SUSTAINABILITY CASE STUDY

Bath level management in the Consteel DC Electric Arc Furnace

A CASE STUDY AT NUCOR STEEL HERTFORD COUNTY ON THE IMPACT OF USING CORETEMP TO CONTROL HOT HEEL LEVEL AND END-POINT BATH LEVEL IN THE CONSTEEL EAF AND THE RESULTING POSITIVE EFFECTS ON INPUT ELECTRICAL ENERGY AND GRAPHITE ELECTRODE USAGE.

25/05/2023

The study evaluated the criticality of temperature, bath level, and hot heel control in a Consteel EAF. Increased control of these parameters resulted in lower input power requirements and lower electrode consumption per heat, increasing EAF operating efficiency.

INTRODUCTION

Is the Consteel EAF process in control with regards to temperature? Can the control of the hot heel level be improved and what are the benefits of doing so? What Is the necessary endpoint bath level to run the Consteel EAF the most efficiently?

The control (or lack thereof) of the steel temperature directly impacts how much energy must be input into the charge to fully melt and heat. Does the steel bath heat homogeneously and how does that impact the melting process?

What effect does the residual hot heel level have on the melting and heating process for the following heat?

Does the hot heel level need to be measured directly or can it be controlled by controlling end point bath level?

SUMMARY

CoreTemp, a no-one-on-the-floor, on-demand level and temperature measurement system was Installed on the EBT of NUCOR Steel Hertford County's Consteel EAF. Unlike traditional immersion probe measurement methods, CoreTemp feeds optical fiber cored wire into the melt to perform the measurements.

The EAF operators used the system to measure both steel bath temperature and level on every heat with the following objectives:

1) Increase temperature control of the melting process and assess bath temperature homogeneity.

2) Control the endpoint steel bath level

3) Control the residual hot heel level after tap

The ultimate goal of the project was to increase the life of the furnace refractory for each campaign and Increase the operational efficiency of the Consteel EAF process.

RESULTS

2.47
MWH/HEAT

A reduction of electrical input energy per heat of 0.70 MWh to 2.47 MWh, depending on the maintained endpoint bath level (resultant hot heel level).

0.074
KG/TON

A reduction in graphite electrode usage of 0.074kg per melted metric ton.

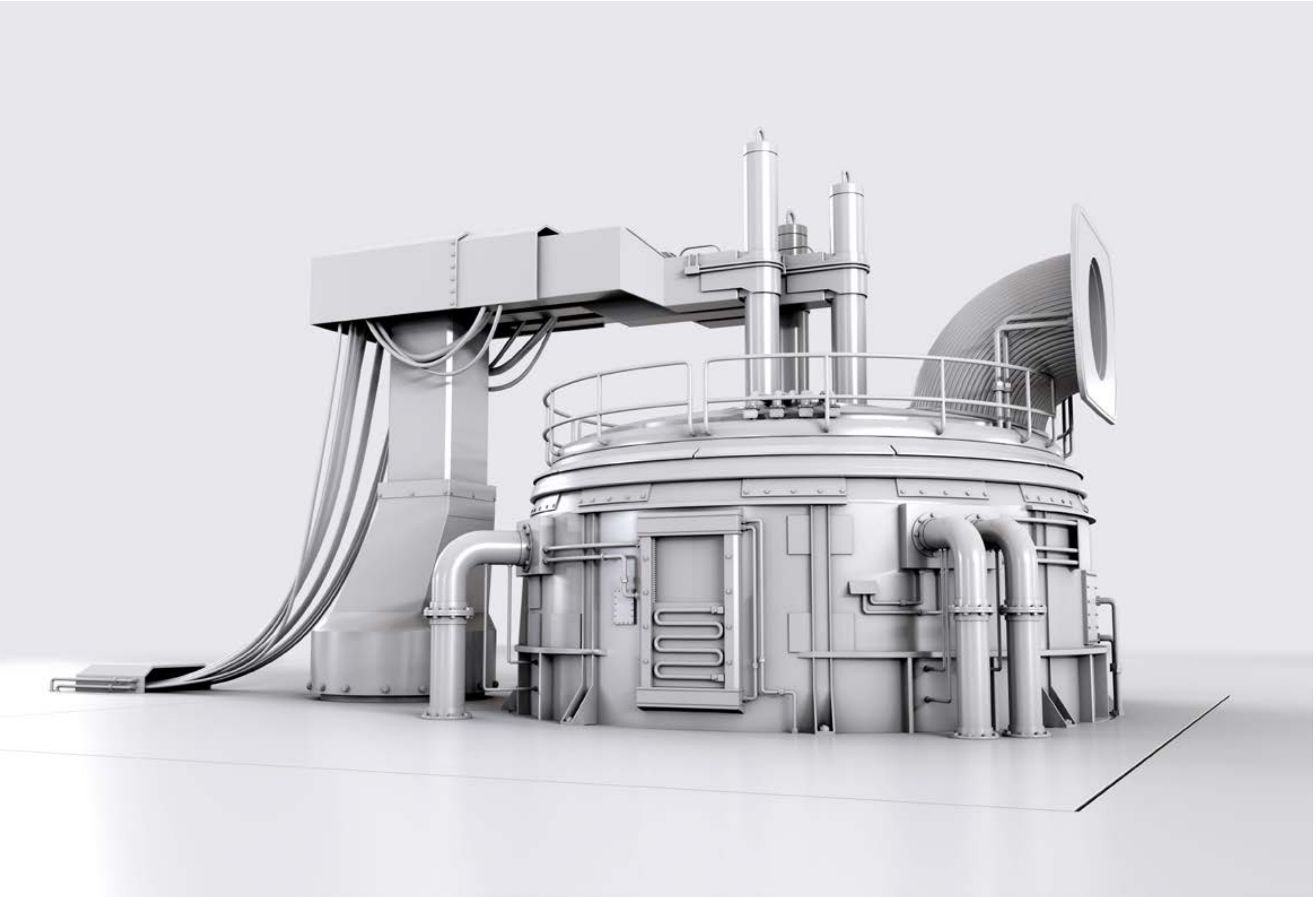
12%
INCREASE

12% increase in the average number of heats on the refractory bottom.

CONCLUSION

1) Operator safety was improved by reducing or eliminating the need to go out on the operating floor for measurements.

2) Input electrical energy per heat and graphite electrode consumption per melted ton were significantly decreased, reducing plant Scope 1 and Scope 2 carbon emissions.



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Technical Paper

Bath Level Management in the Consteel DC Electrtic Arc Furnace

Bath Level Management in the Consteel DC Electric Arc Furnace

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ABSTRACT

The hot heel and end point bath level are important factors for optimal furnace efficiency when operating an EAF, even more so for the operation of a Consteel DC EAF. A new bath level management system was implemented into practice at NUCOR Steel Hertford County (NSHC) with the goal of improved control over these aspects of the process. Without costing any additional process time, NSHC operators are able monitor steel bath level throughout the Consteel EAF process. In addition to improving operational control of the Consteel EAF, noticeable process gains were realized as well.

INTRODUCTION

Nucor Steel Hertford County (NSHC) was built as a greenfield investment and started up in the year 2000. It currently produces discrete plate between 3/16" & 4" gauge at widths between 72" & 125", across product types of plain carbon, high strength low alloy (HSLA), normalized, and quench & temper. Several investments have been made since its greenfield start-up in 2000 to achieve its current product offering including: a direct reduced iron (DRI) handling system, a twin vacuum tank degasser (VTD), and a quench and temper line quickly followed up by a normalizing line.

To feed the entire mill the melt shop operates a single 255-ton SMS DC electric arc furnace (EAF) with Consteel, utilizing 140MW of electrical power. Specific investments at the EAF include: 4-point coherent sidewall lances, tilt wheel load cell pins, pneumatic flux addition systems, as well as a 6-axis robot for taking temperatures through the sidewall. All these upgrades have been meant to create a safe, robust, reliable process capable of producing the liquid steel to meet the needs of our customers. The most recent project at the EAF was the installation of a manless, on demand measurement system, CoreTemp. The average anode bottom life at the EAF was approximately 645 heats, which was lower than desired. Suspected root cause for the lower than desired bottom life was superheating of the steel in contact with the anode resulting in premature wear. This being the case, the initial goal of the CoreTemp project was to characterize temperature control and homogeneity of the Consteel EAF by measuring in a different location than the 6-axis robot and with more frequency than could be accomplished by the 6-axis robot. Early in the project it was determined that the temperature control of the furnace was sufficient and often bath temperatures in the sump of the furnace were similar to bath temperatures near the slag door. However, during the course of this investigation control of the hot heel level, accomplished by measuring and controlling the end point bath level, was more critical for consistent operation of the furnace and addressing premature wear to the anode. The details of how this measurement was accomplished, the system employed, results and further actions are discussed in the balance of this paper.

CONSTEEL STEELMAKING AT NUCOR STEEL HERTFORD COUNTY

To the readers who may be unfamiliar with Consteel, Tenova's website explains "The Consteel system continuously feeds and pre-heats the metallic charge (scrap, pig iron, etc.) to the EAF, while simultaneously controlling gaseous emissions".[1] Scrap is loaded onto a horizontal reciprocating conveyor, which is a series of cascading steel pans that oscillate towards and away from the EAF in such a way that the scrap ultimately moves towards the EAF. This conveyor carries the scrap into a "preheat" section of the conveyor where the scrap is exposed to the counter-current flow of the EAF off-gas, absorbing heat from the off-gas. Most of NSHC's metallic needs are charged into the EAF via the Consteel conveyor; however, a significant portion of the charge metallics comes from roof fed DRI. These two methods of metallic charging are meant to be "continuous", while the EAF is operating. A simple schematic of the components of the Consteel system is shown in Figure 1.

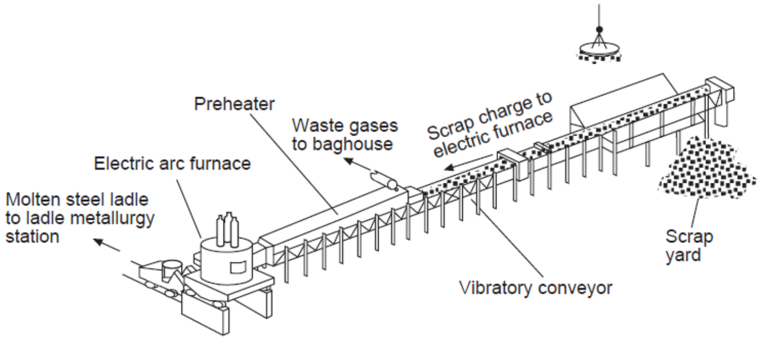


Figure 1. Overview of an EAF with Consteel.[2]

In contrast, a traditional bucket charged EAF utilizes a bucket layered with specific charge. The bucket is commonly loaded by crane in the scrap yard or set in a pit inside the mill and loaded by dump truck. This allows a "known" amount of scrap to be charged. This charging method differentiates a Consteel furnace from a "bucket charged" shop and has broad impacts to operating an EAF. A basic description of a "bucket charge" operation includes four phases of steel making operation: charging, melting, refining, and tapping. However, in a Consteel operation the charging phase is simultaneous with melting, leaving the phases: charging & melting, refining, and tapping. A basic description of the Consteel operation begins with the furnace containing a significant hot heel (~50-75% of tap weight). Then scrap steel that has been layered and specifically positioned on the Consteel conveyor is moved on the conveyor through the preheat section entering the EAF through a hole in the side wall. At NSHC this area is called the lintel. The NSHC lintel is positioned opposite the mast arm and the furnace has the tap hole positioned in the EBT nose opposite from the slag door. A picture of the EAF, lintel, and the Consteel conveyor at NSHC is shown on the left portion of Figure 2 with a section view of a Consteel EAF shown on the right portion of Figure 2.

Figure 2. Left, view of the EAF, lintel and Consteel conveyor at NSHC. Right, section view a Consteel EAF.[3]

At the beginning of the heat, scrap is conveyed and added in sufficient quantity to the heel to reduce the temperature and oxygen composition from the tapping condition to a reasonable operating range, typically between 2850°F to 2900°F, without "freezing off" or over-cooling the heel.[4] At this point the scrap feed rate from the conveyor is reduced, and power is applied from the electrode. The heating processing continues by feeding a balanced amount of scrap weight to the power applied, otherwise known as specific energy (kWh/ton/min), to maintain a constant bath temperature. Additionally, during this time slag fluxes are pneumatically injected to allow the evolving slag chemistry to be adjusted throughout the heating process. As the sum of scrap weight added to the EAF, nears the total scrap weight desired, the Consteel furnace moves into "refining" phase. While the move to refining phase may not be as distinct of a transition as a bucket charge shop, the Consteel conveyor will slow the scrap feed while continuing to apply power and lance oxygen, reaching the desired tap temperature and oxygen content. Lastly the tapping phase is indistinguishable between a bucket charged and Consteel EAF. Safety inspections follow, then another heat begins.

While the previous description of a Consteel operation seems elegant, NSHC had realized that obtaining a consistent charging weight is more difficult to achieve in practice than in theory. Without the "known" charging amount achieved in a bucket charge operation, NSHC is left approximating the quantity of charge metallics added. NSHC has always performed safety inspections after tapping the furnace, which allows a visual estimate of heel height (weight). During heat processing temperature measurements are taken using a 6-axis robot through a port in the spray cooled shell, at regular intervals to measure the bath heating rate which is compared to total kWh consumed to approximate the total charge metallics. Additionally, load pins were added to the tilt wheels, resulting in measuring the growth in weight during a heat processing. None of these tools are precise. Inspections vary on slag carryover and furnace depth. Heating rate assumes uniform scrap conveyance and heating efficiency. Load pins are weighing the entire tilt structure, steel bath, hearth, upper shell, electrode mast, water, etc., rendering them more qualitative than quantitative.

As NSHC looks toward advancements in furnace control technology for Consteel, using a specific energy balance control method is proving valuable across the industry. To further improve the control that has developed over NSHC operating history, a combination of loadcell feedback and regular frequency of temperature measurements, an interest in a "continuous" bath temperature measurement system became apparent.

When Heraeus presented the CoreTemp, manless, optical measurement system, it appeared to be a desirable tool for NSHC:

1) Equipment that could take temperature measurements nearly on-demand, as frequent as ~30 seconds
2) Temperature measurements could be taken earlier in heat, when the metal level was as low as 7" below the tap hole
3) Temperature measurements could be taken without occupying a team member to swap probes,

This would allow NSHC a means to nearly continuously monitor the specific energy use. After an initial learning curve, CoreTemp was used to measure temperature progression during heats. It was able to measure the heats progression from starting "cold" through reaching tap specifications. Measurements of bath temperature validated how the operators skillfully maintained a temperature profile with a variety of tool accuracies. NSHC was not super-heating the anode early in the heat as was previously believed. Unfortunately, this was information the operators knew too well already. NSHC did not value knowing the exact temperature of the steel at this point in the heat progression. The current assessment methods employed during the heat processing provided enough information to know that the bath was cold early in the heat; knowing this was enough to take appropriate actions.

That said, CoreTemp proved to be reliable, and the operators adopted it quickly as a ready back-up to the robot temperatures. Then Heraeus introduced the concept of bath level measurement, using the same optical measurement system. Providing a measurement of the top of the liquid steel level relative to the tap hole height, the bath level has given our operators a target to aim for. Across crews and levels of experience, NSHC has been able to develop improved control over a fixed, minimum bath level heat to heat. While exceedances still happen, the operators are aware of the situation and make small adjustments over time to return to a desired bath level before a slag excursion, anode wear, or other EAF inefficiency causes a process delay.

As this paper will share, a larger heel size leads to a more productive furnace. That larger heel provides a head start on melting the scrap charged by allowing a large amount scrap to be immediately immersed in the hot heel and heating the scrap immediately by conduction and convection, getting to a flat bath more quickly.[5, 6, 7]

CORETEMP SYSTEM AND LEVEL MEASUREMENT FUNDAMENTALS

An overview of the CoreTemp, optical measurement system is given in Figure 3. It is comprised of an HMI (located in the pulpit), control unit, optical cored wire coil, a cored wire feeder, wire guide tube, wire straightener, and an entry port into the furnace. To keep the entry port into the EAF clear of slag, compressed air is purged through the entry port, into the EAF.

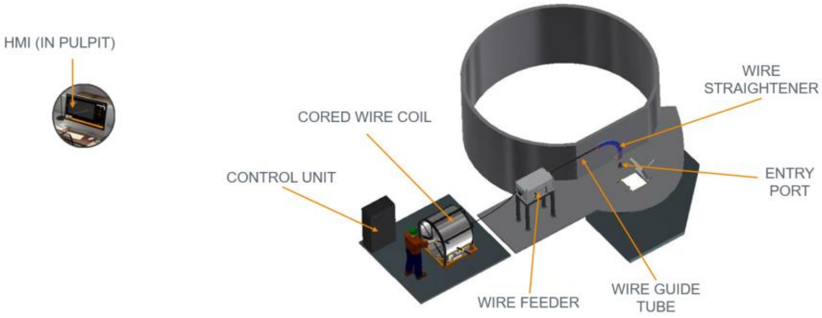


Figure 3. CoreTemp on-demand measurement system components. NOTE: the model of a person is only shown for the purposes of providing scale to the image.

The system overview in Figure 3 presents a general picture of the system components. Pictures of the actual installation at NSHC can be seen in Figure 4.

Figure 4. LEFT, picture of the CoreTemp installation on the EAF sump as viewed from the sanding hole. RIGHT, picture of the CoreTemp installation on the EAF sump as viewed from the wire feeder.

A photo of the optical cored wire traveling through the EAF freeboard down towards the bottom on an empty furnace is shown in Figure 5. In practice the wire is first fed at a fast rate to traverse the freeboard of the furnace and is then fed slowly as it approaches the level of the steel bath for improved measurement resolution.

Figure 5. Optical cored wire feeding into the EAF.

As the wire is fed into the EAF during a measurement, the response (or signal) of the optical temperature measurement trace is monitored for a sharp inflection point before a stable temperature plateau is reached. This inflection point is indicative of the tip of the optical cored wire entering the steel bath and is used to determine the length of optical wire fed into the EAF to reach the steel bath, using the hot face of the sump panel as the 0 reference. An example measurement trace has been marked up to illustrate how the distance of wire fed into the steel bath is determined and is shown in Figure 6. Once the distance between the bath and the sump panel hot face is known, the measured distance to the bath is entered into Equation 1 to convert that distance into steel height above the tap hole, in units of inches.

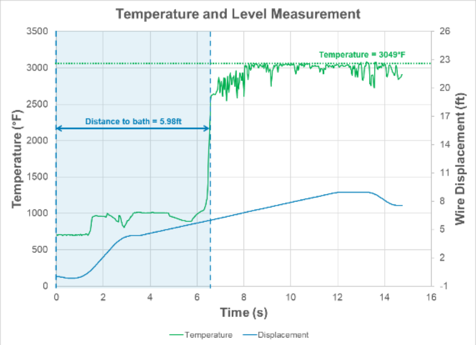


Figure 6. Temperature and level measurement marked-up to show how the distance to the steel bath and temperature values are determined.

$$Bath\ level\ (in.) = C(D_1 - D_2 \cos\theta) \qquad (1)$$

$Where:$

$\boldsymbol{C} = unit\ conversion\ factor$
$\boldsymbol{D_1} = constant, vertical\ distance\ from\ sump\ panel\ hot\ face\ to\ the\ top\ of\ the\ tap\ hole, in\ feet$
$\boldsymbol{D_2} = measured\ value, amount\ of\ optical\ cored\ wire\ fed\ from\ the\ hot\ face\ to\ the\ bath, in\ feet$
$\boldsymbol{\theta} = angle\ of\ optical\ cored\ wire\ entry\ into\ EAF\ in\ degrees$

EARLY RESULTS

As stated earlier, the main goal at the start of the project was to determine if superheating of the steel bath was occurring early in the heat, causing premature anode bottom wear. An assessment of the heating trend of the steel bath throughout the heat, as well as temperature homogeneity in the EAF, was made. This was accomplished by comparing the temperature measurements taken by the robot near the slag door to those taken by CoreTemp in the sump. Individual heats were examined for trends. Three observations were made:

1) On many heats the furnace was homogeneous throughout the entire melting process.

2) On some heats the sump was hotter than the slag side of the furnace, on others it was colder.

3) On certain heats, there was a convergence effect, where the sump started out colder than the slag side of the furnace, but then equalized in temperate with the slag side of the furnace near the end of the heat.

Examples of each case are given in Figures 7 and 8 respectively.

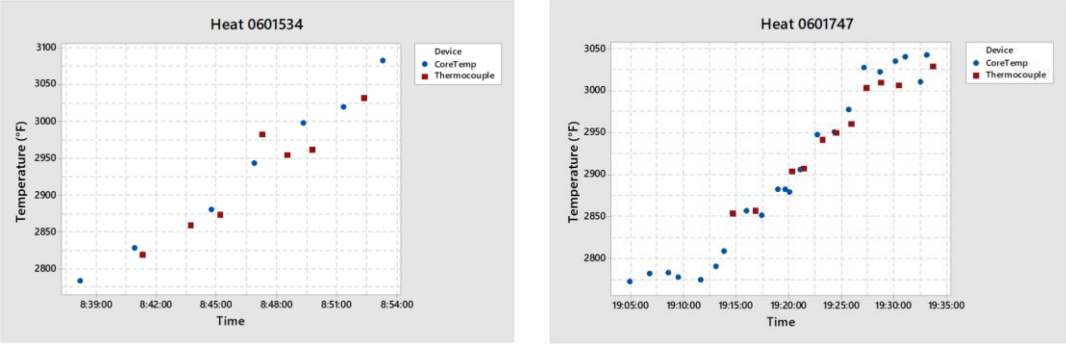


Figure 7: Example heats where measurements between the sump (CoreTemp) and slag door (6-axis robot with thermocouple) trended together throughout the entire heat.

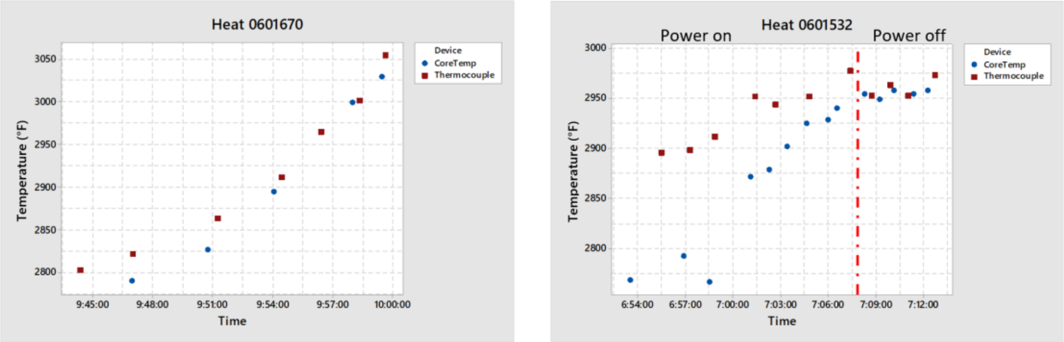


Figure 8: Example heats where measurements between the sump (CoreTemp) and slag door (6-axis robot with thermocouple) converged near the end of the heat.

Once it was established that superheating of the steel in contact with the anode was not occurring early in the heat, attention was refocused to determine if the CoreTemp system could reliably measure bath level throughout the entire Consteel process. For the proof-of-concept study, bath level measurements were taken according to the previously described optical method, automatically every four minutes. The measurements were triggered automatically by the NSHC level I system when the operator indicated they wanted to start automatic level measurements. Many of the heats analyzed indicated that level measurements throughout the Consteel process were indeed possible. Example heats are shown in Figure 9.

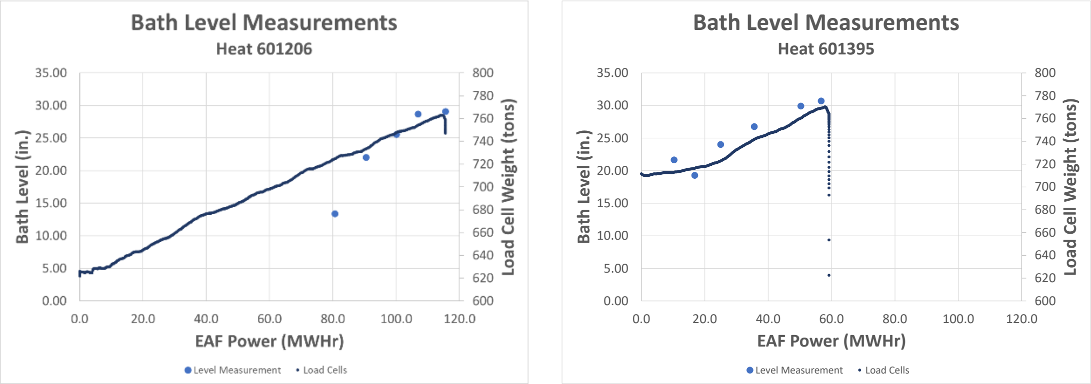


Figure 9: Example heats where automatic level measurements were taken throughout the heat.

Throughout the initial study, operators worked to carry a higher bath level (resulting in a higher hot heel level after tap) as this condition was favorable for obtaining temperature and level measurements in the sump throughout the Consteel process. Coincidentally, this furnace anode bottom lasted 744 heats, about 100 heats more than the typical furnace life at NSHC. This provided anecdotal evidence that an increased hot heel level was beneficial to increasing anode bottom life.[8]

As a result, NSHC management and operators made a process change defining a minimum end of heat bath level target of 20" above the tap hole, measured using the optical cored wire measurement method. The process was put into place in June of 2020, being fully adopted by NSHC operators on June 5, 2020. Early on two observations were made:

1) The average input electrical energy per heat decreased as the controlled hot heel level (weight) increased, as a result of improved control of the endpoint bath level

2) Anode pin temperatures either dropped or stabilized as the controlled hot heel level (weight) increased, as a result of improved control of the endpoint bath level

Figure 10 illustrates the effect on input electrical power as the level control process change was implemented. The column chart on the left shows the utilization rate of the level measurements while the time series plot on the right shows the trend in average input power per heat and empty EAF weight. A vertical black line was drawn on both charts to illustrate the date that the level measurement practice was fully adopted by all furnace crews. NOTE: EAF empty weight is the weight of the EAF as measured by the load cells after fast back, prior to charging. Monitoring this weight heat-to-heat provides an indication if the hot heel in the furnace is growing or diminishing throughout the campaign.

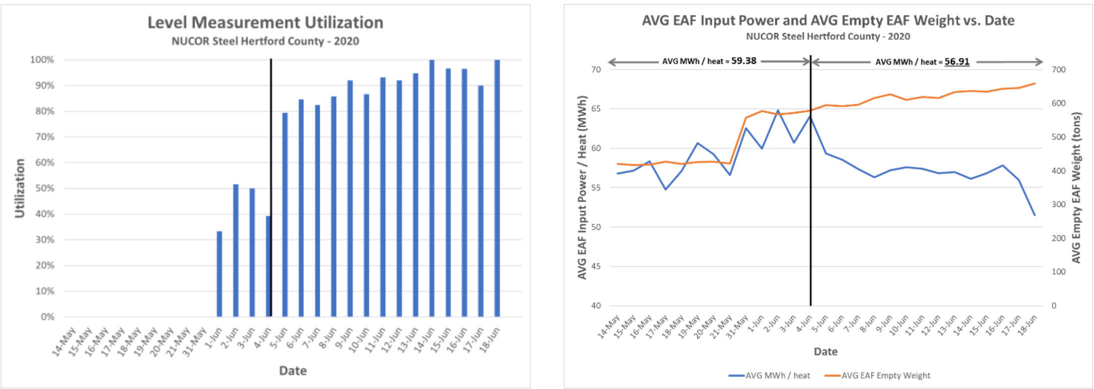


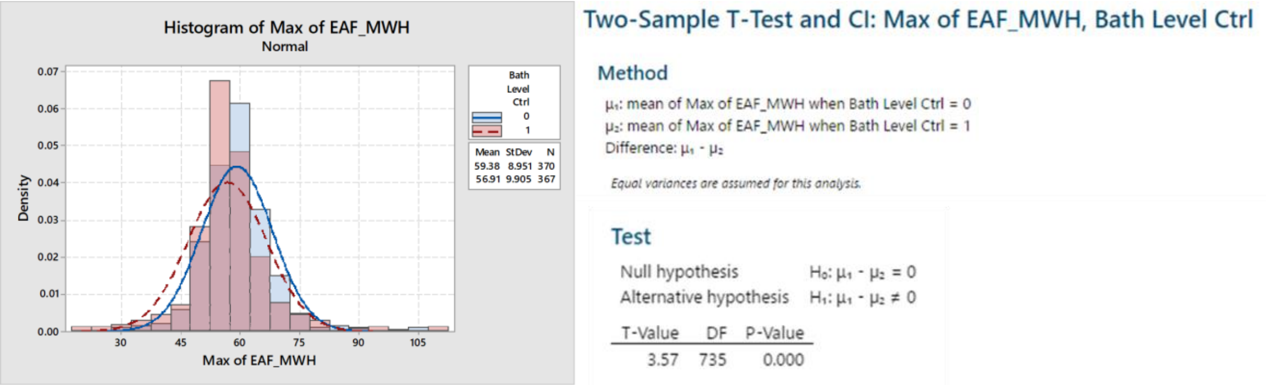
Figure 10: Plot of level measurement utilization by date and plot of average input electrical power and empty EAF weight (heel weight) by date. Note: the dramatic change in AVG Empty EAF Weight between 21-MAY-20 and 31-MAY-20 was due to a change in the channels which were measuring the load cells. While this created a mean shift, the load cell resolution remained the same.

Figure 10 shows a couple of interesting points:

1) Prior to the implementation of bath level control on this EAF, the AVG MWh/heat was higher, and the trend was noisier.

2) The AVG EAF empty weight began to increase at a higher rate than the time period prior to the implementation of bath level control.

To verify if the change in AVG MWh/heat was statistically significant, a Two-Sample T-test was performed at the α=0.05 level. The results of the test are given in Figure 11. The resultant P-value of 0.000 indicates that the change in AVG MWh/heat of 2.47MWh was statistically significant. This agrees with the findings of other research which indicated that an increased hot heel level (weight) leads to lower electrical power consumption in the EAF.[6, 7, 9]



Mean	StDev	N
59.38	8.951	370
56.91	9.905	367

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Two-Sample T-Test and CI: Max of EAF_MWH, Bath Level Ctrl

Method
μ₁: mean of Max of EAF_MWH when Bath Level Ctrl = 0
μ₂: mean of Max of EAF_MWH when Bath Level Ctrl = 1
Difference: μ₁ - μ₂

Equal variances are assumed for this analysis.

Test
Null hypothesis          H₀: μ₁ - μ₂ = 0
Alternative hypothesis   H₁: μ₁ - μ₂ ≠ 0

T-Value   DF   P-Value
   3.57  735     0.000
```

Figure 11: Histogram and Two-Sample T-Test output from MINITAB.

When looking at the anode pin temperatures, empty EAF weight, and AVG DC current, some additional insight was gained. The maximum upper temperature limit of the anode bottom at NSHC is 1125°F; once the anode reaches that temperature, the furnace is taken out of service. At around 450 heats in the furnace campaign, it appeared as though the furnace was going to be removed from service imminently. At that point it can be seen in the graphs of Figure 12 that the EAF operator made two changes:

1) Increased the amount of retained heel in the furnace, due to being able to measure end of heat bath level

2) Decreased the AVG DC current

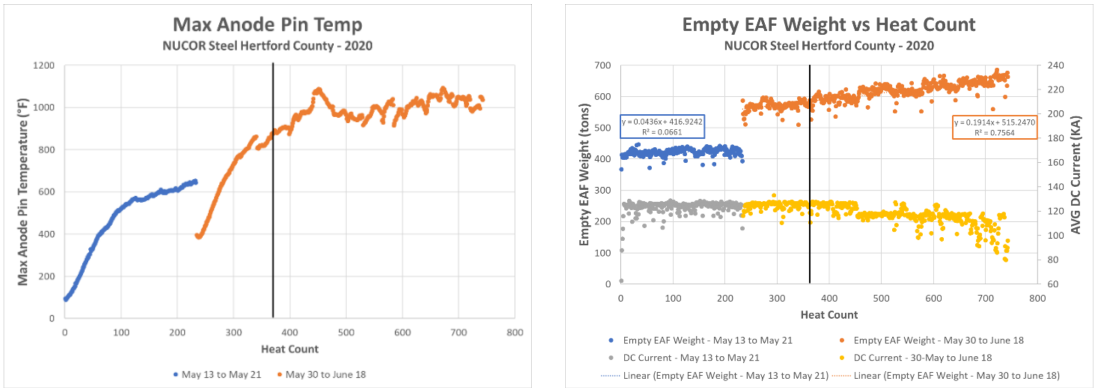


Figure 12: Left, plot of maximum anode pin temperature by heat count. Right, plot of empty EAF weight (heel weight inference) and AVG DC current by heat count.

Both actions combined decreased the temperature of the anode back under 1000°F and extended the life of the anode another 300 heats, approximately. This agreed well with the findings of Lee et al. in 1997, specifically that higher hot heel levels were quintessential for improved anode life and that lower input electrical current also lowers anode pin temperatures, thus extending the anode bottom life.[8]

EXTENDED TRIAL RESULTS

In December of 2020, there were sufficient operational data to see what the potential long-term impacts of a bath level control practice in the Consteel DC EAF could be. Three main KPIs were focused on for this analysis:

1) Graphite electrode consumption
2) Input EAF MWh
3) Anode bottom life

Since graphite electrode consumption could not be analyzed in the early results due to the relatively small sample size, it was the first KPI of interest. Plotting the monthly electrode consumption by month revealed that the electrode consumption after implementing bath level control decreased and appeared to be more consistent. This plot is shown in Figure 13.

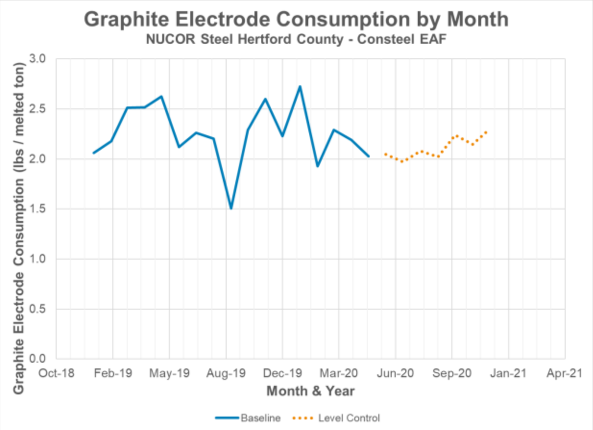
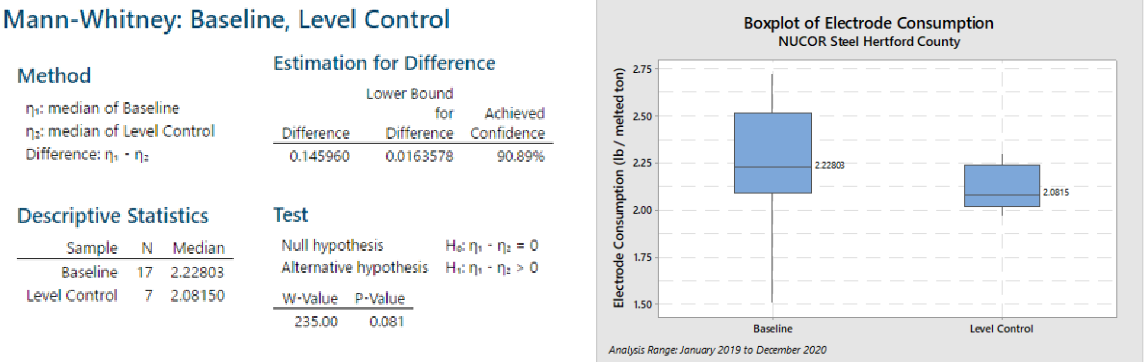


Figure 13: Plot of monthly electrode consumption at the Consteel EAF during the baseline analysis period (blue, solid line) and after implementing level control (orange, dotted line). NOTE: instances of electrode breaks were removed so as not to contaminate the analysis.

To determine if the observed difference was statistically significant, a Mann-Whitney U-Test was performed at the $\alpha = 0.10$ significance level. This test was chosen due over the Two-Sample T-Test due to the relatively small and unequal sample sizes. The results of the test accompanied with a boxplot of the data can be seen in Figure 14.



Mann-Whitney: Baseline, Level Control

Method

η₁: median of Baseline
η₂: median of Level Control
Difference: η₁ - η₂

Estimation for Difference

Difference	Lower Bound for Difference	Achieved Confidence
0.145960	0.0163578	90.89%

Descriptive Statistics

Sample	N	Median
Baseline	17	2.22803
Level Control	7	2.08150

Test

Null hypothesis H₀: η₁ - η₂ = 0
Alternative hypothesis H₁: η₁ - η₂ > 0

W-Value	P-Value
235.00	0.081

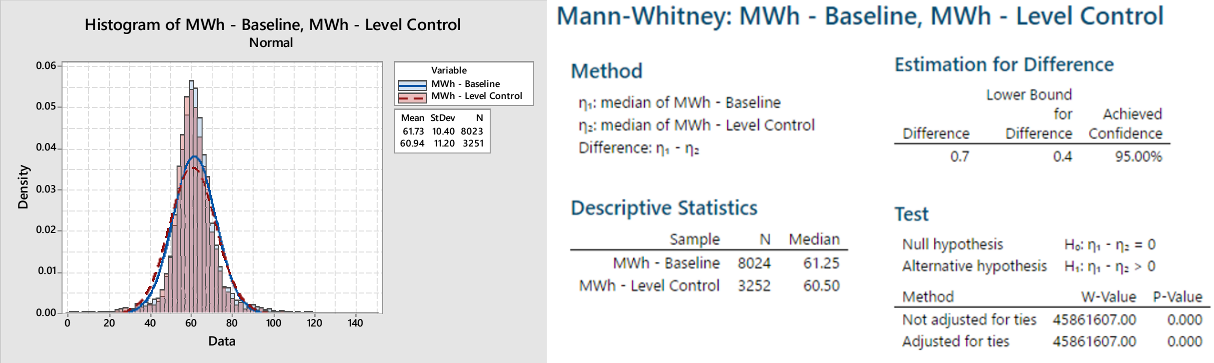
Figure 14: Left, results of the Mann-Whitney U-Test on electrode consumption. Right, boxplot of the electrode consumption during the baseline period and after implementing level control. NOTE: The non-parametric Mann-Whitney test was selected instead of the Two-Sample T-Test due to the relatively small and unequal sample sizes.

Examining Figure 14, the following can be seen:

1) There is some evidence that the decrease in electrode consumption of 0.146lbs / melted ton is statistically significant at an α = 0.10 level, due to the obtained test P-value of 0.081 being less than 0.10.

2) The variation in electrode consumption month to month decreased nearly 3 times since implementing bath level control.

Next the change in EAF input electrical MWh was examined on a large scale to see what the potential long-term impact was. Looking at the histograms of Figure 15, the bath level control histogram appeared to be shifted left, indicating lower MWh long term using bath level control. This needed to be validated with statistical testing. Again, due to significantly different sample sizes in number of heats made between the baseline period and the period after implementing bath level control, in addition to non-normal distributions, the Mann-Whitney U-Test was selected at the α=0.05 level. The output of the test from Minitab is given in Figure 15 as well.



Mann-Whitney: MWh - Baseline, MWh - Level Control

Method

η₁: median of MWh - Baseline
η₂: median of MWh - Level Control
Difference: η₁ - η₂

Estimation for Difference

Difference	Lower Bound for Difference	Achieved Confidence
0.7	0.4	95.00%

Descriptive Statistics

Sample	N	Median
MWh - Baseline	8024	61.25
MWh - Level Control	3252	60.50

Test

Null hypothesis H₀: η₁ - η₂ = 0
Alternative hypothesis H₁: η₁ - η₂ > 0

Method	W-Value	P-Value
Not adjusted for ties	45861607.00	0.000
Adjusted for ties	45861607.00	0.000

Figure 15: Left, histograms of input electrical MWh per heat from the baseline analysis period and level control analysis period. Right, results of the Mann-Whitney U-Test on input electrical MWh.

With a P-value of 0.00, which is less than the α of 0.05, the results of the Mann-Whitney U-Test confirm that the observed difference in input electrical MWh was 0.7MWh and was statistically significant. This finding agrees other research on the effect of keeping a larger hot heel in the EAF and its positive benefits on input electrical MWh for single shell furnaces.[6, 7, 9] What was interesting when comparing Figures 15 to Figures 10 and 11 was that the decrease in input MWh over a longer period was not as significant as was observed in the first campaign when level control was implemented. Two non-exclusive explanations for this may be found. First was the variation in median bath level over time, shown in Figure 16. While a minimum end point bath level of 20” was successfully maintained a majority of the time, the median bath level by month did vary from a max of 27” down to 19”, for a total deviation of 8” or up to 80 tons of steel (1” of bath level = approximately 10 tons of steel in the NSHC EAF). Average input electrical energy trended inversely to median bath level, suggesting carrying a hot heel larger than 20” was favorable for reducing input electrical energy. Secondly, another potential cause could be the influence of regular power curtailments during the months of July, August, September and October, which caused operations to stop periodically and thereby increased the number of heats with input electrical MWh over 70MWh due to resuming operations on cold furnaces.

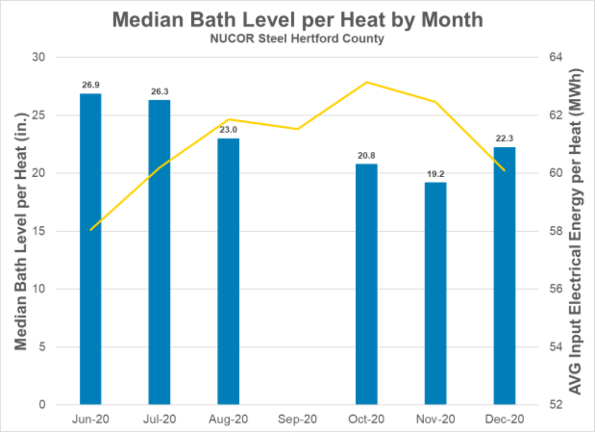


Figure 16: Median bath level by month. September 2019 was excluded from the analysis due to extended downtime of the CoreTemp equipment during that month

The last KPI examined was the life of the anode bottom. After implementing level control, several anode bottoms were removed from service prior to reaching their maximum service life (i.e. maximum pin temperature limit), as a result of market conditions and other actions being taken in the steel plant. For this reason it was difficult to make a direct comparison on anode life during the baseline period and after implementing bath level control. However, the anode pin temperatures follow a logarithmic function with the number of heats made, which has a high correlation and makes it possible to predict what the life the anode bottom could have been had it not been removed from service early. By transforming the data into the log domain, regression analysis and prediction of the life of the anode bottom could be performed. The anode life for each campaign from the baseline period and the projected anode life from the level control period are given in Figure 17 along with summary statistics in Table I.

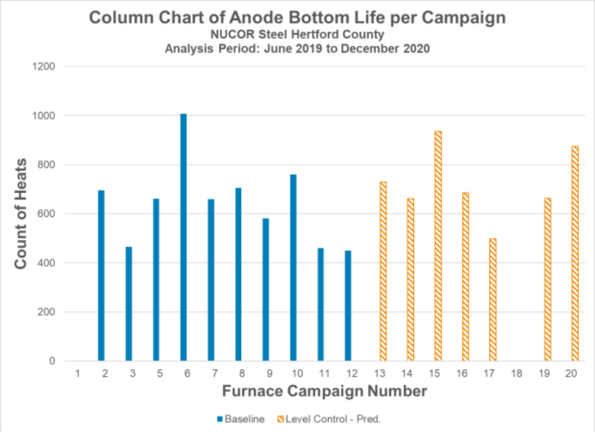


Figure 17: Column chart of anode bottom life per campaign. NOTE: campaign 1 was removed due to partial available data and campaign 18 was removed due extremely early removal of the furnace resulting in insufficient data to analyze.

Table I: Summary statistics for the data presented in Figure 17.

Summary Statistics of Anode Life		
	Baseline	**After Level Control**
Average	645	721
Median	661	685
StDev	170	146

Both Figure 17 and Table I indicate, somewhat anecdotally, that the life of the anode bottom could be extended due to improved control of the bath level. However, the relationship is not 100% clear since the method used to determine this was predictive modeling as the actual anode life was not known. This is not entirely unexpected as the next phase of the project is aimed at determining the ideal ending bath level, resulting in an ideal starting heel level for maximizing the anode life

During the last few months of the project, an additional benefit of optical cored wire measurements was realized, the ability to measure higher temperatures than achievable with a Type-S thermocouple. While rare, there are occasions where the Consteel conveyor can jam, preventing scrap from entering the furnace and creating a situation where the steel bath is heated well beyond the desired operational range of 2850°F to 2900°F. One such heat was observed where the temperature of the steel reached in excess of 3400°F, and was unmeasurable with a Type-S, platinum / platinum-rhodium thermocouple as a Type-S thermocouple fails open circuit at above 3216°F, the melting point of platinum.[10, 11] Examining data from this heat, it was clear that the optical fiber based measurement of CoreTemp could indeed detect these higher temperatures and is shown in Figure 18.

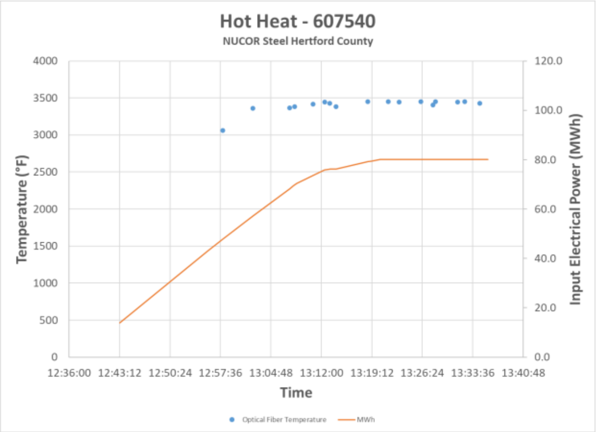


Figure 18: Temperature measurements from hot heat, Heat 607540.

FUTURE WORK

The next phase of the project involves operating the EAF at different endpoint bath level targets over a series of weeks to determine the ideal endpoint bath level at NSHC, thus resulting in the ideal starting hot heel level. For example: 2 weeks at 20", 2 weeks at 24", and 2 weeks at 28". The goal of the study is to determine at which ending bath level (i.e. starting heel level) are the greatest process gains with regards to anode bottom life, electrode consumption, power-on-time, and input electrical MWh achieved. Improvements are also being made to the installation by the addition of an optical cored wire cutter. Adding the cutter will provide the following benefits:

1) A more consistent home (or start) location of the cored wire before a level measurement due to being cut in the same location each time.

2) Reduced cycle time between level measurements.

A simple diagram of the cutter is provided in Figure 19.

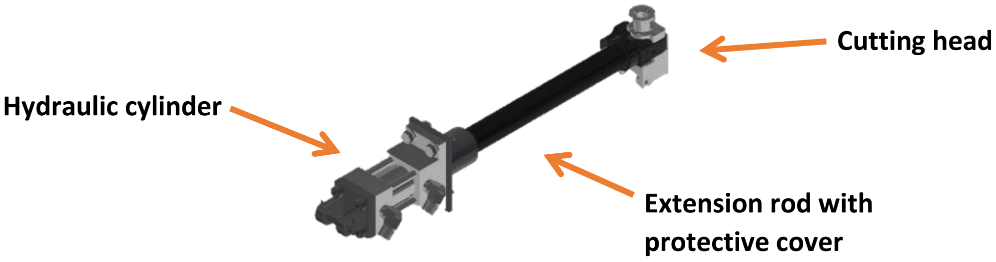


Figure 19: Model of the cored wire cutter installed at NSHC

As of the time of writing this paper, a cutting device, similar to what is shown in Figure 19, has been installed and is undergoing testing. In order to ensure the cutting device survives the harsh environment of the EAF sump, significant amounts of heat shielding were added. A picture of the installation at NSHC with the cored wire cutter and added heat shielding is given in Figure 20.

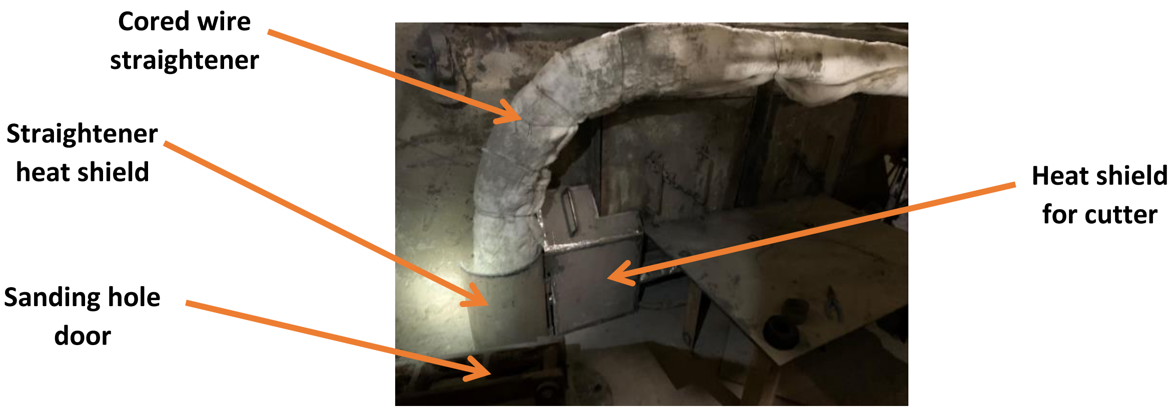


Figure 20: Installation of the cored wire cutter with the optical cored wire feeding system on the sump of the NSHC Consteel EAF.

CONCLUSIONS

Conclusions from the from the bath level management work at NSHC in the Consteel EAF thus far are as follows:

1) A larger hot heel facilitates melting of scrap, thus lowering required input electrical energy (MWh). A reduction of electrical input energy between 0.70MWh and 2.47MWh, depending on maintained endpoint bath level (resultant hot heel level) was seen.

2) A reduction in median graphite electrode usage of 0.146lbs / melted ton was observed by improving control over the endpoint bath level (starting hot heel level).

3) There is evidence that carrying a larger hot heel in the EAF extends the life of the anode bottom in a DC EAF. Since this was difficult to measure due to furnaces being removed from service early due to market conditions rather than being allowed to run to end of life, this metric will be studied more closely in future work.

4) The above points agree well with previous research on the effect the hot heel level has on DC EAF and Consteel DC EAF operational metrics.

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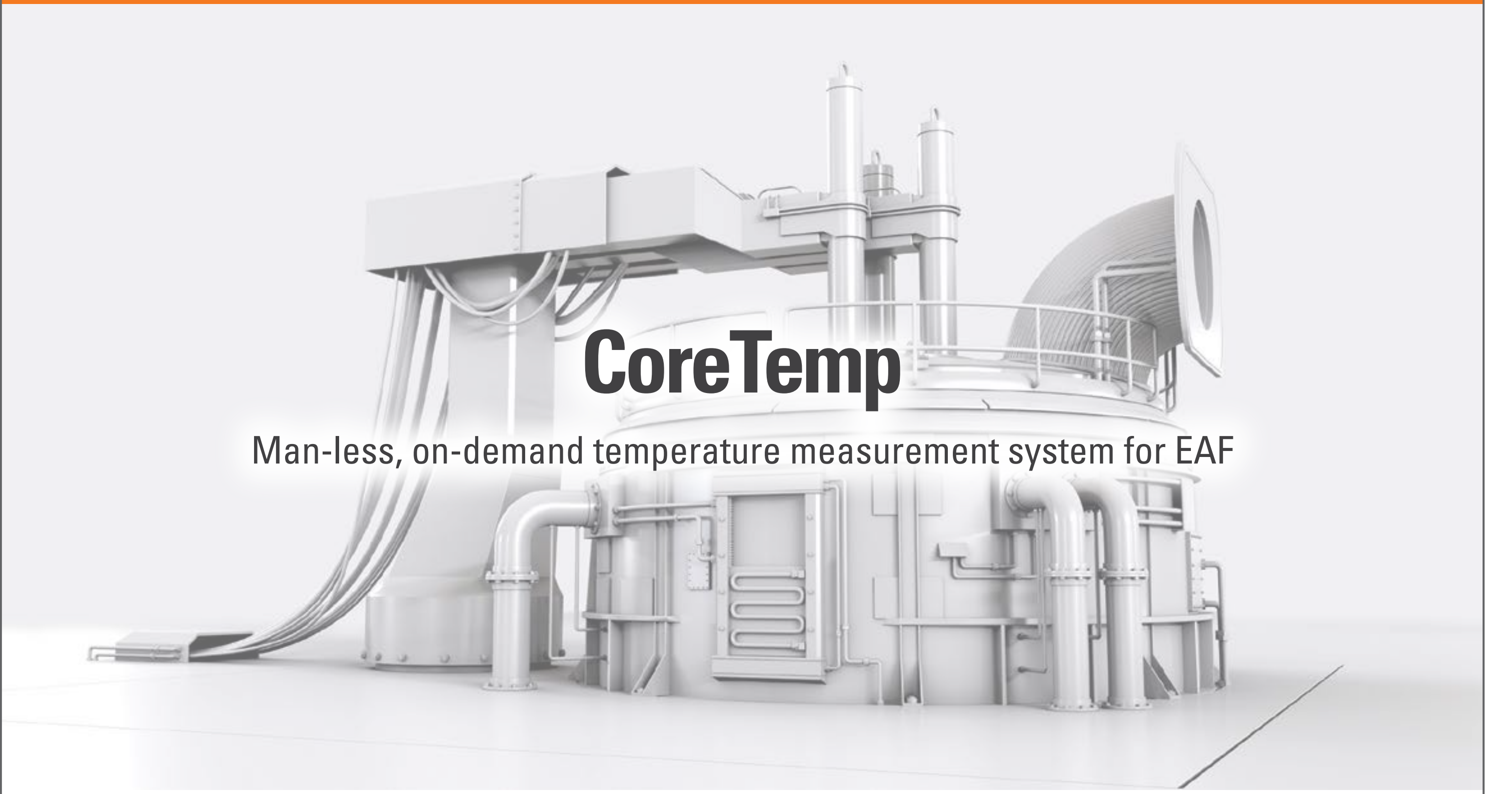
CoreTemp
Man-less, on-demand temperature measurement system for EAF