

# CH402 Chemical Engineering Process Design

Class Notes L5

Flow Measurement  
Storage of Fluids

# Lesson 5 Agenda

Vessel design considerations

Homework – Problem 12-14

Flow Measurement – Orifice

Orifice Demo, CHEMCAD

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Lab this week, DS (1245 Friday)

Design Problem 2

Files will be in CANVAS

Due end of lab hour

Make sure Adobe is working

## Tanks and Vessels – Design Thickness

# Storage Tanks and Vessels

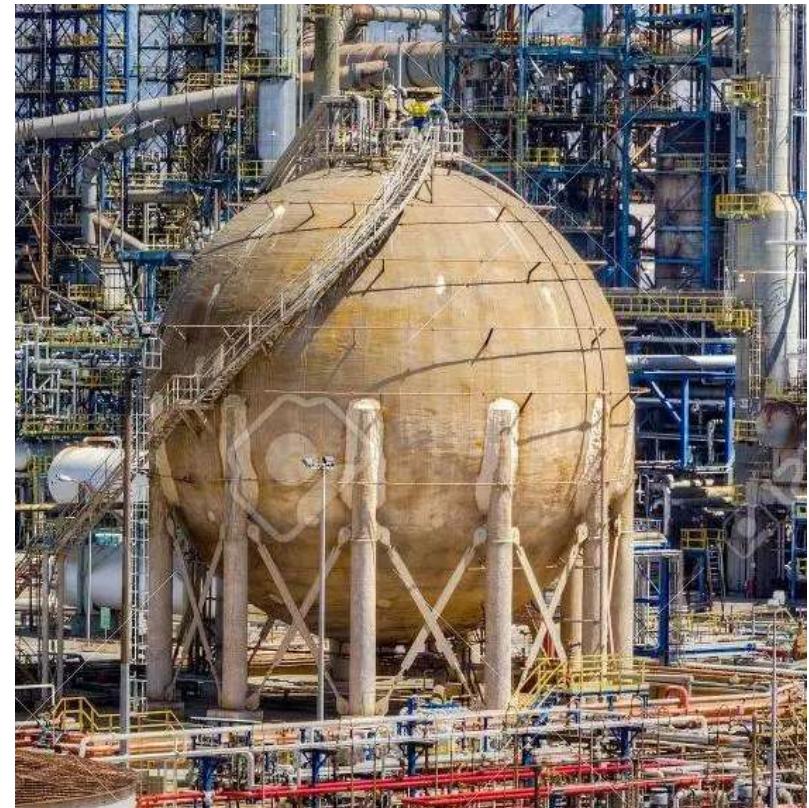
Vertical cylindrical storage tank fabricated on-site from flat plates



Small vertical cylindrical storage tanks with elliptical endcaps.



Large spherical storage tank in a refinery.



Cost determined by volume and material:

- |                     |                     |
|---------------------|---------------------|
| Spherical           | Fig. 12-52, p. 557  |
| Horizontal          | Fig. 12-54, p. 558  |
| Small field-erected | Fig. 12-55, p. 559  |
| Large field-erected | Fig. 12-56, p. 559  |
| Small containers    | Table 12-13, p. 560 |

# Vessel Design Calculations

Thickness must be calculated for safe design and cost

spherical tank

$$t = \frac{P \cdot r_i}{S \cdot E_j - .2 \cdot P} + C_c$$

cylindrical tank

$$t = \frac{P \cdot r_i}{S \cdot E_j - .6 \cdot P} + C_c$$

ellipsoidal end caps

$$t = \frac{P \cdot D_a}{2 \cdot S \cdot E_j - .2 \cdot P} + C_c$$

spherical end caps

$$t = \frac{P \cdot L_a}{S \cdot E_j - .2 \cdot P} + C_c$$

**Table 12-10, pages 554-555**

Check your “limiting conditions”

$t$  = shell thickness, m

$P$  = maximum allowable working pressure, kPa

$r_i$  = inside radius of shell, without corrosion allowance, m

$S$  = maximum allowable working stress, kPa, Table 12-10

$E_j$  = joint efficiency (for welds), dimensionless, Table 12-10

page 555; depends on weld

$C_c$  = corrosion allowance, m

$D_a$  = major axis of ellipsoidal head, without corrosion allowance, m

$L_a$  = inside radius of spherical head

next  
slide

pressure vessel

$$\text{Cost} = 73 \cdot W_v^{-.34}$$

Cost figures for vessels

Figures 12-52 to 12-57, Table 12-13

PTW website

# Types of Welds

Needed to understand Table 12-10 formulas

A weld is a joining of two materials, normally metals or plastics, with or without the use of a filler.  
Welding is a highly specialized field and there are about 30 different types.

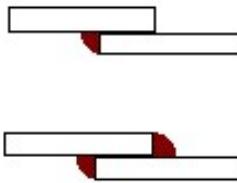
If all welds pass radiography test, then  $E_J = 1.0$

butt-weld



spot examined double butt weld  $E_J = 0.85$   
unradiographed double butt weld  $E_J = 0.70$   
spot examined single butt weld  $E_J = 0.60$

lap-weld



spot examined lap weld  $E_J = 0.80$

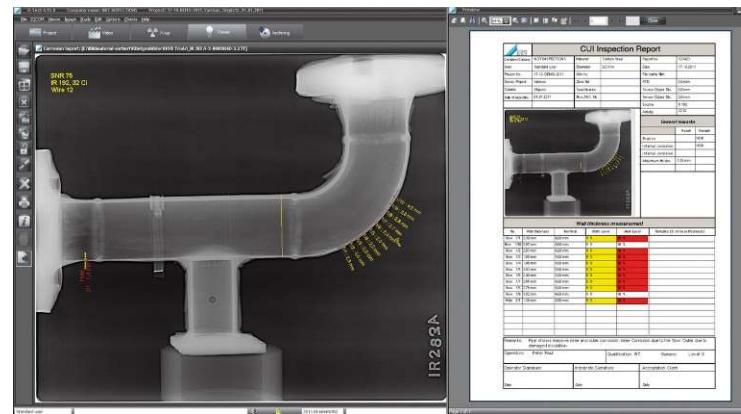
Butt-weld with backing plate



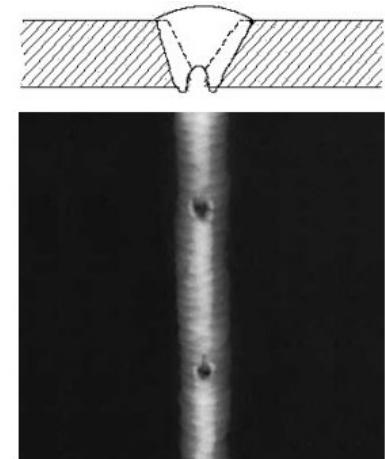
spot examined  $E_J = 0.90$



Shielded-metal arc welding is popular for heavy steel structures and industrial fabrication. Flux on electrode disintegrates forming a vapor barrier.  
<http://welderstation.com/>



Radiographic testing of welds and weld testing are necessary steps in any pipeline construction process to detect flaws and defects within welded materials. One common method of non-destructive testing is radiographic testing, whereby radiographic images, or x-rays, of the weld are produced.



Radiographers identify typical welding defects in the image image. The localized dark area is "burn-through." <https://sawyermf.com/>

### Problem 12-14 (Problem Set 3)

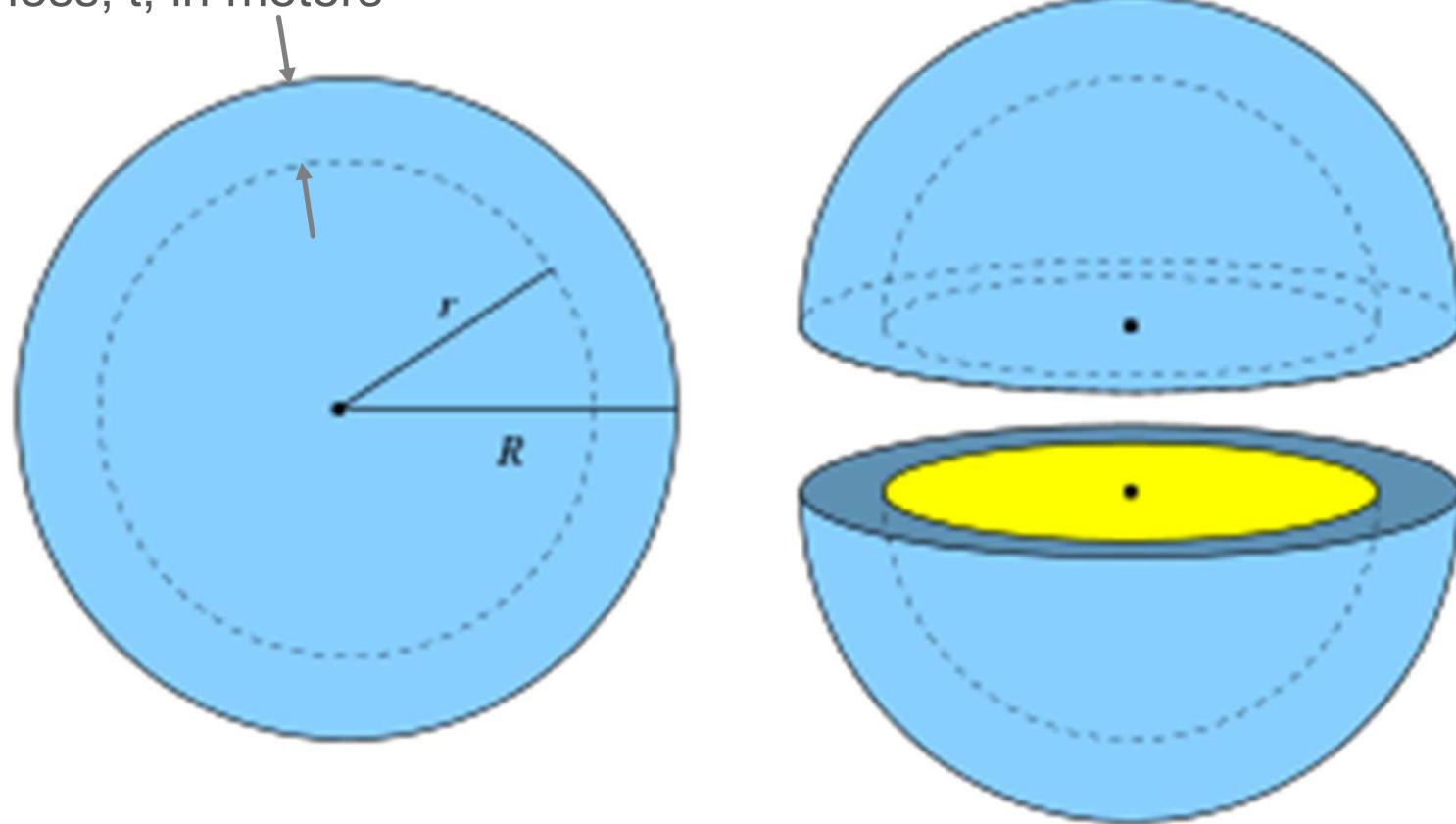
A spherical carbon-steel tank with an inside diameter of 9 m will be subjected to a working absolute pressure of 310 kPa and a temperature of 27 °C. All of the welds on the tank are butt-welded with a backing strip. Assuming no corrosion allowance is required, what is the required wall thickness of the tank? Estimate the cost of steel for this tank if the cost of steel sheet is \$1.10 per kilogram. On the bases of the data in Figure 12-52, determine the fraction of the purchased cost of the tank that is due to the cost for the steel.

backing plate

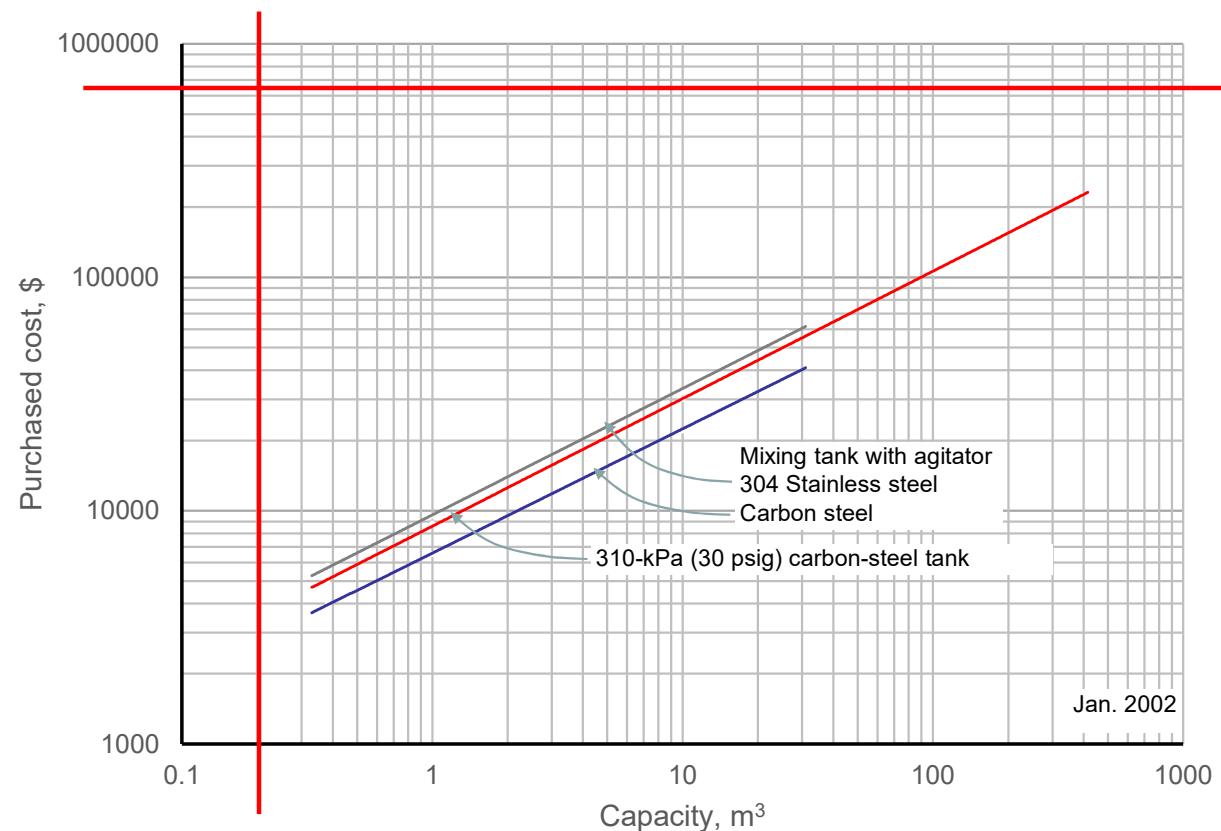


## Sketch of Spherical Shell for Problem 12-14

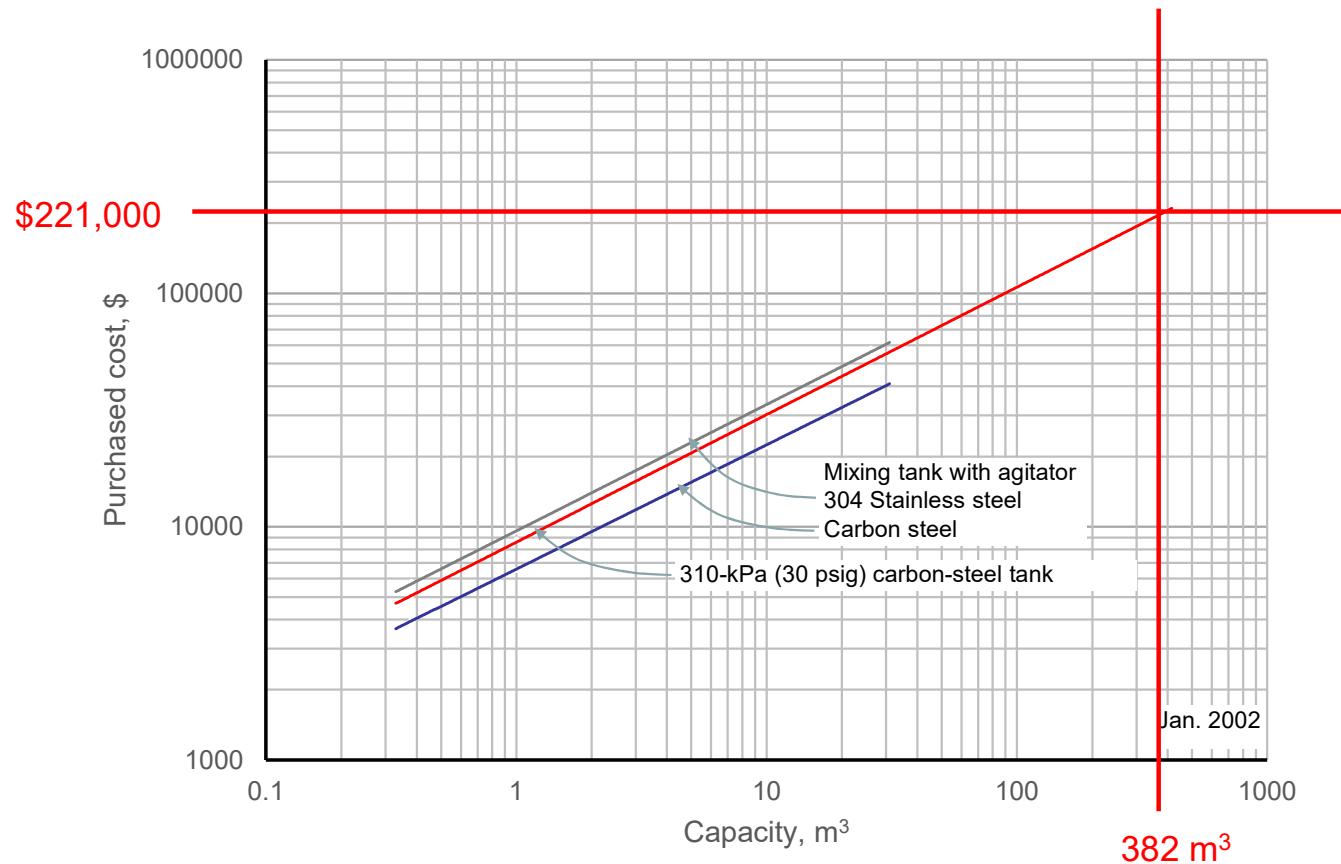
Thickness,  $t$ , in meters



[https://en.wikipedia.org/wiki/Spherical\\_shell](https://en.wikipedia.org/wiki/Spherical_shell)



**Figure 12-52.** Purchased cost of mixing and storage tanks. Price for mixing tank includes the cost of the driving unit.



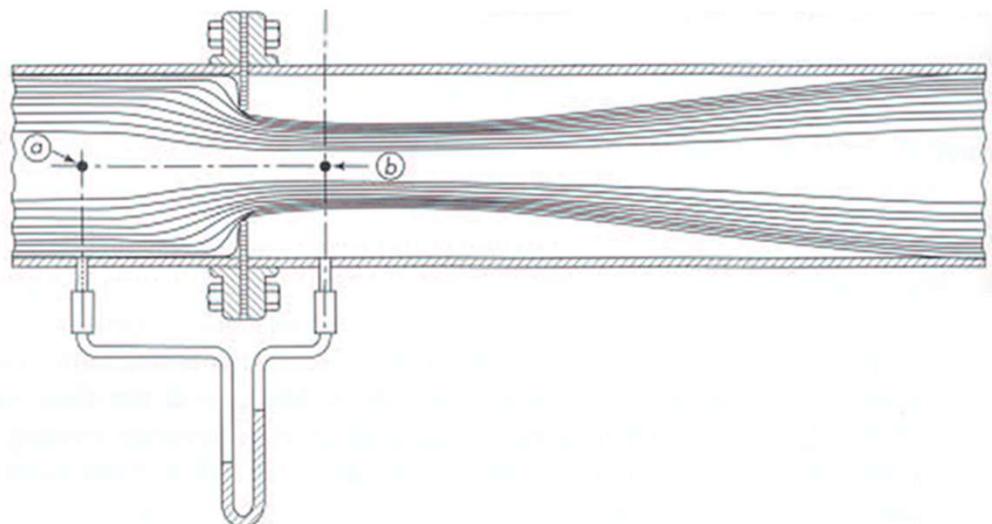
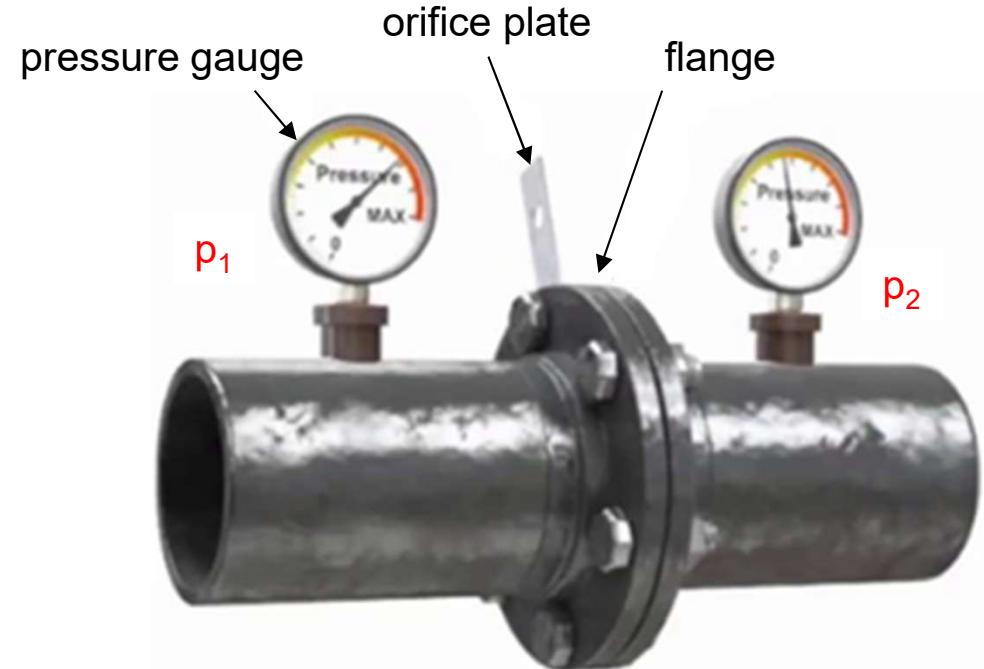
**Figure 12-52.** Purchased cost of mixing and storage tanks. Price for mixing tank includes the cost of the driving unit.

# Flow Measurement – Orifice Plates

# Flow Measurement with Orifice Meters

A constriction is added to the pipe – Bernoulli's equation

$\Delta V$  induces  $\Delta P$  across orifice - gives flow rate



# Flow Measurement with Orifice Plates

$$\dot{m}_v = Y \cdot C_d \cdot A_c \cdot \left[ \frac{2 \cdot (p_1 - p_2)}{\rho \cdot (1 - \beta^4)} \right]^{1/2}$$

Eq. 12-47, p. 550

Rotameters,  
Eq. 12-46, p. 550

$\dot{m}_v$  = volumetric flow rate,  $\text{m}^3 / \text{s}$

$C_d$  = discharge coefficient, dimensionless, Fig. 12 – 51

$A_c$  = cross-sectional area at minimum,  $\text{m}^2$

$\rho$  = fluid density,  $\text{kg/m}^3$

$\beta$  = ratio of throat diameter to pipe diameter

$p_1$  = static pressure upstream before constriction, kPa

$p_2$  = static pressure at minimum flow area, kPa

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$Y$  = expansion factor, dimensionless

liquids:  $Y = 1$  (for liquids)

gasses:  $Y = \left[ r^{2/k} \cdot \left( \frac{k}{k-1} \right) \cdot \left( \frac{1-r^{(k-1)/k}}{1-r} \right) \cdot \left( \frac{1-\beta^4}{1-\beta^4 \cdot r^{2/k}} \right) \right]^{1/2}$

Eq. 12-48, p. 550

$$r = p_2 / p_1$$

$$k = C_p / C_v$$

Plot, Fig. 12-50, page 551

# Demo – Orifice Plate

Cadets have separate slide deck with instructions