

# CH402 Chemical Engineering Process Design

Class Notes L5

Flow Measurement  
Storage of Fluids

# Lesson 5 Agenda

Orifice Demo, CHEMCAD

Flow Measurement – Orifice

Vessel design considerations

Homework – Problem 12-14

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Lab this week

DS (1245 Friday) and next week (1245 Tuesday)

Design Problem 2

Files will be posted in CANVAS

Due end of lab hour (1445)

Make sure Adobe is working

# Demo – Orifice Plate Design

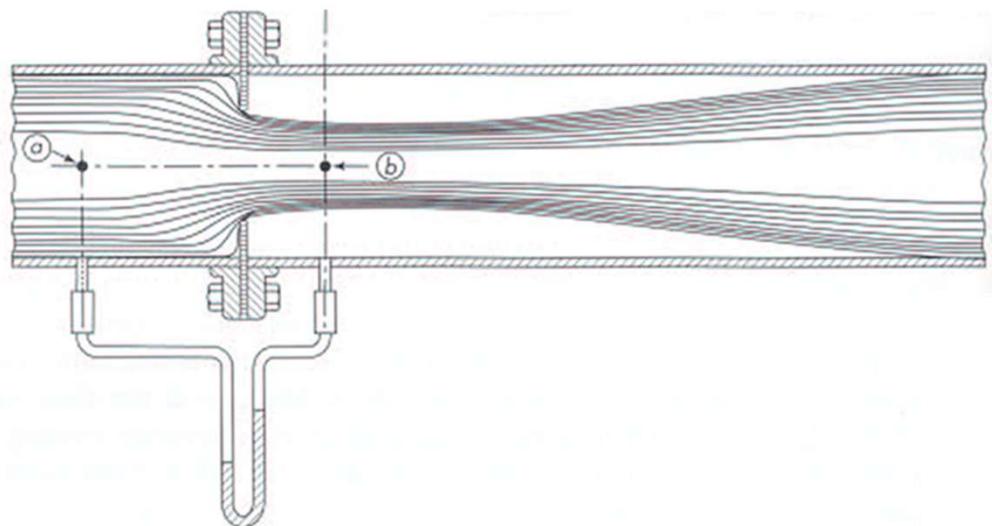
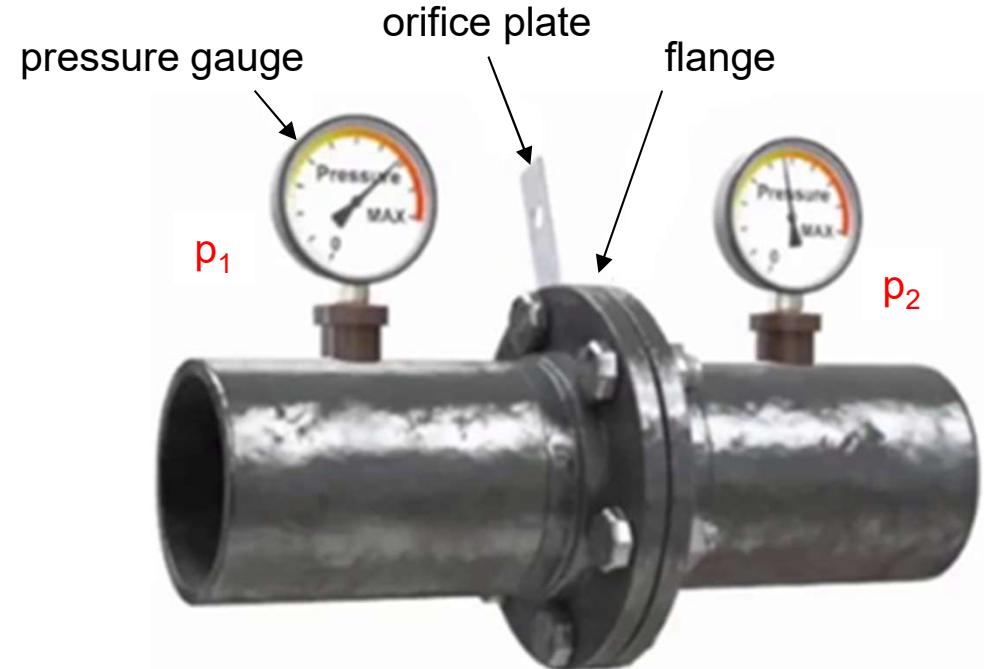
Cadets have separate slide deck with instructions in CANVAS

# 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

## Tanks and Vessels – Design Thickness

# Storage Tanks and Vessels

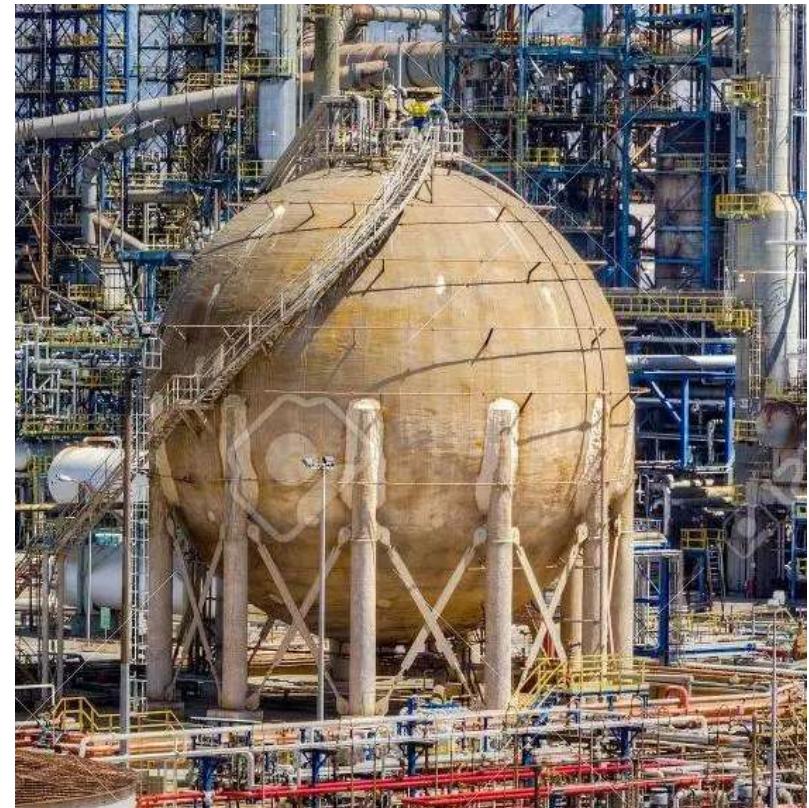
Vertical cylindrical storage tank fabricated on-site from flat plates



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.

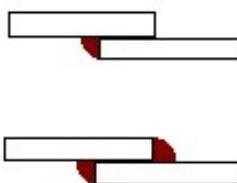
If all welds pass radiography test, then  $E_J = 1.0$

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  $E_J = 0.80$

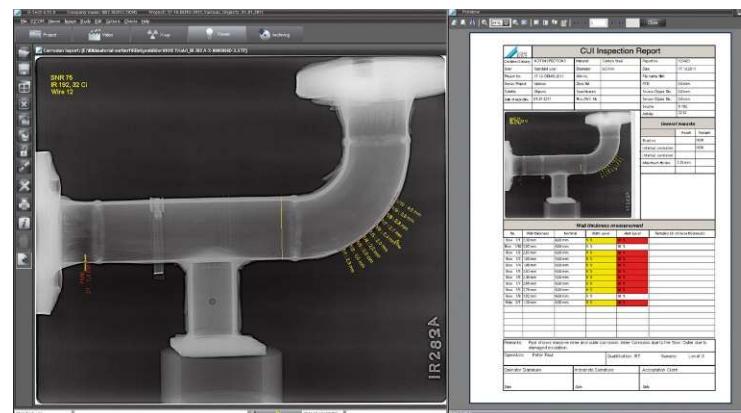
Butt-weld with backing plate



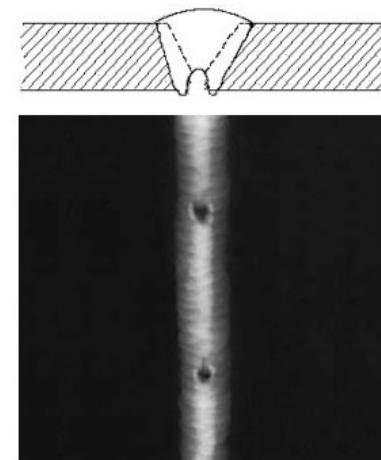
spot examined  $E_J = 0.90$



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/>

Questions?