KEY DESIGN ISSUES ASSOCIATED WITH LARGE BLAST FURNACES[1]

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Abstract

The SVAI first blast furnace contract came in 1929. This was the "Josephine" furnace built for Ford of 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, SVAI has completed over 170 new blast furnaces and has rebuilt many more. 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. It is clearly accepted that the operation of a larger blast furnace unit is more complex than that of the smaller units – larger blast furnaces are less forgiving to changes 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, casthouse. Large blast furnaces usually operate at higher pressures, are more susceptible to burden distribution, need constant monitoring and as such benefit from high quality automation and control systems.

Key words: Blast Furnace; Design; Large Blast Furnace.

PRINCIPAIS QUESTÕES ASSOCIADAS AO PROJETO DE GRANDES ALTOS-FORNOS

Resumo

O primeiro contrato da SVAI para altos-fornos foi assinado em 1929. Tratava-se do forno "Josephine" construído para a Ford de Dagenham no Reino Unido. Este forno atingiu padrões de mecanização e controle automático acima daqueles vistos em sua época, e deteve todos os recordes no que diz respeito a produção e taxa de consumo de coque por mais de uma década, quando fornos muito maiores começaram a ser construídos. Desde então, a SVAI construiu mais de 170 fornos e reformou um número ainda maior. Em sua longa existência, a companhia acumulou consideráveis conhecimentos no que concerne a projeto de altos-fornos. Estes conhecimentos vêm sendo aplicados em projetos de altos-fornos cada dia maiores. Sabe-se que a complexidade da operação de altos-fornos maiores é maior do que aquela de fornos menores, uma vez que um alto-forno maior admite menos flexibilidade em seu ambiente de operação. No entanto, o impacto do tamanho do alto-forno na engenharia dos projetos não está claramente determinado. Além dos aspectos físicos do projeto – maior tamanho e peso, entre outros – há outros pontos a serem considerados. Este trabalho descreve as necessidades ligadas ao projeto de um alto-forno grande, considerando o impacto do aumento do diâmetro do cadinho sobre todo o equipamento auxiliar – sistemas de refrigeração, limpeza de gases, casa de corrida. Altos-fornos maiores geralmente operam a pressões mais altas e são mais suscetíveis à distribuição de carga, necessitam de constante monitoramento e, portanto, de sistemas de controle e monitoramento de alta qualidade.

Palavras-chave: Alto-forno; Projeto; Alto-forno Grande.

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1 INTRODUCTION

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 designing and contracting for blast furnace plant. Determined to maintain a lead and to offer clients the best available technology and equipment, SVAI's predecessors formed its first collaborations with the world's leading blast furnace operators and designers at that time. he company's first blast furnace contract came in 1929. This was the "Josephine" furnace built for Ford of 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, SVAI has completed over 170 new blast furnaces and has rebuilt many more. The technology, equipment and innovative design features provided by SVAI produce iron in an efficient and cost effective manner with minimum environmental impact. This is achieved by extending campaign life, by maintaining quality of product, by creating good working conditions, by minimising maintenance, by conserving energy and resources and by safeguarding the local environment. 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 in the world today 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 it has been in existence. This knowledge has been applied to the design of progressively larger blast furnaces over the life of the company. t is clearly accepted that the operation of a larger blast furnace unit is more complex than that of the smaller units – larger blast furnaces are less forgiving to changes 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.

2 FURNACE DESIGN INPLICATIONS

2.1 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 lead 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. This arrangement has been proven on many blast furnace installations around the world. The only accepted complication is the introduction of the extra restraint associated with the design standards associated with the location of the site, specifically 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. It can therefore be stated that there are no specific design issues relating to the furnace proper as the size increases. s noted above, it is expected that a large blast furnace will operate at a higher level of top pressure. The currently accepted levels of maximum top pressure of around 3 bar g can be accommodated through the application of design standards to the shell arrangement.

2.2 Casthouse Operations

The casthouse is an area where considerable effort has been applied to improve the working conditions for the operator. 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. 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 taphole also being considered. 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 plan does not represent a radical change in design philosophy that will challenge the furnace designer.

2.3 Furnace Cooling Systems

The traditional method of cooling the furnace shell with cooling plates has now been largely superseded by the use of staves. The use of staves allows the furnace profile to be maintained throughout the campaign and reduces the overall amount of refractory that has to be used 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. This is due to copper providing a greater level of shell protection in these critical areas. Other less critical areas in the furnace 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 therefore the inside of the cooling water mains can be kept clean. This ensures that the heat transfer can be kept at a maximum at all times.

As the furnace size increases then the size of the water cooling system also increases proportionally. The number of staves around the shell is proportional to diameter. 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 flowrates per circuit of the order of 3000 to 5000 m3/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 flowrate per pump is at a limiting level with regard 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.

2.4 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 SVAI employs is the use of a cyclone followed by a two-stage wet scrubber (SVAI Davy Cone type). The use of a cyclone increases the efficiency of dust separation at this first point thereby reducing the load at the scrubber and effluent treatment plant when compared to the traditional dustcatcher approach. The next step is the SVAI 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 dustcatcher is removed. The gas is then passed through a movable cone assembly which allows the top pressure of the furnace to be controlled accurately and consistently, thus aiding good furnace operation.

After the SVAI Davy cone, the saturated off gas is subjected to a further major direction change. The off gas is then passed through a demister to remove the free water and therefore dust contained within the water and is 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 then 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.

SVAI accept this requirement and have specifically created a development of the proven ‘single’ cone unit as can be seen in figure 1. 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. There is inherent redundancy in this arrangement that will allow continued secure operation should one of the elements fail.

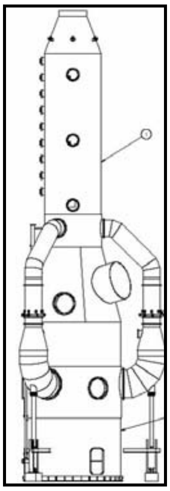

Figure 1. SVAI Gas Cleaning System.

2.5 Hot Blast Stoves

The modern SVAI internal combustion chamber stove is a proven high temperature unit, which has been developed from the older more traditional design. The high temperature internal combustion chamber stove provides an economical alternative to the more complex external combustion chamber designs. Stoves of this design are suitable for operation with dome temperatures of up to 1400^{o}C and will produce a straight line blast temperature of 1250^{o}C.

As an alternative, the SVAI external combustion chamber hot blast stove is a development of the successful Krupp Koppers design. SVAI are the sole owners of this technology. This design allows a maximum operating dome temperature of 1550^{o}C and blast temperatures of up to 1350^{o}C. The external combustion chamber concept is particularly suited to ultra high temperature operation combined with large blast volumes. Figure 2 shows a plant in Sweden where SVAI installed a 4th stove and rebuilt 2 of the other 3 existing stoves. The new stove was of the internal combustion chamber type and had the same operational duty as the existing external combustion chamber stoves. The arrangement then shows the two basic alternatives available for stove operation.

Figure 2. SVAI Stove Designs.

Now utilised in both of our stove designs, SVAI ceramic burner is a high combustion efficiency unit with low CO, SO_x and NO_x emissions. This burner has been in service in the 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. SVAI has installed these units on new and existing stoves.

As the blast furnace size increases then 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 internal combustion chamber stove that can comfortably engineered. It is the opinion of the writer that a maximum internal combustion stove size of 10 m diameter can be achieved. Beyond this level, the size of the dome of the stove becomes excessive – 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.

2.6 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.

2.7 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 $8m^3$/tonne 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 flowrate 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 tonnes per minute of slag with peak levels of around 10 tonnes per minute. With progressively larger blast furnaces then 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. As such, the granulation system design will not restrict the decision to increase the size of the blast furnace. Figure 3 shows inside the screw conveyor of RASA slag granulation system.

Figure 3. RASA Slag Granulation – Screw Conveyor

2.8 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. This is mainly to reduce the amount of coke consumed by the furnace and therefore raw material and processing costs. Initially, coal injection rates of 50 kg/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 it 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.

2.9 Summary of Design Implications

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

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 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.

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, grinding mills etc. This does not represent a problem and should current limitations be reached then such problems could be resolved through the use of parallel streams.

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. his 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.

3 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. 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 for the operation of blast furnaces has been developed by SVAI. VAiron is based on advanced process models, artificial intelligence, a closed loop expert system and enhanced software applications. It also features integrated operational / statistical data. VAiron allows operators to ‘look’ inside the furnace from a metallurgical point 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.

4 OPERATION

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

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 of either short or long term then iron production is reduced accordingly. At the time of a furnace outage, iron production will decrease 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.

5 CONCLUSION

The purpose of this paper was to preset comments on the implications of designing a large blast furnace. The conclusion being presented in the paper is that from an engineering organisation's point of view, this is definitely possible. On the other hand, the difficulties in operating such a large blast furnace, may actually mean that the dreams of the engineer may never be realised.