Innovative Energy Conservation through Scrap Pre-heating in an Electric Arc Furnace

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ABSTRACT

Consteel®, an innovative energy conservation technology for scrap pre-heating in an Electric Arc Furnace (EAF) developed by Tenova was implemented in an industrial facility in Ontario. The objective of the paper is to examine the electrical and operational benefits of implementing this technology, as well as the challenges in accurately evaluating the project viability as part of an incentive program.

Highlights of the conservation measure are as follows:

- Recovery of heat from furnace off-gas to pre-heat scrap metal prior to charging in the furnace
- 10% reduction in specific electrical energy (measured in kilowatt-hour per ton of liquid steel)
- Reductions in oxygen, carbon and electrode usage
- Increased production rate due to decreased tap-to-tap time

The assessment of the new technology's benefits was determined through the technical review process to evaluate the eligibility of the project for government incentive funding.

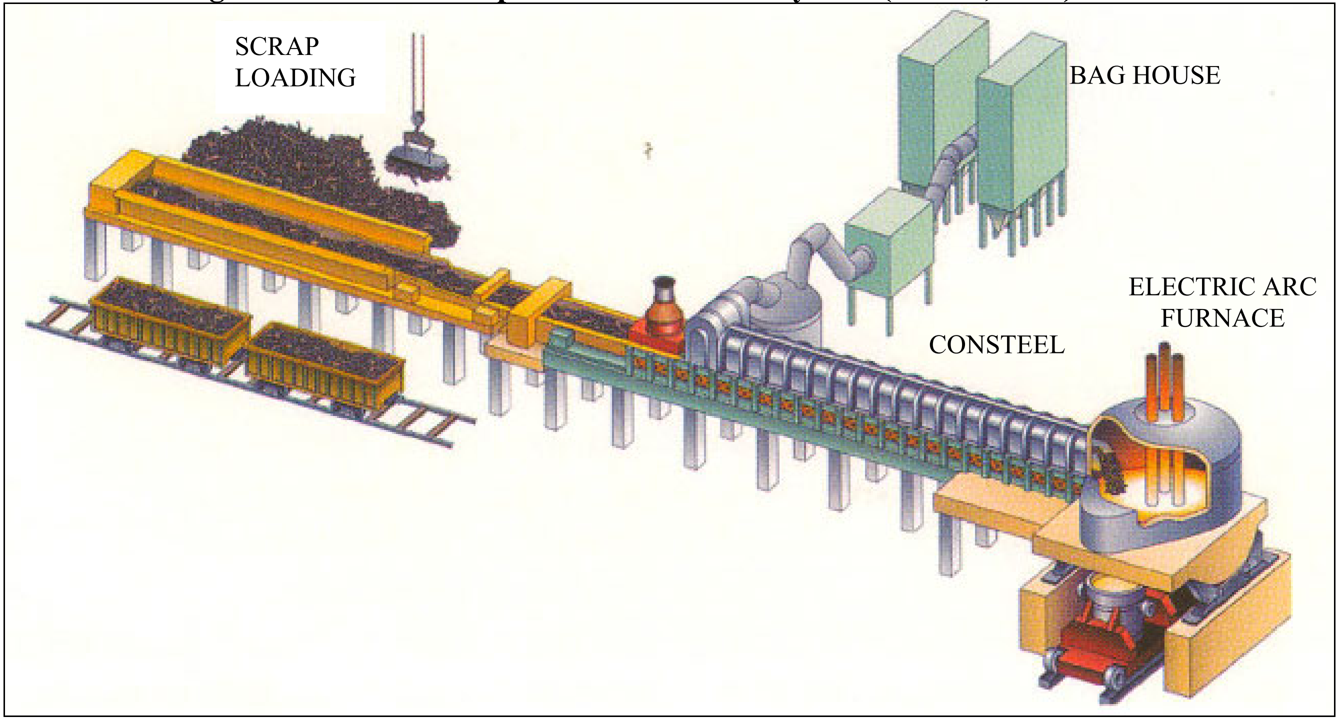
Background

With assistance from government incentives, the facility was able to upgrade their electric arc furnace (EAF). In order to acquire the incentive, the facility was required to submit an application and information to support the savings and costs of the project which were required to be accurate to ±10% and ±25% respectively. The project was required to be reviewed for its technical and financial merits to confirm the value of the project to the ratepayers. As a condition of the contract for the incentive, the facility is required to provide measurement and verification (M&V) data to demonstrate the measure's electricity savings for 10 years after the measure is declared to be in service.

Prior to the upgrade, the EAF at Ivaco Rolling Mills 2004 L.P. ("Ivaco") melted recycled steel scrap for casting into billets that were eventually rolled into steel wire products on site. The scrap melting process at the facility was a batch process. The EAF roof was periodically opened to load or "charge" the furnace with scrap. Electricity, natural gas, oxygen, carbon, and electrodes were all consumed in the furnace during the melting process. Once the furnace finished melting the scrap, it was "tapped" into a ladle to allow the liquid steel to be transferred to the next step of the process.

The facility proposed to modify this process with the Consteel® or continuous steel, system. This would no longer require the roof to be opened for normal charging as a conveyor carries scrap into the furnace through a tunnel. It is in this tunnel where the off-gas also flows out of the furnace and heat is recovered to preheat the scrap. This pre-heating of scrap is the primary mechanism of reducing electrical input required to melt scrap. Electricity consumption is further offset by the use of natural gas burners to further pre-heat the scrap as it traverses the conveyor. Additional benefits associated with this project are significant, and result from savings in oxygen, carbon, and electrode consumption in the EAF.

Figure 1. Schematic Depiction of Consteel® System (Jiemin, 2005)



Base Case

In order to evaluate the accuracy of the potential electricity savings of the project, it was necessary to establish a base case. The base case is the configuration of equipment that will act as the benchmark for calculating the savings.

Historical production of liquid steel at Ivaco has varied between 180,000 and 380,000 short tons of liquid steel (tls) per year. The maximum throughput capacity of the EAF was understood to be 450,000 tls/yr due to limitations of the EAF and other downstream equipment within the mill.

Ivaco provided EAF production data from 2011 which was used to determine the electricity consumption and tons of steel throughput of the base case. It was found that 260,000 tls was produced during 2011. Analysis of the heat data for 2011 determined an overall energy intensity of 343 kWh/tls.

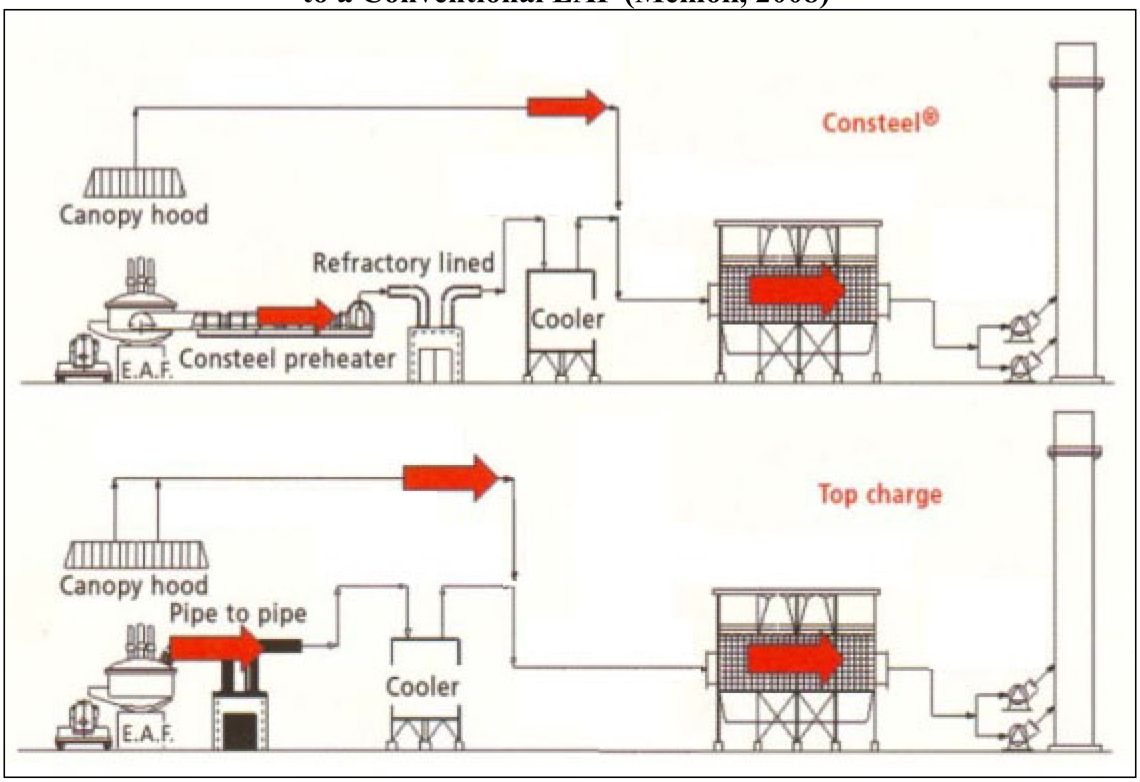
The Consteel® system allows the batch processing time of the furnace ("tap-to-tap" time) to be reduced. In doing so, the maximum annual production of the facility could increase to 575,000 tls after installation of the measure. Achieving this level of production also requires upgrades to the caster which turns the liquid steel into billets.

The treatment of the above situation for electricity savings and costs is analogous to a new construction scenario where no base case baseline exists. Although this situation is a retrofit of the EAF, the result of the entire mill upgrade will be higher throughput and higher energy use.

Therefore, the savings and costs must be calculated incrementally against a base case which was determined to be the least cost upgrade that is available that meets the future production requirements.

The facility provided a least cost alternative to reach a maximum annual production capacity of 575,000 tls. The upgrades include an increase in the size of the transformer, new electrical feeder lines and flicker control. These upgrades would allow the EAF to operate at a higher power and process the scrap into liquid steel at a higher rate. Analysis of the data showed the energy intensity of the projected base case was 343 kWh/tls for production up to 575,000 tls/yr. This results in a projected base case baseline of 197,000 MWh/yr assuming production of 575,000 tls/yr.

Figure 2. Off-gas Treatment in a Typical Consteel® Plant, Compared to a Conventional EAF (Memoli, 2008)



Electricity Savings Analysis

Three possible approaches for reviewing the proposed electricity savings were identified: first principles calculation of heat transfer from off-gas to scrap, benchmarking analysis of operational data from a comparable mill with an operating Consteel® system, and a literature review of published case studies for Consteel® installations.

Given the information obtained through from the vendor on the heat and mass balance of the Consteel® system a comprehensive energy model based on first principles was partially successful. A range of possible savings was estimated using engineering principles and assumptions for the heat recovery portion of the measure. An energy model was developed to calculate the heat absorbed by scrap in Consteel® tunnel through the two pre-heating stages:

combustion of natural gas and EAF's off-gas. To calculate the transferred heat in each stage, the simplified heat equation was used,

$$Q = m \times c\ (T_2 - T_1)$$

where Q is the transferred heat, m is the total mass of scrap, c is the heat capacity of scrap and T_1 and T_2 are the scrap temperatures before and after the heat transfer process respectively. Assumptions made in developing the heat model include the heat transfer efficiency values and the final temperature of scrap before entering EAF. The final temperature of scrap in the Consteel® tunnel could vary from 300°C to 600°C (Jones, 1997; Herin, 1996. Therefore, a sensitivity analysis was performed to determine the change in energy intensity improvement. The results predicted savings ranging from 20 kWh/tls to 60 kWh/tls. The energy model did not consider the effects of other process inputs such as oxygen and carbon.

In order to benchmark the measure and the potential electricity savings, operating data obtained independently from a mill of similar size and having a Consteel® installation was required. However, this type of detailed operating information is proprietary and not available.

In the absence of detailed benchmarking data, the fall-back approach involves comparing the proposed savings against available literature and case studies on EAF scrap pre-heating and Consteel® technology. The literature review indicated energy intensity improvements of 45 kWh/tls to 65 kWh/tls (Jones, 1997; Memoli, 2010; Martin et. al., 2000). Case studies have been published from two plants where Consteel® has been implemented. The findings are summarized in Table 1.

One major difference between the proposed Consteel® process at the facility and the other two plants is the preheating of scrap by natural gas burners before it enters the Consteel® tunnel. This additional stage of preheating makes the projected energy intensity of 343 kWh/tls more probable.

Table 1. Proposed vs. Case Studies

	Ivaco (Projected), ON	**Ameristeel NC (Henin, 1996)**	**Co-Steel Sayreville, NJ (Seaburg, 1998)**
Year Consteel® Installed	2013	1990	1994
Year Data Reported	2012	1995	1998
Capacity, MW	35.7	24	35
Capacity, Mt/hour	82.6	54	82
Capacity, Mt/year	521,630	551,268	680,388
Tap to tap time, minutes	50	49	53
Electricity Consumption, kWh/Mt	343	373	390
Electrode Consumption, kg/Mt	1.20	1.7	1.75
Oxygen Consumption, Nm^3/Mt	30.40	22.2	23
Natural Gas Consumption, Nm^3/Mt	9.50	0	not available
Carbon Consumption, kg/Mt	19.60	not available	not available
Simple Payback, year	1.98	2	not available

Note: Mt is "metric tonne" of product

The facility's application was an estimated energy intensity improvement of 38 kWh/tls. Since the 38 kWh/tls improvement in energy intensity is within the range estimated by our energy model with reasonable operating assumptions and is supported by the literature review findings, it was concluded that the predicted electricity savings are reasonable and achievable.

It was identified that additional connected load would be required for ancillary equipment to support the Consteel® system which would be netted out from the electricity savings estimate.

This equipment is comprised of ancillary pumps and conveying equipment which were estimated to require 900 MWh/yr. The ancillary equipment's annualized energy consumption is small compared to the estimated savings that result from the pre-heating and well within the uncertainty range of the analysis. For the final assessment of the savings, the ancillary loads were ignored. The consumption of the ancillary loads would be captured through the M&V reporting after the measure is in service.

Based on the expected future production rate of 575,000 tls/yr and 38 kWh/tls savings it was determined that 21,686 MWh/yr of savings can be achieved.

Additional benefits and costs were identified in the context of the proposed heat and mass balance and changes in the use of consumables (electrodes, oxygen, carbon and natural gas) that were expected through the implementation of the Consteel® system. Additional costs would be incurred because of the natural gas that would be used in the tunnel section of the Consteel® system. Additional savings would result from the reductions in the consumption of electrodes, oxygen and carbon. The facility expects a net benefit of $9.77/tls ($CDN). Further reductions in operating costs are expected from a reduction in the frequency of EAF relining though these savings were not quantified.

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