Problema y sistema

s

Para su tratamiento en una planta, 20500 kg.hr-1 de una salmuera de NaCl al 15% debe ser calenta
10°C a 40°C por intercambio de calor con una corriente de agua, la que será enfriada desde los 80°C ha
Se dispone de un cierto número de horquillas múltiples de 6 m de longitud, consistente de un tubo e
3,5" y 8 tubos interiores de 3/4" BWG 14, Acero SS, (conductividad térmica: 16.27 W.m-1.°C-1), po
circula la salmuera. Determinar el número y configuración de los hairpins requeridos, teniendo en cu
no puede despreciarse el efecto de la temperatura de pared. Asumir: que los factores de ensuciamien
0.0005 m2.°C.W-1 y 0.0001 m2.°C.W-1 para los fluidos que circulan por los tubos y el anulo respect
una eficiencia de bombeo de 0.8; que el costo de cada hairpins es de 500 um (um: unidad mone
interés anual del 3%; que el costo de energía de bombeo es de 0.15 um.kWh-1;que la planta funciona
al año. Se solicita resolución por el método ε-NTU.

DATOS

$Q_{ms} := 20500 \frac{kg}{hr}$ $ws := 0.15$ $Temp_{Cin} := 10$ $Temp_{Cout} := 40$ $N_t := 8$

$Temp_{Hin} := 80$ $Temp_{Hout} := 45$ $Temp_{Hink} := Temp_{Hin} + 273.$

Intercambiador múltiple tubo
Fluido de servicio: agua
Fluido de trabajo: salmuera
ánulo Dnom: 3.5in
tubo Dnom: 3/4 in
BWG 14 Acero SS

$Long_t := 6\ m$ $k_{wall} := 16.27 \frac{W}{m \cdot \Delta°C} = 16.27 \frac{kg \cdot m}{s^3 \cdot K}$ $\varepsilon :$

$D_s := 3.5\ in - (2 \cdot 2.11\ mm) = 3.334\ in$

$D_o := \frac{3}{4}\ in = 19.05\ mm$ $D_{in} := D_o -$

$R_{ad} := 0.0005 \frac{m^2 \cdot \Delta°C}{W} + 0.0001 \frac{m^2 \cdot \Delta°C}{W} = (6 \cdot 10^{-4}) \frac{s^3 \cdot K}{kg}$ $\eta :$

DESARROLLO

INCISO A n° de horquillas y caída d presión

Ecuaciones

$$\delta_w(Temp) := \frac{999.83952 + 16.945176 \cdot (Temp) - 7.9870401 \cdot 10^{-3} \cdot (Temp)^2 - 46.170461 \cdot 10^{-6} \cdot (Temp)^3}{1 + 16.87950 \cdot 10^{-3} \cdot (Temp)}$$

$$B(Temp) := \frac{1.3272 \cdot (20 - Temp) - 0.001053 \cdot (Temp - 20)^2}{Temp + 105}$$

$$\mu_w(Temp) := 1.002 \cdot 10^{-3} \cdot 10^{B(Temp)} \cdot Pa \cdot s$$

$$C_1 := \frac{276370}{18.0153} = 1.534 \cdot 10^4 \qquad C_2 := \frac{-2090.1}{18.0153} = -116.018 \qquad C_3 := \frac{8.125}{18.0153} = 0.451$$

$$C_4 := \frac{-0.014116}{18.0153} = -7.836 \cdot 10^{-4} \qquad C_5 := \frac{9.3701 \cdot 10^{-6}}{18.0153} = 5.201 \cdot 10^{-7}$$

$$cP_w(Temp) := \left(C_1 + C_2 \cdot Temp + C_3 \cdot Temp^2 + C_4 \cdot Temp^3 + C_5 \cdot Temp^4\right) \frac{J}{kg \cdot \Delta°C}$$

$$S_1 := -0.432 \qquad S_2 := 0.0057255 \qquad S_3 := -0.000008078 \qquad S_4 := 1.861 \cdot 10^{-9} \qquad S_5 := 0$$

$$k_w(Temp) := \left(S_1 + S_2 \cdot Temp + S_3 \cdot Temp^2 + S_4 \cdot Temp^3 + S_5 \cdot Temp^4\right) \frac{W}{m \cdot \Delta°C}$$

$$D_0 := -0.003241 \qquad D_1 := 0.063635 \qquad D_2 := 1.013714 \qquad D_3 := 0.014595 \qquad D_4 := 3317.349$$

$$\delta_{ap}(ws, Temp) := \frac{(ws \cdot D_0 + D_1) \cdot \exp\left(1 \cdot 10^{-6} \cdot (Temp + D_4)^2\right)}{(ws + D_2 + Temp \cdot D_3)} \cdot \left(\frac{kg}{m^3}\right)$$

$$\delta_{sol}(ws, \delta_{ap}, Temp) := \left(\left(\frac{ws}{\delta_{ap}(ws, Temp)}\right) + \frac{(1 - ws)}{\delta_w(Temp)}\right)^{-1}$$

$$V_1 := 16.221789 \qquad V_2 := 1.322931 \qquad V_3 := 1.484860 \qquad V_4 := 0.007469 \qquad V_5 := 30.780201 \qquad V_6 :=$$

$$\mu_{ap}(ws, Temp) := \frac{\exp\left(\frac{V_1 \cdot ws^{V_2} + V_3}{Temp \cdot V_4 + 1}\right)}{\left(V_5 \cdot ws^{V_6} + 1\right)}$$

$$\mu_{sol}(ws, Temp) := \mu_{ap}(ws, Temp)^{ws} \cdot \left(\mu_w(Temp) \cdot 1000 \frac{m \cdot s}{kg}\right)^{(1 - ws)} \cdot 10^{-3} \frac{kg}{m \cdot s}$$

$a_1 := -0.06936$ $a_2 := -0.07821$ $a_3 := 3.847985$ $a_4 := -11.2762$ $a_5 := 8.731877$ $a_6 := 1.8124$

$\alpha(ws, Temp) := a_2 \cdot Temp + a_3 \cdot \exp(0.01 \cdot Temp) + a_4 \cdot ws$

$$cPi(\alpha, ws, Temp) := \left(a_1 \cdot \exp(\alpha(ws, Temp)) + a_5 \cdot ws^{a_6}\right) \frac{J}{kg \cdot \Delta°C}$$

$cPsol(\alpha, ws, Temp, cP_w) := (1 - ws) \cdot cP_w(Temp) + ws \cdot cPi(\alpha, ws, Temp)$

$Mnacl := 58.44277$

$$b := \left(Mnacl \cdot \left(\frac{1}{ws} - 1\right)\right)^{-1}$$

$ksal(Temp, b) := \left(\left(0.5621 - 0.01394 \cdot b + 0.00177 \cdot b^2\right) + \left(0.00199 - 0.000294 \cdot b - 6.3 \cdot 10^{-5} \cdot b^2\right) \cdot Tem\right.$

$$D_{eq} := \frac{\left(D_s{}^2 - N_t \cdot D_o{}^2\right)}{D_o \cdot N_t}$$

$$D_{hid}(D_s, D_o) := \frac{\left(D_s{}^2 - N_t \cdot D_o{}^2\right)}{D_s + D_o \cdot N_t}$$

$$G(Q_m, D_{in}) := \frac{Q_m}{\pi \cdot \frac{D_{in}{}^2}{4}}$$

$G_{an}(Q_m, D_s, D_o) := \frac{}{\pi \cdot}$

$$Rey(\mu, D_{in}, Q_m) := \frac{G(Q_m, D_{in}) \cdot D_{in}}{\mu}$$

$Rey_{an}(\mu, D_s, D_o, Q_m) := \frac{G_{an}}{}$

$$Pr(\mu, k, cP) := \frac{cP \cdot \mu}{k} \qquad Pr_{wall}(\mu, k, cP) := \frac{cP \cdot \mu}{k}$$

$$f_D(\varepsilon, \mu, D_{in}, Q_m) := \frac{1}{\left(-2 \cdot \log\left(\frac{\frac{\varepsilon}{D_{in}}}{3.7065} - \frac{5.0452}{Rey(\mu, D_{in}, Q_m)} \cdot \log\left(\frac{1}{2.8257} \cdot \left(\frac{\varepsilon}{D_{in}}\right)^{1.1098} + \frac{5.8506}{Rey(\mu, D_{in}, Q_m)^{0.8}}\right.\right.\right.}$$

$f_{an}(\mu, D_s, D_o, Q$

$$f\left(\mu, D_{in}, Q_m\right) := \left(1.821 \cdot \log\left(Rey\left(\mu, D_{in}, Q_m\right) - 1.64\right)\right)^{-2}$$

$$K_G\left(\mu, k, cP\right) := \left(\frac{Pr\left(\mu, k, cP\right)}{Pr_{wall}\left(\mu, k, cP\right)}\right)^{0.11}$$

$$Nu\left(\mu, D_{in}, Q_m, k, cP, K_G\right) := \left(\frac{\left(\frac{f\left(\mu, D_{in}, Q_m\right)}{8}\right) \cdot \left(Rey\left(\mu, D_{in}, Q_m\right) - 1000\right) \cdot Pr\left(\mu, k, cP\right)}{1 + 12.7 \cdot \left(\frac{f\left(\mu, D_{in}, Q_m\right)}{8}\right)^{\frac{1}{2}} \cdot \left(Pr\left(\mu, k, cP\right)^{\frac{2}{3}} - 1\right)}\right) \cdot K_G$$

Nu_{an}

Resolución

$$Temp_{proH} := \frac{Temp_{Hin} + Temp_{Hout}}{2} = 62.5$$

$$Temp_{proC} := \frac{Temp_{Cin} + Temp_{Cout}}{2} = 25$$

$Temp_{pro}$

$$\delta_a := \delta_w\left(Temp_{proH}\right) = 981.905 \ \frac{kg}{m^3}$$

$$\mu_a := \mu_w\left(Temp_{proH}\right) = \left(4.495 \cdot 10^{-4}\right) \ \frac{kg}{m \cdot s}$$

$$cP_a := cP_w\left(Temp_{proHk}\right) = \left(4.182 \cdot 10^{3}\right) \ \frac{m^2}{s^2 \cdot K}$$

$$k_a := k_w\left(Temp_{proHk}\right) = 0.65 \ \frac{kg \cdot m}{s^3 \cdot K}$$

$\delta_s := \delta_{sol}\left(ws, \delta_{ap}, Temp_{proC}\right) = (1.1$

$\mu_s := \mu_{sol}\left(ws, Temp_{proC}\right) = 0.001$

$cPsol\left(\alpha, ws, Temp, cP_a\right) := (1 - w$

$cP_s := cPsol\left(\alpha, ws, Temp_{proC}, cP_a\right.$

$k_s := ksal\left(Temp_{proC}, b\right) = 0.606$

$$q := \left(Q_{ms} \cdot cP_s \cdot \left(Temp_{Cout} - Temp_{Cin}\right)\right) \cdot K$$

$$q = 607.612 \ kW$$

lores de prueba

$$Q_m := 1 \ \frac{kg}{hr}$$

Va

Restricciones

$$q = \left(Q_m \cdot \int_{Temp_{Hout}}^{Temp_{Hin}} cP_a \, \mathrm{d}Temp \right) \cdot K$$

Solver

$$Q_{ma} := \mathbf{find}\left(\mathbf{Q_m}\right) = \left(1.494 \cdot 10^4\right) \frac{kg}{hr}$$

$$K_G := 1$$

$$h_i\left(\mu, D_{in}, Q_m, k, cP, K_G\right) := \frac{Nu\left(\mu, D_{in}, Q_m, k, cP, K_G\right) \cdot k}{D_{in}}$$

$$h_o\left(\mu, D_s, D_o, Q_m, k, cP, K_G\right) := \frac{Nu_{an}}{}$$

$$h_i\left(\mu_s, D_{in}, Q_{ms}, k_s, cP_s, K_G\right) = \left(6.439 \cdot 10^4\right) \frac{kg}{s^3 \cdot K}$$

$$h_o := h_o\left(\mu_a, D_s, D_o, Q_{ma}, k_a, cP_a, K_G\right)$$

$$h_{io}\left(\mu, D_{in}, D_o, Q_m, k, cP, K_G\right) := h_i\left(\mu, D_{in}, Q_m, k, cP, K_G\right) \cdot \frac{D_{in}}{D_o}$$

$$h_{io} := h_{io}\left(\mu_s, D_{in}, D_o, Q_{ms}, k_s, cP_s, K_G\right) = \left(5.013 \cdot 10^4\right) \frac{kg}{s^3 \cdot K}$$

Efecto de la pared

$$Temp_{wall} := \frac{\left(Temp_{proH} \cdot h_{io} + Temp_{proC} \cdot h_o\right)}{h_{io} + h_o} = 59.027$$

$$Temp_{wallk} := Temp_{wall} + 273 = 332.02$$

$$\delta_{aw} := \delta_w\left(Temp_{wall}\right) = 983.707 \frac{kg}{m^3}$$

$$\delta_{sol}\left(ws, \delta_{ap}, Temp\right) := \left(\left(\frac{}{\delta_{ap}(}\right.\right.$$

$$\mu_{aw} := \mu_w\left(Temp_{wall}\right) = \left(4.735 \cdot 10^{-4}\right) \frac{kg}{m \cdot s}$$

$$\delta_{sw} := \delta_{sol}\left(ws, \delta_{ap}, Temp_{wall}\right)$$

$$cP_{aw} := cP_w\left(Temp_{wallk}\right) = \left(4.18 \cdot 10^3\right) \frac{m^2}{s^2 \cdot K}$$

$$\mu_{sol}\left(ws, Temp\right) := \mu_{ap}\left(ws, T\right.$$

$$k_{aw} := k_w\left(Temp_{wallk}\right) = 0.647 \frac{kg \cdot m}{s^3 \cdot K}$$

$$\mu_{sw} := \mu_{sol}\left(ws, Temp_{wall}\right) = (6$$

$$cPsol\left(\alpha, ws, Temp, cP_a\right) :=($$

$$cP_{sw} := cPsol\left(\alpha, ws, Temp_{wa}\right.$$

$$k_{sw} := ksal\left(Temp_{wall}, b\right) = 0.6$$

$$Pr\left(\mu_{aw}, k_{a}\right.$$

$$Pr\left(\mu_{sw}, k_{sw}, cP_{sw}\right) = 3.609$$

$$K_{G1} := \left(\frac{Pr\left(\mu_s, k_s, cP_s\right)}{Pr\left(\mu_{sw}, k_{sw}, cP_{sw}\right)}\right)^{0.11} = 1.076$$

$$K_{G2} := \left(\frac{P}{Pr}\right.$$

$$h_i\left(\mu, D_{in}, Q_m, k, cP, K_G\right) := \frac{Nu\left(\mu, D_{in}, Q_m, k, cP, K_G\right) \cdot k}{D_{in}}$$

$$h_o\left(\mu, D_s, D_o, Q_m, k, cP, K_G\right) := \frac{Nu}{}$$

$$h_i\left(\mu_s, D_{in}, Q_{ms}, k_s, cP_s, K_{G1}\right) = \left(6.931 \cdot 10^4\right) \frac{kg}{s^3 \cdot K}$$

$$h_{oc} := h_o\left(\mu_a, D_s, D_o, Q_{ma}, k_a, cP\right.$$

$$h_{io}\left(\mu, D_{in}, D_o, Q_m, k, cP, K_G\right) := h_i\left(\mu, D_{in}, Q_m, k, cP, K_G\right) \cdot \frac{D_{in}}{D_o}$$

$$h_{ioc} := h_{io}\left(\mu_s, D_{in}, D_o, Q_{ms}, k_s, cP_s, K_{G1}\right) = \left(5.396 \cdot 10^4\right) \frac{kg}{s^3 \cdot K}$$

$$U_{gd} := \left(\frac{1}{h_{ioc}} + \frac{1}{h_{oc}} + R_{ad} + \frac{D_o}{2 \cdot k_{wall}} \cdot \ln\left(\frac{D_o}{D_{in}}\right)\right)^{-1} = \left(1.04 \cdot 10^3\right) \frac{kg}{s^3 \cdot K}$$

$$U_{gc} := \left(\frac{1}{h_{ioc}} + \frac{1}{h_{oc}} + \frac{D_o}{2 \cdot k_{wa}}\right.$$

$$C_H := cP_a \cdot Q_{ma} = \left(1.736 \cdot 10^4\right) \frac{kg \cdot m^2}{s^3 \cdot K}$$

$$C_C := cP_s \cdot Q_{ms} = \left(2.025 \cdot 10^4\right) \frac{kg \cdot m^2}{s^3 \cdot K}$$

$$C_{min} := C_H = \left(1.736 \cdot 10^4\right) \frac{kg \cdot m^2}{s^3 \cdot K}$$

$$\Delta T_{max} := (Temp_{Hin} - Temp_{Cin}) \cdot K = 70\ K$$

$$q_{max} := C_{min} \cdot \Delta T_{max} = (1.215 \cdot 10^3)\ kW$$

$$\xi := \frac{q}{q_{max}} = 0.5$$

$$LMTD_{ctc} := \left(\frac{(Temp_{Hout} - Temp_{Cin}) - (Temp_{Hin} - Temp_{Cout})}{\ln\left(\frac{(Temp_{Hout} - Temp_{Cin})}{(Temp_{Hin} - Temp_{Cout})}\right)} \right) \cdot \Delta°C = 37.444\ K$$

Valores de prueba

$$NTU := 1$$

Restricciones

$$\xi = NTU \cdot \frac{LMTD_{ctc}}{\Delta T_{max}}$$

Solver

$$NTU := \mathbf{find}(NTU) = 0.935$$

Valores de prueba

$$A_{tctc} := 1\ m^2$$

Restricciones

$$NTU = U_{gd} \cdot \frac{A_{tctc}}{C_{min}}$$

Solver

$$A_{tctc} := \mathbf{find}(A_{tctc}) = 15.607\ m^2$$

$$A_{h} := N_{t} \cdot \pi \cdot D_{o} \cdot Long_{h} = 5.745\ m^2$$

$$N_h := \left(\frac{A_{tctc}}{A_h}\right) = 2.717$$

$$N_h := 3$$

$$A_{treal} := N_h \cdot A_h = 17.236\ m^2$$

$$\Delta P_{it}\left(Q_m, D_{in}, \delta, \mu\right) := N_t \cdot \frac{G\left(Q_m, D_{in}\right)^2}{2 \cdot \delta} \cdot \left(f_D\left(\varepsilon, \mu, D_{in}, Q_m\right) \cdot \frac{N_h \cdot Long_h}{D_{in}} \cdot \left(\frac{\mu}{\mu_{sw}}\right)^{-0.14} + \left(N_h - 1\right)\right) \qquad \Delta P_{an}$$

$$\Delta P_{it}\left(Q_{ms}, D_{in}, \delta_s, \mu_s\right) = \left(2.41 \cdot 10^5\right)\ kPa \qquad \Delta P_{an}$$

$$Pot_{it} := \frac{\frac{\Delta P_{it}\left(Q_{ms}, D_{in}, \delta_s, \mu_s\right) \cdot Q_{ms}}{\delta_s}}{\eta} = \left(1.55 \cdot 10^3\right)\ kW \qquad Pot_{an} := \frac{\frac{\Delta P_{ant}\left(\mu_a, D_s, D_o, Q_{ma}, \varepsilon, \delta_a\right) \cdot Q}{\delta_a}}{\eta}$$

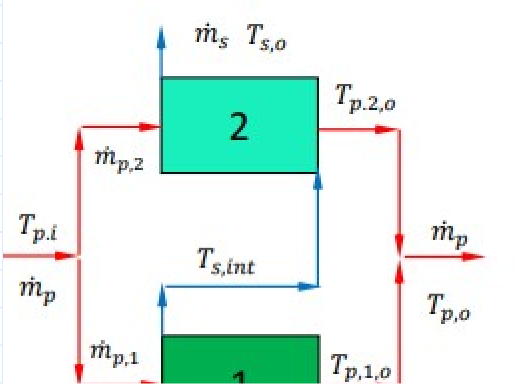
$$Pot_{bom} := Pot_{it} + Pot_{an} = \left(1.55 \cdot 10^3\right)\ kW$$

Para disminuir la potencia de la bomba se va a poner en paralelo a los tubos internos, adoptando una configuración paralelo- serie
Se considera que el caudal de la salmuera se divide en 2 partes iguales

$$C_H := cP_a \cdot Q_{ma} = \left(1.736 \cdot 10^4\right) \frac{kg \cdot m^2}{s^3 \cdot K}$$

$$C_C := cP_s \cdot \frac{Q_{ms}}{2} = \left(1.013 \cdot 10^4\right) \frac{kg \cdot m^2}{s^3 \cdot K}$$

$$C_{min} := C_C = \left(1.013 \cdot 10^4\right) \frac{kg \cdot m^2}{s^3 \cdot K}$$

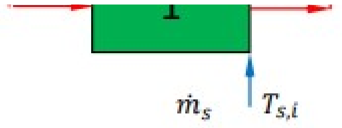


$$T_{pi} := Temp_{Cin} = 10$$

$$T_{po} := Temp_{Cout} = 40$$

$$T_{si} := Temp_{Hin} = 80$$

$$T_{so} := Temp_{Hout} = 45$$



paralelo (tubo) – serie (ánulo)

Valores de prueba

$$Temp_{Cp2} := 1$$

$$Temp_{Cp1} := 1$$

$$Temp_{Hint} := 1$$

Restricciones

$$\frac{(Temp_{Cp1} - Temp_{Cin})}{(Temp_{Hin} - Temp_{Cin})} = \frac{(Temp_{Cp2} - Temp_{Cin})}{(Temp_{Hint} - Temp_{Cin})}$$

$$cP_a \cdot Q_{ma} \cdot (Temp_{Hint} - Temp_{Hout}) \cdot K = cP_s \cdot \frac{Q_{ms}}{2} \cdot (Temp_{Cp2} - Temp_{Cin}) \cdot K$$

$$cP_a \cdot Q_{ma} \cdot (Temp_{Hin} - Temp_{Hint}) \cdot K = cP_s \cdot \frac{Q_{ms}}{2} \cdot (Temp_{Cp1} - Temp_{Cin}) \cdot K$$

Solver

$$\begin{bmatrix} Temp_{Hint} \\ Temp_{Cp1} \\ Temp_{Cp2} \end{bmatrix} := \mathbf{find}\left(Temp_{Hint}, Temp_{Cp1}, Temp_{Cp2}\right) = \begin{bmatrix} 59.497 \\ 45.147 \\ 34.853 \end{bmatrix}$$

$$\xi := \frac{(Temp_{Cp1} - Temp_{Cin})}{(Temp_{Hin} - Temp_{Cin})} = 0.502 \qquad \xi := \frac{(Temp_{Cp2} - Temp_{Cin})}{(Temp_{Hint} - Temp_{Cin})} = 0.502$$

$$LMTD_{ctc} := \left(\frac{(Temp_{Hout} - Temp_{Cin}) - (Temp_{Hin} - Temp_{Cout})}{\ln\left(\frac{(Temp_{Hout} - Temp_{Cin})}{(Temp_{Hin} - Temp_{Cout})} \right)} \right) \cdot \Delta°C = 37.444\ K$$

Transferencia de calor para cada tramo

$$q_1 := \left(cP_s \cdot \frac{Q_{ms}}{2} \cdot (Temp_{Cp1} - Temp_{Cin}) \right) \cdot K = 355.931\ kW$$

$$q_2 := \left(cP_s \cdot \frac{Q_{ms}}{2} \cdot (Temp_{Cp2} - Temp_{Cin}) \right) \cdot K = 251.681\ kW$$

$q = 607.612\ kW$ $q_t := q_1 + q_2 = 607.612\ kW$

Valores de prueba

$NTU := 1$

Restricciones

$$\xi = NTU \cdot \frac{LMTD_{ctc}}{\Delta T_{max}}$$

Solver

$NTU := \text{find}(\text{NTU}) = 0.939$

Valores de prueba

$A_{tctc} := 1\ m^2$

Restricciones

$$NTU = U_{gd} \cdot \frac{A_{tctc}}{C_{min}}$$

Solver

$A_{tctc} := \text{find}(A_{tctc}) = 9.143\ m^2$

área de una parte de la configuración en paralelo

$A_{tint} := A_{tctc} \cdot 2 = 18.285\ m^2$

$A_h := N_t \cdot \pi \cdot D_o \cdot Long_h = 5.745\ m^2$

$$N_{hp} := \left(\frac{A_{tint}}{A_h}\right) = 3.183$$

$N_{hp} := 3$

$$A_{treal} := N_{hp} \cdot A_h = 17.236\ m^2$$

$$\Delta P_{it}\left(Q_m, D_{in}, \delta, \mu\right) := N_t \cdot \frac{G\left(Q_m, D_{in}\right)^2}{2 \cdot \delta} \cdot \left(f_D\left(\varepsilon, \mu, D_{in}, Q_m\right) \cdot \frac{N_{hp} \cdot Long_h}{D_{in}} \cdot \left(\frac{\mu}{\mu_{sw}}\right)^{-0.14} + \left(N_{hp} - 1\right)\right)\ \Delta$$

$$\Delta P_{it}\left(\frac{Q_{ms}}{2}, D_{in}, \delta_s, \mu_s\right) = \left(6.099 \cdot 10^4\right)\ kPa$$

Δ

$$Pot_{itp} := \frac{\dfrac{\Delta P_{it}\left(\dfrac{Q_{ms}}{2}, D_{in}, \delta_s, \mu_s\right) \cdot Q_{ms}}{\delta_s}}{\eta} = 392.288\ kW$$

$$Pot_{anp} := \frac{\dfrac{\Delta P_{ant}\left(\mu_a, D_s, D_o, Q_{ma}, \varepsilon, \delta\right.}{\delta_a}}{\eta}$$

$$Pot_{bomp} := Pot_{itp} + Pot_{anp} = 392.531\ kW$$

INCISO b costos

$i := 0.03$ $n := 10$

Donde
i:interés
n: vida útil
a: amortización

$$a := \left(\frac{i \cdot (1+i)^n}{(i+1)^n - 1}\right) \frac{1}{yr} = 0.117 \frac{1}{yr}$$

$$C_{hp} := 500$$

$$C_{thp} := C_{hp} \cdot a = 58.615 \frac{1}{yr}$$

$$Costo := C_{thp} \cdot N_h = 175.846 \frac{1}{yr}$$

$$Costo_{par} := C_{thp} \cdot N_{hp} = 175.846 \frac{1}{yr}$$

Costo de la potencia

$$C_{bom} := \left(\frac{0.15}{1000 \cdot 3600}\right) \frac{1}{J} = \left(4.167 \cdot 10^{-8}\right) \frac{1}{J}$$

$$t := 335 \frac{day}{yr} \cdot 24 \frac{hr}{day} = \left(8.04 \cdot 10^{3}\right) \frac{hr}{yr}$$

$$C_{potserie} := C_{bom} \cdot t \cdot Pot_{bom} = \left(1.87 \cdot 10^{6}\right) \frac{1}{yr}$$

$$C_{potpar} := C_{bom} \cdot t \cdot Pot_{bomp} = \left(4.734 \cdot 10^{5}\right) \frac{1}{yr}$$

$$C_{tserie} := C_{potserie} + Costo = \left(1.87 \cdot 10^{6}\right) \frac{1}{yr}$$

$$C_{tpar} := C_{potpar} + Costo_{par} = \left(4.736 \cdot 10^{5}\right) \frac{1}{yr}$$