Webology, Volume 18, Number 5, 2021
ISSN: 1735-188X
DOI: 10.29121/WEB/V18I5/86

A Computational Study of the Blast Furnace Cooling Stave Based on the Analysis of Heat Transfer

Pravin P Patil[1], ReshamTaluja[2]

[1]Department of Mechanical Engineering,Graphic Era Deemed to be University, Dehradun, Uttarakhand India, 248002
[2]Department of Mechanical Engineering,Graphic Era Hill University, Dehradun, Uttarakhand India, 248002

ABSTRACT

The metallurgical sector is becoming increasingly concerned about reliable furnace cooling technology because it has the potential to dramatically improve process intensities, productivity, and furnace campaign times. Although using cooling systems has many benefits, it also comes with a number of drawbacks, most notably issues with safety, heat loss, and the long-term viability of the business. Therefore, choosing a cooling system involves making trade-offs and is unique for each metallurgical application.

Based on heat transfer research, this paper provides a comprehensive investigation and assessment of blast furnace cooling stave lining materials utilised in the metallurgical sectors. In addition, a model is described in the study that will be created using Pro-E modelling software. The model will also be used to analyse the behaviour of lining materials under various loads using ANSYS, a programme that uses the finite element method.

The blast furnace cooling stave will be lined with silicon carbide and high alumina bricks in this study. Additionally, two different types of skulls are taken into consideration, with the first having negligible thickness and the other having a certain thickness (thickness in mm is taken into consideration). With these two skulls, heat transfer analysis will be performed at various temperatures (loads) ranging from 773 K to 1573 K.

Keywords: .

INTRODUCTION

Virtual The blast furnace is essentially a vertical shaft with a hearth that is approximately 8.5 metres in diameter and a height that ranges from 24 to 33 metres. The most popular method for producing iron is this one. More than 1400 cubic metres of space are taken up in total. At the top of the blast furnace are charging mechanisms, and at the bottom are running-off mechanisms for the pig iron and slag. The furnace's bottom is where air is forced in, which speeds up combustion and maintains the required higher temperature. Due to rising global steel market competition and the availability of less expensive steel substitutes, blast furnace performance has grown significantly over the last 15 years. Daily production and productivity must be high, and downtime must be kept to a minimum. The cost of operation and upkeep must be as little as feasible without affecting the lifespan of the furnace, whose lifespan is now up to 15 years. As a result, even while the total output of all operating furnaces is declining annually, there are fewer blast furnaces in operation globally. Despite the fact that growing output throughout the globe puts the furnace under more stress, its lifespan must be extended to assure a better return on investment.

Factors affecting the longevity of blast furnaces

Since numerous metallurgical trends place more demands on the smelting vessels, furnace cooling technology is becoming more and more significant for the metallurgical sector. The progression toward greater process intensities is the first tendency. Higher production rates may be reached and smaller smelting vessels with lower capital and operational costs may be employed. This involves both an increase in process temperatures to enhance reaction thermodynamics and an increase in bath agitation to improve reaction kinetics. The development of more complicated and corrosive metallurgical phases, which is primarily motivated by the need for new and more effective procedures to create and recycle materials, is a second trend in the metallurgical sector.

Faster furnace deterioration is often a consequence of trends towards greater process intensities and more complicated metallurgical processes. Chemical, thermal, and mechanical stresses are the typical factors responsible for the deterioration of conventional furnace walls. These may function as independent stressors on the furnace liner, but most often they work in tandem. Slag corrosion, metallic/slag infiltration, metal oxide/carbon bursting, redox reactions, sulphate assault, and hydration are the most significant chemo-thermal wear processes of conventional furnace linings. The low viscosity of the acidic fayalitic slag used in the copper industry allows it to seep into the bricks' porous pores. The wettability of the refractory oxides, the surface tension and temperature of the infiltrate, the temperature gradient of the brickwork, and the size and distribution of the pores all have a role in determining the depth of the infiltration. As a consequence, the brick's microstructure degenerates (softens) as a result of chemical damage[1, 2].

The blast furnace's lining and cooling system is put under significant stress as a result of increased production. When the blast furnace's refractory lining and cooling system reach the end of their useful lives and must be relined, the furnace is typically retired. Consequently, it is crucial to reduce the lining/cooling system's rate of wear.

Three factors, each of which may be adjusted once each cycle, affect the liner cooling system's wear rate.

phase distinct from the deigning stage forward. The first is the calibre of the design of the lining and cooling system, which can only be modified before the actual relining begins. The second issue is that it is only possible to improve the lining/cooling system installation quality during the reline process. The third variable is blast furnace operation, which may be modified throughout the campaign life that begins with starting after the reline.

The quality of the lining/cooling system design and operation of the blast furnace is the most critical of these factors, whereas installation quality is the least important (Tijhuis et al., 2013). Particularly crucial to ensuring successful and lengthy furnace campaigns is the functioning of the blast furnace.

The quality of raw materials and the even distribution of the load within the furnace have both seen great improvements in recent years. In today's world, a furnace will be run in a manner that ensures the most consistent results possible. Considerations including load quality, load distribution, tapping without interruption, and shutdown frequency are all part of this category. Anything that might be called a "deviation from regular functioning" will happen. To begin, even in steady or typical operation, there are always some little variations in the pressure drop and heat flux to the wall. The furnace must be built to withstand this, of course [3].

However, while designing the cooling/lining system, it is more crucial to take in mind the possibility of abnormal operating circumstances or significant deviations. The design of the lining/cooling system may be drastically affected by factors such as the quality of the coke used, distribution issues, the makeup of the load, the length of the furnace stop, and the frequency of the pauses. Particularly, these alterations boost heat flux level and temperature swings in bosh and lower stack, which in turn increases lining wear.

As an example, it is clear that frequent shutdowns are not helpful for protecting the refractory materials and ensuring a long campaign life. In their study, Wilms et al.[4] demonstrate that fewer shutdowns and more continuous operation of the blast furnace are necessary for a long lifespan.

Therefore, a blast furnace's longevity and performance are not dictated by its typical mode of operation, but rather by the harsh working circumstances under which it is often put to work. Blast furnace liner and cooling systems must be robust enough to withstand the most extreme variations that might occur throughout a campaign. Each blast furnace has its own unique set of requirements for the design of the refractory liner and cooling system.

Blast furnace cooling stoker creation

Water cooling the blast furnace walls is the most effective method for keeping them in good condition, regardless of the employment of so-called refractory materials. Famous blast furnace worker Fritz W. Lurman[5] said this just before the turn of the century.

The cooling system's primary goal is to keep the furnace shell from melting. The cooling system must be efficient enough to absorb the surplus heat produced by the furnace and sent to the shell in order to achieve this. If the cooling system is inefficient, the heat will raise the temperature of the shell and liner to unsafe levels.

This invention pertains to the use of stave coolers in blast furnaces and, more generally, to the cooling of metallurgical units whose walls are exposed to thermal fluxes of increased temperature. Controlling heat fluxes and their transmission is crucial in modern blast furnaces because to their growing use at high velocities and pressures, especially in the bosh, body, and lower, middle, and upper shaft zones. For self-supporting units in particular, it is crucial that the shell not be impacted by the temperature level or exposed to the swings in temperature that might reduce the shell's resistance to the forces to which it is subjected. In order to collect the heat flux emitted in the blast furnace's various zones, a heterogeneous system is used, which consists of a lining, a cooling element, that is, the stave cooler, and a shell. The cooling element serves the dual purpose of efficiently cooling the lining and screening the passage of the flux towards the shell.

The hot side of this kind of cooling stave, which ranges in thickness from 70 to 140 millimetres, is smooth, making it ideal for use in environments with high temperatures. Its primary use is as the inner lining of the BF hearth's cooling system in the tuyere and lower section. Regular Inlaid Brick Style Spacing-lined refractory brick forms the hot face of cooling staves, which are often installed in the bosh, belly, and middle/lower levels of a stack. Bricks such as high alumina brick, silicon carbide brick, and others are used for the inlaying.

Staves of this kind are often employed in the bosh, belly, middle, and lower levels of a stack, and have a hot face that is spaced lined dove tail with crushing refractory materials within. Clay bricks made of alumina carbon or silicon carbide are used for ramming.

Type of Brick Inlaid Completely Enclosed CoolingStave:-

Cooling staves are distinguished by the fact that the hot face (working face) is entirely covered with bricks with thin or no lining structure, which increases the furnace's capacity. Bosh, belly, and the middle to bottom section of stack are typical locations for its utilisation. As a cooling mechanism, the staves are placed against the shell's interior face, midway between the shell and the refractory covering. Cast iron, steel, and copper parts are used to make the staves, and inside them is a network of tubes carrying a cooling fluid—typically water—that boils when it comes into touch with the heat flux that must be absorbed by the stave cooler.

This study intends to do just that, reviewing key elements of the procedure. The primary objective of this research is to use ANSYS, a finite element technique programme, to conduct a heat transfer analysis of the behaviour of lining materials under varying loads.

Different types of bricks, including silicon carbide brick and high alumina brick, will be used as the lining material for the blast furnace cooling stave. Additionally, two types of skull are considered: one with a very thin wall and the other with a thicker wall (thickness measured in millimetres).

Review of the Work Related to Section

This part of the study offers a concise overview of the materials used for blast furnace cooling stave lining, based on heat transfer studies. Many researchers have identified issues with blast furnace components including the hearth, bosh, tuyere, and so on, and have offered numerous solutions. The erosion of the blast furnace walls, particularly around the bosh, hearth, etc., has not received a great deal of attention up to this point. Many different materials, including cast iron, steel, copper, and many different types of refractory linings, are utilised for blast furnace cooling staves, therefore there is a huge amount of room for further research in this area. Therefore, it is crucial to do thorough research and analysis based on how each lining material responds to a variety of loads and temperatures. In other words, the durability of the blast furnace's walls has a direct bearing on the blast furnace's longevity. A number of variables, including the thickness of the linings, the velocity of the linings, the inter distances of the cooling channel, the radius of the cooling pipes, the thickness of the inlaid bricks, and many more, have been calculated in order to optimise the cooling stave. Previous research has been conducted on individual refractory lining materials, such as silicon carbide, high alumina, graphite, and so on.

The pyrometallurgical sector is becoming more interested in a dependable furnace cooling system, as outlined in a 2006 paper by Karel Verscheure et al [6]. This technology has the potential to greatly boost process intensities, productivity, and furnace campaign periods. Their research summarises several cooling configurations utilised in the ferrous, non-ferrous, and alloying sectors. Their research also included a comprehensive analysis of the many factors involved in the use of water-cooled refractories, including but not limited to material choice, production, installation, water quality, and furnace monitoring.

Using a variety of cooling pipe designs, Wu Lijun et al. [7] devised (and executed) a three-dimensional model for heat transfer calculations in a blast furnace cooling stem in 2006. Pipes were first round, then elliptical, and finally oblate. All the necessary research and analysis have been performed based on these geometrical details. Stave temperature and thermal stress on various tube types were calculated using the finite element technique software ANSYS. The maximum temperature and thermal stress of the hot face are concluded to not be high when an elliptical tube is used in lieu of a cooling pipe. This is because the maximum temperature and thermal stress of the hot face drop with increasing (a/b) value. With respect to the oblate tube, the hot face temperature fell when the value of (a/b) was raised, leading the authors to conclude that the oblate tube cannot be regarded an ideal cooling channel because its maximum temperature is unstable.

According to research published by Qian et al. [8] in 2007, cast steel blast furnace (BF) cooling staves are extensively employed in the Chinese steel industry. The authors constructed a mathematical model of a BF cast steel cooling stave's heat transmission that was validated by thermal state measurements. They used the model to calculate the steady-state temperature distribution inside a cooling stave, and they discussed the impact of two factors—the thickness of the scale on the cooling water pipes and the gas clearance between the pipes and main body—that are difficult to measure experimentally but can be determined mathematically. They concluded that these two criteria have a significant impact on cooling stave capabilities and, by extension, BF operation, and that more attention to these aspects should be paid during cooling stave production.

A three-dimensional mathematical model of blast furnace cooling stave temperature was proposed in 2007. They put out a set of parameters upon which the heat transfer study is based. For their analyses, they have employed both the modelling programme Catia (version 3) and ANSYS (version 10.0). Based on the values of temperature and stresses, the authors concluded that the cooling water velocity affects the maximum temperature of the hot face but has no effect on the thermal stress of the stave by solving conduction and convection heat transfer rate using different equations.

A three-dimensional mathematical model of the blast furnace stave's temperature and thermal stress field was presented in 2008. They have not accounted for the impact of radiation heat passed from solid materials (coke and ore) to the inner surface of the stave in their study. Here, we do a heat transfer study to determine how the coating layer on the cooling water pipe's outside affects the maximum temperature and thermal stress on the stave's hot surface. According to their findings, the maximum temperature and thermal stress of the stave hot surface rise in proportion to the scale's thickness, suggesting that water scale has a cooling impact on stave. The authors also draw the conclusion that water pipes have a disproportionately large impact on the stress intensity on the hot side, and vice versa for the cold side. As a byproduct of their efforts, they also received findings about fracture development. A blast furnace's lower stave is where the furnace's heat is most focused during high-temperature smelting. One of the primary factors necessitating a blast furnace's extensive renovation is the need to cool the staves. Lifespan of cooling staves is therefore an important indicator of blast furnace durability.

Process

Inside the blast furnace, the real process is briefly described below. At first, a tremendous surge of fuel gases is released via the tuyere. the process by which pulverised coal injection (PCI) coal is injected through the tuyere lance and bustle pipe air is passed to the raceway region, where combustion occurs, and then a massive blast travels down the raceway and into the bosh region, where coke, flux, and ore are introduced. Bosh is where the smelting process occurs (smelting region). The molten iron is subsequently transferred to the blast furnace's hearth, where the wall is subjected to an assault by the combustion fumes. Slag's low density means it will flow across the blast furnace's hearth and then settle down to create a coating on the furnace wall.

Along the outside edge of the blast furnace wall, cooling staves are positioned. Because of this, the cooling staves' workloads will vary depending on their location; for example, the cooling stave closest to the bell valve (top) will experience lower temperatures than the stave closest to the smelting area. For this reason, the lower stave is evaluated independently, since here is where the blast furnace's greatest heat load is focused during the smelting process.

It is suggested in this work that the blast furnace cooling stave be studied and analysed for five different loads, ranging from 773k to 1573k.

Our study assumes the water temperature to be 303k, and the simulation and analysis sections will detail the modelling and analysis parameters.

Stave Model for Cooling Blast Furnaces

The above described issue may be represented by building a model in the modelling programme and then exporting it as an.IGES file. The material choice, assumptions, and boundary conditions will now be supplied by the ANSYS software upon import of the model.

The issue has been established, and an initial model has been created in the modelling programme used in this investigation. Additionally, an.IGES file export of the model is required. Importing the model into the ANSYS software, where the material choice, material characteristics, additional assumptions, and therefore boundary conditions will be given for a systematic study and analysis, is necessary for the right mathematical study and analysis.

In the next parts of this work, we will explain the mathematical analysis and solution approach along with pertinent partial findings and outcomes.

SUGGESTIONS FOR A APPROPRIATE APPROACH TO THE PROBLEM

The first step in our suggested solution technique is to simulate and analyse the model constructed in the previous section. Both the modelling and the analysis will involve some guesswork. The top and bottom of the stave are set in stone during the modelling phase, and certain presumptions must be made during the analysis phase, including that there is no heat transmission between the linings, the stave, the filler material, and the furnace shell.

The ANSYS study of this Pro-E design will provide temperature contours that will be shown on the model's exterior. The thermal structural calculations used to verify the model's bulging and eventual collapse at higher temperatures will use the temperature values derived from the temperature contour (loads) By analysing the stress and temperature measurements in both linings, we can determine the peel stress, shear stress, and von Mises stress and compare them. The material choice, assumptions, and boundary conditions will be supplied at the time the model is loaded into the ANSYS software programme. Following this, thermal calculations will be performed, and the resulting temperature value will be included into the calculations for the thermal-structural analysis, also known as the coupled field analysis.

The suggested analysis requires the computation of various stresses, such as peel stress, shear stress, and von- mises stress, followed by the study and interpretation of the resulting profiles, contours, and graphs. The process of simulation and analysis may be broken down into the following steps:

Importing the.IGES file from Pro-E results in a model with five distinct sections: the filler, the lining, the skull, the stave, and the furnace shell.

The next phase is selecting the right materials. Specifically, silicon carbide brick and high alumina brick are chosen as the lining material, while silicon carbide brick is used for the inlaid bricks.

iii)Subsequently, you will be given information on the material's characteristics, such as its young's modulus, thermal conductivity, expansion ratio, Poisson ratio, and so on. Once you have entered all of these values, the meshing procedure is complete. Accurate results at every node are obtained via the process of meshing. After these steps are completed, loads will be made available. For both the thermal and the thermal-structural computations, the aforementioned assumptions and boundary conditions are used.

Because of the shifting locations of the cooling stave, five distinct stresses are exerted on its heated surface. The staves will be stacked in descending order from the top to the bottom (near the smelting zone). Therefore, the plan is to test the stave's stability in a range of temperatures. vi.To illustrate, the hot face temperature of the top stave (near the bell valve) will be different at that particular combustion compared to the temperature near the bosh region because a massive blast with a high temperature attacks the wall near the smelting zone, but its temperature reduces as it goes to the up side of the blast furnace.

The model is updated with a single change. viii. The stave has a hard top and lower edge, limiting its flexibility and making it difficult to play.

Water and water scale convection (forced convection), water scale conduction on the inner surface of cooling water pipes, and steel pie conduction are not taken into account in this investigation. In this part, we offer a detailed description of the solution technique, including analysis and simulation of the suggested model, carried out for the establishment and simulation of the stave model. This section of the present paper work also illustrates the systematic analysis processes using applicable methodology. More findings need to be displayed, which is our future effort, so that people can grasp the analytical portion.

Goals and Expectations

In the simulation phase, a solution is generated after the input of material attributes and loads. The final results will be computed in the form of contour plots and graphs from the whole post processing. The results of the thermal calculation will be re-used in the structural analysis calculation after being converted to temperature values.

The thermal analysis of the cooling stave will provide graphical and contour plots for both the with skull model and without skull model of alumina and silicon carbide lining at various loads. Future study will include the determination of contour plots and graphical plots relating to displacement, von-misses, peel stress, and shear stress in the hot face of the stave over all four planes (i.e. linings) of the stave and the plotting, critical analysis, and discussion of these plots.

Therefore, the proposed outcome includes a detailed discussion of the model, the values and advantages and disadvantages of both the linings (alumina and silicon carbide), and some effects of using those linings in any blast furnace at different load conditions would be clearly stated and discussed based on the simulation and analysis results, and the linings would be specified in detail. The thesis then moves on to a discussion of its findings and conclusions on the suggested problem and solution approach of blast furnace cooling stave.

CONCLUSION AND FUTURE STUDIES

In this last chapter of the thesis, I describe the overarching findings of the research presented here. The primary aspect of the suggested modelling and analysis technique for the cooling stave is the simulation tool. In this case, Pro-E is utilised for the modelling, whereas ANSYS is used for the analysis. Parameters, assumptions, and boundary conditions will determine the final outcome. Plants, periodicals, books, etc., will be used to determine all of these qualities.

Therefore, the primary purpose of this research is to suggest a technique for analysing and comparing the linings under various settings. The primary goal of this research was to use ANSYS, a finite element technique programme, to conduct heat transfer analysis to better understand how lining material performed under varying loads. The lining material of the blast furnace cooling stave is believed to be either silicon carbide bricks or high alumina bricks, and the skull is either thin or thick, measured in millimetres. Our next steps include simulating these two skulls and doing the heat transfer study at varying temperatures (loads) between 773 kelvin and 1573 kelvin to determine which lining will provide the best results.

REFERENCES

1. Zhang, H., Jiao, K. X., Zhang, J. L., & Chen, Y. (2019). A new method for evaluating cooling capacity of blast furnace cooling stave. *Ironmaking & Steelmaking*, *46*(7), 671-681.
2. Deng, Y., Jiao, K. X., Wu, Q. C., Zhang, J. L., & Yang, T. J. (2018). Damage mechanism of copper stave used in blast furnace. *Ironmaking & Steelmaking*, *45*(10), 886-892.
3. Xu, X., & Wu, L. (2017). Performance optimization criterion of blast furnace stave. *International Journal of Heat and Mass Transfer*, *105*, 102-108.
4. Li, Y., Chen, L., & Ma, J. (2019). Numerical study on the relationship between the localized depression erosion of a commercial blast furnace hearth lining and the heat flux of cooling staves. *IEEE Access*, *7*, 60984-60994.
5. An, J., Zhang, J., Wu, M., She, J., & Terano, T. (2018). Soft-sensing method for slag-crust state of blast furnace based on two-dimensional decision fusion. *Neurocomputing*, *315*, 405-411.
6. Li, F. G., Zhang, J., & Guo, R. (2017). Study on the influence of materials on heat transfer characteristics of blast furnace cooling staves. In *8th International Symposium on High-Temperature Metallurgical Processing* (pp. 799-810). Springer, Cham.
7. Huo, Y., & Chen, L. Y. (2018, November). Analysis on heat transfer characteristics for bosh copper cooling stave with shaped tube. In *IOP Conference Series: Materials Science and Engineering* (Vol. 439, No. 2, p. 022003). IOP Publishing.
8. Jiao, K. X., Zhang, J. L., Liu, Z. J., & Jiang, H. B. (2019). Cooling efficiency and cooling intensity of cooling staves in blast furnace hearth. *Metallurgical Research & Technology*, *116*(4), 414.