Simplified Wall Heat Transfer Model

Dr. Jerry J.W. Yuan

Process Simulations Ltd.
2386 East Mall, Suite 204
Vancouver, B.C.,
V6T 1Z3, Canada

May, 2000

Simplified Wall Heat Transfer Model

In the case of gasifier and lime kiln (except mud), the temperature gradients in axial and circumferential directions are much smaller than that in radial direction. It is therefore that only the conduction heat transfer in radial direction is considered in this model.

1 Heat conduction in the wall

The conduction heat transfer through the multi-layer wall of the cylindrical vessel can be calculated by the following equation.

$$Q_{cond} = \frac{T_{W,in} - T_{W,out}}{\sum_i R_{\lambda,i}} \tag{E1}$$

Here, $T_{W,in}$ — Inside wall temperature, K

$T_{W,out}$ — Outside wall temperature, K

$R_{\lambda,i}$ — Heat resistance of i th layer, K/W

$$R_{\lambda,i} = \frac{\ln \dfrac{r_{out,i}}{r_{in,i}}}{2\pi\lambda_i L}$$

$r_{out,i}$ — Outside radius of *ith* layer, m

$r_{in,i}$ — Inside radius of *ith* layer, m

L — Height of the cylinder, m

λ_i — Thermal conductivity of *ith* layer, W/(m K)

2 Heat convection and radiation outside

The heat transfer from outside wall to ambience includes the heat convection and the heat radiation as following.

$$Q_{out} = 2\pi r_{out} L h_{out} (T_{W,out} - T_{am}) + 2\pi r_{out} L \sigma \varepsilon_{out} (T_{W,out}^4 - T_{am}^4) \tag{E2}$$

Here, r_{out} — Outside radius of the cylinder, m

h_{out} — Convection heat transfer coefficient outside of the cylinder, W/(m^2 K)

T_{am} — Ambient air temperature, K

σ — Stefan-Boltzmann constant, 5.67×10^{-8} W/(m^2 K^4)

ε_{out} — Emissivity of outside wall

In the case of laminar natural convection, the convection heat transfer coefficient can be simply calculated as

$$h_{out} = 1.42\left(\frac{T_{W,out} - T_{am}}{L}\right)^{1/4}$$

3 Heat convection and radiation inside

The heat transfer on the inside wall includes three parts, convection heat transfer between combustion gas and the wall, radiation heat transfer from combustion gas to the wall, and radiation heat transfer from the wall to combustion gas. The first two parts are provided by CFD calculation, while the third part is a function of the inside wall temperature. It is expressed as following.

$$Q_{net} = Q_{in} - 2\pi r_{in} L \sigma \varepsilon_{in} T_{W,in}^4 \qquad \text{(E3)}$$

Here, Q_{net} — net heat transfer to the wall refractory, W

Q_{in} — Sum of convection and radiation heat transfer from combustion gas to the wall, W

r_{in} — Inside radius of the cylinder, m

ε_{in} — Emissivity of inside wall

Based on the one dimension assumption, the above three amounts of heat should be equal.

$$Q_{out} = Q_{cond} = Q_{net} \qquad \text{(E4)}$$

An equation for the inside wall temperature can be derived as following.

$$
\begin{aligned}
Q_{in} - A_{in}\sigma T_{W,in}^4 = A_{out}h_{out}\left[T_{W,in} - (Q_{in} - A_{in}\sigma T_{W,in}^4)\sum_i R_{\lambda,i} - T_{am}\right] \\
+ A_{out}\sigma\left\{\left[T_{W,in} - (Q_{in} - A_{in}\sigma T_{W,in}^4)\sum_i R_{\lambda,i}\right]^4 - T_{am}^4\right\}
\end{aligned}
\qquad \text{(E5)}
$$

4 Calculation procedure:

(1) Assume an initial inside wall temperature $T_{W,in}$, impose it as the boundary condition, and do the CFD iteration;

(2) The heat transfer from combustion gas to the inside wall, Q_{in} , can then be calculated from the CFD results;

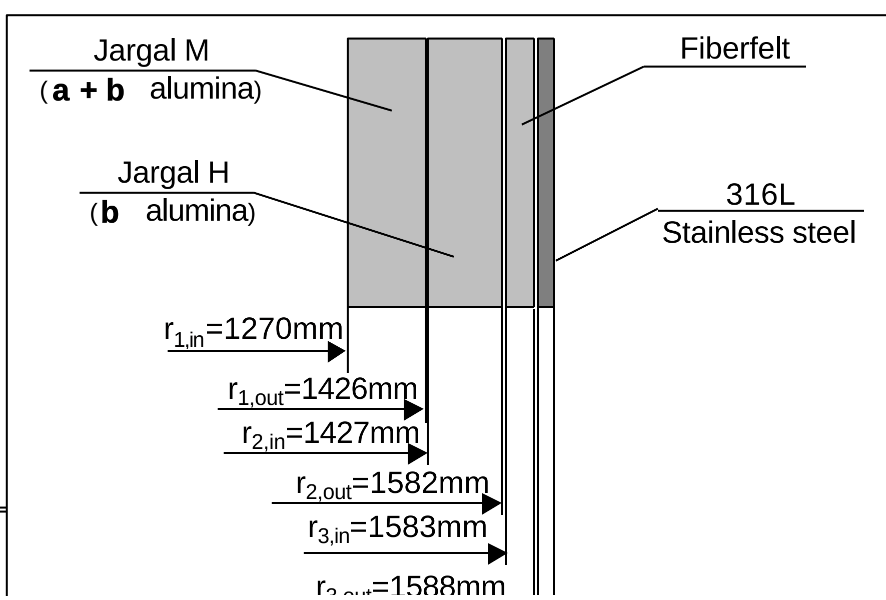
(3) Calculate the new inside wall temperature by solving above equation (E5) in Newton-Raphson method. Since the above equation for $T_{W,in}$ is not linear, there exist more than one solutions in the acceptable temperature range;

(4) Calculate the outside wall temperature, and only one solution of $T_{W,in}$ can give a reasonable $T_{W,out}$;

(5) Set this calculated new inside wall temperature $T_{W,in}$ as the new boundary condition, and do the next CFD iteration.

This procedure is performed on each cell of the wall in order to get the inside wall temperature. Since the combustion field is 3 dimensional, the inside wall temperature will be not uniform in the circumferential and axial directions although the heat conduction in these two directions is not accounted.

5 Wall structure of the gasifier at New Bern



6 Thermal conductivity and density of wall materials

	Jargal M	Jargal H	Fiberfelt	316L SS
λ (W/m K)	$=a_1T^4+a_2T^3+a_3T^2+a_4T+a_5$ $a_1=-0.63\times10^{-12}$ $a_2=-0.18\times10^{-9}$ $a_3=8.84\times10^{-6}$ $a_4=-10.23\times10^{-3}$ $a_5=7.36$ T: temperature [C] (4.284~6.871 between 50~1000C)	$=a_1T^4+a_2T^3+a_3T^2+a_4T+a_5$ $a_1=-1.19\times10^{-12}$ $a_2=5.30\times10^{-9}$ $a_3=-3.97\times10^{-6}$ $a_4=0.95\times10^{-3}$ $a_5=1.70$ T: temperature [C] (1.738~2.79 between 50~1000C)	0.4	62.07
ρ (kg/m^3)	3500	3220	192	7800