2.0 Concept and design of crown

The TERI-designed recuperative furnace differs in design from the traditional pot furnace in a crucial aspect. Unlike the traditional furnace which is fired by a coal grate/gas burner at the base of the furnace, the recuperative furnace is ‘top-fired’ by a gas burner positioned in the ‘eye’ of its crown and facing downwards. The crown in the recuperative furnace is given a pronounced rounded shape (like a dome) compared to the nearly flat crown of the traditional furnace. The additional height of this rounded crown gives it stability, and provides sufficient space for complete combustion of fuel (natural gas) and for transfer of heat inside the furnace. (Figure 2.1).

The rounded crown is built with high-quality refractory bricks to give it longer life than the traditional flattish crown, which usually lasts no more than a year. The outermost row of bricks in the rounded crown is made from refractory bricks with grooves cut into them. These specially shaped bricks are known as ‘skewbacks’. The skewbacks together act as the supporting layer for the entire crown. The skewbacks are fixed so that their grooves are supported on MS (mild steel) tie rods, which in turn are supported on the furnace pillars [Figure 2.2 (a), Figure 2.2 (b), Figure 2.2 (c)]. Each tie rod is of square section of side 2.5 inches (6.35 cm), with a straight length of 51 inches (129.5 cm); bent portion of vertical length 7 inches (17.8 cm); and threaded end of 7½ inches (19.0 cm).

The skewback layer is followed by three rows of IS-8 bricks, 22 rows of silica/Sillimanite bricks and a centre block. The standard dimensions of both IS-8 and silica bricks are 9 × 4.5 × 3 inches (22.9 cm × 11.4 cm × 7.62 cm). However, the shapes of bricks in different rows differ from one another in terms of width and taper. Hence, sets of bricks have to be shaped for each row according to the required dimensions.

2.1 Construction procedure

Construction of the crown is carried out in five stages as listed below:
1. Finalization of crown height
2. Construction of temporary dome structure
3. Cutting refractory bricks
4. Fixing refractory bricks and blocks over the temporary structure
5. Removal of temporary structure

2.1.1 Finalization of crown height

The crown height is defined as the vertical height measured from the top of the pillar to the apex or ‘eye’ of the crown, excluding the thickness of the brick layer on the crown. In the traditional 12-pot furnace, the crown height is about 9 inches (22.9 cm). In the recuperative furnace, the crown height can vary from 24 inches to 30 inches (61 cm–76 cm) depending on the number of pots employed in the furnace. The crown heights that yield optimum operations in a few furnaces of different capacities are shown in Table 2.1.

Table 2.1: Crown heights for recuperative furnaces of various capacities

<table>
<thead>
<tr>
<th>Furnace capacity</th>
<th>Crown height (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 pots</td>
<td>30</td>
</tr>
<tr>
<td>11 pots</td>
<td>27</td>
</tr>
<tr>
<td>10 pots</td>
<td>24</td>
</tr>
</tbody>
</table>

2.1.1.1 Shaping bricks for height and curvature

Each of the refractory bricks used in the crown has to be shaped at two levels—one for height, and once for curvature. The former contributes to achieving the required crown height, while the latter contributes to giving the crown its circular shape.

The shape of the brick varies only slightly from row to row. Also, in a given row the depths of the cuts required for each brick are quite small. These factors make accurate cutting of bricks very difficult. At the same time, it is vital for the bricks in a given row to be cut as uniformly as possible in order to achieve a smooth and regular crown surface (in terms of both height and circumference). Non-uniformity of brick shapes in a given row will not only mar the smooth circular shape of the crown and give it a serrated edge; it may affect the stability and strength of the crown.

As mentioned earlier, the bricks used in the first (outermost) row of the dome are cut into the shape of skewbacks. The exact shapes of the skewbacks required, and the height of the crown itself, are finalized by a trial-and-error method as described in the following section.

2.1.1.2 Freezing crown height

To start with, the targeted crown height for the new furnace is decided upon. As shown in Table 2.1, the crown height could vary from 24–30 inches, depending on the number of pots in the new furnace. Having decided the targeted crown height, and
knowing the diameter of the furnace (see Table 1.2), an outline of the crown’s arch is drawn to scale on the factory floor.

The taper level required for the first row of bricks (that is, the skewbacks) is determined using standard mathematical techniques. The first 100 bricks are shaped into skewbacks according to the calculated taper. These skewbacks are then placed along the outline of the crown’s arch on the floor, and the height so obtained for the crown is measured to see how far it deviates from the required height. By using a trial and error method, the depths of cuts made on the skewbacks are adjusted till eventually the required crown height is achieved. This exercise helps ‘freeze’ the crown height. It also enables determination of the exact shapes of the skewbacks for constructing the first row of bricks in the crown. The next step is to prepare a ‘dummy crown’ or temporary dome structure, on which the actual crown can be built.

2.1.2 Construction of temporary dome structure

Two methods are generally followed for construction of the temporary dome. In the first method, which is commonly followed abroad, a wooden structure is assembled for construction of the temporary dome. This procedure requires time and entails more expenditure. Hence, most pot furnace units in Firozabad make a temporary dome using mud, bamboo and plaster as explained below.

2.1.2.1 Red brick structure

The spaces between the pillars of the furnace are packed with red bricks as shown in Figure 2.3. The centre portion of the furnace is also raised with a red brick structure that stands to a height equal to the desired height of the crown, as determined earlier (see 2.1.1.2).

2.1.2.2 Bamboo/wooden support and gunny bags

Bamboo sticks are closely packed together in the space between the outer wall of the central red brick structure and the wall along the pillars, as shown in Figure 2.4. The space in the middle of the central red brick structure is packed with wooden planks. The entire plank-and-bamboo structure is then covered with gunny bags.

2.1.2.3 Mud filling

The plank-and-bamboo structure is now filled with mud in a symmetrical manner (Figure 2.5). Care must be taken to ensure that big particles or stones are not present in the mud while filling. The entire mud-filled structure is rammed on all sides to give it solidity. Once the ramming is completed, mud is filled again and ramming repeated till the structure reaches the required height.
2.1.2.4 Pre-levelling

A wooden leveller is made to match the required curvature of the crown. The leveller is fitted with a pivot, placed at the centre point of the crown structure (marked earlier) and moved over the entire surface of the dome (Figure 2.6) to identify uneven areas on the mud surface, that is, places with either too much or too little mud. Any excess mud found is removed, while mud is filled in where necessary. This procedure ensures uniform curvature on all sides of the crown structure, and makes it easier to lay bricks during construction of the crown.

2.1.2.5 Plastering and levelling of mud structure

The mud structure is then sprinkled regularly with water and plastered to the required level. The leveller is moved over the structure to verify the thickness of the plastering (Figure 2.7).

2.1.3 Cutting refractory bricks and blocks

Cutting of refractory bricks/blocks could be done both manually as well as by using a brick cutting machine. The latter enables much greater precision in the cutting of bricks to the exact dimensions required. Hence, it is recommended that bricks for constructing and/or repairing the recuperative furnace—in particular, its crown—are shaped using a brick cutting machine.

2.1.3.1 Cutting of skewbacks

The dome height in the recuperative furnace is much greater (24–30 inches) than that in the traditional furnace (9 inches). Hence, a much larger number of bricks are required to construct the recuperative furnace crown, making it correspondingly heavier than the traditional furnace crown. Therefore, skewbacks (being stronger bricks that are shaped to ‘lock’ into one another) are used in the outermost row to strengthen the recuperative furnace crown.

Refractory blocks of $18 \times 16 \times 6$ inches ($457 \times 406 \times 152$ mm) size are used for preparing skewbacks of the required dimensions (Figure 2.8). The slope or taper for each skewback is arrived at by drawing the crown arch to scale on the floor and resting the brick tangential to the curvature (see Section 2.1.1.2). Four skewbacks are cut from each block. An isometric view of a skewback is shown in Figure 2.9 and its dimensions are shown in Figure 2.10.

The block is first cut manually, since the size of the blade in the brick-cutting machine (Figure 2.11) is generally suitable for cutting only standard-size refractory bricks. Because of manual cutting, the cut surfaces are not smooth. Later, the brick-cutting machine is used to further grind these cut surfaces.
2.1.3.2 Cutting of IS-8 and silica bricks

Standard refractory bricks of size $9 \times 4.5 \times 3$ inches ($229 \times 115 \times 76$ mm) are used for constructing all the remaining rows in the recuperative furnace crown. The initial cutting of both IS-8 and silica bricks is done with the brick-cutting machine, and the finishing operations are usually carried out manually.

For the first row of IS-8 bricks, each refractory brick is cut on all four sides. This row of bricks gives the crown its circular periphery. For all the other brick rows, each brick is cut only on two sides; one gives it curvature, and the other gives it height. While fixing a fresh row of bricks, it is advisable first to prepare two or three sample bricks and verify them for proper alignment. Thereafter, the remaining bricks are cut accordingly.

Table 2.2 shows the dimensions of the cut IS-8/silica bricks. It may be noted that the brick height is reduced from 76 mm to 72 mm in the first cut. In the second cut, the brick width of 115 mm is reduced on either side both at the top and bottom, as shown by $W_{LT}$, $W_{LB}$, $W_{RT}$ & $W_{RB}$.

**Table 2.2:** Dimensions of silica bricks after cutting for different rows in a typical recuperative pot furnace crown

<table>
<thead>
<tr>
<th>Row nos</th>
<th>Height (H)</th>
<th>Left top (WLT)</th>
<th>Left bottom (WLB)</th>
<th>Right top (WRT)</th>
<th>Right bottom (WRB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 3</td>
<td>72</td>
<td>110</td>
<td>115</td>
<td>106</td>
<td>109</td>
</tr>
<tr>
<td>4 to 7</td>
<td>72</td>
<td>110</td>
<td>115</td>
<td>106</td>
<td>109</td>
</tr>
<tr>
<td>8 to 11</td>
<td>72</td>
<td>110</td>
<td>115</td>
<td>104</td>
<td>109</td>
</tr>
<tr>
<td>12 to 14</td>
<td>72</td>
<td>109</td>
<td>115</td>
<td>103</td>
<td>109</td>
</tr>
<tr>
<td>15 to 16</td>
<td>72</td>
<td>108</td>
<td>115</td>
<td>102</td>
<td>109</td>
</tr>
<tr>
<td>17 to 18</td>
<td>72</td>
<td>106</td>
<td>115</td>
<td>100</td>
<td>109</td>
</tr>
<tr>
<td>19 to 20</td>
<td>72</td>
<td>104</td>
<td>115</td>
<td>98</td>
<td>109</td>
</tr>
<tr>
<td>21 to 22</td>
<td>72</td>
<td>104</td>
<td>115</td>
<td>96</td>
<td>109</td>
</tr>
</tbody>
</table>

2.1.3.3 Preparation of centre block

The centre block of the crown accommodates the gas burner. It is usually made by assembling two similarly shaped refractory blocks. The size of each block is $12 \times 18 \times 36$ inch ($305 \times 457 \times 914$ mm). The cutting of the centre block is done manually, given the huge size of the block and the complicated nature of the cuts required (Figure 2.12).

The centre block consists of an outer tapering circular structure with a square hole in its middle, called quarl, which houses the burner assembly. The quarl has a side of 12.5 inches (320 mm) and a depth of 6 inches (152 mm). Figure 2.13 shows the dimensional details of the centre burner block.
2.1.4 Fixing refractory bricks and blocks over the temporary structure

2.1.4.1 Support rods
First, support rods for the crown are fixed over the furnace pillars. The support rods are made of mild steel (MS). The number of support rods depends on the number of pots in the furnace—12 rods are used for a 12-pot furnace. Each rod is square in cross-section with a side of 2.5 inches (6.35 cm) and a length of 54 inches (about 135 cm). Each rod is provided with screws that can be tightened or loosened during crown construction.

2.1.4.2 Fixing of skewbacks
The skewbacks, cut and trimmed to the sizes required as described above, are placed so that their grooves fit into the support rods. In order to handle thermal expansion problems, care must be taken to ensure that: (i) there is a gap of about 5 mm between the bottom of the groove in the skewback and the rod, and (ii) there is no gap between the rod and the top of the groove in the skewback.

2.1.4.3 Cross-checking number of brick rows
Once the skewbacks are mounted on to their positions, fresh refractory bricks are placed diagonally over the temporary dome surface to count the number of rows till the centre block. The counted number of rows may be verified against the calculated number of rows and corrections made, if required.

2.1.4.4 Fixing of IS-8 and silica bricks
As described earlier (see Section 2.1.3.2), except for one row of IS-8 bricks, which are cut on four sides, the bricks for all the remaining rows are cut on two sides. Some minor differences in dimensions are likely to be found between the bricks after they are cut. It is advisable to carry out a physical alignment check on the first three or four bricks for each row immediately after cutting. This would help minimize errors in brick cutting and reduce wastage of bricks.

The procedure followed for fixing both IS-8 bricks and silica bricks is the same (Figure 2.14). Silica mortar is used as the binding material between bricks. A paper strip of size 9 × 3 inches (229 x 76 mm) is placed between alternate sides of the bricks. When the furnace is fired, these paper strips will burn away and create small spaces between the bricks to accommodate thermal expansion.

In order to monitor the temperature of the furnace, a thermowell is cut into one of the bricks in the crown as shown in Figure 2.15.
The last five rows of silica bricks are left out to provide enough space for handling the centre block while placing it in position. After the centre block is positioned properly, these rows are completed.

2.1.4.5 Fixing centre block

The two half-blocks that make up the centre block are lifted manually and placed on top of the crown. Their positions are adjusted for symmetry (Figure 2.16), so that equal spacing is left on all sides after the two halves are aligned.

2.1.4.6 Fixing of key bricks

After aligning the centre half-blocks, three of the five remaining rows of silica bricks are fixed. The last two rows are crucial, as they comprise the ‘key bricks’ that complete the crown. The dimensions of the last two rows are adjusted to suit the remaining space between the centre block and the fixed brick rows. The bricks in the last row are placed in such a way that about 2 inches (5 cm) project above the surface of the crown. These key bricks are then hammeredin gently (using a plastic hammer) to level them with the other bricks (Figure 2.17). Hammering is done uniformly over the entire row. Water is sprinkled on the bricks whenever it becomes difficult to hammer. The top view of the completed crown is shown in Figure 2.18.

2.1.4.7 Coating crown top with silica mortar

After all the key bricks have been fitted, the crown top is coated with a lean solution of silica mortar to smoothen its surface and fill any gaps that may exist between bricks.

2.1.5 Removal of temporary structure

The temporary structure beneath the completed crown is now carefully dismantled.

The red brick structure between the pillars is removed, section-by-section. Following this, the bamboo sticks, gunny bags, and the red brick structure in the centre of the furnace are removed. Finally, the plaster is removed.

2.1.5.1 Inspection of crown from inside

Following the removal of the entire temporary structure (red bricks, mud and other materials), the floor and pillars of the furnace are cleaned and the crown is inspected from the inside. Each row of bricks is inspected carefully for gaps. Any gaps that are found are filled completely with silica mortar.

Now, the crown is ready for the burner to be mounted on to the quarl.