Blast Furnace Sizing Considerations for Incredible India

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Abstract
The expansion of the steel industry in India has been substantial in recent years and will continue to be substantial for another number of years. Equipment sizes and capacities have grown accordingly. Blast Furnace volumes have become larger and currently, the country’s largest furnaces have inner volumes of over 4,000 m³ while a 4,506 m³ is being built for NMDC at their green field integrated plant in Nagarnar, Chhattisgarh. Some steel producers are contemplating the virtues of building even bigger furnaces, which would follow a trend that has been prominent in countries such as Japan and Korea, where furnaces of 5000–6000 m³ inner volume are operated successfully.

In the global steel industry, it is a widely accepted fact that blast furnace productivity (rated as e.g., tonnes of hot metal per cubic meter of working volume per 24 hours) decreases with increasing furnace size. In general, this mechanism of diminishing returns is not prohibitive for investment in larger furnaces. This article presents considerations other than size-related productivity that may impose limits on furnace sizing. Factors that are considered are raw material granulometry, its chemical composition and raw material development practices at steel producers’ sites.

Keyword: Blast Furnace, Productivity, Profile, Inner Volume, Working Volume

Introduction
In the steel industry, it is a widely accepted fact that blast furnace productivity (rated as e.g. tonnes of hot metal per cubic meter of working volume per 24 hours) decreases with increasing furnace size. The main reason for this effect is that the blast furnace process primarily takes place within the outer 3 meters of the blast furnace interior, i.e. a 3 meter periphery against the blast furnace wall. The larger the furnace diameter, the larger the “inactive” (or relatively less active) area in the center of the furnace.

Figure - 1 illustrates a related phenomenon. While with an increasing furnace diameter, the raceway may penetrate somewhat deeper into the furnace depending on the hot blast
parameters, it does not do so proportionally to the furnace diameter. Since the reduction processes are largely gas–based, this phenomenon demonstrates how a larger portion of the furnace content will be metallurgically activated in the case of a smaller furnace.

Figure - 1: Penetration of raceway in medium sized and larger furnaces

Figure - 2 shows which percentage of the burden is located within this outer 3 meters of the furnace against the vessel diameter at a chosen elevation of the furnace.

Figure - 2: Portion of burden within 3 m of furnace wall

The diminishing returns of larger furnace sizes are best evaluated by comparing different sizes of furnace operated within a single site, since this rules out influences of different operational practices applied from site to site. As a rule of thumb, productivity may drop by up to 5% when comparing medium size furnaces with small furnaces and large furnaces with medium size furnaces respectively. This is illustrated in Figure - 3, which plots furnace productivity and working volume for a handful of multiple blast furnace sites. Some sites may show a productivity drop of over 10% in such comparison, but the root causes for such more dramatic differences are usually in differing process conditions (such as different feeds of raw materials or distribution of available coals for tuyere injection). Very few sites may demonstrate higher productivity for a larger furnace, but this can usually be attributed to the larger furnace
being the more modern furnace at the site. Whatevsoever may be the productivity drop, evaluation and assessment of investment projects can take it into account while matching projected demand, available raw materials and equipment size.

Figure - 3: Examples of furnace productivities for multiple blast furnace sites around the world

Through its nature, the process affects this in terms of balance between production and size. When raw materials join the equation, however, another aspect becomes relevant: after assessment of the available raw material qualities, it may be found that furnace dimensioning is not simply affected, but even the raw materials impose limits.

Since in blast furnace ironmaking, the ascending gas drives the reduction and melting, gas distribution within the furnace is essential. Given the differences in permeability between the layers of coke and ferrous burden, the layer structure within the furnace dictates gas flow. A stable, high performance process requires parallel burden layers with equal permeability and pre-determined thickness over the diameter of the furnace. The larger the furnace, the more difficult it is to realize and maintain such a layer structure and hence such a gas flow distribution. The following paragraphs describe how the furnace profile and raw materials relate to this effect.
Furnace Profile

In blast furnace design, there are several reasons for preferring a profile with a limited belly to throat ratio over a profile with a “fatter” belly.

Firstly, a larger belly to throat ratio will result in relatively thinner coke slits, which are undesirable for process performance since this further complicates creating and maintaining the desired layer structure while at the same time limiting coal injection levels since eliminating more coke would drive permeability towards or beyond reasonable limits and pushes the furnace towards its flooding limits.

The second reason is related to the fines that are charged in the blast furnace. The preferred charging position for fines is close to the furnace wall in order to not jeopardize furnace permeability. Since fines tend to travel down the furnace vertically rather than distribute over the descending and widening burden layers, a larger belly to throat ratio will result in a larger portion of fines that were intended to remain close to the furnace wall ending up closer to the heart of the furnace. This makes gas flow (velocity and distribution of upward gases) more difficult to control.

Figure - 4 : Schematic presentation of ideal layer structure and gas distribution inside the blast furnace
These phenomena make it desirable, from the process perspective, to design the furnace with a somewhat larger throat diameter. However, the throat diameter should also be kept limited for achieving good burden distribution control with chute-based top charging equipment.

**Raw Materials**

Larger blast furnaces have more stringent raw material quality requirements for maintaining an internal layer structure that ensures good gas distribution and process stability. Larger and higher strength raw materials are highly beneficial in this respect; granulometry affects permeability and better resistance against degradation during descent through the furnace ensures that its advantage remains throughout the burden's journey from throat to cohesive zone.

More importantly, it is important to maximize consistency of raw material qualities (both ferrous burden and coke). While lower quality raw materials are detrimental for the process, raw material quality consistency allows the operator to accommodate for available raw material...
qualities, even if these are suboptimal. Varying raw material feeds to the furnace may eliminate these possibilities for optimizing process performance and stability.

Part of the variability of the feedstock may be evened out by consistent blending of the ferrous burden materials in the stock yards/blending piles. Establishing such a practice calls for the development of well-organized raw material monitoring practices with respect to all of the relevant parameters. In India, the focus of the metallurgical staff is largely on chemical and thermal control, while focus on some other parameters is lacking when compared to international levels. Reduction disintegration properties are such an example; this is not only relevant with respect to blending practices.

In general, the steel industry in India is confronted with somewhat lower quality raw materials. This is obviously a problem for those producers, who wish to establish high productivity operations. In addition, it imposes limits with respect to furnace size through the mechanisms related to internal layer structure and gas distribution described above. More specifically, with respect to raw material quality:

- Ferrous ores are generally high in Al2O3, as is illustrated in Figure 6 below, which compares this parameter for two plants in India against that for a plant in Brazil. In many plants, maximum levels of e.g., 1.2 % or 1.7 % are accepted; the data from India clearly shows considerably higher levels.

  This complicates slag drainage given the higher slag volumes as well as the slag chemistry and liquidus temperatures. In addition, higher Al2O3 ore fines produce lower strength sinter. This causes substantial degradation in the furnace shaft, introducing growing amounts of fines that hamper gas distribution into the process.

- Raw materials typically have a somewhat higher alkali content. Alkali may increase coke reactivity, which in turn promotes direct reduction. This is undesirable for any furnace size, as is the 5 - 10 kg/thm coke penalty associated with a higher alkali input. A consequence that is a particular risk for larger furnace is the fact that alkali promote degradation of both ferrous burden and coke, which reduces permeability. Also, alkali tend to accumulate against the furnace wall in the form of accretion or even scaffolds. This negatively affects burden descent and may lead to hanging and slipping. This hanging and slipping behaviour disrupts the internal layer structure, blocking gas distribution in
some locations while creating gas jets in others.

**Figure - 6 : Al₂O₃ percentage in sinter for two plants in India (left, monthly data) compared to that for a plant in Brazil (right, daily data)**

Not only are the typical raw material qualities used in the steel industry in India somewhat lower than in most other regions, variability of qualities is also higher. This is largely caused by the two following issues:

- Natural variations of the available ferrous burden components (such as sinter fines) are relatively large. With sophisticated raw material development and blending practices this can be evened out to some extent but there are of course limits. The effects of the natural variations in raw material quality parameters are aggravated during monsoon.
- Blast furnaces, especially larger ones, are operated on substantial portions of lump ore in the ferrous burden. Lump ore is far less consistent in nature than beneficiated burden components such as sinter or pellets.

**Conclusion**

Whereas in situations or areas where good and sufficiently consistent quality raw materials are easily sourced, furnace size only matters to the extent that for larger furnaces, a slight productivity drop will have to be accommodated for in investment planning, while additional training for production staff as well as more substantial operational assistance during the establishing of stable operations will have to be accepted. We have covered how in India, with its higher ash coke and higher alumina/alkali ferrous burden components, ultra large blast furnaces may be less attractive given the risks associated with difficulties in establishing and maintaining the desired internal layer structure and gas flow distribution.

In that respect, it needs to be noted that the furnaces with working volumes up to around
3500 m³ currently operating in India are performing quite well when taking into consideration the available raw material qualities and associated slag volumes. Additional benefits can be expected from larger furnaces such as the one that NMDC is currently building at their Nagarnar greenfield plant. Furnaces up to around 3800 m³ working volume or slightly larger are suitable for Indian raw materials when operated by well-trained staff but the authors argue against any substantially larger volumes.

Finally, it needs to be emphasized that especially with the lower and more inconsistent quality raw materials, furnace lining stability is essential given its interdependence with stable burden descent and hence influence on the integrity of the burden layer structure and gas flow distribution. The integrated blast furnace cooling and lining technology based on copper plate coolers and high-conductivity graphite refractories has demonstrated to be the only design capable of long and stable operations without imposing limits on operators or being restricted with respect to the applied raw materials.

Figure - 7: IJmuiden blast furnace bosh after 15 years of high productivity operations (bosh has continued its campaign, which is currently in its campaign, which is currently in its 25th year)
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