

**APÉNDICE C. CÁLCULO TERMODINÁMICO DEL SECADOR Y DEL REACTOR****ANÁLISIS SECADOR**

$Q_{in}$ =Calor suministrado para el proceso

$Q_{lost}$ =Calor de perdidas por ineficiencia

$Q_{air,in}$ =Calor que contiene el aire atmosférico al ingresar al proceso

$Q_{air,out}$ =Calor a la salida del aire

$Q_w$ =Calor que requiere el agua para evaporarse

$M_{air,in}$ =Masa de entrada de aire

$M_w$ =Masa de agua involucrada en el proceso

$H_{air,in}$ =Entalpía del aire a la entrada

$H_{air,hot}$ =Entalpía del aire posterior a su calentamiento

$H_{air,out}$ =Entalpía del aire a la salida

$H_{w,vaporization}$ =Entalpía de vaporización del agua

$H_{u,abs,air,in}$ =Humedad absoluta del aire en la entrada del proceso

Parametros de entrada

$$M_{in} = 1 \text{ [kg]}$$

$$M_w = 0,7 \cdot M_{in}$$

$$T_{amb} = 298 \text{ [K]}$$

$$T_{in,biomass} = 298 \text{ [K]}$$

$$T_{in,air} = 298 \text{ [K]}$$

$$T_{out,air} = 313 \text{ [K]}$$

$$C_{p,air} = 1,005 \text{ [kJ/(kg}\cdot\text{k)]}$$

Balance de energia

$$Q_{in} = Q_{lost} - Q_{air,in} + Q_{air,out} + Q_w - Q_{w,in} + Q_{biomass}$$

$$Q_{air,in} = M_{air} \cdot H_{air,in}$$

$$H_{air,in} = C_{p,air} \cdot T_{in,air}$$

$$\text{Humidity}_{air,in} = 0,018$$

$$M_{air} = \frac{Q_w}{H_{air,hot}}$$

$$H_{air,hot} = C_{p,air} \cdot T_{air,hot}$$

$$T_{air,hot} = 393 \text{ [K]}$$

$$Q_{air,out} = M_{air} \cdot H_{air,out}$$

$$H_{air,out} = C_{p,air} \cdot T_{out,air}$$

$$Q_w = M_{w,t} \cdot H_{w,vaporization}$$

$$M_{w,t} = M_w + \text{Humidity}_{air,in} \cdot M_{air}$$

$$H_{w,vaporization} = 2257 \text{ [kJ/kg]}$$

$$Q_{w,in} = M_{w,t} \cdot H_{w,in}$$

$$H_{w,in} = 104,83 \text{ [kJ/kg]}$$

$$Q_{lost} = 0,1 \cdot (Q_{air,out} - Q_{air,in} + Q_w - Q_{w,in})$$

$$Q_{biomass} = M_{biomass} \cdot C_{p,biomass} \cdot \delta T_{biomass}$$

$$M_{biomass} = M_{in} - M_w$$

$$C_{p,biomass} = 2,73 \text{ [kJ/(kg}\cdot\text{k)]}$$

$$\delta T_{biomass} = T_{out,biomass} - T_{in,biomass}$$

$$T_{out,biomass} = 313 \text{ [K]}$$

## Balance de entropía

$$\delta S = \delta S_{\text{air}} + \delta S_{\text{w}} + \delta S_{\text{biomass}}$$

$$\delta S_{\text{air}} = M_{\text{air}} \cdot C_{p,\text{air}} \cdot \ln \left[ \frac{T_{\text{out,air}}}{T_{\text{in,air}}} \right]$$

$$\delta S_{\text{w}} = M_{\text{w},1} \cdot (s_{\text{w}2} - s_{\text{w}1})$$

$$\delta S_{\text{biomass}} = M_{\text{biomass}} \cdot C_{p,\text{biomass}} \cdot \ln \left[ \frac{T_{\text{out,biomass}}}{T_{\text{in,biomass}}} \right]$$

$$s_{\text{w}1} = 0,3672 \text{ [kJ/(kg}\cdot\text{k)]}$$

$$s_{\text{w}2} = 7,3542 \text{ [kJ/(kg}\cdot\text{k)]}$$

## Balance de exergía

$$\delta X = \delta X_{\text{air}} + \delta X_{\text{w}} + \delta X_{\text{biomass}}$$

$$\delta X_{\text{air}} = M_{\text{air}} \cdot (H_{\text{air,out}} - H_{\text{air,in}}) - T_{\text{amb}} \cdot \delta S_{\text{air}}$$

$$\delta X_{\text{w}} = M_{\text{w},1} \cdot (h_{\text{w}2} - h_{\text{w}1}) - T_{\text{amb}} \cdot \delta S_{\text{w}}$$

$$\delta X_{\text{biomass}} = M_{\text{biomass}} \cdot \delta h_{\text{biomass}} - T_{\text{amb}} \cdot \delta S_{\text{biomass}}$$

$$\delta h_{\text{biomass}} = C_{p,\text{biomass}} \cdot \delta T_{\text{biomass}}$$

$$h_{\text{w}1} = 104,83 \text{ [kJ/kg]}$$

$$h_{\text{w}2} = 2675,6 \text{ [kJ/kg]}$$

## Exergía Química antes de que la biomasa entre al secador

$$Ex_{Q,1} = \beta \cdot Q_{\text{ic},1}$$

$$\beta = \left[ 0,0143 \cdot \frac{C_1}{O_1} + 1,5019 \right] \cdot \left[ \frac{0,76 - 0,1 \cdot \frac{C_1}{O_1} + 0,052 \cdot \frac{H_1}{C_1}}{1 - 0,487 \cdot \frac{H_1}{O_1}} \right]$$

$$Q_{\text{ic},1} = Q_{\text{sc},1} - 226 \cdot H_1 - 25,1 \cdot W_1$$

$$Q_{\text{sc},1} = 3,55 \cdot C_1^2 - 232,2 \cdot C_1 - 2230 \cdot H_1 + 51,2 \cdot C_1 \cdot H_1 + 131 \cdot N_1 + 20600$$

$$C_1 = 0,635 \cdot \text{FC} + 0,46 \cdot \text{VM} - 0,095 \cdot \text{ASH}$$

$$O_1 = 0,34 \cdot \text{FC} + 0,469 \cdot \text{VM} - 0,023 \cdot \text{ASH}$$

$$H_1 = 0,059 \cdot \text{FC} + 0,06 \cdot \text{VM} + 0,01 \cdot \text{ASH}$$

$$N_1 = 0$$

$$S_1 = 0$$

$$W_1 = \frac{0,7}{0,3} \cdot 100$$

$W_1$ =contenido de humedad en base seca, según indica el artículo

$$\text{FC} = 10,532$$

$$\text{VM} = 68,393$$

$$\text{ASH} = 17$$

$$Q_{\text{ic},1;\text{prueba}} = 348,3 \cdot C_1 + 882,6 \cdot H_1 - 102,72 \cdot O_1 - 24,8 \cdot W_1 - 10,8 \cdot S_1 + 65,1$$

Exergia Quimica despues de que la biomasa sale del secador

$$Ex_{Q,2} = \beta \cdot Q_{ic,2}$$

$$Q_{ic,2} = Q_{sc,1} - 226 \cdot H_1 - 25,1 \cdot W_2$$

$$W_2 = 25$$

$$Q_{ic,2;prueba} = Q_{sc,1} - H_{w,vaporization} \cdot \left[ 9 \cdot \frac{H_1}{100} + \frac{MC}{100} \right]$$

$$MC = \frac{20}{50} \cdot 100$$

MC=contenido de humedad en base humeda, según indica el articulo

## ANALISIS REACTOR

### Balance de energia

$$Q_{in,r} = Q_{biomass,r} + Q_{by,products} + Q_{lost,r}$$

$$Q_{biomass,r} = M_{biomass,r} \cdot C_{p,biomass} \cdot \delta T_{biomass,r} + M_{biomass,r} \cdot C_{p,biomass} \cdot \delta T_{biomass,r} \cdot \frac{3000}{1620}$$

$$M_{biomass,r} = 0,4 \cdot M_{biomass}$$

$$\delta T_{biomass,r} = T_{out,biomass,r} - T_{in,biomass,r}$$

$$T_{in,biomass,r} = 298 \text{ [K]}$$

$$T_{out,biomass,r} = 543 \text{ [K]}$$

$$Q_{by,products} = Q_{gas,r} + Q_{oil,r} + Q_{w,r}$$

$$Q_{gas,r} = M_{gas,r} \cdot C_{p,gas,r} \cdot \delta T_{gas,r} + M_{gas,r} \cdot C_{p,gas,r} \cdot \delta T_{gas,r} \cdot \frac{3000}{1620}$$

$$M_{gas,r} = 0,05 \cdot (M_{biomass} - M_{w,r})$$

$$C_{p,gas,r} = 1,8694 \text{ [kJ/(kg*k)]}$$

$$\delta T_{gas,r} = \delta T_{biomass,r}$$

$$Q_{oil,r} = M_{oil,r} \cdot C_{p,oil,r} \cdot \delta T_{oil,r} + M_{oil,r} \cdot C_{p,oil,r} \cdot \delta T_{oil,r} \cdot \frac{3000}{1620}$$

$$M_{oil,r} = 0,25 \cdot (M_{biomass} - M_{w,r})$$

$$C_{p,oil,r} = 0,7 \text{ [kJ/(kg*k)]}$$

$$\delta T_{oil,r} = \delta T_{biomass,r}$$

3000 segundos, equivalen a los 50 minutos de torrefacción a la Temperatura de 270°C  
1620 segundos, equivalen al tiempo utilizado para llegar a la temperatura de torrefacción

$$Q_{w,r} = M_{w,r} \cdot H_{w,vaporization}$$

$$M_{w,r} = 0,2857 \cdot M_w$$

$$Q_{lost,r} = 0,1 \cdot Q_{in,r}$$

### Balance de entropia

$$\delta S_r = \delta S_{biomass,r} + \delta S_{gas,r} + \delta S_{oil,r} + \delta S_{w,r}$$

$$\delta S_{biomass,r} = M_{biomass,r} \cdot C_{p,biomass} \cdot \ln \left[ \frac{T_{out,biomass,r}}{T_{in,biomass,r}} \right]$$

$$\delta S_{gas,r} = M_{gas,r} \cdot C_{p,gas,r} \cdot \ln \left[ \frac{T_{out,biomass,r}}{T_{in,biomass,r}} \right]$$

$$\delta S_{oil,r} = M_{oil,r} \cdot C_{p,oil,r} \cdot \ln \left[ \frac{T_{out,biomass,r}}{T_{in,biomass,r}} \right]$$

$$\delta S_{w,r} = M_{w,r} \cdot (S_{w2} - S_{w1})$$

#### Balance de exergia

$$\delta X_r = \delta X_{biomass,r} + \delta X_{gas,r} + \delta X_{oil,r} + \delta X_{w,r}$$

$$\delta X_{biomass,r} = Q_{biomass,r} - T_{amb} \cdot \delta S_{biomass,r}$$

$$\delta X_{gas,r} = Q_{gas,r} - T_{amb} \cdot \delta S_{gas,r}$$

$$\delta X_{oil,r} = Q_{oil,r} - T_{amb} \cdot \delta S_{oil,r}$$

$$\delta X_{w,r} = Q_{w,r} - T_{amb} \cdot \delta S_{w,r}$$

#### Exergia Quimica despues de que la biomasa sale del reactor

$$Ex_{Q,r} = \beta_{r1} \cdot Q_{ic,r}$$

$$\beta_{r1} = \frac{1,0412 + 0,216 \cdot \frac{H_2}{C_2} - 0,2499 \cdot \frac{O_2}{C_2} \cdot \left[ 1 + 0,7838 \cdot \frac{H_2}{C_2} \right] + 0,045 \cdot \frac{H_2}{C_2}}{1 - 0,3035 \cdot \frac{O_2}{C_2}}$$

$$\beta_r = \left[ 0,0143 \cdot \frac{C_2}{O_2} + 1,5019 \right] \cdot \left[ \frac{0,76 - 0,1 \cdot \frac{C_2}{O_2} + 0,052 \cdot \frac{H_2}{C_2}}{1 - 0,487 \cdot \frac{H_2}{O_2}} \right]$$

$$Q_{ic,r} = Q_{sc,r} - 226 \cdot H_2 - 25,1 \cdot W_3$$

$$Q_{sc,r} = 18000$$

$$Q_{sc,r,prueba} = 3,55 \cdot C_1^2 - 232,2 \cdot C_1 - 2230 \cdot H_1 + 51,2 \cdot C_1 \cdot H_1 + 131 \cdot N_1 + 20600$$

$$C_2 = 0,635 \cdot FC_2 + 0,46 \cdot VM_2 - 0,095 \cdot ASH_2$$

$$O_2 = 0,34 \cdot FC_2 + 0,469 \cdot VM_2 - 0,023 \cdot ASH_2$$

$$H_2 = 0,059 \cdot FC_2 + 0,06 \cdot VM_2 + 0,01 \cdot ASH_2$$

$$N_2 = 0$$

$$S_2 = 0$$

$$W_3 = 3,791$$

$W_3$ =contenido de humedad en base seca, según indica el articulo

$$FC_2 = 19,957$$

$$VM_2 = 59,39$$

$$ASH_2 = 17$$

$$Q_{ic,r,prueba2} = Q_{sc,r} - H_{w,vaporization} \cdot \left[ 9 \cdot \frac{H_2}{100} + \frac{MC_2}{100} \right]$$

$$MC_2 = 3,6526$$

MC=contenido de humedad en base humeda, según indica el articulo

**Unit Settings: SI K kPa kJ mass deg**

ASH = 17	ASH <sub>2</sub> = 17	$\beta = 1,079$
C <sub>2</sub> = 38,38	C <sub>p,air</sub> = 1,005 [kJ/(kg*k)]	C <sub>p,biomass</sub> = 2,73 [kJ/(kg*k)]
$\delta S = 5,712$	$\delta S_{air} = 0,2201$ [1/k]	$\delta S_{biomass} = 0,04022$ [kJ/k]
$\delta S_r = 1,61$	$\delta S_w = 5,452$ [kJ/kg-k]	$\delta S_{w,r} = 1,397$ [kJ/k]
$\delta T_{oil,r} = 245$ [K]	$\delta X = 383,2$	$\delta X_{air} = 1,637$
$\delta X_{oil,r} = 9,099$	$\delta X_r = 219,3$	$\delta X_w = 381,3$ [kJ/kg]
ExQ <sub>r</sub> = 19100	FC = 10,53	FC <sub>2</sub> = 19,96
H <sub>air,hot</sub> = 395 [kJ/kg]	H <sub>air,in</sub> = 299,5 [kJ/kg]	H <sub>air,out</sub> = 314,6 [kJ/kg]
H <sub>w,vaporization</sub> = 2257 [kJ/kg]	MC = 40	MC <sub>2</sub> = 3,653
M <sub>gas,r</sub> = 0,005001 [kg]	M <sub>in</sub> = 1 [kg]	M <sub>oil,r</sub> = 0,025 [kg]
N <sub>1</sub> = 0	N <sub>2</sub> = 0	O <sub>1</sub> = 35,27
Q <sub>biomass</sub> = 12,29 [kJ/kg-k]	Q <sub>biomass,r</sub> = 228,9 [kJ/kg-k]	Q <sub>by,products</sub> = 470,1
Q <sub>ic,2</sub> = 13362	Q <sub>ic,2,prueba</sub> = 13198	Q <sub>ic,r</sub> = 16795
Q <sub>lost</sub> = 174,6 [kJ/kg]	Q <sub>lost,r</sub> = 77,67	Q <sub>oil,r</sub> = 12,23 [kJ/kg-k]
Q <sub>w</sub> = 1761 [kJ/kg]	Q <sub>w,in</sub> = 81,79 [kJ/kg]	Q <sub>w,r</sub> = 451,4 [kJ]
S <sub>w2</sub> = 7,354 [kJ/(kg*k)]	T <sub>air,hot</sub> = 393 [K]	T <sub>amb</sub> = 298 [K]
T <sub>out,air</sub> = 313 [K]	T <sub>out,biomass</sub> = 313 [K]	T <sub>out,biomass,r</sub> = 543 [K]
W <sub>2</sub> = 25	W <sub>3</sub> = 3,791	
$\beta_r = 1,068$	$\beta_{r1} = 1,137$	C <sub>1</sub> = 36,53
C <sub>p,gas,r</sub> = 1,869 [kJ/(kg*k)]	C <sub>p,oil,r</sub> = 0,7 [kJ/(kg*k)]	$\delta h_{biomass} = 40,95$ [kJ/kg]
$\delta S_{biomass,r} = 0,1966$ [kJ/k]	$\delta S_{gas,r} = 0,005609$ [kJ/k]	$\delta S_{oil,r} = 0,0105$ [kJ/k]
$\delta T_{biomass} = 15$ [K]	$\delta T_{biomass,r} = 245$ [K]	$\delta T_{gas,r} = 245$ [K]
$\delta X_{biomass} = 0,2992$ [kJ]	$\delta X_{biomass,r} = 170,3$	$\delta X_{gas,r} = 4,86$
$\delta X_{w,r} = 34,97$ [kJ]	ExQ <sub>1</sub> = 8776	ExQ <sub>2</sub> = 14418
Humidity <sub>air,in</sub> = 0,018	H <sub>1</sub> = 4,895	H <sub>2</sub> = 4,911
h <sub>w1</sub> = 104,8 [kJ/kg]	h <sub>w2</sub> = 2676 [kJ/kg]	H <sub>w,in</sub> = 104,8 [kJ/kg]
M <sub>air</sub> = 4,459 [kg/kJ]	M <sub>biomass</sub> = 0,3 [kg]	M <sub>biomass,r</sub> = 0,12 [kg]
M <sub>w</sub> = 0,7 [kg]	M <sub>w,r</sub> = 0,2 [kg]	M <sub>w,t</sub> = 0,7803
O <sub>2</sub> = 34,25	Q <sub>air,in</sub> = 1335 [kJ/kg]	Q <sub>air,out</sub> = 1403 [kJ/kg]
Q <sub>gas,r</sub> = 6,531 [kJ/kg-k]	Q <sub>ic,1</sub> = 8133	Q <sub>ic,1,prueba</sub> = 7701
Q <sub>ic,r,prueba2</sub> = 16920	Q <sub>in</sub> = 1933	Q <sub>in,r</sub> = 776,7
Q <sub>sc,1</sub> = 15095 [kJ/kg]	Q <sub>sc,r</sub> = 18000 [kJ/kg]	Q <sub>sc,r,prueba</sub> = 15095
S <sub>1</sub> = 0	S <sub>2</sub> = 0	S <sub>w1</sub> = 0,3672 [kJ/(kg*k)]
T <sub>in,air</sub> = 298 [K]	T <sub>in,biomass</sub> = 298 [K]	T <sub>in,biomass,r</sub> = 298 [K]
VM = 68,39	VM <sub>2</sub> = 59,39	W <sub>1</sub> = 233,3