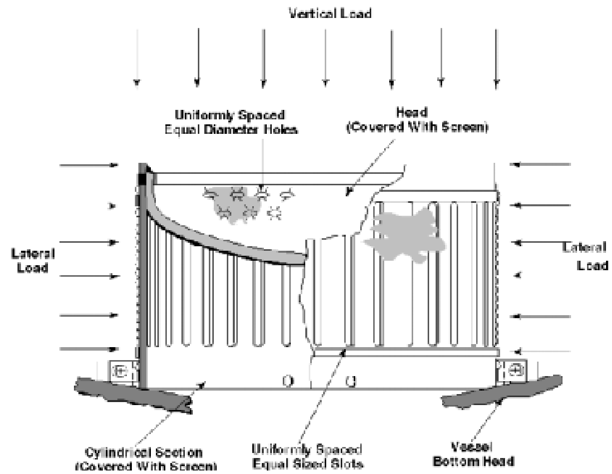
Outlet Collector Evaluation



Affiliate: Note: this is an older version of this worksheet

Unit: __________

Vessel: ___________________

Date: __________________

Engineer: _____________

INPUT VARIABLES

Vessel Data

Inside Diameter	$D := 153.5 \cdot in$	
Design Temperature	824°F	
Pressure Differential	$\Delta P_r := 100 \cdot psi$	*(live loading)*

Collector Data

Material Specification	SA-240 304L
Allowable Stress *(per ASME31.3)*	$S_a := 16803 \cdot psi$
Min Yield Stress *(at design temp)*	$S_y := 18700 \cdot psi$
Modulus *(at design temp)*	$E := 2.4 \cdot 10^7 \cdot psi$
Corrosion Allowance	$CA := 0.0196 \cdot in$
Outside Diameter	$D_c := 61.42 \cdot in$
Cylinder Thickness	$T_c := 0.7874 \cdot in$

Cylinder Slots	
Number	$N := 122$
Width	$w := 0.5 \cdot in$
Actual Length	$l_{act} := 260 \cdot mm$
Siffening rings	
Number of rings	$rings := 1$
Height	$h_{ring} := 0.591 \cdot in$
Width	$w_{ring} := 2.76 \cdot in$
Holes in Head	
Diameter	$d := 0.5 \cdot in$
Pitch	$P := 2.36 \cdot in$

Head Joint Efficiency	$E_{head} := 1.0$
Head Thickness	$T_h := 0.394 \cdot in$

Stress Basis

$f_{a\_allow} := S_a$	allowable axial stress - *S_a, 90%S_y*
$f_{b\_allow} := 1.25 \cdot S_a$	allowable bending stress - *1.25(S_a), 1.25(90%S_y)*
$f_{ab\_allow} := S_a$	allowable axial plus bending stress - *S_a, 90%S_y*
$f_{a\_ring} := S_a$	allowable compressive stress in the stiffening ring - *S_a, 90%S_y*
$Time := 1.0$	time duration: 1.0 for long-term (normal), 1.33 for short-term (upset)

$F_{hor} := 100\%$ percent of vertical load applied as lateral load (40% for nornal conditions, 100% for upset)

Design Loads

When evaluating an **existing** collector, check two (2) cases:

1) Assume lateral load is 40% of vertical load (F_{hor} = 40%)
   Use long-term design allowable stress basis (S_a, Time = 1)
2) Assume lateral load is 100% of vertical load (F_{hor} = 100%)
   Use short-term design allowable stress basis (90%S_y, Time = 1.33)

When designing a **new** or replacement collector:

Assume lateral load is 100% of vertical load (F_{hor} = 100%)
Use long-term design allowable stress basis (S_a, Time = 1)

Calculations

Using the information provided above, this worksheet will evaluate the following:

1) Slot flow area
2) Head thickness
3) Cylinder (ligament) thickness
4) Stiffening ring (if present)

The results of the individual component evaluations are highlighted with ">" on the left margin of the page. The user must review the results manually to see if the requirements are satisfied. Sections that do not apply can be deleted.

Process Data

$A_{vessel} := 0.25\pi \cdot D^2$ $A_{vessel} = 1.851 \times 10^4\, in^2$ Vessel cross-sectional area

Weight of Liquid Holdup $W_L := 0 \cdot lbf$ Liquid holdup for entire vessel (Included in density of catalyst and inerts)

Catalyst: Height $L_{cat} := 290 \cdot in$ Density $\rho_{cat} := 76.162 \cdot lbf \cdot ft^{-3}$

Inert Balls Height $L_{ball} := 45.079 \cdot in$ Density $\rho_{ball} := 103.943 \cdot lbf \cdot ft^{-3}$ *Include other components if necessary.*

Dessicant Height $L_{dess} := 0 \cdot in$ Density $\rho_{dess} := 0 \cdot lbf \cdot ft^{-3}$

$\Delta P_{liq} := \frac{W_L}{A_{vessel}}$ $\Delta P_{liq} = 0\, psi$

$\Delta P_{cat} := \rho_{cat} \cdot L_{cat}$ $\Delta P_{cat} = 12.8\, psi$

$\Delta P_{ball} := \rho_{ball} \cdot L_{ball}$ $\Delta P_{ball} = 2.7\, psi$

Calculate equivalent pressure drops from weight loads *Include pressure drop calculations for additional components if necessary.*

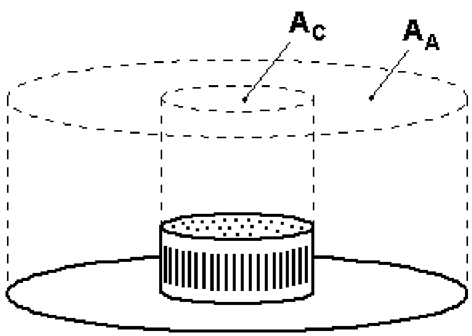
$\Delta P_{dess} := \rho_{dess} \cdot L_{dess}$ $\Delta P_{dess} = 0\, psi$

$\Delta P_{eq} := \Delta P_{liq} + \Delta P_{cat} + \Delta P_{ball} + \Delta P_{dess}$ $\Delta P_{eq} = 15.49\, psi$ Equivalent pressure drop across the collector (dead loading) *Include additional pressure drops if necessary.*

$\Delta P_{tot} := \Delta P_{eq} + \Delta P_r$ $\qquad$ $\Delta P_{tot} = 115.493\ psi$ $\qquad$ Total differential pressure across collector, ΔP_{tot}, (dead plus live loading)

FLOW AREA EVALUATION

$A_c := \frac{\pi}{4} \cdot D_c^2$ $\qquad$ $A_c = 2963\ in^2$ $\qquad$ Cross-sectional area of collector



$a_{open} := \frac{4 \cdot \left(\frac{\pi}{4}\right) \cdot d^2}{(2 \cdot P) \cdot 2 \cdot \sqrt{P^2 - (0.5 \cdot P)^2}}$ $\qquad$ $a_{open} = 0.041$ $\qquad$ Percent open area in head

$A_{holes} := a_{open} \cdot A_c$ $\qquad$ $A_{holes} = 121\ in^2$ $\qquad$ Flow area of holes

$A_a := \frac{\pi}{4} \cdot \left(D^2 - D_c^2\right)$ $\qquad$ $A_a = 15543\ in^2$ $\qquad$ Cross-sectional area of annulus

$A_{slots\_req} := A_{holes} \cdot \left(\frac{A_a}{A_c}\right)$ $\qquad$ $A_{slots\_req} = 633\ in^2$ $\qquad$ Required slot area

$A_{slot\_avail} := \left[N \cdot \left(l_{act} - w\right) \cdot w + \frac{\pi \cdot w^2}{4}\right] - N \cdot w \cdot h_{ring} \cdot rings$ $\qquad$ $A_{slot\_avail} = 558\ in^2$ $\qquad$ Slot area available with stiffening ring(s) installed

> $\quad A_{slot\_avail} - A_{slots\_req} = -75\ in^2$ $\qquad$ A positive value means that the flow area requirements in the Design Practices have been satisfied; otherwise, increase the slot length.

OUTLET COLLECTOR EVALUATION

<u>Ellipsoidal Head Calculations</u> *(if applicable)*

$t := T_h - 2 \cdot CA$ $\qquad$ $t = 0.355\ in$ $\qquad$ corroded head thickness

$K := 1$ $\qquad$ (for 2:1 ellipse) $\qquad$ head proportion factor for ellipsoidal heads $\qquad$ *See Table 1-4.1 in Section VIII, Division 1, Appendix 1 for K valves for elliptical head proportions other than 2:1.*

$\eta_{lig} := \frac{P - d}{P}$ $\qquad$ $\eta_{lig} = 0.788$ $\qquad$ head ligament efficiency

$\eta := \min\left(\eta_{lig}, E_{head}\right)$ $\qquad$ $\eta = 0.788$ $\qquad$ The weld joint efficiency should be used instead of the ligament efficiency if that value is smaller.

> $\quad \Delta P := \frac{2 \cdot S_a \cdot \eta \cdot t}{K \cdot D_c - 2 \cdot t \cdot (K - 0.1)}$ $\qquad$ $\Delta P = 155\ psi$ $\qquad$ must be greater than $\quad \Delta P_{tot} = 115\ psi$

Ligaments

$l := \frac{l_{act}}{rings + 1}$ $l = 5.118\,in$ effective length of ligament

$F_{top} := \frac{\pi \cdot \Delta P_{tot} \cdot D_c^2}{4}$ $F_{top} = 3.422 \times 10^5\,lbf$ total force acting on top of collector

$F_L := \frac{F_{top}}{N}$ $F_L = 2.805 \times 10^3\,lbf$ total force applied to each ligament

Corroded width of each ligament

$C := \pi \cdot D_c$ total collector circumference

$C_L := \frac{C}{N}$ circumference encompassed by one ligament and one slot

$W := C_L - w - 2 \cdot CA$ $W = 1.042\,in$ corroded width of each ligament

$Z := \frac{W \cdot (T_c - 2 \cdot CA)^2}{6}$ $Z = 0.097\,in^3$ section modulus of corroded ligament

Axial and bending stresses, f_a and f_b respectively, in ligament

$$f_a := \frac{F_L}{W \cdot (T_c - 2 \cdot CA)}$$

> $f_a = 3596\,psi$ must be less than $f_{a\_allow} = 16803\,psi$

$f_b := F_{hor} \cdot \Delta P_{tot} \cdot C_L \cdot \left(\frac{l^2}{12 \cdot Z}\right)$ *lateral load is either 40% or 100% of axial load*

> $f_b = 4100\,psi$ must be less than $f_{b\_allow} = 21004\,psi$

It is acceptable to limit f_b to 1.5 S_a instead of 1.25 S_a as long as the vessel design temperature is under the creep range of the material. This is true for the combined stress calculation (denominator) below as well.

Combined stresses

> $f_a + \frac{f_b}{1.25} = 6876\,psi$ must be less than $f_{ab\_allow} = 16803\,psi$

Gross buckling

> $\frac{D_c}{T_c - 2 \cdot CA} = 82$ must be less than 150

Individual ligament buckling

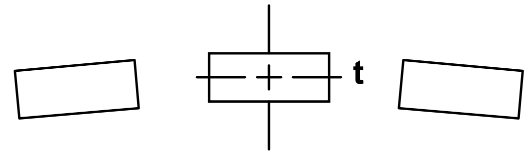
$K := 0.65$ end conditions

$rg_0 := 0.289 \cdot W$ $\quad rg_0 = 0.301\,in$ radius of gyration about radial axis

$rg_1 := 0.289 \cdot (T_c - 2 \cdot CA)$ $\quad rg_1 = 0.216\,in$ radius of gyration about tangential axis

$r := \min(rg)$ $\quad r = 0.216\,in$ least radius of gyration for the ligament cross section

$r_t := rg_1$ $\quad r_t = 0.216\,in$ radius of gyration about tangential axis is used in the bending equation



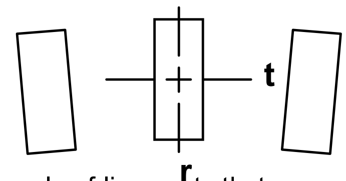
Example of ligaments that are wider than they are deep (thick)

$\frac{K \cdot l}{r} = 15.385$

$$C_c := \sqrt{2 \cdot \pi^2 \cdot \frac{E}{S_y}} \qquad C_c = 159.166$$

$$FS := \frac{5}{3} + \frac{3 \cdot \frac{K \cdot l}{r}}{8 \cdot C_c} - \frac{\left(\frac{K \cdot l}{r}\right)^3}{8 \cdot C_c^3} \qquad FS = 1.703$$

Safety factor



Example of ligaments that are deeper (thicker) than they are wide

$$F_a := Time \cdot \left[\left[1 - \frac{\left(\frac{K \cdot l}{r}\right)^2}{2 \cdot C_c^2}\right] \cdot \frac{S_y}{FS}\right] \qquad F_a = 10931\,psi$$

Allowable axial stress

$$F_b := Time \cdot 0.66 \cdot S_y \qquad F_b = 12342\,psi$$

Allowable bending stress

Calculate F factor considering combined axial and bending loads

$C_m := 1$ adjustment factor

$$F_e := Time \cdot \frac{12 \cdot \pi^2 \cdot E}{23 \cdot \left(\frac{K \cdot l}{r_t}\right)^2} \qquad F_e = 5 \times 10^5\,psi$$

> $$F := \frac{f_a}{F_a} + C_m \cdot \left[\frac{f_b}{\left(1 - \frac{f_a}{F_e}\right) \cdot F_b}\right] \qquad F = 0.664$$

If F < 1, then the ligament is acceptable

Stiffening Ring

Compressive stress in stiffening ring

$$S_{ring} := \begin{cases} 0 \cdot psi & \text{if } rings = 0 \\ \dfrac{1 \cdot \Delta P_r \cdot D_c}{2 \cdot (rings + 1) \cdot (h_{ring} - 2 \cdot CA) \cdot (w_{ring} - 2 \cdot CA)} & \text{otherwise} \end{cases}$$

$S_{ring} = 5.235 \times 10^3\ psi$ must be less than $f_{a\_ring} = 16803\ psi$