Use of blast furnaces

The use of blast furnaces dates back as far as early as fifth century B. C. In China. However, it wasn't until 1828 that the efficiency of blast furnaces was revolutionized by preheating them using hot stoves in conjunction with the process, an innovation created by James Beaumont Nielson.(1) In 1860, the cooperative use of hot stoves with blast furnaces was further transformed by Edward Alfred Cowper(2) by recycling the offgas of the blast furnace rather than receiving solid fuel as did the earlier designs.

Early designs of hot stoves used with blast furnaces were originally placed on top of the furnace rather than next to it, the current layout used today. They used waste heat from the blast furnace delivered via cast iron pipes to the hot stove to preheat the cold air blast. One major problem with using cast iron pipes was the generation of cracks throughout them. This was remedied by eliminating the pipes and using refractory instead. This also furthered the design of the layout of the hot stove with the blast furnace to the use of two to four hot stoves placed in series beside the blast furnace. This allowed for the heating of one blast stove by offgas as the other one was being drained of its heat to preheat the air blast into the blast furnace. As the air blast entered the stove, it was preheated by hot bricks and exited the stove as a hot blast. Cambria Iron Works was the first company in the U. S. to use regenerative stoves in 1854. These stoves were constructed of iron shells lined with refractory and contained multiple passageways of refractory for the blast throughout. A typical stove of this design had about 186-232 m2 of heating surface. In 1870, Whitwell Stoves designed and produced larger stoves with heating surfaces of about 8546 m2, which could deliver 454-566°C hot blast to the furnace. These were also the first stoves to use hexagonal refractory checkers, cast iron checker supports, and semi-elliptical combustion chambers to enhance the distribution of gas throughout the checkers.

Final improvements that are used today include the design of tuyeres, tuyere stocks, and water cooled tuyeres in place of cast iron or copper ones. These were hollow, conical shaped castings that had water circulating throughout the interior. The pipes from the blowing engines had to be redesigned to contain metal-to-metal sheets, and as the blast temperatures increased, the inside of the tuyeres and blast pipes had to be lined with refractory, thus causing an overall increase in size.

General Operation of Hot Stoves

Hot stove operations have generally not changed much since the process was revolutionized in the late nineteenth century. Modern hot stoves are about 30 feet in diameter and 150 feet high.(4) They consist of a circular steel lined with bricks, and are flat on bottom and dome-shaped on top. Offgas from the blast furnace travels to the regeneration chamber of the hot stove, which is lined with checkerwork containing a filling to extract the heat from the offgas. Air is blown through the regeneration chamber to carry the hot offgas into the dome of the hot stove and into the combustion chamber, where it is combusted and returned to the blast furnace in the form of sensible heat. Figure 1 provides the general layout of a hot stove with a blast furnace.

Selection of Refractories and Insulating Materials

The selection of insulating materials will always place dense quality brick in front of the insulating brick to protect them from wear. The insulating bricks are selected based on the temperature of the hot face of the dense bricks in front of them, but without consideration to the temperature drop that occurs through the dense brick. Thermal conductivity and shrinkage at high temperatures are the most important factors when selecting insulating materials, as lower shrinkage can be achieved based on the maximum design temperature, a simple value to quantify. High density quality insulating brick is used on the hot face with a lower density brick as a backup, with a thin layer of slab type insulation mortared to the stove shell. Other important qualities of insulting materials that are taken into consideration include volumetric weight, resistance to thermal shock, residual quartz content, and permanent linear change.

Although the process is rather simple, a lot of work goes into selecting appropriate checkerwork, refractory and insulating materials. Proper selection of these is essential to optimal performance and promotion of a long stove life. It becomes even more essential as the operating temperature of the stove becomes higher. Refractories are chosen according to the expected load and temperature conditions of the hot stove and are zoned for the desired temperature gradients and expansion characteristics. Using 57% and 63% alumina refractories is suitable for high temperature stove operations and are often used in conjunction with silica refractories. Alumina refractories are used for for the top checkers because of their ability to resist spall at all temperatures and their high heat capacity, which is greater than that of silica refractories. Silica refractories are excellent for spall resistance in combination with lack of expansion at temperatures exceeding 600°C, therefore are best suited for applications higher than 600°C. They are best suited for dome, upper combustion chamber wall, and the upper checker chamber wall. Silica refractories also glaze at high temperature, resulting in less clogging of checker flues due to its ability to annihilate the buildup of dirt that can occur with the use of high alumina checkers. For these reasons regarding both alumina and silica checkers, a top layer of several courses of silica checkers is often used with lower layers consisting of high alumina checkers.

There are certain criteria that must be met when choosing refractories and insulating materials. These including evaluating dense brick quality and checker brick quality. When selecting dense brick, the most important quality to take into consideration is its creep characteristics. Each quality of refractory has a designated creep specification which requires that the refractory must have a maximum of 0. 2% at a load of 2 N/mm2 at a specific temperature for a time period of 20 to 50 hours. Once the maximum design temperature is calculated, 50 degrees is subtracted when tabulating the specifications as a safety measure. Table 1 details the information for various dense quality bricks.

Properties of checker brick must also be taken into consideration when pairing with dense quality brick. Dense quality brick recommends evaluating the maximumdesign temperature, whereas the selection of checker bricks is dictated by their respective lower maximum operating temperatures when choosing bricks of the same quality refractory material. There is a difference in the design temperature of both due to the actual design of the checker brick. To ensure a maximum efficiency with checker brick, an interlocking system is incorporated. An interlocking system has the ability to reduce locally the bearing pressure, which can cause a higher bearing pressure locally. Checker location and checker column height reduce the maximum design temperature compared to dense bricks of the same quality refractories. Table 2 includes information regarding the maximum design temperatures for various quality refractories of checker bricks. Again, 50 degrees is subtracted from the final calculated maximum design temperature for safety reasons.

Several factors have to be taken into consideration in detail when choosing checker brick for the regeneration chamber and the checker chamber. Checker bricks in general are selected based on the temperature gradient throughout the checkerwork, which is determined by stove capacity calculations. The upper limit of the temperature gradient is determined by adding 50 degrees to the maximum design temperature given above in Table 2 (this is called the dome design temperature), while the lower limit is equal to the maximum waste temperature. For simplicity’s sake, the temperature gradient is assumed to be linear. The height of the checker quality can then be determined using the following formula:

$$H = [(Tmdt \pm Tldt)/(Tdd \pm Twg)] * \text{Total Checker Height}$$

where H equals the calculated height, Tmdt is the maximum design temperature of subject quality, Tldt is the lower design temperature, Tdd is the design dome temperature, and Twg is the waste gas temperature. The installed height of the quality checker is then determined by converting the calculated height to an even number of checker layers based on the height of a single checker brick. Calculating the height of various qualities of dense brick in the checker chamber wall also uses the aforementioned formula and procedure.

Problems Incurred with Increased Temperatures

Current hot stoves can operate at temperatures exceeding 1000°C. As technologies were invented to increase the temperatures, physical problems were encountered in the hot stoves. These include the shifting and movement of metallic supports, differential thermal expansion in combustion chamber skin and breast walls which caused tilting of the breast walls (also called the “ banana effect”), and differential growth of the ring wall which caused tilting and cracking (and eventually failure) of the stove dome. Higher efficiency interlocking checkers were also needed as the stove size increased to accommodate higher hot blast temperatures.

Conclusion

Using hot stoves with blast furnaces greatly improves the efficiency of the process. By doing so, less fuel and energy are needed to create the amount of heat needed for the blast furnace to operate.