Development of an Electric Arc Furnace Simulator Considering Thermal, Chemical and Electrical Aspects

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1. Introduction

This paper describes the design and development of an industrial electric arc furnace (EAF) simulator, based on the electrical, hydraulic, thermal, chemical and mass-transfer mathematical models proposed in our previous studies.[1–4] The obtained models, the parameters for which were estimated using the actual EAF operational data, are at this point incorporated into an operator and/or technologist training simulator, featuring all the important aspects of the EAF steel-recycling process. The purpose of the presented simulator is to cover most of the main processes in the EAF's operation, as well as to include several possible desirable and undesirable scenarios that occur while operating the EAF. Available EAF simulators are rare, at least as far as can be judged from publications and other accessible sources. One source that covers many steel-making processes, including the online EAF simulator, is the World Steel Association, by the University of Liverpool;[5] their simulator focuses mainly on the chemical parts of the melting process. However, no information about the simulator's background is provided, which would show the depth of the modelling work applied. The other reported EAF simulators are mostly developed to the stage of a software simulation, which cannot be considered as a simulator in the true sense of the word, but rather as a simulation tool for obtaining different study results.[6,7]

2. Project Design and Development

2.1. Simulator Frame

All the modelled EAF processes proposed in our previous studies were implemented in the Matlab engineering software and represent a complete simulational/developmental environment for the EAF processes. Matlab's engineering orientation allows a reasonably unproblematic usage of the various mathematical functions needed in the models. However, the simulations can only be performed by an experienced user with a detailed knowledge of the process and the

program. For this reason, and due to the fact that Matlab lacks a suitable user-friendly interface and graphic support, the Matlab sources were enhanced with all the necessary additional features, and the final version of the EAF simulator was implemented using the software of Evon Automation: XAMControl.[8] The used framework represents a powerful, object-oriented software in the field of industrial automation that utilizes all the modern features from the visualization to the programming of the basic PLCs. Since it is based on the .NET framework, with MS-SQL support and uses the C# programming language with additional mathematics libraries from 2-control Aps[9] its software capabilities are almost unlimited. Some of the main features provided are:

- consistent and continuous object orientation,
- PLC programming in IEC-1131-3 and/or in standard language,
- database support, archiving,
- 3D visualization, animations,
- centralized administration and programming, decentralized execution,
- replay manager, alarm, journal, log-book, *etc*.

The architecture of the simulator is divided in three main layers, *i.e.* from the lowest - field level, utilizing PLCs and other IO (input/output) devices, through the middle - SCADA/database level, to the highest - management/visualization level including operator supervision and support. Since it is designed as supervisory control software, all three layers are scanned and executed in a loop, allowing cycle times as low as 1 ms (dependent on code complexity; lower sample times can be achieved with user-defined loops for each sublevel). The simulator, besides the automation hardware and devices support, also allows real hardware to be replaced with software substitutes on its PLC level, meaning that any hardware part or device can be emulated using the software code and vice versa.

2.2. EAF Simulator

From the developmental point of view, the presented EAF simulator is composed of several objects, each representing a certain sub-model (electrical, hydraulic, chemical, *etc*.) of the complete EAF process. Besides the basic objects describing the sub-models' dynamics, the simulator structure also contains other additional objects used for graphic representations, animations, alarming and user-interface controls. All the objects representing the core of the simulator are interrelated by means of the input/output variables needed for a proper function of the environment. The conceptual flowchart of the program is shown in **Fig. 1**.

Figure 1 shows the conceptual core of the presented simulator, including the flows between the user interface and the simulator core, including its four particular models/objects and inputs to the each model. The inputs to each model underly the corresponding simulator action, such as: transformer control, bucket control, addition control, *etc*. The arrows show the direction of the corresponding data flow and represent the internal inputs/outputs of the models. The values of all displayed models, which are important for the application are used as outputs to the user interface and displayed in a numerical and/or graphical form.

Since the main focus of the simulator's design was to rep-

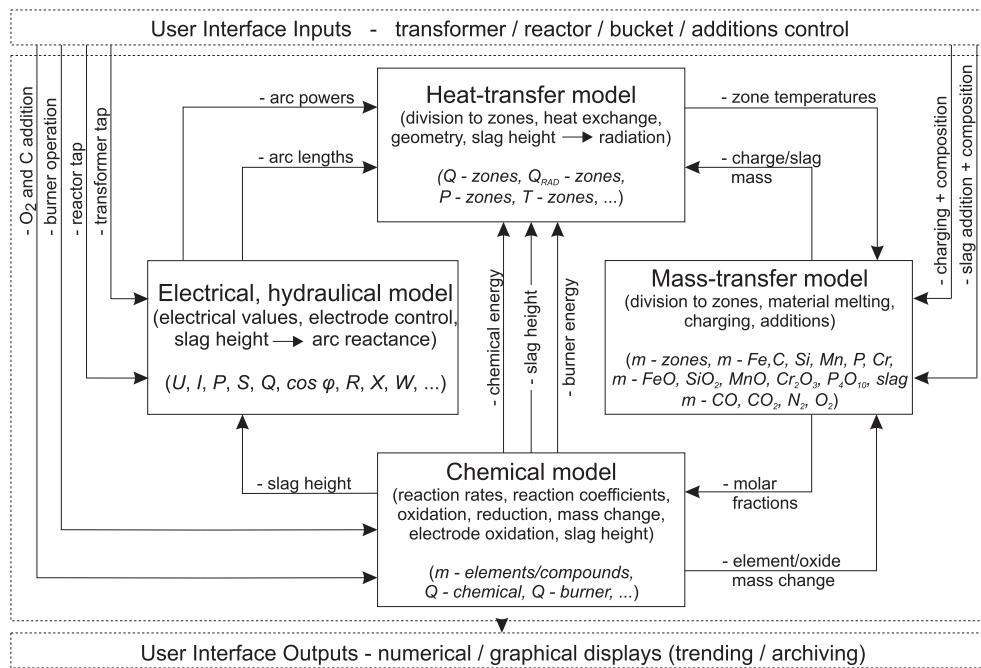* Corresponding author: E-mail: vito.logar@fe.uni-lj.si

Fig. 1. Conceptual flowchart of the program. The upper and the lower frames represent the user interface (inputs/outputs), while the middle frame represents the core of the simulator, composed of several models/objects with display of their main features and the values calculated in them. The meaning of the values and a detailed description of the models are already shown in.[1–3]

resent the EAF melting process in a simple, transparent and concise way, the simulator possesses only the needed features, such as:

- online calculation of over 100 physical values related to the scrap-melting process (voltages, currents, powers, temperatures, masses, energies, chemical compositions, *etc*.),
- calculation of the endpoint simulation values (steel composition, yield, energy consumption, additive consumption, costs per ton, *etc*.),
- online graphical visualization of the EAF process including a numerical display of all the calculated values,
- archiving and online trending of user-selected values with a possible comparison with the measured data,
- selectable auto/manual EAF operation, *i.e.* predefined melting program (auto) or online user interaction (manual) with the process (control of the initial scrap composition, input energies, reactants, oxygen, slag-forming elements and carbon addition, oxy-fuel burners, time-lines, *etc*.),
- alarming in the case of an incorrect user interaction and/or decision (operation over/under the furnace capacity, vessel (panels) overheating, overloading, *etc*.),
- selectable simulation speed (real time or accelerated up to 20 times),
- comparison of the simulated values with the user defined measurements.

Figure 2 shows the graphical layout of the simulator, with the EAF animation display in the center. During the furnace's operation the EAF animation is intended for user-presentational purposes to get a quick look at the current stage and the conditions of the melting process. The animation itself includes the movement of the electrodes, the variable

lengths of the arcs, the movements of solid and liquid scrap due to melting, electrode glow due to the heating and the oxy-fuel burner operation. All the animated actions are proportional to the actual process values obtained from the core models. The left-hand side of the window represents the simulation control panel, designed for the user's interaction with the simulation progress, allowing the user (in manual mode) to start/stop/pause/reset the simulation, adjust the simulation speed, set transformer and reactor taps, determine the number, load, composition and charging time of the baskets, turn on or off the oxy-fuel burners, start/stop the oxygen lancing, carbon injection, slag-forming additions and off-gas fan speed. Whenever the automatic mode is selected, all the adjustments are made according to the predefined melting program included in the simulator or user-predefined settings. The right-hand side of the simulator window represents the simulated-values panel, showing online calculated data, such as: amount of liquid and solid steel; amount of liquid and solid slag; steel composition (elements: Fe, C, Si, Mn, Cr and P in mass%); slag composition (compounds: FeO, SiO_2, MnO, Cr_2O_3, P_4O_{10}, CaO, MgO and Al_2O_3 in mass%); gas composition (gases: CO, CO_2, N_2 and O_2 in mass%); relative pressure; total consumption of oxygen, carbon, gas, lime; and total energy input and output per ton of liquid steel. At the bottom of the main window the trends of the user-defined process values are visible for the selected period of time.

As can be seen in Fig. 2, the presented EAF simulator covers most of the processes appearing during the EAF's steel-recycling process. At this point the simulator layout is displayed in a general (demo) form, mainly focusing on its functionalities; however, due to its modular core design, it can quickly be adopted to suit any industrial application regarding its interface design and graphical layout.[10]
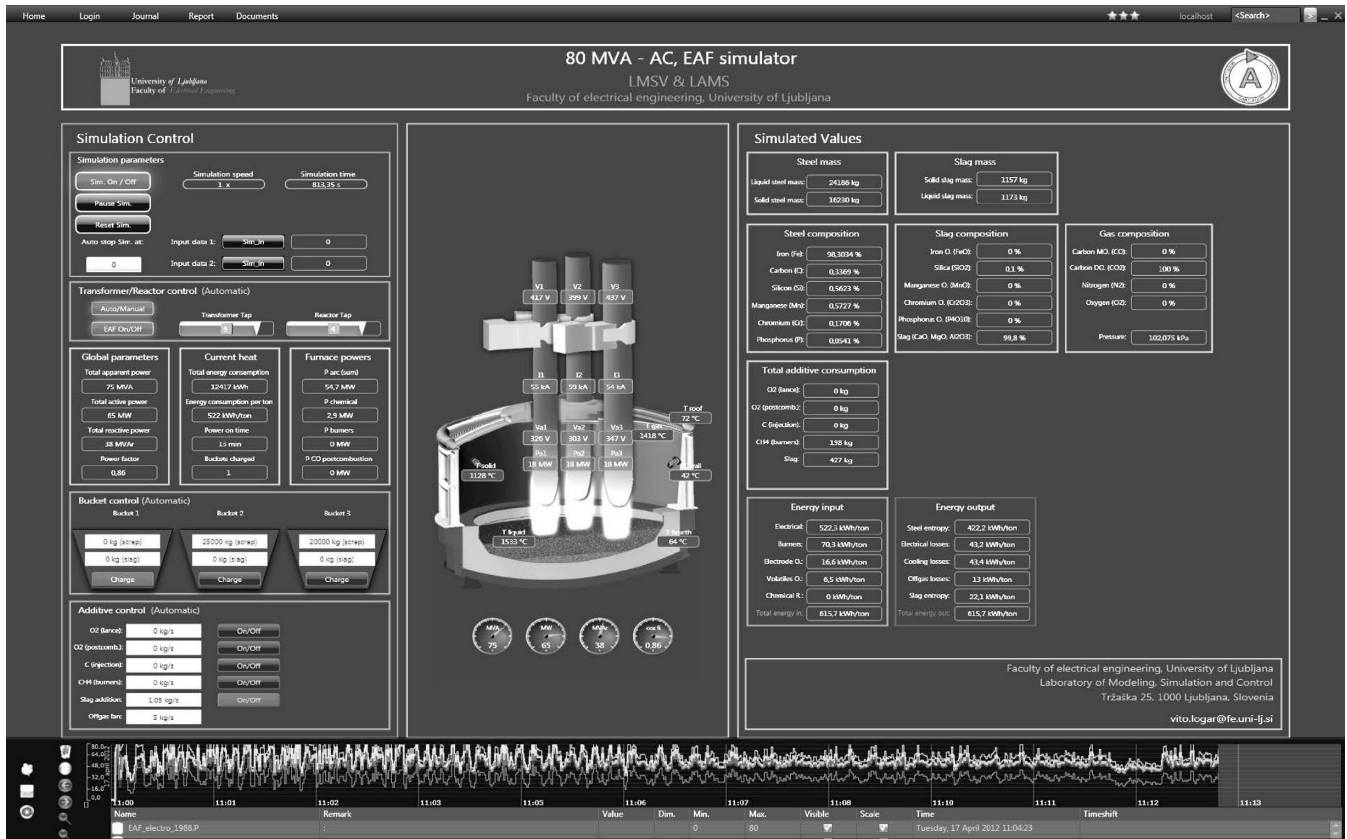
Fig. 2. Electric arc furnace simulator user interface; shown in automatic mode with the arcs engaged.

3. Conclusion

In this paper a simulator of the complete EAF system is presented, covering most of the processes that appear during the steel-refining process. The simulator was developed with the intention to be as transparent and user-friendly as possible. For this reason, some processes and its process values (hydraulics, radiation, input and output thermal and chemical powers, *etc*.) which are otherwise included in the simulator core models are at this point graphically and numerically omitted in the interface. Only the values relevant to the technologists or operators are shown on the screen. However, if needed, due to the modular graphics design, all the necessary values can be added to the existing simulator layout. Possessing a realistic and accurate simulator of the furnace processes can be valuable in terms of operator training or an enhancement of the steel-recycling process. In the latter, the simulator allows fast and process-safe testing of different melting scenarios and/or other changes to the melting program. Moreover, the simulator can also be used in terms of a softsensor, estimating the process values which are crucial for the EAF operation (steel temperature, radiation index, slag height, *etc*.) but are due to the nature of the process not measured online.

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