

Chapter 8

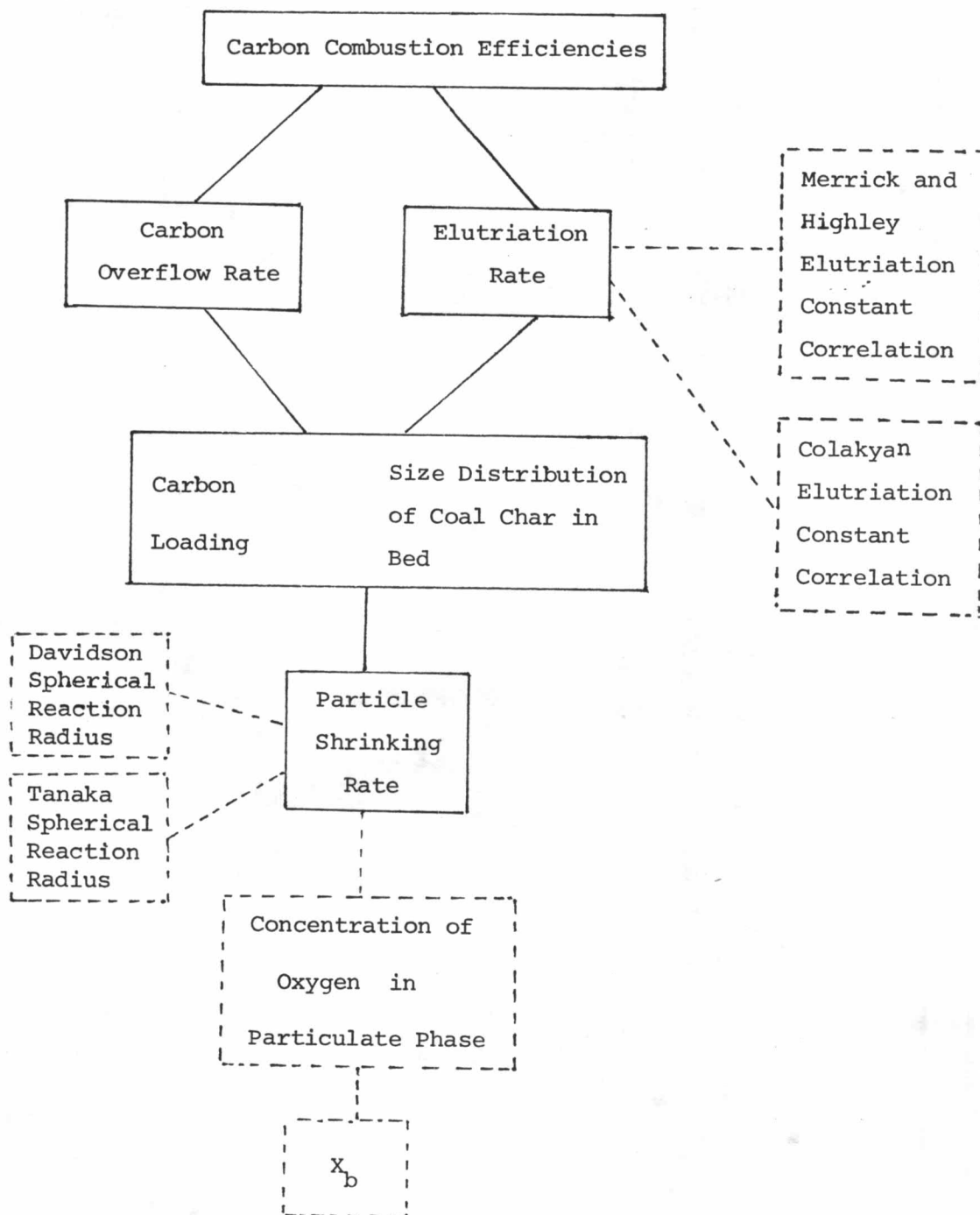
System Model Modification

Generally the values calculated from the system model are approximate in nature. As the system model comprises of several subsystem models, some subsystems may be modified, substituted by new subsystem models or disregarded, if the system model behavior is not significantly affected by the simplification. Some parameters or variables may significantly affect the system model behavior.

The following simulations are performed to determine the sensitivities of the system model to certain subsystem models, parameters and variables, so as to simplify the developed system model. The options of testing these effects on the system model can be seen in Fig. 8.1. The parameters or the variables in the dotted diagrams in Fig. 8.1 are the options to be tested.

8.1 Shrinking Rate Equations Based on Spherical Reaction Radii of Davidson and of Tanaka.

In the developed system model, the particle shrinking rate equation based on Tanaka spherical reaction radius (R') which is assumed to be equal to 1.2 time particle diameter (d_p), $R' = 1.2 d_p$ is used, because Tanaka spherical reaction radius is more accurate



X_b is the number of times the bubble volume is swept out during its time in the bed

The parameters or the variables in the dotted diagrams are the options in modification

Fig. 8.1 Options in Modification

than the Davidson assumption which says that the reaction radius is equal to particle diameter, $R = d_p$.

The shrinking rate equation based on Tanaka reaction radius is

$$\mathcal{R}(d_p) = \frac{57.6 \text{ Sh } D_A C_{Ap}}{d_p \rho_s} \dots\dots\dots(4.4.1)$$

From Section 4.4.2

$$\frac{d d_p}{dt} = \frac{48 R' \text{ Sh } D_A C_{Ap}}{d_p^2 \rho_s} \dots\dots\dots(8.1.1)$$

and from Davidson assumption, $R' = d_p$

hence Eq. 8.1.1 becomes

$$\frac{d d_p}{dt} = \frac{48 \text{ Sh } D_A C_{Ap}}{d_p \rho_s}$$

$$\mathcal{R}(d_p) = \frac{48 \text{ Sh } D_A C_{Ap}}{d_p \rho_s} \dots\dots\dots(8.1.2)$$

Eq. 8.1.2 is based on Davidson reaction radius assumption, and Eq. 4.4.1 is replaced by Eq. 8.1.2 in the developed system model. The system

model including Eq. 8.1.2 is simulated and the data are shown in Table 8.1. The results show that the values of carbon combustion efficiencies of the system model using either Eq. 4.4.1 or Eq. 8.1.2 are not significantly different. Hence either Eq. 4.4.1 or Eq. 8.1.2 can be used in the system model.

8.2 The Elutriation Rate Constant Correlations of Colakyan and of Merrick and Highley.

The Merrick and Highley correlation is used in the developed system model, because it was developed for limestone and coal char, and it is more reasonable than Wen and Hashinger correlation as described previously in Section 3.4.1.

The Colakyan correlation is more simple than the Merrick and Highley correlation.

Merrick and Highley correlation:

$$\frac{K^*}{\rho_g U_o} = A + 130 \exp -10.4 \left(\frac{U_t}{U_o} \right)^{0.5} \frac{U_{mf}}{U_o - U_{mf}}^{0.25} \dots (3.4.10)$$

Colakyan et.al correlation:

$$K^* = 34 \left(1 - \frac{U_t}{U_o} \right)^2 \dots \dots \dots (3.4.13)$$

However the Colakyan correlation is applied to the large bed in which free-board height exceeds the transport disengaging height (TDH).

In this experimental combustor, the crowded heat exchanger is arranged in the freeboard, this behaves like the long freeboard. And even though the combustor is not large, the Colakyan equation may be applied because of the approximate prediction of the system model. Consequently the Merrick and Highley correlation is substituted by the Colakyan correlation for finding the sensitivity of the system model to this substitution.

The simulation results are shown in Table 8.1. The comparisons of simulated carbon combustion efficiencies of both correlations in the system model are significantly the same.

8.3 Concentration of Oxygen in Particulate Phase (C_{Ap}) and X_b

C_{Ap} is one of the important variable in shrinking rate equation, Eq. 4.4.1. C_{Ap} is related to the number of times the bubble volume is swept out during its time in the bed, X_b ($= q_b H/V_b U_b$), which represents the fluid mechanic behavior in the bed. Hence the test of sensitivity of the system model to the value of C_{Ap} is considered.

The values of C_{Ap} are changed between inlet oxygen concentration (C_{AO}) and 60 % C_{AO} and substituted into the system model. The simulated results are shown in Table 8.2. The comparisons show that the system model is not sensitive to the changing of the values of C_{Ap} . From Table 8.2 when the values of C_{Ap} are assumed to be equal to C_{Ap} , the simulated results of

Table 8.1 Comparisons of Experimental Carbon Combustion Efficiencies with the Prediction of Developed and Modified System Models

Description	Experiments	Developes System Model		$R' = d_p$		Colakyan	
		calculated		calculated		calculated	
No of Series 1 Experiments	η_c	η	$ \Delta\eta $	η_c	$ \Delta\eta $	η_c	$ \Delta\eta $
1	92.73	92.04	0.69	92.04	0.69	92.04	0.69
2	90.85	88.77	2.08	88.77	2.08	88.63	2.22
3	96.85	95.14	1.71	95.14	1.71	94.52	2.33
4	86.35	87.77	1.42	87.77	1.42	86.93	0.58
5	91.00	93.83	2.83	93.83	2.83	92.67	1.67
average $ \Delta\eta $			1.75		1.75		1.50

R' = spherical reaction radius

d_p = lignite particle diameter

= elutriation constant

η_c = carbon combustion efficiency

$|\Delta\eta|$ = absolute relative deviation

of η_c from experimental
value

Table 8.2 Sensitivity of the System Model to the Specific Variables

Description	Experiments	Developed System Model		C_{Ap}			$C_{Ap} = C_{Ao}$		
		η_c	calculated η_c	$ \Delta\eta $	% C_{Ao}	calculated η_c	$ \Delta\eta $	calculated η_c	$ \Delta\eta $
No of Series 1 Experiments									
1	92.73	92.04	0.69	100% C_{Ao}	92.04	0.69	92.04	0.69	
2	90.85	88.77	2.08	80% C_{Ao}	88.63	2.22	88.77	2.08	
3	96.85	95.14	1.71	60% C_{Ao}	94.52	2.33	95.14	1.71	
4	86.35	87.77	1.42	30% C_{Ao}	-	-	87.77	1.42	
5	91.00	93.83	2.83	10% C_{Ao}	-	-	93.83	2.83	

C_{Ao} = concentra of oxygen in inlet air

carbon combustion efficiencies are not sensitive to changing of C_{Ap} into C_{Ao} . And from the experiments, the value of C_{Ab} shown in Table 6.1, 6.2 and 6.3 are about 90 % of C_{Ao} , hence the value of C_{Ap} can be assumed to be equal to C_{Ao} in calculation of the system model. This is convenient for designing, because it is not necessary to measure the value of concentration of oxygen in the bubble, which is used in the system model.

From Eq. 3.4.27

$$C_{Ap} = \frac{C_{Ab} - C_{Ao} \text{EXP}(-X_b)}{1 - \text{EXP}(-X_b)}$$

assume $C_{Ab} = C_{Ao}$

$$C_{Ap} = C_{Ao} \frac{(1 - \text{EXP}(-X_b))}{(1 - \text{EXP}(-X_b))}$$

$$C_{Ap} = C_{Ao}$$

Hence when C_{Ab} is assumed to be equal to C_{Ao} , the value of C_{Ap} is independent of X_b . This assumption is reasonable for the high gas velocity of U_o/U_{mf} between 3 and 10, excess air between 100 % and 300 %, and large particles fluidized bed which comprises 99 % of limestone particles (see Table 6.4 and 6.5). Under these

specific conditions, and according to the equation described above, the value of C_{Ap} is independent of X_b . Hence subsystem models incorporated in the subsystem model of X_b can be disregarded and this makes the system model much simpler.

Disregarding X_b in this simplification possibly means that oxygen that reacts with the char particles is in particulate phase since the air is just supplied to the bed, transferring of oxygen from bubble to the particulate phase of the two phase theory is not the mechanism.