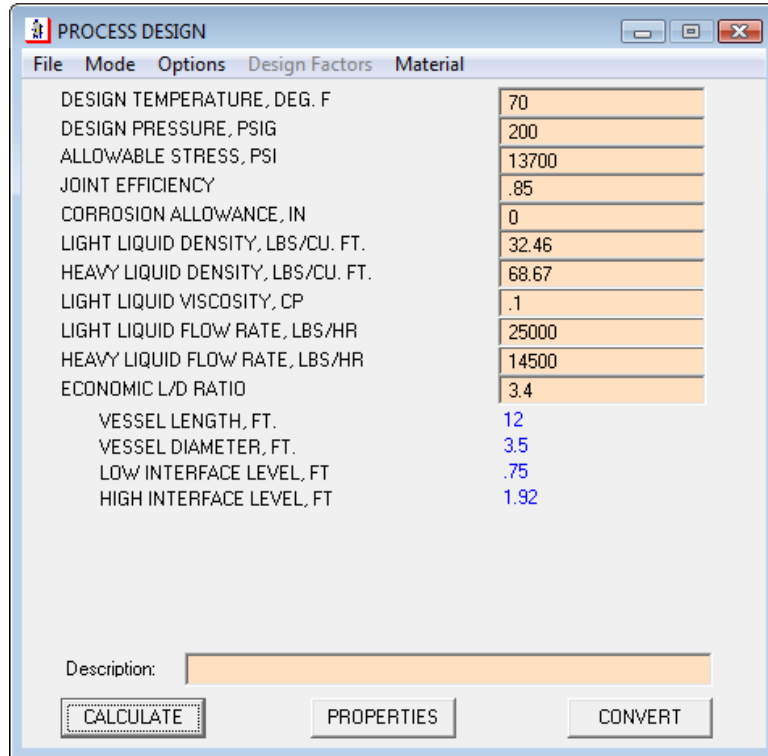
Light continuous phase viscosity = 0.1 cP

Economic L/D ratio = 3.4

### **Step by Step Solution Procedure**

1. Select the *Heavy Phase Re-circulated* option of settling drums from the **Options** menu.
2. Select the *SA240 (316)* grade of *High-Alloy Steel* from the **Materials** menu.
3. Type in the input data for the settler. Click on the desired input cell for which you require data.
4. Click on **Calculate** to view the results.
5. The inputs and results are shown in the figure on the next page.





*Settler with Heavy Phase Re-circulated (Example 5)*

### Example 6

Assume the following data for a SA240(304L) high-alloy steel settler at 10 psig and 60°F designed to completely separate two phases:

Light Phase load, lb/hr = 39,000

Heavy Phase load, lb/hr = 20,000

Light Phase density, lb/ft<sup>3</sup> = 37.17

Heavy Phase density, lb/ft<sup>3</sup> = 65.2

Light Phase viscosity, cp = 0.1

Heavy Phase viscosity, cp = 2

Economic L/D ratio = 2.6

Corrosion Allowance, inches = 0.0325

### Step by Step Solution Procedure

1. Select a settler for *Complete Phase Separation* from the **Options** menu.
2. Select the *SA240(304L)* grade of *High-Alloy Steel* from the **Materials** menu.
3. Type in the input data for the settler.
4. Click on **Calculate** to obtain the results.

| Parameter                                 | Value   |
|---|---------|
| DESIGN TEMPERATURE, DEG. F                | 60      |
| DESIGN PRESSURE, PSIG                     | 10      |
| ALLOWABLE STRESS, PSI                     | 13700   |
| JOINT EFFICIENCY                          | .85     |
| CORROSION ALLOWANCE, IN                   | .0325   |
| LIGHT LIQUID DENSITY, LBS/CU. FT.         | 37.17   |
| HEAVY LIQUID DENSITY, LBS/CU. FT.         | 65.2    |
| VISCOSITY, CP ( LIGHT LIQ.   HEAVY LIQ. ) | .1   2  |
| LIGHT LIQUID FLOW RATE, LBS/HR            | 39000   |
| HEAVY LIQUID FLOW RATE, LBS/HR            | 20000   |
| ECONOMIC L/D RATIO                        | 2.6     |
| VESSEL LENGTH, FT.                        | 9.09999 |
| VESSEL DIAMETER, FT.                      | 3.5     |
| LOW INTERFACE LEVEL, FT                   | .75     |
| HIGH INTERFACE LEVEL, FT                  | 2.46609 |

Description:

CALCULATE      PROPERTIES      CONVERT

*Settler with Complete Phase Separation (Example 6)*

## Reflux Drums

This option allows you to design reflux accumulators with and without demisters. Correct sizing of reflux drums is important as it must allow: (1) droplet disengagement in the vapor phase; (2) enough surge time for the liquid phase; (3) settling of small amounts of a second heavy-liquid phase (usually water). Good judgment is also required when deciding the surge time as it is not only a function of the instrumentation and control schemes, but also a function of the other process steps. You can fix surge times by simply selecting the factors from the design factors menu. This method developed by R. N. Watkins is especially useful for design and process engineers. Labor factors should be selected with proper discretion. Sharp and seasoned personnel would be able to immediately determine and rectify the cause of trouble, but untrained personnel may take a considerably longer time and hence the surge time would be somewhat longer in the latter case. The value of surge time (on half-full basis) may be directly entered in the input field if desired. Given below is the formula and an example of how surge time can be ascertained. The value of the factors may be seen in **Design Factors** menu.

$$\text{Drum Volume} = 2 * F4 * (F1 + F2) * (L + f3 * D)$$

Where,

L = Volumetric reflux flow rate

D = Volumetric distillate flow rate

F1 = Instrument factor

F2 = Labor factor

F3 = Operating characteristics

F4 = Level Control factor

For example, if L = 400 gpm; D = 200 gpm; F1 = 1; F2 = 1.5; F3 = 3; F4 = 1.5.  
Substitution in the above formula yields:

Drum Volume =  $2 * 1.5 * (1 + 1.5) * (400 + 3 * 200) = 7500$  gal, full.

Surge time =  $7500 / (400 + 200) = 12.5$  min, full

= 6.25 min, half-full

As distillate-reflux drums are normally installed horizontally, liquid load being important, this program sizes only horizontal drums. The velocity constant for a horizontal reflux drum without a demister has been taken as 0.13 and a value of 0.26 is used for a horizontal drum with a wire-mesh demister. Some design aspects of reflux drums are as below :

1. Minimum length of reflux drums is 3 ft. to allow space for interface-level controller connections.
2. When a small quantity of a second liquid phase is settled, a draw-off pot is normally provided to make separation of the heavy liquid easier.
3. A minimum pot diameter for reflux drums having 4-8 ft. diameters is 16 inches. For diameters above 8 ft., diameter of the pot should be at least 24 in. The pot must also be placed at a minimum distance from the tangent line that joints the head with the body of the vessel.
4. The minimum vapor space above the high level is 20% of the drum diameter or 10 inches.

## Example Problem for Reflux Drums

### *Example 7*

Determine the reflux-drum dimensions for the following conditions:

Operating pressure = 250 psig

Operating temperature = 550°F

Reflux = 87,400 LB/hr

Product to heater = 28,300

Vapor Load = 14,100 lb/hr

Vapor density = 1.15 lb/ft<sup>3</sup>

Liquid density = 39.9 lb/ft<sup>3</sup>

Mtl. of construction - SA515(55) carbon steel

Joint efficiency = .85

Corrosion allowance = 0.125 inches

Surge Time = 11.6 minutes

## Step by Step Solution Procedure

1. Select a *Reflux Drum* without a demister from the **Options** menu.
2. Select the SA202(55) grade of *Carbon Steel* from the **Materials** menu.
3. Type in the input data for the reflux drums.
4. Click on **Calculate** to obtain the results.

The figure on the next page shows the input and output screens for this example.

The screenshot shows a software window titled "PROCESS DESIGN" with a menu bar (File, Mode, Options, Design Factors, Material) and a list of input and output parameters. The input parameters are in orange boxes, and the output parameters are in blue boxes. At the bottom, there are buttons for "CALCULATE", "PROPERTIES", and "CONVERT", along with a "Description:" text field.

|                                 |         |
|---------------------------------|---------|
| DESIGN TEMPERATURE, DEG. F      | 550     |
| DESIGN PRESSURE, PSIG           | 250     |
| ALLOWABLE STRESS, PSI           | 13700   |
| JOINT EFFICIENCY                | .85     |
| CORROSION ALLOWANCE, IN         | .125    |
| VAPOR DENSITY, LBS/CU. FT.      | 1.15    |
| LIQUID DENSITY, LBS/CU. FT.     | 39.9    |
| VAPOR LOAD, LBS/HR              | 14100   |
| MASS FLOW OF REFLUX, LBS/HR     | 87400   |
| MASS FLOW OF DISTILLATE, LBS/HR | 28300   |
| SURGE TIME, MIN                 | 11.1689 |
| VESSEL LENGTH, FT.              | 19.5    |
| VESSEL DIAMETER, FT.            | 7.5     |
| SURGE VOLUME, CU. FT.           | 539.783 |
| LOW LIQUID LEVEL HT., FT        | 3.5775  |
| HIGH LIQUID LEVEL HT., FT       | 5.4     |

*Example of Reflux Drum Calculations (Example 7)*

## Storage Tanks

Time variations in the supply of raw material and the demand for the product influence the sizes and numbers of storage tanks. Storage tanks are mainly classified into the cone roof type and the floating roof type. Tanks are generally cylindrical in shape, although spherical tanks are sometimes used. Tanks could be of varying shapes in certain high pressure or some other specific applications (*Chemical Process Machinery* - E. R. Riegel).

Some basic design practices for storage tanks (*Chemical Process Equipment - Selection and Design*, Stanley M. Walas) are as under:

- a) Liquids with high vapor pressures, liquefied gases, and gases at high pressure are stored in elongated horizontal vessels. They are also sometimes stored in spherical vessels).

- b) Gases are usually stored at pressures close to atmospheric in gas holders with floating roofs that are sealed with liquid in a double wall.
- c) Liquefied gases are maintained at sub-atmospheric temperatures with external refrigeration or auto refrigeration.
- d) Liquids that have a freezing point close to atmospheric or become highly viscous under ambient conditions are stored in jacketed vessels and kept at a suitable temperature above the ambient.
- e) Liquids that are subject to breathing losses may be stored in tanks with floating or expansion roofs for conservation.
- f) Liquid storage tanks are provided with a certain amount of vapor space or freeboard, commonly 15% below 500 gallons and 10% above 500 gallons.
- g) Liquid storage tanks with a capacity of less than 1000 gallons are usually vertical and mounted on legs.
- h) Liquid storage tanks with a capacity between 1000 and 10,000 gallons are usually horizontal and mounted on concrete supports.
- i) Liquid storage tanks with a capacity greater than 10,000 gallons are usually vertical and mounted on concrete foundation.
- j) Capacity of storage tanks are at least 1.5 times the size of connecting transportation equipment.

The storage tank design is based on the API-650 code (7<sup>th</sup> edition). This module designs both the cone roof type and the floating roof type storage tanks. The inputs are simply the height and the diameter of the tank. The output consists of the capacity, the number of shell courses and the thickness of each course. The design criteria is as below:

1. Wind = 100 MPH
2. Seismic - Zone 0
3. Design Specific Gravity = 1.0
4. Corrosion Allowance = 0
5. Design Pressure = Atmospheric
6. Design Metal Temperature = +15°F

---

**Notes:** The capacity is based on a flat bottom and the shell filled to full height. Material = Plates A36, A36 MOD and A573-58, Structural A36. Bottom Thickness = 1/4"; Roof/Roof Deck = 3/16"

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## Example Problems for Storage Tanks

### ***Example 8***

What would be the thickness of each course of a Cone Roof and a Pontoon Floating Roof Storage Tank which is 40 feet in diameter and 60 feet tall.

## Step by Step Solution Procedure

1. Select a *Cone Roof Storage Tank* from the **Options** menu.
2. Type in the height and diameter of the tank.
3. Click on **Calculate** to obtain the results.
4. Select the *Floating Roof Storage Tank* from the **Options** menu.
5. Repeat steps 2 and 3 above to obtain the results for a floating roof storage tank.

The figures below show the input and output screens for the Cone Roof Storage Tank and the Pontoon Floating Roof Storage Tank.

The screenshot shows a software window titled "PROCESS DESIGN" with a menu bar containing "File", "Mode", "Options", "Design Factors", and "Material". The main area contains input fields for "HEIGHT, FT." (60) and "DIAMETER, FT." (40). Below these are output results for capacity and thickness. At the bottom, there are three buttons: "CALCULATE", "PROPERTIES", and "CONVERT".

|                           |          |
|---------------------------|----------|
| HEIGHT, FT.               | 60       |
| DIAMETER, FT.             | 40       |
| CAPACITY, GAL.            | 564007.3 |
| CAPACITY, BARRELS.        | 13428.78 |
| NUMBER OF COURSES         | 6        |
| THICKNESS, IN. - COURSE 1 | .313     |
| THICKNESS, IN. - COURSE 2 | .219     |
| THICKNESS, IN. - COURSE 3 | .188     |
| THICKNESS, IN. - COURSE 4 | .188     |
| THICKNESS, IN. - COURSE 5 | .188     |
| THICKNESS, IN. - COURSE 6 | .188     |

Description:

*Cone Roof Storage Tanks (Example 8)*

| Parameter                 | Value    |
|---------------------------|----------|
| HEIGHT, FT.               | 60       |
| DIAMETER, FT.             | 40       |
| CAPACITY, GAL.            | 564007.3 |
| CAPACITY, BARRELS.        | 13428.78 |
| NUMBER OF COURSES         | 6        |
| THICKNESS, IN. - COURSE 1 | .263     |
| THICKNESS, IN. - COURSE 2 | .25      |
| THICKNESS, IN. - COURSE 3 | .25      |
| THICKNESS, IN. - COURSE 4 | .25      |
| THICKNESS, IN. - COURSE 5 | .25      |
| THICKNESS, IN. - COURSE 6 | .25      |

Description:

*Floating Roof Storage Tanks*

## Calculation Basis

The mechanical design section has been based on the ASME Boiler and Pressure Vessel Code, Section VIII, Part I and II. The process design section has been based on methods by R. N. Watkins and B. Sigales for drum sizing, and the API Standard 650 for Tank Sizing. The vapor velocity factor is determined from Blackwell's correlation. For reflux and settling drums, curves are internally plotted - one representing values that satisfy the input conditions and the other a cost curve. The intersection between these is obtained and the next available commercial diameter is obtained. The length is calculated based on this diameter.

### Assumptions and Design Criteria

1. Droplet size of .005 inches.
2. Volume of dished heads is not considered in vessel-sizing calculations (conservative approach).
3. Vapor velocity factor is calculated at 85% flooding.
4. A vapor velocity factor of 0.13 ft/sec is used for reflux drums without a wire-mesh demister and a value of 0.26 ft/sec has been used for reflux drums having a wire-mesh demister.
5. A minimum vapor space = 20% of the drum diameter or 10 inches (whichever is higher) has been used for reflux drums.
6. For settling drums, a minimum space for the heavy phase in the bottom of the drum is set by fixing the low interface level to 20% of the drum diameter or 8 inches (whichever is higher).
7. Refer the Storage Tanks section for the design criteria for Cone Roof and Floating Roof storage tanks.

### Limitations

1. Thickness calculations for vessels are for internal pressure only.
2. Minimum thickness and Maximum Allowable Working Pressure values are valid only for vessels without loading.
3. A fixed droplet size of .005 inches is used for calculations.

## Equations

### *Cylindrical Vessels*

Circumferential Stress (longitudinal joints):

when  $t \leq 0.5 R$  or  $P \leq 0.385 S E$

$$t = \frac{PR}{SE - 0.6P}$$



when  $t > 0.5 R$  or  $P > 0.385 S E$

$$t = R \left( Z^{\frac{1}{2}} - 1 \right) = R_o \frac{\left( Z^{\frac{1}{2}} - 1 \right)}{Z^{\frac{1}{2}}}$$

where

$$Z = \frac{SE + P}{SE - P}$$

Longitudinal stress (circumferential joints):

when  $t \leq 0.5 R$  or  $P \leq 1.25 S E$

$$t = \frac{PR}{2SE + 0.4P}$$

when  $t > 0.5 R$  or  $P > 0.385 S E$

$$t = R \left( Z^{\frac{1}{2}} - 1 \right) = R_o \frac{\left( Z^{\frac{1}{2}} - 1 \right)}{Z^{\frac{1}{2}}}$$

where

$$Z = \frac{P}{SE} + 1$$

### ***Spherical Vessels***

when  $t \leq 0.356 R$  or  $P \leq 0.665 S E$

$$t = \frac{PR}{2SE - 0.2P}$$

when  $t > 0.356 R$  or  $P > 0.665 S E$

$$t = R \left( Y^{\frac{1}{3}} - 1 \right) = R_o \frac{\left( Y^{\frac{1}{3}} - 1 \right)}{Y^{\frac{1}{3}}}$$

where

$$Y = \frac{2(SE + P)}{2SE - P}$$

**Vessel Heads:**

Ellipsoidal Head:

$$t = \frac{PDK}{2SE - 0.2P}$$

Torispherical Head:

$$t = \frac{PLM}{2SE - 0.2P}$$

Hemispherical Head:

when  $t \leq 0.356 L$  or  $P \leq 0.665 S E$

$$t = \frac{PL}{2SE - 0.2P}$$

Conical Head:

$$t = \frac{PD}{2\cos\alpha(SE - 0.6P)}$$

Toriconical Head:

$$t = \frac{PD_i}{2\cos\alpha(SE - 0.6P)}$$

knuckle thickness

$$t = \frac{PLM}{2SE - 0.2P}$$

where,

$$L = \frac{D_i}{2\cos\alpha}$$

Flat Head:

$$t = CD_e \sqrt{\frac{P}{S}}$$

### **Nomenclature**

|          |   |
|----------|---|
| C        | design constant depending on edge constraint  |
| D        | inner diameter of skirt or length of major axis, inches   |
| $D_e$    | nominal plate diameter, inches  |
| $D_i$    | inner diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, inches |
| E        | lowest efficiency of any joint in the head  |
| h        | inner height of head, inches  |
| K        | ratio of the major axis of ellipsoidal head to its minor axis =   |
| $D/2h$   |   |
| L        | inside spherical or crown radius, inches  |
| M        | ratio of the inner crown radius to inner knuckle radius = $L/r$   |
| P        | internal design pressure, psi   |
| r        | inner knuckle radius, inches  |
| R        | inner radius of shell course, inches  |
| $R_o$    | outer radius of shell course, inches  |
| S        | maximum allowable stress in tension, psi  |
| t        | minimum required shell or head thickness, inches  |
| $\alpha$ | half the included apex angle of cone at the center line of head   |

### **Recommendations**

1. Use the mechanical design section for quickly obtaining the minimum thickness or MAWP values for vessels that are not subject to external loading and are subjected to internal pressure.
2. The length to diameter ratio for drums should be between 3 and 5. An economical design may sometimes give a ratio smaller than 3.

### **References**

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2. Walas, S. M., *Chemical Process Equipment Selection and Design*, Butterworth-Heinemann, Stoneham, MA (1990).
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6. Coker, A. K., *Oil & Gas Journal*, 55, (May 10, 1993).
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