Key design issues associated with large blast furnaces

The last 50 years have seen significant increases in blast furnace size, process control and productivity. An assessment of the capability of designers to produce furnaces even larger than today`s maximum of 15.6m hearth diameter indicates that this is entirely feasible. Each aspect of furnace and ancillary equipment is discussed. The factors that will probably prevent such a furnace being built are the increased complexity of operation and associated impact on the rest of the steelworks.

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Siemens VAI has expanded over a number of years to become the leading supplier of blast furnace technology in the world. Previous names for the organisation have included Ashmore Benson and Pease, Davy, Davy McKee, Davy International, Trafalgar House and Kvaerner. In 1928, a department was formed whose sole purpose was for the design and contracting for blast furnace plant. Determined to maintain a lead and to offer clients the best available technology and equipment, Siemens VAI`s predecessors formed its first collaborations with the world's leading blast furnace operators and designers at that time.

The company's first blast furnace contract came in 1929 for the Josephine furnace for Ford at Dagenham in the UK. For its time, this furnace reached new standards in mechanisation and automatic control and also held all records for output and coke consumption until much larger furnaces were built over a decade later.

Since then, Siemens VAI has completed over 170 new blast furnaces and has rebuilt many more. The technology, equipment and innovative design features produce iron in an efficient and cost effective manner with minimum environmental impact. This is achieved by extending campaign life, maintaining quality of product, creating good working conditions, minimising maintenance, conserving energy and resources and by safeguarding the local environment.

Siemens VAI's engineering strengths and process knowledge are underpinned by practical experience in the field, by the acquisition of advanced, proven technology, by licensing arrangements with leading iron and steel makers, and by a long tradition of continuous improvement through research and development. The company has accumulated considerable knowledge relating to the design of blast furnaces over the many years that the company has been in existence. This knowledge has been applied to the design of progressively larger blast furnaces over the life of the company (see table 1).

It is clearly accepted that the operation of a larger blast furnace unit is more complex than that of smaller units - larger blast furnaces are less forgiving to changes

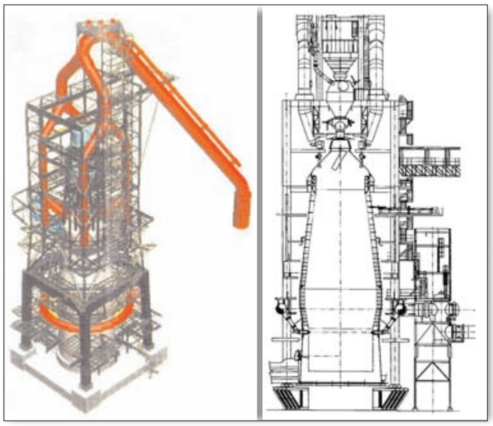

Fig.1 Furnace design

Blast furnace	Inner volume m^3	Hearth dia, m	Period	Productivity tpd/m^3 IV	Productivity tpd/m^3 HSA	Utilisation %
SMI Kashima BF 3	5050	15	2003	1.9	54.3	98.3
JFE Chiba BF 6	5153	15	2003	1.8	52.5	97.5
Thyssen Schwelgern BF 2	5513	14.9	2005	2.1	66.4	95.3
NSC Kimitsu BF 4	5555	15.2	2003	1.9	58.2	97.0
Severstal Cherepovets BF 5	5500	15.5	2002	2.0	59.1	98.0
NSC Oita BF 2	5775	15.6	2003 Campaign No.2	2.26	68.0	97.1

Table 1 **Key data for the worlds largest blast furnaces**

in their environment. However, the impact of blast furnace size on the engineering is not so clear. In addition to the physical aspects of the design (bigger, heavier etc), there are other points to be considered.

This paper describes the requirements for larger blast furnace design by considering the impact of the increase in hearth diameter on all of the ancillary equipment - cooling system, hot blast stoves, gas cleaning and casthouse. Large blast furnaces usually operate at higher pressures, require more precise burden distribution, and need constant monitoring but, because of this, they benefit from high quality automation and control systems.

BLAST FURNACE DESIGN

The furnace shell must withstand high operating and refractory pressures, thermal stresses, burden loads and have numerous cut-outs for internal cooling water systems. The use of finite element techniques, along with the most sophisticated design practices, ensure that a fully optimised 'thin' shell can be utilised to withstand cracking, even in the latter parts of the furnace campaign. Furthermore, the redesign of the furnace support structure has led to a substantially lighter but equally effective design. Furnace support structure design has evolved to the modern concept of the so-called free-standing tower design *(see Fig. 1)*. This arrangement has been proven on many blast furnace installations around the world, the only accepted complication being the introduction of the extra restraint associated with the design standards related to the location of the site, specifically for seismic conditions.

The key point to note regarding the design of the blast furnace as the size increases is that plate thicknesses need to be carefully considered to ensure that the structural integrity is maintained, including an allowance for rebuild conditions. The tower design needs to take into account any additional stresses associated with the support of the larger furnace.

As noted above, it is expected that a large blast furnace will operate at a higher level of top pressure than a smaller one. The currently accepted levels of maximum top pressure of around 3 bar g can be accommodated through the application of appropriate design standards to the shell arrangement.

In summary there are no specific design issues relating to the furnace itself as the size increases.

Fig.2a Casthouse design

CASTHOUSE OPERATIONS

The casthouse is an area where considerable effort has been applied to improve the working conditions for the operator *(see Fig. 2)*. Modern casthouse design includes flat floors, where the runner covers are fully covered and are fitted flush with the floor. This allows the safer and easier use of mobile vehicles in the casthouse area. The use of radio controlled equipment and other devices have helped to reform casthouse work, and these, along with effective emission control systems, have improved working conditions beyond recognition.

As the blast furnace hearth diameter increases there is a consequential need to increase the size of the casthouse. Large blast furnaces should be designed with four tapholes with consideration to the provision of a fifth. With a four taphole configuration, the casthouse arrangement needs to provide sufficient space for movement around the floor itself. There are no design issues associated with this requirement as long as there is the necessary space provided in the site plan. Increasing the size of the casthouse in terms of floor

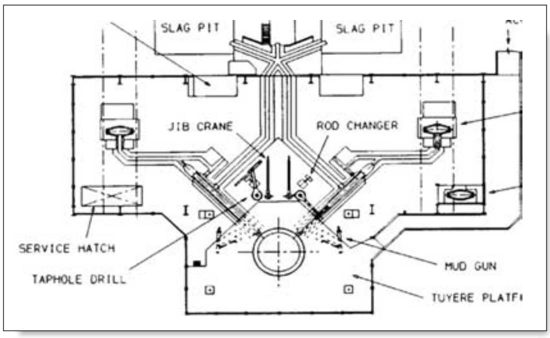

Fig.2b Casthouse design. Two tapholes

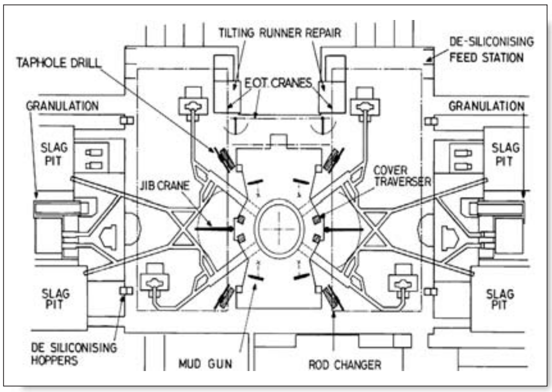

Fig.2c Casthouse design. Four tapholes

plan does not represent a radical change in design philosophy that will challenge the furnace designer.

FURNACE COOLING SYSTEMS

The traditional method of cooling the furnace shell with cooling plates has now been largely superseded by the use of staves. These allow the furnace profile to be maintained throughout the campaign and reduce the overall amount of refractory in the furnace shaft. Also, for the same internal furnace dimensions, the shell diameter is smaller for stave cooled furnaces. Furthermore, with plate coolers, as the refractory wears, the incidence of plate cooler loss increases and hence water leakage into the furnace increases.

In the high heat flux areas around the bosh, belly and lower stack, copper staves are used which provide a greater level of shell protection in these critical areas. Other less critical areas are cooled by cast iron staves. Water systems are now designed to operate in closed loops rather than open circuits. This allows the chemistry of the cooling water to be monitored and so the inside of the cooling water mains can be kept clean, ensuring that the heat transfer can be kept at a maximum at all times.

As the furnace size increases the size of the water cooling system also increases proportionally, with the number of staves around the shell being proportional to diameter *(see Fig. 3)*. The water cooling system demand in terms of circulation flow rate is a function of the number of staves and the stave water demand per pipe in the stave. Water flow rates per circuit of the order of 3000 to 5000 m^3/h can be achieved on modern blast furnaces. Should there be a need to increase this amount of water then larger pumps may be required, however, there is no suggestion that the water flow rate per pump is at a limiting level with regard to design. Even if this was the case, by splitting the water system into more than one circuit or by splitting the duty for each circuit over more than one pump, the problem could be solved.

From a technical point of view, it is considered that for a large blast furnace, the demand to monitor performance and operation will require that the water system is split into multiple circuits and that the instrumentation applied to these circuits will permit adequate heat flux monitoring.

A blast furnace cooling system is not simply a number of pumps and pieces of pipework. Key to the furnace cooling is the actual element that facilitates the heat exchange within the furnace i.e. the stave or plate. The cooling element design is not sensitive to the size of the furnace. The furnace designer acknowledges that the cooling element size is limited and simply increases the number of elements to adapt to the revised furnace sizing.

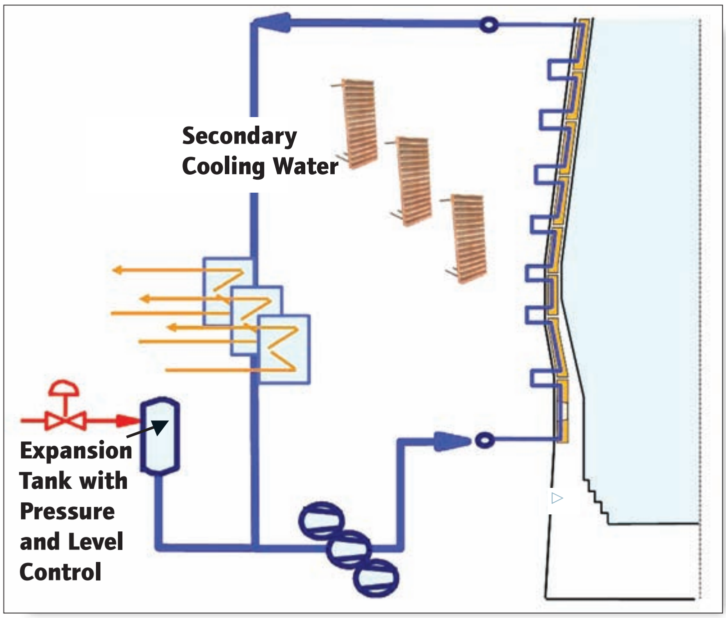

Fig.3 **Cooling circuit design**

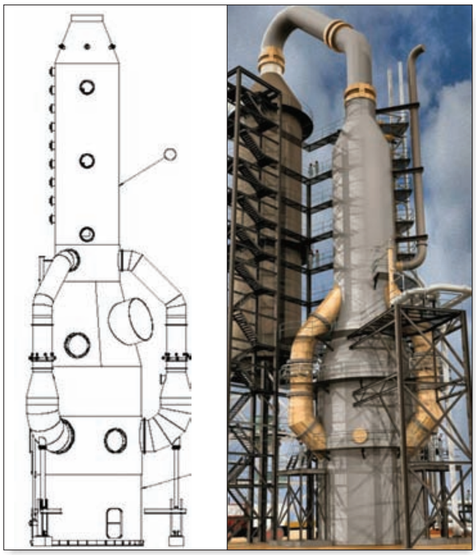

Fig.4 **Gas cleaning plant design**

GAS CLEANING

The removal of dust from the blast furnace off-gas is a very important operation as the gas can then be used as a fuel for the stoves and elsewhere on the plant. The solution that Siemens VAI employs is a cyclone followed by a two-stage wet scrubber (Davy Cone type, *see Fig. 4)*. The use of a cyclone increases the efficiency of dust separation at this first cleaning point thereby reducing the load at the scrubber and effluent treatment plant when compared to the traditional dust catcher approach. The next step is the Siemens VAI Davy Cone Annular Gap Scrubber. Here the blast furnace gas is cooled and saturated by a number of water sprays in the conditioning tower part of the plant. At this point, 70% of the dust in the gas from the dust catcher is removed. The gas is then passed through a movable cone assembly which allows the top pressure of the furnace ▷

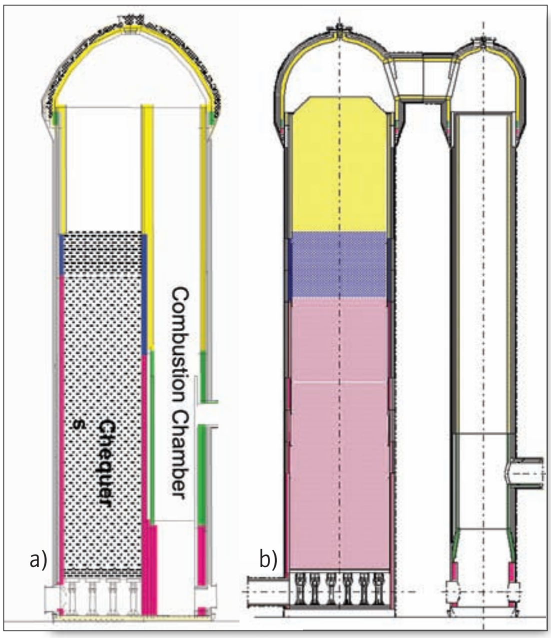

Fig.5 **Hot blast stove design**

to be controlled accurately and consistently, thus aiding good furnace operation.

After the Davy Cone, the saturated off-gas is subjected to a further major direction change and is then passed through a demister to remove the free water and therefore the dust contained within the water, and is then ready for use as a fuel. In total, more than 99.9% of the dust contained in the furnace off-gas is removed using this process.

As the furnace size increases so does the volume of gas flowing and, to a certain extent, the pressure at the top of the furnace. As a result, for increasing furnace size, the key duty of the gas cleaning plant becomes more onerous in terms of the forces acting on the cleaning elements i.e. the Davy Cone. The forces acting on the Davy Cone increase as the volume flow increases and the pressure drop increases. It is therefore realised and accepted that as the gas volume increases there is an apparent need to use more than one Davy Cone unit.

Siemens VAI accept this requirement and have specifically created a development of the proven single cone unit as shown in *figure 4*. The key point to note regarding this design is that the design integrity of the single cone is maintained in the multiple unit. There could be much debate as to what number of additional cone units are required. If one unit is sufficient for a medium sized blast furnace then surely only two are required for a large furnace? However, it is considered that a three cone unit is the most logical solution as there is inherent redundancy in this arrangement that will allow continued secure operation should one of the elements fail.

HOT BLAST STOVES

The modern Siemens VAI internal combustion chamber stove is a proven high temperature unit, which has been developed from the older, more traditional design *(See Figure 5a)*. The high temperature internal combustion chamber stove provides an economic alternative to the more complex external combustion chamber designs. Stoves of this design are suitable for operation with dome temperatures of up to 1400°C and will produce a straight line blast temperature of 1250°C.

As an alternative, the Siemens VAI external combustion chamber hot blast stove is a development of the successful Krupp Koppers design *(see Fig. 5b)*. Siemens VAI are the sole owners of this technology which allows a maximum operating dome temperature of 1550°C and blast temperatures of up to 1350°C. The external combustion chamber concept is particularly suited to ultra high temperature operation combined with large blast volumes.

Now utilised in both of our stove designs, the Siemens VAI ceramic burner is a high combustion efficiency unit with low CO, SOx and NOx emissions. This burner has been in service in external combustion chamber design stoves for over thirty years and has now been developed for use in our internal combustion chamber stoves. Another feature which can be used to help reduce costs either by increasing stove efficiency or by reducing the need for expensive enrichment fuels is the use of waste heat recovery. Siemens VAI has installed these units on new and existing stoves.

As the blast furnace size increases so does the blast volume. Stove size is clearly dependent upon the hot blast volume required for the blast furnace. In order to maintain acceptable levels of flue gas velocity, combustion density and the ratio of stove height to diameter, stove size must increase as the furnace size increases. It has been noted in the above comments that there are two options available for stove design - internal and external arrangement. There is a practical limit to the size of an internal combustion chamber stove that can comfortably engineered. It is the opinion of the authors that a maximum internal combustion stove size of 10m diameter can be achieved. Beyond this, the size of the dome becomes excessive and maintaining dome integrity is, therefore, somewhat suspect. As a result, the use of an external combustion chamber stove is recommended for large blast furnaces.

Consideration must also be given to the number of stoves themselves. With the use of modern stove valve systems, particularly those utilising hydraulic actuators, high levels of availability can be achieved. Therefore, it is recommended that a three stove system will be adequate even for large blast furnaces. The decision to utilise a fourth stove would then depend upon the desire to achieve parallel blast/gas patterns and the further redundancy that this would represent. Notwithstanding the decision to only use three stoves, provision would always be made for a fourth stove in the site plan.

REFRACTORIES

Blast furnace refractories, and specifically the hearth refractories, are the most critical element in a successful long campaign life. Carbon hearths, with water under-cooling and with or without a ceramic cup, remain the main solution for this area of the furnace. The philosophy is to maintain the iron freeze line in a reasonable position within the refractory. This is where a solid layer of iron forms and therefore protects the refractory from wear damage. As the hearth size increases then it is simply considered that the number of hearth bricks will need to be increased. There should be no limitation applied to the hearth size by the refractory design.

SLAG HANDLING AND TREATMENT

For modern blast furnaces, the solution for slag treatment is to use granulation plants which utilise high water flow rates (typically $8m^3/t$ slag) to produce cement grade granulate by the super-fast quenching of slag with water at a high velocity within an enclosed granulation box. The steam emissions produced by this process are then recycled by use of a condensation tower. This ensures that the emissions from the plant are kept to a minimum.

Granulation systems are rated to handle a slag flow rate from the blast furnace which can be considered to be a number of tonnes of slag per minute. This number is of far greater use than the slag make per day, be that expressed in tonnes per day or tonnes slag per tonne of iron. This so-called instantaneous slag rate gives a better expression of the requirement to process slag. Modern blast furnaces can reach levels of up to 6 t/min of slag with peak levels of around 10 t/min. With progressively larger blast furnaces this peak level of slag may increase further, particularly as forms of overlap casting are practiced.

The RASA slag granulation system is particularly suited to this duty since the primary dewatering element i.e. the screw conveyor is readily able to handle slag flows in excess of 10 tonnes per minute thus, the granulation system design will not restrict the decision to increase the size of the blast furnace.

TUYERE INJECTION SYSTEMS

Whilst oil and gas injection through the tuyeres has been an available technology for a number of years, it is coal injection that is currently being preferred as a means to reduce the amount of coke consumed by the furnace and, therefore, raw material and processing costs. Initially, coal injection rates of 50kg/thm were used, however today, rates of up to 250kg/thm are considered world's best operation.

The debate at this time is not with regard to what level of coal to inject but as to what capacity of equipment that can be installed. With increasing furnace size comes greater iron production and therefore for the same coal injection rate (kg/thm) then greater grinding and injecting capacity is required of the system. The increased demand for injection can be achieved through the use of progressively larger grinding mills and injection vessels with the logical proviso that should the size reach some form of maximum then parallel streams would be required.

SUMMARY - FURNACE DESIGN IMPLICATIONS

The above sections can then be summarised with the implications of the increasing furnace size effectively being split into three categories:-

1) Furnace size increases mean that the vessel, structure etc., become bigger but we are simply handling more pieces to make the bigger article. The furnace shell can be made bigger through the use of more shell pieces; the furnace hearth can be made bigger using more bricks even if they are of the same size. With regard to fundamental design issues, the number of tuyeres and the number of staves around the furnace are simply increased to accommodate the increased capacity. This comment applies to the process equipment that is under the direct control of the furnace designer. This does not represent a problem.

2) A second category can be envisaged where the furnace size increase requires that larger pieces of proprietary equipment of a standard nature are required to be used to accommodate the overall size increase. Examples of this category are water pumps and grinding mills. This does not represent a problem and should current limitations be reached then such problems could be resolved through the use of parallel streams.

3) The third and last category applies to proprietary equipment of a non-standard nature that is affected by the increase in furnace size. Perhaps the best example of this instance is the hot blast valve. This is a piece of equipment specific to the blast furnace application for which a new solution would be needed for the ▷

progressively larger furnace application. For this review, these are again not considered to be a problem since it is believed that the limitations of design have not been reached. However, it should be noted that any ability to copy an existing design could not be achieved - there is a cost implication to this decision.

The overall conclusion then is that progressively larger blast furnaces can be engineered by design organisations.

PROCESS AUTOMATION AND CONTROL

The blast furnace is a complex chemical reactor which operates in a continuous batch-type operation. It is therefore necessary to provide the means for understanding its thermodynamics along with chemical and physical processes. The process can only be analysed through investment in instruments and sensors along with computational mathematical models *(see Fig. 6)*.

Modern furnaces are equipped with a wide range of probes, sensors and other monitoring equipment which are used to gather information on burden profiles, refractory condition, cooling systems and many other areas.

A new automation package, VAiron, for the operation of blast furnaces has been developed by Siemens VAI and is based on advanced process models, artificial intelligence, a closed loop expert system and enhanced software applications *(see Fig. 7)*. It also features integrated operational and statistical data. VAiron allows operators to 'look' inside the furnace from a metallurgical point of view during operation. Corrective actions are continuously determined and are executed in a closed loop cycle. This allows stable furnace operation, lower production costs and constant hot metal quality to be achieved. This would be an essential part of a large blast furnace arrangement.

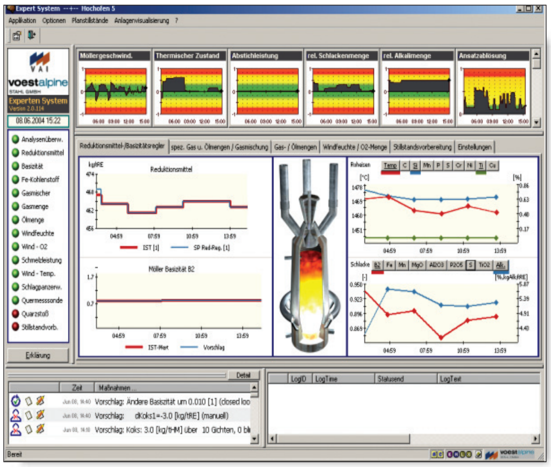

Fig.7 **VAIron expert system**

BF OPERATION

Whilst the above analysis has considered the ability of the engineering organisation to supply progressively larger blast furnaces, it is also essential to consider the implications for operation of such a large device. From operating data that is available for the current fleet of larger blast furnaces in the world, i.e. those with hearth

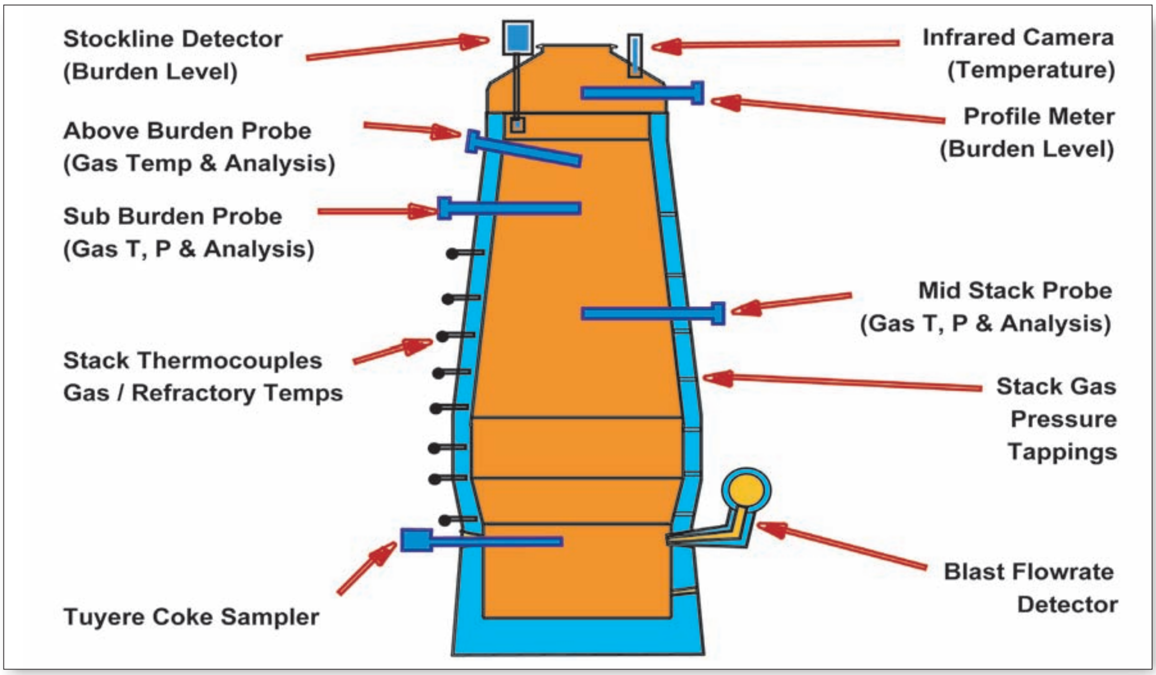

Fig.6 **Furnace monitoring and control**

Blast furnace	Small	Medium	Large
Hearth diameter, m	8.5	12	15.5
Inner volume, m^3	1550	3300	5700
No. tuyeres	24	32	42
Production, tpd	3358	7150	12350
Blast volume, Nm^3/min	2565	5500	9434
Injection rate, kg/THM	150	150	150
Injection rate per tuyere, tph	0.9	1.4	1.8

Table 2 Furnace operating data comparison for increasing size

diameters in excess of 15m, it is clear that high levels of productivity are not regularly achieved.

Table 2 summarises data for nominal small, medium and large blast furnaces. The sizes taken for the three furnaces are arbitrary in terms of hearth diameter, but for these three sizes, further key parameters have been defined using the standard empirical rules. It is important to note that the same rules have been applied to each furnace size. This simple analysis illustrates a simple point regarding the operational characteristic of the blast furnace as size increases. Production related parameters are related to furnace volume yet the number of tuyeres is related to hearth diameter. As a result, as furnace size increases, the blast volume per tuyere and the injection rate per tuyere both increase.

A further observation relating to the concept of a large blast furnace relates to the impact of such a piece of equipment on the balance of equipment on the site. If there is downtime then iron production is reduced accordingly. At the time of a furnace outage, iron production will cease for a considerable period of time. It is therefore necessary to ask whether or not the use of a large blast furnace is justified since it presents operational and associated equipment difficulties

CONCLUSION

The purpose of this paper was to present comments on the implications of designing even larger blast furnaces than currently. The conclusion is that from an engineering organisation' s point of view, this is definitely possible. However, the difficulties in operating ever larger blast furnace, may actually mean that the dreams of the engineer may never be realised.

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