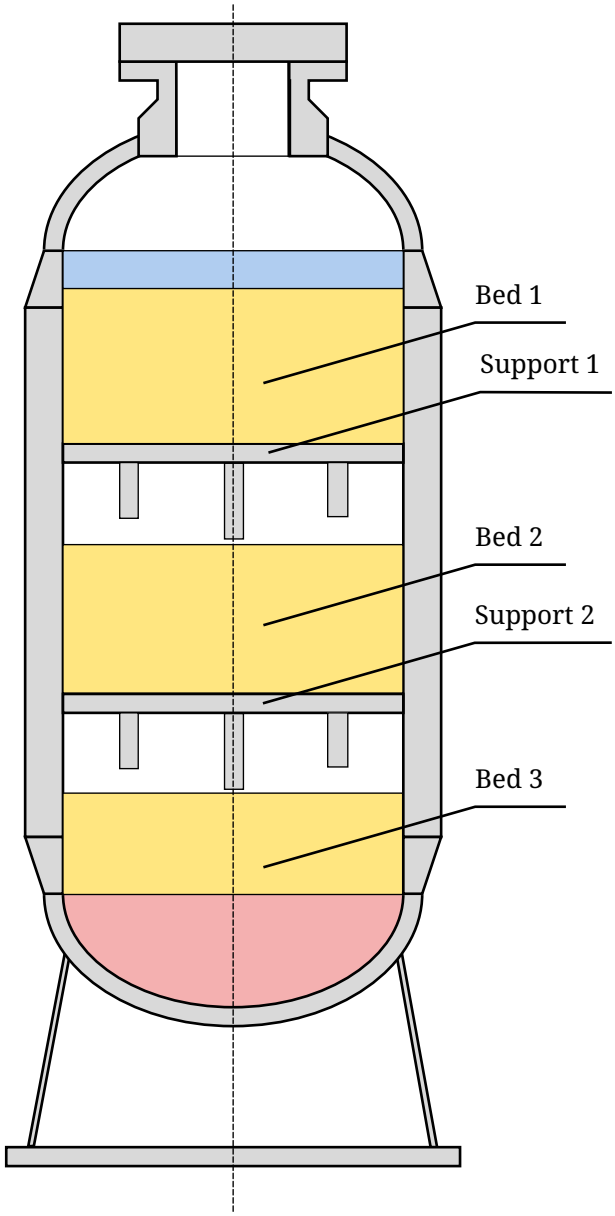
GP Petroleum Reactor Revamp Catalyst Bed Support Analysis

Rev	Description .	Date	Maker	Checker	Approver
2B	-	xx-xx-2020	-	-	LL
2	Pressure drop updated	24-Dec-2019	MAMJ	OL	LL
1	As indicated	4-Nov-2019	PTN	OL	LL
0	First Issue	14-Oct-2019	MAMJ	PTN	LL

Summary

During revamp of desuphorization line reactor R201, the catalyst bed support needs to be replaced, since the pressure drop and temperature is increased. It is found by analysis of said structure, what dimensions are needed for structural integrity during all loads. It is found that some rearrangement of the layout and beam sizes is needed. Both bed support items 1 and 2 need replacement. The replacement enables the reactor beds to contain more catalyst and higher pressure drop.



Reactor R201: Existing layout before revamp

Introduction

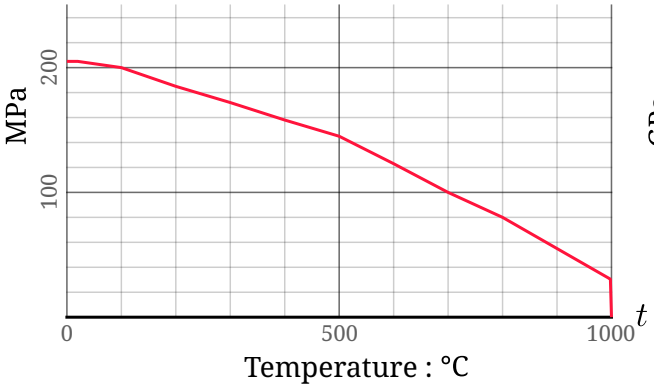
The new operating conditions after revamp for R201 is as follows. The End of life condition is mostly caused by the fouling of the reactor beds. This increases pressuredrop and for this reason the temperature is lowered to compensate.

	Startup condition	Normal conditions	End of life condition
Temperature	420°C	400°C	380°C
Pressure		100 bar	
Pressure drop bed 1	2 bar	2.2 bar	3.4 bar
Pressure drop bed 2	2 bar	2.2 bar	3.2 bar
Pressure drop bed 3	1.5 bar	1.8 bar	3.0 bar

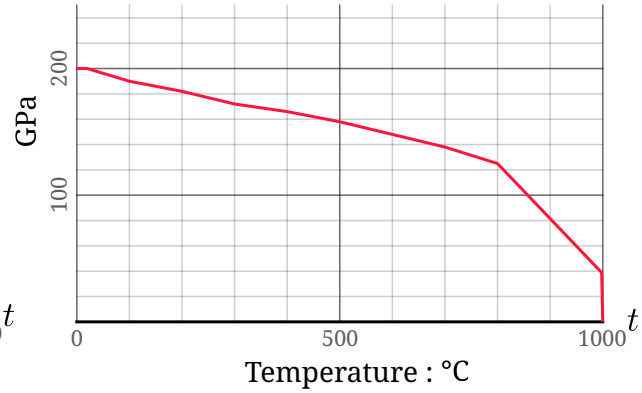
Material

All structural elements of the old and new design are made in SS316 Stainless steel.
The material properties for SS316 Stainless steel:

Yield strength
$\sigma_y(t)$



Youngs modulus
$E(t)$



Density of steel:

$$\rho := \text{Rhomat}(\text{"SS321"}) \cdot \frac{\text{kg}}{\text{m}^3} = 7.92 \cdot 10^3 \frac{\text{kg}}{\text{m}^3}$$

Existing design

The existing design consists of a three beam design with the majority of the load on the center Beam. The material is SS316 austenitic stainless steel.

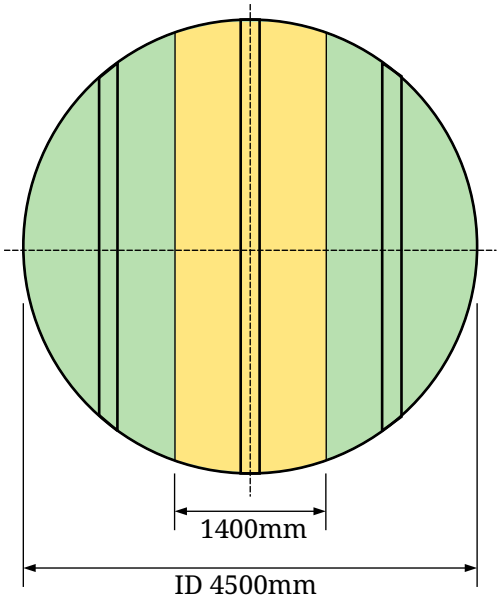


Illustration: Area of load for center beam and outer beams

Dimensions

Dimension of Old Center Beam and Outher Beam

$$Dim_{\text{OldCB}} := \begin{bmatrix} 200\,\text{mm} \\ 500\,\text{mm} \\ 4500\,\text{mm} \end{bmatrix} \qquad Dim_{\text{OldOB}} := \begin{bmatrix} 200\,\text{mm} \\ 400\,\text{mm} \\ 2800\,\text{mm} \end{bmatrix}$$

Reactor Size:

$$ID_{\text{R}} := 4500\,\text{mm} \qquad IR_{\text{R}} := \frac{ID_{\text{R}}}{2}$$

Size of Bed on beams:

$$W_{\text{OldCBLoad}} := 1400\,\text{mm} \qquad W_{\text{OldOBLoad}} := \frac{ID_{\text{R}} - W_{\text{OldCBLoad}}}{2}$$

Area of bed as represented by the load that the beams carry
Area of circle slice:

$$\theta := \text{acos}\left(\frac{W_{\text{OldCBLoad}}}{ID_{\text{R}}}\right) \cdot 2 = 143.748\,°$$

$$A_{\text{RXS}} := \pi \cdot IR_{\text{R}}^2 = 15.904\,\text{m}^2$$

$$A_{\text{OldOBLoad}} := \frac{1}{2} \cdot IR_{\text{R}}^2 \cdot (\theta - \sin(\theta)) = 4.854\,\text{m}^2$$

$$A_{\text{OldCBLoad}} := A_{\text{RXS}} - 2\,A_{\text{OldOBLoad}} = 6.197\,\text{m}^2$$

Volume of old beams for mass calculation:

$$V_{\text{OldCB}} := Dim_{\text{OldCB}_X} \cdot Dim_{\text{OldCB}_Z} \cdot Dim_{\text{OldCB}_Z} = 4.05\,\text{m}^3$$

$$V_{\text{OldOB}} := Dim_{\text{OldOB}_X} \cdot Dim_{\text{OldOB}_Z} \cdot Dim_{\text{OldOB}_Z} = 1.568\,\text{m}^3$$

Mass of beams and beds:

$$M_{\text{OldCB}} := \rho\,V_{\text{OldCB}} = 32.076\,\text{tonne}$$

$$M_{\text{OldOB}} := \rho\,V_{\text{OldOB}} = 12.419\,\text{tonne}$$

$$M_{\text{OldBed1}} := 15\,\text{tonne}$$

Beam Integrity analysis

A beam integrity analysis is performed on the existing design to determine if a new design is needed. Since the bed support structure for bed 1 and 2 are identical the top bed is to be stressed the most, only that bed will taken into consideration.

$\delta p_0 := 2.8\,\text{bar}$ $\quad t_0 := 420\,°\text{C}$

$\delta p_1 := 3.0\,\text{bar}$ $\quad t_1 := 400\,°\text{C}$

$\delta p_2 := 3.4\,\text{bar}$ $\quad t_2 := 370\,°\text{C}$

$$F_{\delta p} := \delta p \cdot A_{RXS} = \begin{bmatrix} 4.453 \cdot 10^6 \\ 4.771 \cdot 10^6 \\ 5.407 \cdot 10^6 \end{bmatrix} \text{N}$$

Area ratio for old center beam and old outer beams.

$$\varphi_{OldCB} := \frac{A_{OldCBLoad}}{A_{RXS}} = 0.39 \qquad \varphi_{OldOB} := \frac{1 - \varphi_{OldCB}}{2} = 0.305$$

$$F_{LOldCB} := M_{OldCB}\, g_e + F_{\delta p}\, \varphi_{OldCB} + M_{OldBed1}\, g_e\, \varphi_{OldCB}$$

$$F_{LOldOB} := A_{OldOBLoad} \cdot \delta p + M_{OldOB}\, g_e + M_{OldBed1}\, g_e\, \varphi_{OldOB}$$

$$I_{OldCB} := \frac{Dim_{OldCB_X} \left(Dim_{OldCB_Y}\right)^3}{12} = 0.002\,\text{m}^4$$

$$\omega_{OldCB} := \frac{F_{LOldCB}}{ID_R}$$

$$M_{bOldCB}(z) := \frac{\omega_{OldCB} \cdot ID_R \cdot z}{2} - \frac{\omega_{OldCB}\, z^2}{2} \qquad F_{vOldCB}(z) := \omega_{OldCB} \left(\frac{ID_R}{2} - z\right)$$

$$\sigma_b(z) := \frac{M_{bOldCB}(z) \cdot \frac{Dim_{OldCB_Y}}{2}}{I_{OldCB}} \qquad \tau_{OldCB}(z) := \frac{3\, F_{vOldCB}(z)}{2\, Dim_{OldCB_X} \cdot Dim_{OldCB_Y}}$$

$$\sigma_b\left(\frac{ID_R}{2}\right) = \begin{bmatrix} 142.218 \\ 150.583 \\ 167.315 \end{bmatrix} \text{MPa} \qquad \tau_{OldCB}(0\,\text{mm}) = \begin{bmatrix} 15.802 \\ 16.731 \\ 18.591 \end{bmatrix} \text{MPa}$$

$i := 0..2$ $\qquad S_f := 1.5$

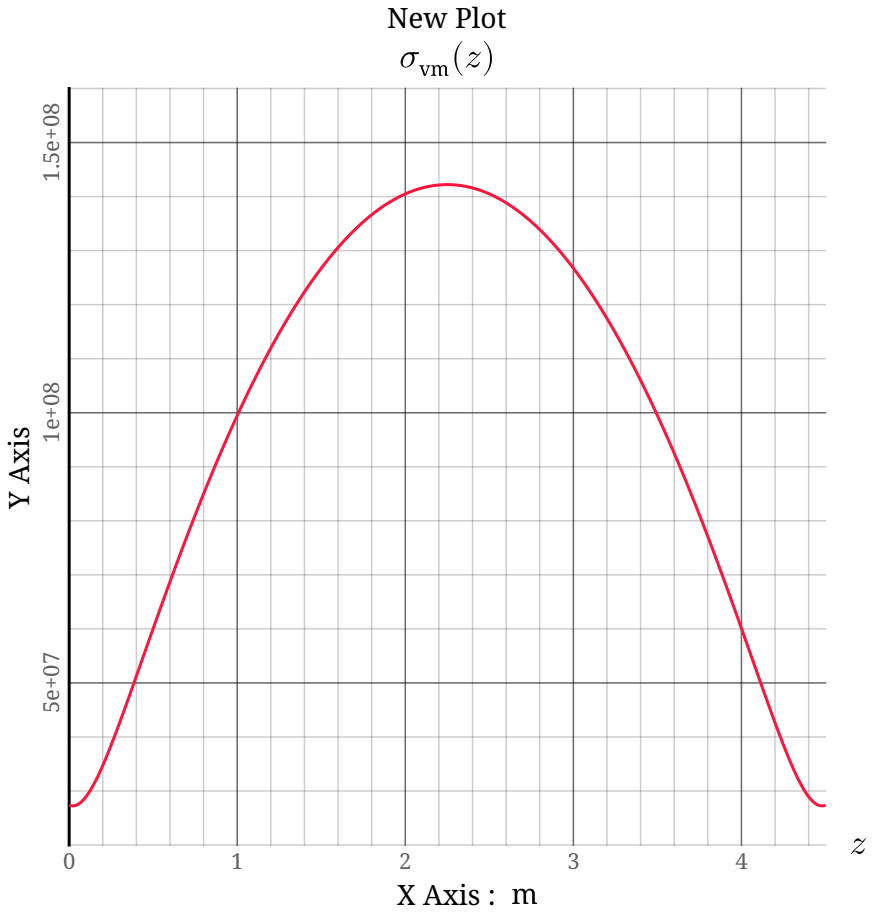
$$\varphi_i := \frac{\sigma_y(t_i)}{S_f\, \sigma_{vm}\left(\frac{ID_R}{2}\right)} = \begin{bmatrix} 0.728 \\ 0.741 \\ 0.76 \end{bmatrix} \qquad \sigma_{vm}(z) := \sqrt{\sigma_b(z)_0^{\,2} + 3\, \tau_{OldCB}(z)_0^{\,2}}$$

$$\sin(50\,°) = 0.766$$

New design

Conclusion

The new design leaves more room for catalyst and allows for a higher pressuredrop.



Python Functions

The functions of these Python files are called by the sheet. Their code follows the list. The digest of a file (SHA-256 of its content, first 12 characters) shows whether a file is the one this calculation used.

material.py SHA-256 c4b61dae2d84

Functions: getinterpolated (get_interpolated), σy, Emat, σt, Rhomat

material.py

```
"""Functions of the sheet, called like the built-in functions."""
import numpy as np
MATERIALS = {
    "SS316": {
        "Tensile": [(20, 515e6), (100, 485e6), (200, 450e6), (300, 420e6), (400, 395e6), (500, 380e6), (600, 355e6), (700, 300e6), (800, 220e6), (1000, 100e6)],
        "Yield": [(20, 205e6),(100, 200e6),(200, 185e6),(300, 172e6),(400, 158e6),(500, 145e6),(600, 123e6),(700, 100e6),(800, 80e6),(1000, 30e6)],
        "E": [(20, 200e9),(100, 190e9),(200, 182e9),(300, 172e9),(400, 166e9),(500, 158e9),(600, 148e9),(700, 138e9),(800, 125e9),(1000, 38e9)],
        "Rho": 7980
    },
    "SS321": {
        "Tensile": [(20, 515e6), (100, 485e6), (200, 450e6), (300, 420e6), (400, 395e6), (500, 380e6), (600, 355e6), (700, 300e6), (800, 220e6), (1000, 100e6)],
        "Yield": [(20, 205e6),(100, 200e6),(200, 185e6),(300, 172e6),(400, 158e6),(500, 145e6),(600, 123e6),(700, 100e6),(800, 80e6),(1000, 30e6)],
        "E": [(20, 200e9),(100, 190e9),(200, 182e9),(300, 172e9),(400, 166e9),(500, 158e9),(600, 148e9),(700, 138e9),(800, 125e9),(1000, 38e9)],
        "Rho": 7920
    },
    "S235": {
        "Tensile": [(20, 360e6), (100, 350e6), (200, 330e6), (300, 290e6), (400, 220e6), (500, 140e6)],
        "Yield": [(20, 235e6), (100, 215e6), (200, 185e6), (300, 155e6), (400, 120e6), (500, 80e6)],
        "E": [(20, 210e9), (100, 205e9), (200, 195e9), (300, 185e9), (400, 175e9), (500, 165e9)],
        "Rho": 7850
    },
    "S355": {
        "Tensile": [(20, 470e6), (100, 455e6), (200, 430e6), (300, 380e6), (400, 300e6), (500, 190e6)],
        "Yield": [(20, 355e6), (100, 325e6), (200, 285e6), (300, 245e6), (400, 195e6), (500, 130e6)],
        "E": [(20, 210e9), (100, 205e9), (200, 195e9), (300, 185e9), (400, 175e9), (500, 165e9)],
        "Rho": 7850
    },
    "Al6061-T6": {
        "Tensile": [(20, 310e6), (100, 260e6), (150, 180e6), (200, 110e6), (250, 60e6)],
        "Yield": [(20, 276e6), (100, 240e6), (150, 160e6), (200, 95e6), (250, 50e6)],
        "E": [(20, 68.9e9), (100, 65.0e9), (150, 62.0e9), (200, 58.0e9), (250, 53.0e9)],
        "Rho": 2700
    },
    "Al7075-T6": {
        "Tensile": [(20, 572e6), (100, 490e6), (150, 330e6), (200, 200e6)],
        "Yield": [(20, 503e6), (100, 440e6), (150, 300e6), (200, 180e6)],
        "E": [(20, 71.7e9), (100, 68.0e9), (150, 65.0e9), (200, 60.0e9)],
        "Rho": 2810
    },
    "C36000": {
        "Tensile": [(20, 380e6), (100, 340e6), (150, 280e6), (200, 210e6)],
        "Yield": [(20, 310e6), (100, 275e6), (150, 225e6), (200, 165e6)],
        "E": [(20, 103e9), (100, 99e9), (150, 96e9), (200, 93e9)],
        "Rho": 8500
    },
    "C11000": {
```

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        "Tensile": [(20, 220e6), (100, 200e6), (150, 170e6), (200, 140e6)],
        "Yield": [(20, 70e6), (100, 65e6), (150, 60e6), (200, 55e6)],
        "E": [(20, 115e9), (100, 112e9), (150, 110e9), (200, 107e9)],
        "Rho": 8940
    }
}

def get_interpolated(MAT: list, t: float):
    last_val = -1
    last_temp = -1
    for i in range(len(MAT)):
        if t < MAT[i][0]:
            if last_temp > -1:
                diff_val = MAT[i][1] - last_val
                ratio_temp = (t - last_temp) / (MAT[i][0] - last_temp)
                interp_ys = last_val + diff_val * ratio_temp
                return interp_ys
            return MAT[i][1]
        last_val = MAT[i][1]
        last_temp = MAT[i][0]
    return 0

def Sy(name: str, t: float):
    t -= 273.15
    if name in MATERIALS:
        MAT = MATERIALS[name]["Yield"]
        return get_interpolated(MAT, t)
    return 0

def Emat(name: str, t: float):
    t -= 273.15
    if name in MATERIALS:
        MAT = MATERIALS[name]["E"]
        return get_interpolated(MAT, t)
    return 0

def St(name: str, t: float):
    t -= 273.15
    if name in MATERIALS:
        MAT = MATERIALS[name]["Tensile"]
        return get_interpolated(MAT, t)
    return 0
def Rhomat(name: str):
    if name in MATERIALS:
        return MATERIALS[name]["Rho"]
```