CHAPTER 3

HEURISTIC APPROACH TO MODELING THE BOILER FURNACE

3.1 INTRODUCTION

Modeling and simulation of boiler systems has been an interesting subject of investigation for many years. Mathematical modeling and simulation of boiler or total power plant is often required for analyzing the transient behavior of critical process parameters of the boiler, designing suitable control philosophies and calculating the possible life expenditure of thick walled components during startups and load swings.

A heuristic approach employs a practical method to problem solving, learning or discovery. It may not be perfect or optimal, but sufficient enough for the immediate goals. They include a rule of thumb, an educated guess or an intuitive judgement. They are strategies derived from experience. In this context, a simplified, yet, accurate model of the furnace in the form of model equations that adequately describe the various heat losses by direct radiation within the furnace and the flue gas temperature at furnace outlet plane is developed. A Heuristic approach which involves operational experience and an intuitive guess is combined to develop the model equations of the boiler subsystems and the results are validated against the values obtained from the detailed mathematical model of a 500 MW boiler.
3.2 BOILER FURNACE DESCRIPTION

In this research work, a pulverized coal corner fired furnace is considered. The furnace consists of water walls also known as riser tubes. The drum, down comer and water walls together constitute the circulation system as shown in Fig.3.1.

Fig.3.1. Schematic diagram of Circulation System

For a full load 500 MW, fuel is fired through nine elevations with appropriate burner tilt. The number of elevations and burner tilt vary depending upon the part load. The first pass of the boiler includes furnace and few superheaters located at the top of the furnace. Pulverized coal is admitted into the furnace along with required quantity of air. The required air is supplied in two
modes: (i) primary air for carrying pulverized coal from pulverizer to the burners and (ii) secondary air for combustion of pulverized coal. There are nine elevations through which coal can be sent to the furnace. The sectional elevation of a boiler shown in Fig. 3.2 is based on BHEL’s design for a 500 MW utility boiler. The furnace and different heat exchangers like panel super-heater, platen super-heater and re-heater which are located at the top of the furnace in the flue gas path are shown in the Fig.3.2.

Fig. 3.2. Sectional Elevation of a 500 MW Utility Boiler

The water from economizer goes to the boiler drum and gets converted into steam in the circulation system. The steam from the drum gets super-heated in various super-heaters and enters the high pressure turbine. A major portion of high pressure turbine exhaust steam comes back to the boiler and gets superheated in re heater system. Flue gas is the product of combustion with high temperature. The flue gas is formed in the furnace as a result of combustion. The flue gas flows past the super-heaters thereby transforming the
saturated steam that comes out of the drum through the water walls into superheated steam. The steam and flue gas path explained is shown in Fig 3.3.

Fig.3.3. Steam and Flue Gas Circuit in a Boiler

The primary focus of the current research work is to develop model equations that adequately describe the furnace behavior and are yet computationally simple and easy to implement. Towards this purpose, data from the Predicted Performance of the boiler (usually provided by Original Equipment Manufacturers (OEM) at different loads has been used extensively and the model equations have been derived in the sense of least squares.
3.3 FURNACE MODELING

The furnace that has been considered for this research work is based on M/s BHEL’s design for a 500 MW boiler. The Net Heat Input (NHI) to the furnace is decided by the amount of coal flow rate with known calorific value, the primary air flow rate and secondary air flow rate and the air temperatures.

The water walls where in the steam generation takes place receive heat only by direct radiation. The panel super-heater which is located at the top left corner of the furnace receives heat mostly by direct radiation. The platen super-heater and reheater which are also located at the top of the furnace receive heat partly by direct radiation and mostly by convection due to the fact that flue gas passes over the platen and preheater surfaces with significant flue gas velocity. The flue gas leaves the furnace outlet plane with a temperature depending on the sensible heat available in flue gas which in turn is the resultant of the net heat input minus all useful heat transferred by direct radiation, convection and unaccounted heat losses. The quantities of direct radiation heat transfer and convection to different systems (waterwalls, super-heaters and reheaters) are further affected by burner tilt. Thus the process dynamics within the furnace is quite complex and hence modeling of furnace poses severe challenges. The designers use sophisticated computer software such as computational fluid dynamics (CFD) and validated advanced heat transfer correlations for modeling of the furnace. The complex heat transfer dynamics in the furnace of a boiler can thus be summarized as follows:

- The water walls receive heat from furnace totally by direct radiation.
• The panel super-heater is located at the left corner and below the penthouse. Hence, no convective heat transfer is possible and this section also receives heat totally by direct radiation.

• On the contrary, the platen super-heater and reheater receive heat both by direct radiation and convective heat transfer.

• From operational experience, it is observed that the flue gas temperature drop across the platen super-heater and reheaters is nearly a constant for varying loads.

• The flue gas temperature at the furnace outlet is to be determined based on sensible heat available at the furnace outlet plane.

• As per the design procedure, about 8% of the Net Heat input is considered as unaccounted radiative losses.

Based on these facts, the following variables can be determined as furnace output variables.

• Heat transferred to water walls by direct radiation in Kcal/sec \( Q_{gain-cir} \)

• Heat transferred to Divisional Panel Super-heater by direct radiation in Kcal/sec \( Q_{gain-pn} \)

• Heat transferred to Platen Super-heater by radiation in Kcal/sec \( Q_{dr-pt} \)

• Heat transferred to re-heater 1 by direct radiation in Kcal/sec \( Q_{dr-rh1} \)

• Heat transferred to re-heater 2 by direct radiation in Kcal/sec \( Q_{dr-rh2} \)

• Temperature of flue gas at the furnace outlet plane in deg C \( T_{gfop} \)

• Flue gas mass flow rate in Kg/sec \( m_g \)

The schematic diagram of the furnace with the input and output variables is shown in Fig.3.4.
Fig. 3.4 Schematic diagram of the furnace with the input - output variables

Predicted Performance of the boiler at different loads is usually provided by Original Equipment Manufacturer. The pressure, temperature and flow parameters at different nodes is available. Further, the burner tilt and calorific value of the fuel will also be available. The enthalpies of water or steam can be calculated from pressure and temperature measurements using steam tables.

3.4 DEVELOPMENT OF HEURISTIC MODEL

Based on the operational experience on 500 MW boilers for more than two decades, the current research attempts to develop the simple model equations of the furnace components like water walls, super-heaters and reheaters.

The heat flux to water walls is totally by direct radiation and is directly proportional to the net heat input to the furnace. Further, this is corrected by the burner tilt. A positive burner tilt shifts the mean flame zone upwards and a negative burner tilt shifts the mean flame zone downwards.
Direct radiation to the water walls gets affected with burner tilt.
The following statements / assumptions hold good for the development of furnace model.

1. The heat energy transferred from furnace to water walls by direct radiation is equal to the heat gained in converting the feed water at economizer outlet to saturation steam corresponding to drum pressure. The blow down of water from boiler drum is assumed to be zero.

2. The heat gained in platen super-heater, panel super-heater and re-heaters are due to two parts, the first part is due to direct radiation from furnace and the second due to convective heat transfer due to flue gas flow. The flue gas temperature drop across the panel, platen and re heaters is observed to be constant at different loads. But the total convective heat transfer at different loads differs due to change in flue gas rate.

3. The above understanding and arguments hold good for the platen super-heater (final super-heater) and re-heaters as well.

4. The net heat input brought into the furnace by coal and hot air (primary and secondary) results in an adiabatic flame temperature. The resultant mean flame zone along the vertical axis of the furnace is influenced by the burner tilt. In order to account for the effect of burner tilt, the net heat input is resolved into vertical and horizontal components with respect to burner tilt.

The flue gas temperature drop across the panel, platen and re heaters is observed to be constant at different loads as shown in Fig. 3.5.a. and Fig.
3.5.b. But the total convective heat transfer at different loads differs due to change in flue gas mass flow rate. Fig. 3.5.a shows the flue gas temperature profile for the platen super-heater. The variation in inlet and outlet temperature of flue gas across the platen for various load is plotted. It is observed that the flue gas temperature drop across the platen super-heater represented by the distance between the input and output curves remains nearly a constant at 110°C for various loads. The flue gas temperature at platen inlet varies from 1048°C to 1145°C whereas the flue gas temperature at platen outlet varies from 925°C to 1040°C for loads varying from 250 MW to 500 MW.

Fig.3.5.a. Flue gas temperature profile at inlet and outlet of Platen Super-heater
The flue gas temperature profile for the reheater is shown in Fig. 3.5.b. The variation in inlet and outlet temperature of flue gas across the reheater for various loads is plotted. It is observed that the flue gas temperature drop across the reheater which is represented by the distance between the input and output curves remains nearly a constant at 115°C for various loads. The flue gas temperature at reheater inlet varies from 925°C to 1040°C whereas the flue gas temperature at platen outlet varies from for loads varying from 760°C to 905°C for loads varying from 250 MW to 500 MW.

Fig.3.5.b Flue gas temperature profile at inlet and outlet of Reheater

With the above stated design criteria, the model equations for the circulation system, super-heaters and reheaters can be formulated using the
value of the Net heat input (NHI) to the furnace. This is calculated using the expression given in Eq. 3.1.

\[
NHI = m_c \cdot C_v + (m_{sa} \cdot C_{psa} \cdot T_{sa}) + (m_{pa} \cdot C_{ppa} \cdot T_{pa})
\]  

(3.1)

where

- \( m_c \) - Mass Flow Rate of Coal in Kg
- \( C_v \) - Calorific Value of Coal in Kcal/kg
- \( m_{sa} \) - Mass Flow Rate of Secondary Air in Kg/s
- \( C_{psa} \) - Specific Heat Capacity of Secondary in Kcal/Kg\(^0\)C
- \( T_{sa} \) - Temperature of Secondary Air in C
- \( m_{pa} \) - Mass Flow Rate of Primary Air in Kg/s
- \( C_{ppa} \) - Specific Heat Capacity of Primary Air Kcal/Kg\(^0\)C
- \( T_{pa} \) - Temperature of Primary Air in deg C

For a typical 500 MW unit, the value of NHI at different loads, calculated using relation (3.1) is given in Table 3.1. The burner tilt associated with different loads is obtained from the predicted performance data and is given in Table 3.1.

**Table 3.1 Net Heat Input at different Loads**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Load (MW)</th>
<th>NHI (Kcal/s)</th>
<th>Burner Tilt (BT) in deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>358976</td>
<td>-21</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>294076</td>
<td>-10</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>226934</td>
<td>+7</td>
</tr>
</tbody>
</table>
The procedure to determine the model equations for the circulation system and super-heaters has been discussed in the subsequent sections.

3.4.1. Circulation System

The heat gained by the circulation system $Q_{gain\text{-}cir}$ can be calculated using measurements for more than two different loads and the two unknown parameters $\alpha_1$ and $\alpha_2$ can be estimated in the sense of least squares.

$$Q_{gain\text{-}cir} = m_1(h_2 - h_1) = \alpha_1 NHI \cos(BT) + (BT) \alpha_2 NHI \sin(BT) \quad (3.2)$$

where

- NHI - Net Heat Input to the furnace in Kcal/s
- $m_1$ - feed water flow rate in Kg/s
- $h_1$ - enthalpy of feed water at economizer outlet in Kcal/kg
- and

$$h_1 = f(P_1, T_1)$$
- $h_2$ - enthalpy of saturated steam in Kcal/kg and
- $h_2 = f(P_2)$
- $\alpha_i - \alpha_{10}$, unknown model parameters to be estimated

For a typical 500 MW unit, the values of $Q_{gain\text{-}cir}$ at different loads, calculated using the first part of Eq. 3.2 is given in Table 3.2.
Table 3.2 Heat flux to water walls at different loads

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Load (MW)</th>
<th>( m_1 ) (Kg/s)</th>
<th>( h_1 ) (Kcal/kg)</th>
<th>( h_2 ) (Kcal/kg)</th>
<th>Qgain-cir (Kcal/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>411.11</td>
<td>360.57</td>
<td>594.69</td>
<td>96251.52</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>315.8</td>
<td>346.26</td>
<td>601.49</td>
<td>80601.63</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>229.5</td>
<td>332.54</td>
<td>606.23</td>
<td>62811.09</td>
</tr>
</tbody>
</table>

Now the unknown values of \( \alpha_1 \) and \( \alpha_2 \) in the second part of Eq (3.2) can be solved by formulating three algebraic equations—corresponding to three different loads using the values of NHI and Burner Tilt given in Table 3.1 and \( Q_{gain-cir} \) given in Table 3.2.

\[
Q_{gain-cir} = \alpha_1 NHI \cos(BT) + (BT)\alpha_2 NHI \sin(BT)
\]

The above set of equations can be represented in matrix form as follows:

\[
A X = B
\]

(3.3)

where

\[
A = \begin{bmatrix}
335104 & -2701041 \\
209606 & -510510 \\
225231 & 193641
\end{bmatrix} ; X = \begin{bmatrix}
\alpha_1 \\
\alpha_2
\end{bmatrix} ; B = \begin{bmatrix}
96251 \\
80601 \\
62811
\end{bmatrix}
\]

Eq (3.3) can be solved in the sense of minimum Least Squares Method as follows:

\[
[A^T A]^{-1} [A^T B] = [A^T A]^{-1} A^T B
\]

\[
X = [A^T A]^{-1} A^T B
\]

(3.4)

The values of \( \alpha_1 \) and \( \alpha_2 \) from Eq. 3.2 are obtained as

\[
\begin{bmatrix}
\alpha_1 \\
\alpha_2
\end{bmatrix} = \begin{bmatrix}
0.2780 \\
-0.0011
\end{bmatrix}
\]
3.4.2. Panel Superheater

The heat flux to the panel super-heater is mostly by direct radiation and is directly proportional to the net heat input to the furnace which is further corrected by the burner tilt. With this perception, a heuristic relationship for heat flux by direct radiation to panel super-heater can be written as shown in Eq. 3.5

\[ Q_{gain-pn} = m_2 (h_4 - h_3) = \alpha_3 NHI \cos(BT) + (BT) \alpha_4 NHI \sin(BT) \]  (3.5)

Where \( \alpha_3, \alpha_4 \) are to be evaluated using known values of NHI, \( Q_{gain-pn} \) and burner tilt for different MW ratings given in Table 3.3.

Table 3.3 Heat flux to Panel Super-heater at different loads

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Load (MW)</th>
<th>( m_2 ) (Kg/s)</th>
<th>( h_3 ) (Kcal/kg)</th>
<th>( h_4 ) (Kcal/kg)</th>
<th>( Q_{gain-pn} ) (Kcal/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>416.11</td>
<td>673.22</td>
<td>755.01</td>
<td>34032.08</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>333</td>
<td>666.02</td>
<td>750.13</td>
<td>30002.42</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>252.5</td>
<td>644.51</td>
<td>743.77</td>
<td>25064.05</td>
</tr>
</tbody>
</table>

The Eq (3.5) is represented in the form of a matrix equation and solved in the sense of least squares.

\[ A X = B \]

Where

\[ A = \begin{bmatrix} 335104 & -2701041 \\ 209606 & -510510 \\ 225231 & 193641 \end{bmatrix}; X = \begin{bmatrix} \alpha_3 \\ \alpha_4 \end{bmatrix}; B = \begin{bmatrix} 34032 \\ 30002 \\ 25064 \end{bmatrix} \]

The values of \( \alpha_3 \) and \( \alpha_4 \) thus obtained are
\[
\begin{bmatrix}
\alpha_3 \\
\alpha_4
\end{bmatrix} =
\begin{bmatrix}
0.1026 \\
0.0000
\end{bmatrix}
\]

### 3.4.3 Platen Superheater

The heat flux to the platen super-heater is partly by convective heat transfer from flue gas and the remaining by direct radiation. However, the total heat flux to the platen super-heater can be written as determined from steam side as

\[
Q_{gain\text{-}pt} = Q_{dr\text{-}pt} + Q_{conv\text{-}pt}
\]  
(3.6)

where

\[
Q_{gain\text{-}pt} = m_2(h_6 - h_5) = \alpha_5 NHI \cos(BT) + (BT)\alpha_6 NHI \sin(BT)
\]  
(3.7)

Here, \(\alpha_5\) and \(\alpha_6\) of Eq. 3.7 are to be evaluated using known values of NHI, \(Q_{gain\text{-}pt}\) and burner tilt for different MW ratings.

The convective component of heat transfer to the platen super-heater is obtained by the relation

\[
Q_{conv\text{-}pt} = m_g C_p \Delta T_{g\text{-}pt}
\]  
(3.8)

where

- \(m_g\) - Mass Flow Rate of Flue Gas in Kg/s
- \(C_p\) - Specific Heat Capacity of Flue Gas in Kcal/Kg/°C
- \(\Delta T_{g\text{-}pt}\) - Temperature drop across the Platen Super-heater

The temperature drop across the Platen Super-heater, \(\Delta T_{g\text{-}pt}\) remains very nearly a constant for a wide range of loads. This value can usually be found.
from the predicted performance curves supplied by the OEMs and this drop is found to be roughly a constant at 110° C.

The value of $Q_{gain\_pt}$ is calculated from Eq. 3.7, $Q_{conv\_pt}$ from Eq. 3.8 and $Q_{dr\_pt}$ from Eq. 3.7. The values obtained are tabulated in Table 3.4. The matrix equations are formed and the unknown constants $\alpha_5$ and $\alpha_6$ are determined.

Table 3.4 Heat flux to Platen Super-heater at different loads

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Load (MW)</th>
<th>$m_3$ (Kg/s)</th>
<th>$h_5$ (Kcal/kg)</th>
<th>$h_6$ (Kcal/kg)</th>
<th>$Q_{gain_pt}$ (Kcal/s)</th>
<th>$Q_{conv_pt}$ (Kcal/s)</th>
<th>$Q_{dr_pt}$ (Kcal/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>416.38</td>
<td>755.1</td>
<td>810.8</td>
<td>23192</td>
<td>16688</td>
<td>6504</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>330.05</td>
<td>750.6</td>
<td>811.5</td>
<td>20283</td>
<td>13728</td>
<td>6555</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>252.5</td>
<td>744.1</td>
<td>812</td>
<td>17144</td>
<td>10716</td>
<td>6428</td>
</tr>
</tbody>
</table>

The matrix equations are formed using the values given

$$A = \begin{bmatrix} 335104 & -2701041 \\ 209606 & -510510 \\ 225231 & 193641 \end{bmatrix}; \quad X = \begin{bmatrix} \alpha_5 \\ \alpha_6 \end{bmatrix}; \quad B = \begin{bmatrix} 6504 \\ 6555 \\ 6428 \end{bmatrix}$$

The values of the unknown constants thus obtained are

$$\begin{bmatrix} \alpha_5 \\ \alpha_6 \end{bmatrix} = \begin{bmatrix} 0.0258 \\ 0.0008 \end{bmatrix}$$

3.4.4 Reheater

The heat flux to the reheater 1 and reheater 2 is also partly by convective heat transfer from flue gas and the remaining by direct radiation.
However, the total heat flux to the reheater 1 and 2 can be written as
determined from steam side as

\[ Q_{gain-rh1} = Q_{dr-rh1} + Q_{conv-rh1} \]  
\[ Q_{gain-rh2} = Q_{dr-rh2} + Q_{conv-rh2} \]

where

\[ Q_{gain-rh1} = m_4 (h_7 - h_8) = \alpha_7 NHI \cos(BT) + (BT) \alpha_8 NHI \sin(BT) \]  
\[ Q_{gain-rh2} = m_5 (h_9 - h_{10}) = \alpha_9 NHI \cos(BT) + (BT) \alpha_{10} NHI \sin(BT) \]

Here, the values of co-efficient \( \alpha_7, \alpha_8 \) for reheater 1 and \( \alpha_9, \alpha_{10} \) for reheater 2 and are to be evaluated using known values of NHI, \( Q_{gain-rh1}, Q_{gain-rh1} \) and burner tilt for different MW ratings using Eq. 3.11 and 3.12.

The convective component of heat transfer to the reheaters is obtained by the relation

\[ Q_{conv-rh1} = m_g C_p \Delta T_{g-rh1} \]  
\[ Q_{conv-rh2} = m_g C_p \Delta T_{g-rh2} \]

where

\( m_g \) - Mass Flow Rate of Flue Gas in Kg/s
\( C_p \) - Specific Heat Capacity of Flue Gas in Kcal/Kg/°C
\( \Delta T_{g-rh1} \) - Temperature drop across the Reheater 1
\( \Delta T_{g-rh2} \) - Temperature drop across the Reheater 2

The temperature drop across the reheater 1 and 2, \( \Delta T_{g-rh1} \) and \( \Delta T_{g-rh2} \) remains very nearly a constant for a wide range of loads. This value
can usually be found from the predicted performance curves supplied by the OEMs and this drop is found to be roughly a constant at $110^\circ$C.

The values of $Q_{\text{gain} - \text{rh}_1}$, $Q_{\text{conv} - \text{rh}_1}$ and $Q_{\text{dr} - \text{rh}_1}$ are obtained using Eq. 3.11, 3.13 and 3.9 respectively and are tabulated in Table 3.5. The matrix equations are formed and the unknown constants $\alpha_7$ and $\alpha_8$ are determined.

**Table 3.5 Heat flux to Reheater 1 at different loads**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Load (MW)</th>
<th>$m_4$ (Kg/s)</th>
<th>$h_7$ (Kcal/kg)</th>
<th>$h_8$ (Kcal/kg)</th>
<th>$Q_{\text{gain} - \text{rh}_1}$ (Kcal/s)</th>
<th>$Q_{\text{conv} - \text{rh}_1}$ (Kcal/s)</th>
<th>$Q_{\text{dr} - \text{rh}_1}$ (Kcal/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>370.8</td>
<td>729.0</td>
<td>802.6</td>
<td>27291</td>
<td>24274</td>
<td>3017</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>299.44</td>
<td>729.4</td>
<td>805.8</td>
<td>22877</td>
<td>19967</td>
<td>2910</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>229.44</td>
<td>729.9</td>
<td>809.5</td>
<td>18263</td>
<td>15586</td>
<td>2677</td>
</tr>
</tbody>
</table>

The matrix equations are formed using the tabulated quantities and the values of the unknown constants $\alpha_7$ and $\alpha_8$ are determined as follows

$$
\begin{bmatrix}
\alpha_7 \\
\alpha_8
\end{bmatrix}
= 
\begin{bmatrix}
0.0110 \\
0.0003
\end{bmatrix}
$$

In the same way, the values of $Q_{\text{gain} - \text{rh}_2}$, $Q_{\text{conv} - \text{rh}_2}$ and $Q_{\text{dr} - \text{rh}_2}$ using Eq. 3.12, 3.14 and 3.10 respectively and are tabulated in Table 3.6. The matrix equations are formed and the unknown constants $\alpha_9$ and $\alpha_{10}$ are determined.
Table 3.6 Heat flux to Reheater 2 at different loads

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Load (MW)</th>
<th>( m_5 ) (Kg/s)</th>
<th>( h_9 ) (Kcal/kg)</th>
<th>( h_{10} ) (Kcal/kg)</th>
<th>( Q_{gain-rh2} ) (Kcal/s)</th>
<th>( Q_{conv-rh2} ) (Kcal/s)</th>
<th>( Q_{dr-rh2} ) (Kcal/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>370.8</td>
<td>809.5</td>
<td>847.8</td>
<td>14201</td>
<td>13031</td>
<td>1170</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>299.44</td>
<td>805.8</td>
<td>846.3</td>
<td>12127</td>
<td>10732</td>
<td>1395</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>229.44</td>
<td>802.6</td>
<td>844.2</td>
<td>9545</td>
<td>8377</td>
<td>1168</td>
</tr>
</tbody>
</table>

The matrix equations are formed using the tabulated quantities and the values of the unknown constants \( \alpha_9 \) and \( \alpha_{10} \) are determined as follows

\[
\begin{bmatrix}
\alpha_9 \\
\alpha_{10}
\end{bmatrix} = \begin{bmatrix}
0.0051 \\
0.0002
\end{bmatrix}
\]

The value of the co-efficient thus obtained using design coal specifications is summarized in Table 3.7.

Table 3.7 Table of co-efficient obtained for design coal

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Component</th>
<th>Co-efficients</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water walls</td>
<td>( \alpha_1 )</td>
<td>0.2780</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \alpha_2 )</td>
<td>-0.0011</td>
</tr>
<tr>
<td>2</td>
<td>Panel Super-heater</td>
<td>( \alpha_3 )</td>
<td>0.1076</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \alpha_4 )</td>
<td>0.0008</td>
</tr>
<tr>
<td>3</td>
<td>Platen Super-heater</td>
<td>( \alpha_5 )</td>
<td>0.0258</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \alpha_6 )</td>
<td>0.0008</td>
</tr>
<tr>
<td>4</td>
<td>Reheater1</td>
<td>( \alpha_7 )</td>
<td>0.0110</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \alpha_8 )</td>
<td>0.0003</td>
</tr>
<tr>
<td>5</td>
<td>Reheater2</td>
<td>( \alpha_9 )</td>
<td>0.0051</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \alpha_{10} )</td>
<td>0.0002</td>
</tr>
</tbody>
</table>
3.5 CONCLUSION

Based on the calculations, the salient equations describing the complex process taking place within the furnace of a generic 500 MW boiler are summarized in Table 3.8.

**Table 3.8 Heuristic Model Equations and co-efficient values**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Component</th>
<th>Heuristic Model Equation</th>
<th>Co-efficient</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water walls</td>
<td>$Q_{gain-clr} = \alpha_1 NHI \cos(BT) + (BT)\alpha_2 NHI \sin(BT)$</td>
<td>$\alpha_1$</td>
<td>0.2780</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\alpha_2$</td>
<td>-0.0011</td>
</tr>
<tr>
<td>2</td>
<td>Panel Superheater</td>
<td>$Q_{gain-pn} = \alpha_3 NHI \cos(BT) + (BT)\alpha_4 NHI \sin(BT)$</td>
<td>$\alpha_3$</td>
<td>0.1076</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\alpha_4$</td>
<td>0.0008</td>
</tr>
<tr>
<td>3</td>
<td>Platen Superheater</td>
<td>$Q_{gain-pu} = \alpha_5 NHI \cos(BT) + (BT)\alpha_6 NHI \sin(BT)$</td>
<td>$\alpha_5$</td>
<td>0.0258</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\alpha_6$</td>
<td>0.0008</td>
</tr>
<tr>
<td>4</td>
<td>Reheater 1</td>
<td>$Q_{gain-rh1} = \alpha_7 NHI \cos(BT) + (BT)\alpha_8 NHI \sin(BT)$</td>
<td>$\alpha_7$</td>
<td>0.0110</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\alpha_8$</td>
<td>0.0003</td>
</tr>
<tr>
<td>5</td>
<td>Reheater 2</td>
<td>$Q_{gain-rh2} = \alpha_9 NHI \cos(BT) + (BT)\alpha_{10} NHI \sin(BT)$</td>
<td>$\alpha_9$</td>
<td>0.0051</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\alpha_{10}$</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

It can be seen from the algebraic equations that the effect of burner tilt is properly accounted. For a negative burner tilt, the heat flow rate to the waterwalls is more while for a positive burner tilt the heat flow rate to the waterwalls is less. A positive burner tilt results in more direct radiation to super-heater sections hanging from the penthouse. This is in good agreement with the physics of the process. Further, the calculated values using the above heuristic equations (algorithms) for various sections are in good agreement with those obtained through design procedure.