CONSTEEL® EVOLUTION, THE SECOND GENERATION OF CONSTEEL® TECHNOLOGY[1]

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Abstract

After more than 20 years from its first commercial installation, with 41 references worldwide (8 of which are on the way), Tenova's Consteel® technology has become a proven steelmaking technology, appreciated for its efficient use of energy and raw materials, operational and maintenance ease, and environmental friendliness. The experience made throughout these years, on Consteel® electric arc furnaces running in quite different scenarios have given Tenova's team several ideas how to improve the technology.(1) Improvements were investigated with a deep look on the complex scrap heating phenomenon taking place inside the Consteel® system by means of lab tests and CFD analysis. The changes introduced with the new Consteel® Evolution span on the entire system: from the EAF design up to the heating tunnel section, where the most noteworthy change in the system has taken place. The main driver for the whole development has been the reduction the electrical energy consumption by means of an improved scrap heating inside the tunnel: reshaping the tunnel geometry, using EFSOP® off gas analysis measurements and using Air/Gas Burners to help the initial melting of the charge. Replacing electric energy with chemical energy provided by burners reduces the operating costs, in particular for all those areas where natural gas has become largely available and inexpensive as the United States with the development of the Shale Gas industry.

Key words: Consteel® System; Continuous charging; Steelmaking; CFD; Burners.

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1 INTRODUCTION

After more than 20 years from its first commercial installation, with 41 references worldwide (8 of which are on the way), Tenova's Consteel® technology has become a proven steelmaking technology, appreciated for its efficient use of energy and raw materials, operational and maintenance ease, and environmental friendliness. The experience made throughout these years, on Consteel® electric arc furnaces running in quite different scenarios have given Tenova's team several ideas how to improve the technology.(1) Improvements were investigated with a deep look on the complex scrap heating phenomenon taking place inside the Consteel® system by means of lab tests and CFD analysis.

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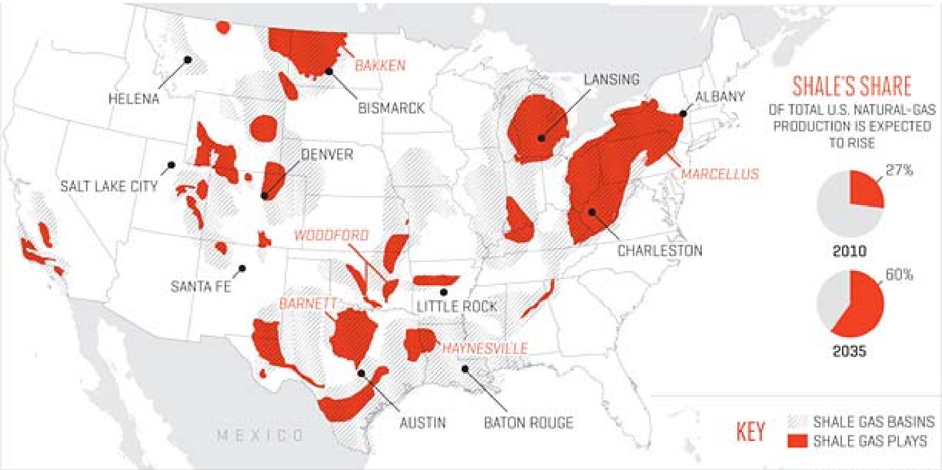

SOURCES: EIA; IHS

Figure 1. Shale gas basins and plays.

2 THE CONCEPT OF CONSTEEL® EVOLUTION

In a standard Consteel® system, scrap is conveyed to the EAF through a heating tunnel where it encounters the off gasses coming out of the furnace at about 1,500 degrees C, so to exchange heat with the gasses increasing its temperature before entering the molten bath of liquid steel.

The Evolution concept starts with splitting this heating tunnel in two sections: the tunnel A, which remains the same one of the standard system and the tunnel B where scrap is heated by burners, a dedicated scrap heating tunnel burners. Basically a reheat furnace, tunnel B, is placed on top of the Consteel® conveyor before the scrap enters the standard Consteel®, tunnel A.

Tunnel B is refractory lined and provided with air/natural gas burners located on the roof, at a relatively short distance from the scrap surface. In such configuration the burner flames impinges, relatively undisturbed, on the scrap layer with sufficient momentum to penetrate its cavities, heating it more uniformly.

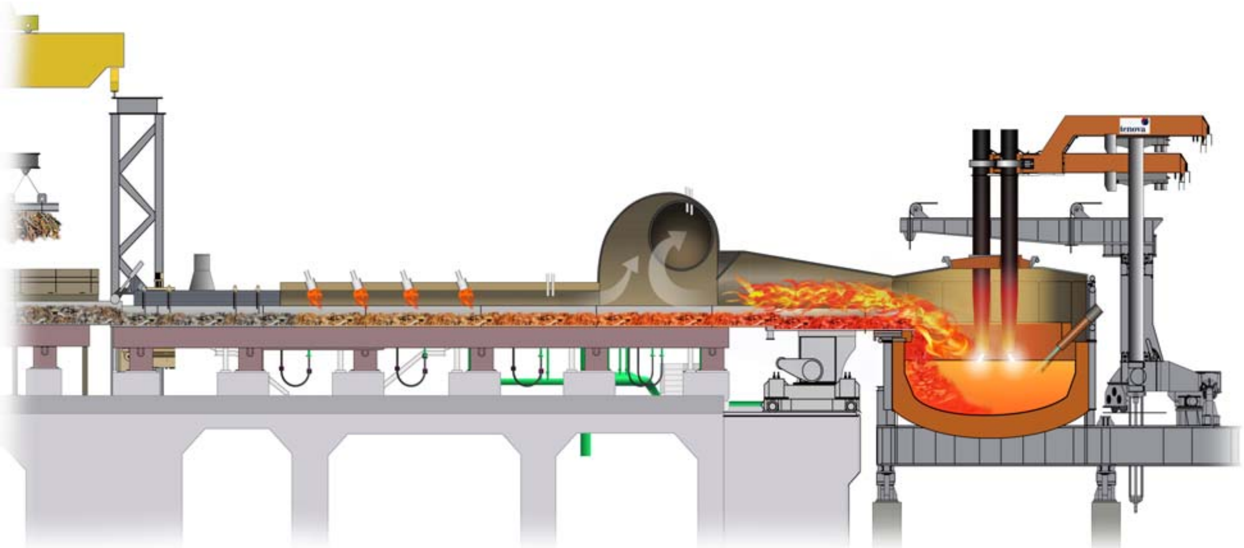

Figure 2. Conceptual configuration of the Consteel® Evolution EAF.

Tunnel B configuration was studied by means of a synergic approach between a series of laboratory trials, to investigate the effects of an impinging flame on the heating process of scrap located inside a conveyor, and CFD simulations based on an original scrap model validated by experimental data.

3 HEAT EXCHANGE MODELLING IN THE SCRAP DUE TO FLAME IMPINGEMENT

Flame impingement heating of solids has been used for many years to enhance the convective heat transfer from combustion products to the charge. Some typical applications include melting of scrap metal, shaping glass, heating metal bars, metal fabrication and assembly including soldering, brazing, cutting and welding.(2) In EAF steelmaking is common practice to use oxygen/fuel burners in order to achieve a faster and more uniform meltdown of the charge, avoiding cold spots;(3) in such case, the main goal is to achieve a fast scrap meltdown in a specific zone. On the contrary, in the envisioned application of burners to a continuous charging process, the burners will heat the scrap bed that has a speed ranging from 1.5 m/min to 5 m/min. Any significant melting must be avoided to prevent meltdowns on the bottom of the steel slip-stick conveyor; the uniformity of the heat flux is, therefore, an important feature for this new type of scrap heating process.

Very limited literature is available on air-gas burners for scrap heating, therefore physical and mathematical models have been set up to evaluate the effects of the various parameters affecting the heating phenomenon. Parameters to consider are:

- the position of the burner in respect of the scrap bed;
- the burner operating conditions;
- the different shape and layering of the scrap pieces.

3.1 Physical Modeling

Experimental test rig includes:

- ceramic fiber lined furnace characterized by internal dimension of 2,020 mm x 1,740 mm x 1,470 mm;
- scrap bucket (800 mm x 780 mm x 750 mm), water cooled on two sides.

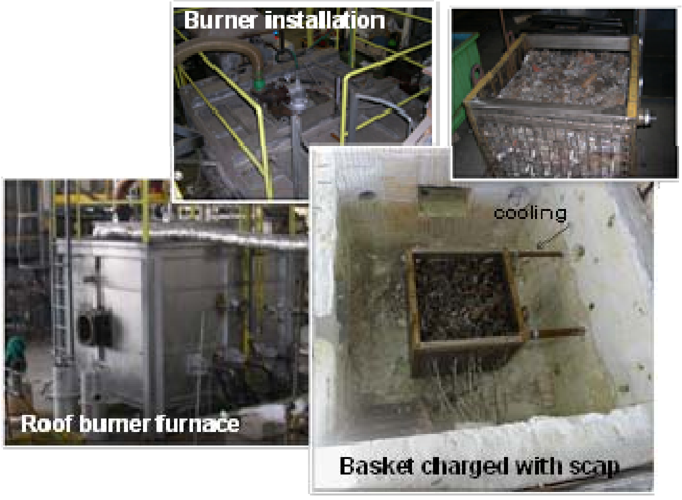

Figure 3. Experimental test rig set up at CSM's Combustion Station.

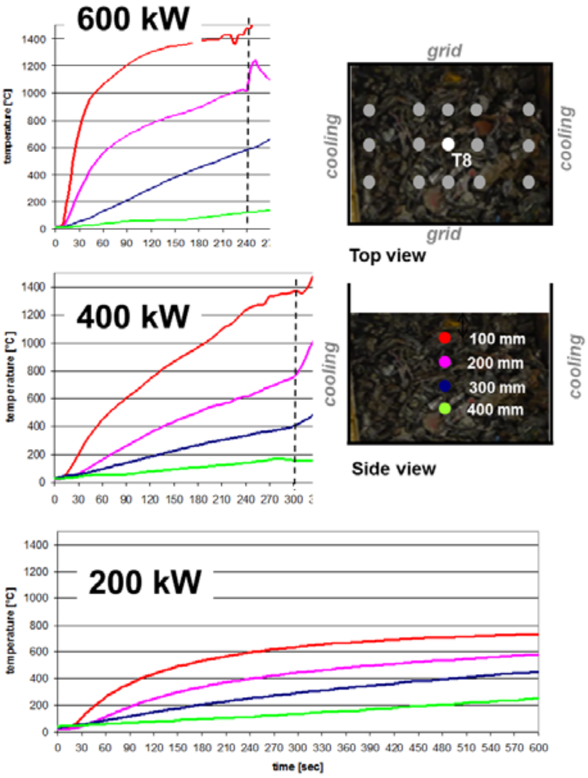

Figure 4. Temperature measurement for a bucket charged with shredded scrap.

The tests have been performed using a commercial available 600 kW Tenova's THS burner(4) with combustion air at ambient temperature. The bucket, charged with about 500 kg of scrap (layer of 600 mm), has been instrumented with 75 thermocouples to monitor the temperature evolution during the heating process at different scrap height from the top (100/200/300/400/50 mm); other four thermocouples have been placed very close to the scrap surface (5 mm), just to monitor the initial heating.

Figure 4 reports the temperature evolution with time for the thermocouple 8 (T8) placed at the center of the scrap bulk; this test was performed using shredded scrap, with three different level of the burner power: 200 kW, 400 kW and 600 kW. In order to preserve the test setup from local scrap meltdowns it was chosen to stop the test at a temperature of about 1,250°C on the top layer.

These first results have provided useful information regarding:

- the required distance between the burner and the scrap surface;
- the correct power density to be achieved inside the heating tunnel equipped with multiple burners; and
- maximum amount of heat to the charge before the occurrence of a significant superficial meltdown.

3.2 Mathematical Modeling

One of the goals of the scrap heating trial was to provide data for the tuning of a mathematical model of the scrap, to be used in a complete Computational Fluid Mechanics (CFD) simulation of scrap heating inside the tunnel equipped with burners. The CFD model was targeted, also, at the definition of the proper distance between the scrap and the burner, to achieve the most uniform heating, taking into account the interaction between several burners and include the effects of radiation in the evaluation of the scrap heating phenomenon, since it is known that radiation plays an important role in the case of a complete tunnel; the mathematical model has been developed inside AnsysFluent® CFD code.

The task has involved the development of a comprehensive model of the fluid dynamic, mixing and reaction of the gaseous species, heat transfer between the tunnel and the moving scrap. Towards this end, several sub-models have been necessary, including:

- proper turbulence model to represent the burner flame;
- reaction mechanism of natural gas;
- interaction between turbulence and chemistry;
- radiation from the flame to wall and from wall to scrap;
- solid scrap movement;
- flame penetration inside the scrap charge cavities.

The main effort has been the achievement of a suitable scrap representation, being the other sub-model already set-up and validated at CSM for the modeling of burners and re-heating furnaces.(5) Multiphase transport phenomena in porous media is an issue. Literature on the matter approaches this problem assuming local thermal equilibrium between the solid and the fluid phase. That assumption is not realistic in this specific case. Attempts have been done by Dr. Gordon Irons of McMaster University to model the scrap melting process in EAF by oxygen/fuel burners and electric arcs without this assumption,(7) however, a validated model that includes, also, the effects of radiation within the scrap pieces has not been available in literature yet. Therefore, due to the difficulty of developing a comprehensive model for the complex heating phenomena taking place in such heterogeneous material as the scrap, a simplified model has been set up for the case.

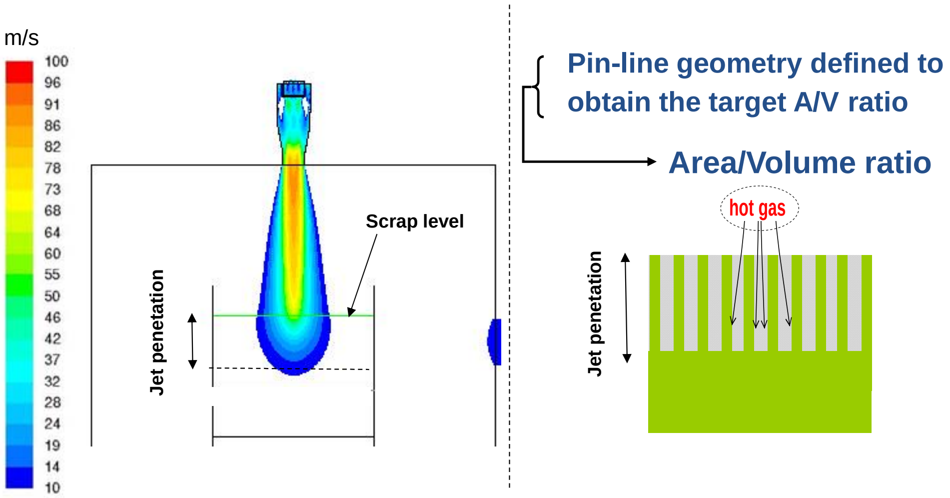

Figure 5. Scrap representation developed for the case.

First, the penetration of the flame inside the scrap cavities has been obtained considering the scrap as a porous media, using the Brinkman-Forschheimer extended Darcy Model.(8) The porosity and permeability of the various scrap types have been defined by using the above noted McMaster University formulation and parameters (void/filled volume ratio, scrap characteristic lenght) for scrap characterization. To take into account the convective heat transfer due to penetration of the flame and, at the same time, the heat transfer by radiation, the scrap has been represented with a "groove geometry": the depth of the groves has been assumed equal to the flame penetration length calculated in the previous step, whilst the groove's width has been selected in order to maintain the same ratio between area and volume (A/V) of the scrap being considered.

Area (A) and volume (V) have been calculated according to the porosity and characteristic dimension of voids considered in the previous step. Then the scrap has been represented as a solid material with equivalent density (r_{equiv}) and equivalent conductivity (k_{equiv}) calculated as follows:

$$\rho_{equiv} = \frac{\dot{m}_{charge}}{S_{charge} \cdot V_{charge}} \qquad k_{equiv} = \frac{k_{Fe} \cdot \%}{100} - \frac{k_{air} \cdot (1 - \%)}{100}$$

Where m_{charge} is the mass flow of scrap inside the conveyor, S_{charge} is the cross section of the scrap layer, V_{scrap} is the transport velocity of scrap inside the conveyor, k_{Fe} is the conductivity of pure iron, k_{air} is the conductivity of the air, % is the ratio between equivalent density of the charge (r_{equiv}) and density of iron (r_{Fe}).

The accuracy of the model has been verified comparing the results of the experimental trials with shredded scrap. The test rig, including the furnace, the burner and the bucket have been modeled first for the heating test with the burner set at 200 kW of power, in order to reach a steady state condition.

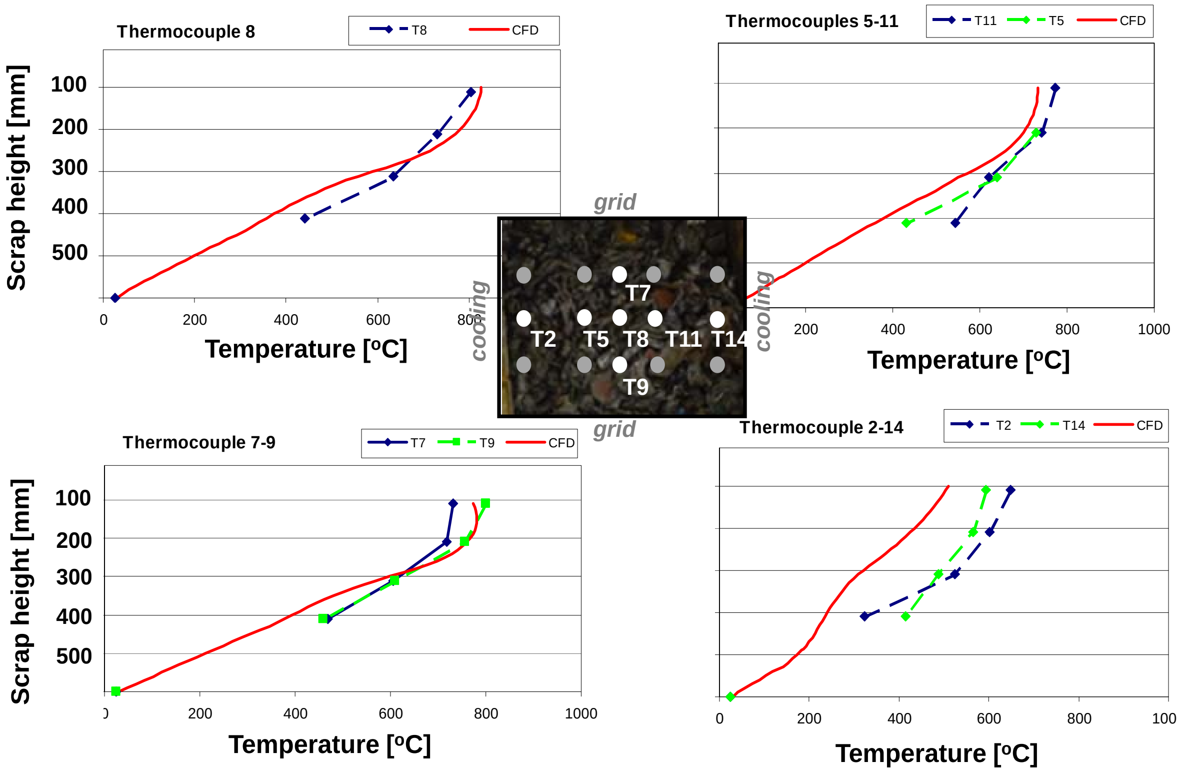

Figure 6. Scrap model validation: 200 kW burner power on shredded scrap at steady state conditions, experimental vs. CFD results.

Due to the good results for the steady state case, the test with 600 kW has been also considered. In this condition, since the steady condition could not be reached experimentally, a translation velocity has been imposed on the scrap layer, to simulate the proper residence time under the burner. The quality of the comparison between measured and calculated temperature is very similar to the previous case. In Figure 7 is reported the temperature map for the vertical plane, just under the burner axis, for the physical test and CFD simulation.

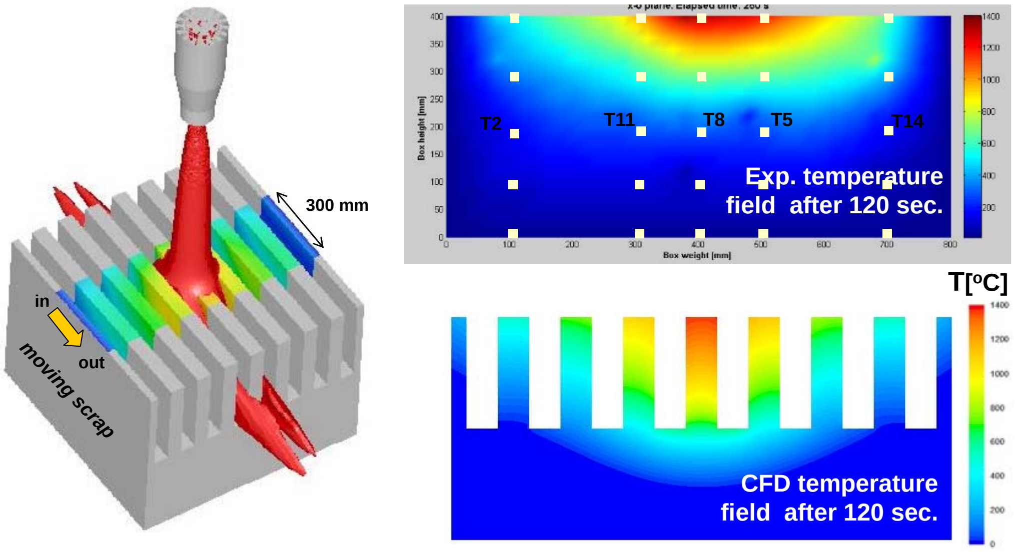

Figure 7. 600 kW burner on a moving shredded scrap, experimental vs. CFD results.

Measurement and calculations using different scrap mixes have confirmed the capability of the approach to predict the flame penetration and the effects of flame impingement heating, including the representation of radiation within the scrap.

4 SCRAP HEATING MODELING IN THE CONSTEEL® TUNNELS

The scrap model developed for the representation of the scrap heating with burners – tunnel B – has been also applied to the simulation of the classic scrap heating by means of the melting process off-gas – tunnel A – considering the effects of draft air intake and the combustion of CO inside this tunnel. Figure 8 reports the comparison of the heating curve in a conventional tunnel (20,000 mm x 2,000 mm x 2,000 mm), for the same working condition of the EAF, in the case of scrap modeled as a moving solid (no porosity) and with the new model, still considering the use of shredded scrap. With the new scrap model, a higher average temperature of the scrap is achieved towards the connecting car zone (the last part of the conveyor that discharges scrap into the furnace) where the draft air ingress produces a vortex structure that attaches the CO combustion to the scrap surface, generating a velocity field characterized by significant vertical component towards the scrap. These results coming from CFD simulations have been confirmed by field observations that have pointed out a better heating of the charge inside the last portion of the tunnel when operating a Consteel® with a porous scrap charge.

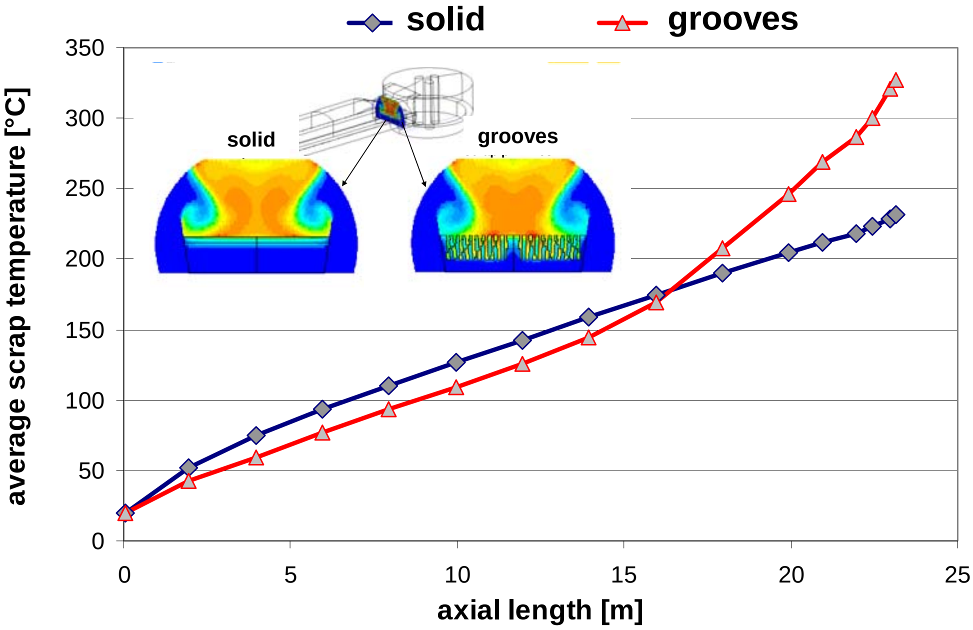

Figure 8. Scrap heating curve for different scrap types: solid and porous (shredded).

After achieving a satisfactory scrap model, it was possible to continue the CFD study for different configurations of the tunnel implementing the flame impingement heating concept. The main goal for this work has been the definition of design guidelines for this tunnel in order to achieve the best possible heat transfer efficiency, with a natural gas consumptions similar to those used in conventional Electric Arc Furnace (<9 Nm^3/t). Soon it was discovered that a modular approach, such as the one shown in Figure 9, was the way to go.

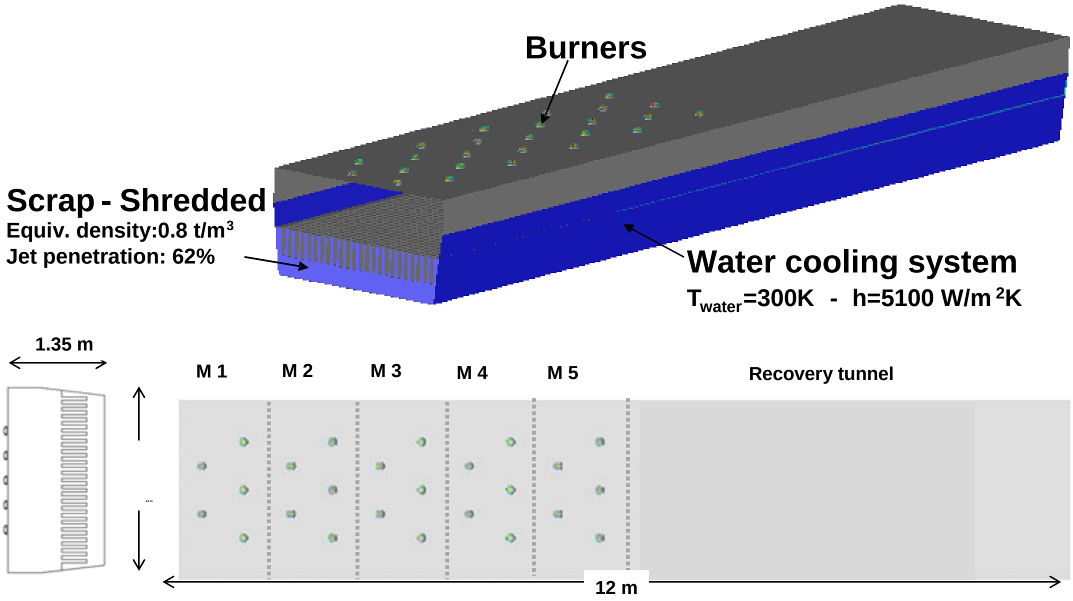

Figure 9. Example of a heating tunnel equipped with burners: 5 zones, each made by 5 burners.

Figure 10 reports some CFD simulations for this tunnel configuration. The tunnel length is maintained fixed (12 m) while the burner zones are switched on to maintain a constant specific consumption (5.7 Nm^3/t) at a different scrap feeding rate and, consequently, different scrap velocity: zone 1 and 2 for 1.76 t/min, zone 1 to 3 for 2.64 t/min, zone 1 to 4 for 3.53 t/min and, finally, all the five zones for 4.4 t/min.

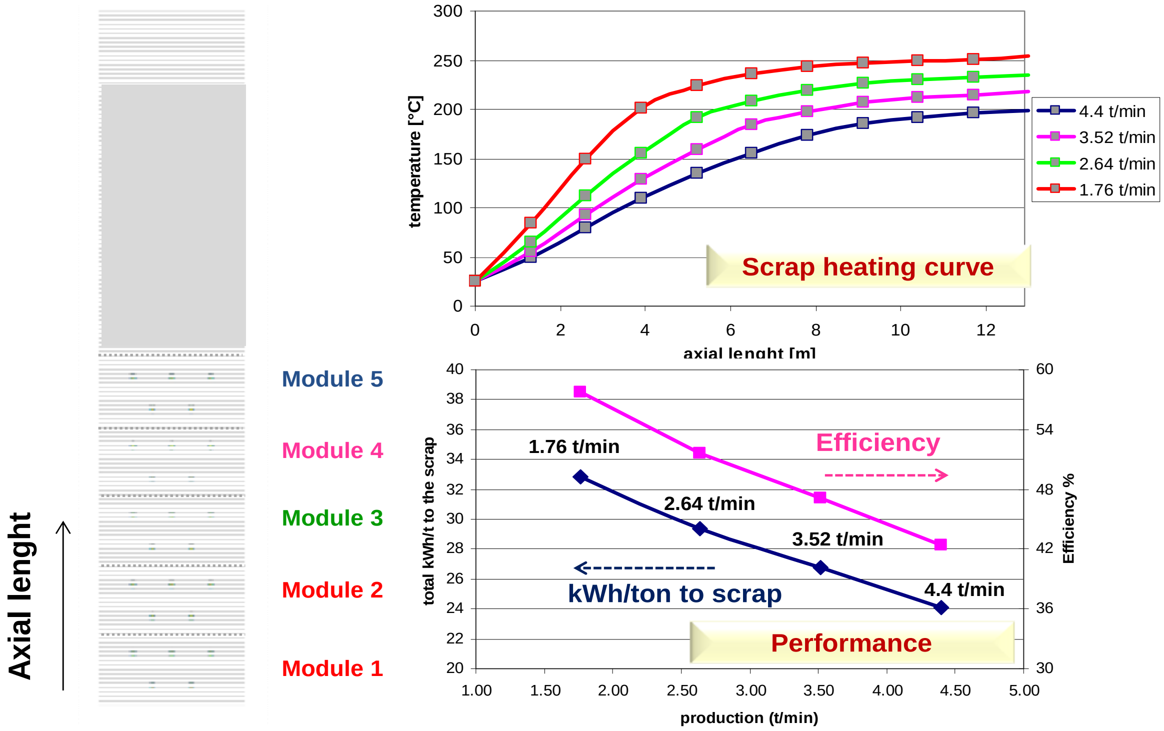

Figure 10. Example of CFD simulation results for tunnel equipped with burners.

According to these findings the value of the specific consumption and calculated efficiency are in the range of those typically recognized for wall mounted oxy/fuel burners used in conventional top-charge EAFs. Considering that combustion is performed with gas and cold air and extrapolating the cold air/fuel burner to an equivalent oxy/fuel burner, an average efficiency higher than 60% is expected, indicating the effectiveness of the flame impingement heating technology also in this type of application.

5 A NEW GENERATION OF FURNACES, THE CONSTEEL® EVOLUTION

The results shown above refer to the very first stage of the research that has led to the configuration of the new Consteel® Evolution system. Thanks to that, a great potential has been found for scrap heating by convection. That has brought to the definition of design criteria for both tunnel B, but also for tunnel A, introducing solutions that increase the turbulence in the primary off-gas stream and, hence, the heating of scrap.

These changes on heating section of the Consteel® process lead to a revision of how to charge and layer scrap on the Consteel® conveyor: the best practice for charge scrap in these new heating conditions is to achieve a porous layer of scrap at the top and placing pig iron and other denser materials in the lower layers.

Improvements have been made also in the configuration of the burners: the burners to be used are rated for a power input higher than 700 kW and their flame has been optimized for the application.

The control system for the burner section, and for the entire system, will take advantage of Tenova Goodfellow's EFSOP® technology, to achieve a dynamic optimization of the operational parameters.

Table 1 reports performance level achievable with a Consteel® Evolution furnace.

Table 1. Performance achievable with Consteel® Evolution EAF technology

Heat size	100	tls
Power on	33	min
Power off	7	min
Electric energy	297	kWh/tls
Oxygen	33	Nm^3/tls
Natural gas	8.5	Nm^3/tls
Coal	20	kg/tls
Electrode	1	kg/tls

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