REVIEW ON STATISTICAL ENERGY DEMAND MODELS FOR THE EAF AS PROCESS EVALUATION TOOLS

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INTRODUCTION

Efforts to optimize the steelmaking process in the EAF are difficult to evaluate because of the overall variability of the EAF steelmaking process. In addition, some varying boundary conditions of the process are still difficult to determine like scrap quality, water content of the scrap, slag foaming, hot heel.

Hence and since the available analytical models are still limited, for practical use a number of statistical or empirical models were developed and will be presented and discussed in the presentation.

ENERGY DEMAND MODELS

A number of empirical models for the prediction of the energy demand of EAFs in the steel industry were developed in the recent decades. Some predict the overall energy demand, most predict the specific electrical energy demand.

Köhle[1] was the first to publish in 1992 an empirical model for the electrical energy demand of electric arc furnaces. The model can be used to determine the specific electrical energy demand of an EAF process W_R in kWh/t from typical operational data of the heat:

$$W_R = 300\frac{kWh}{t} + 900\frac{kWh}{t}\left[\frac{G_E}{G_A} - 1\right] + 1600\frac{kWh}{t}\frac{G_Z}{G_A} + 0.7\frac{kWh}{t \cdot K}\left[T_A - 1600°C\right] + 0.85\frac{kWh}{t \cdot min}t_C - 8\frac{kWh}{m^3}M_G - 4.3\frac{kWh}{m^3}M_L \quad (1)$$

with

W_R	Specific electrical energy demand, calculated with the model [kWh/t]	t_C	Heat duration from power-on to begin of tapping [min]
G_A	Furnace tap weight [t]	T_A	Tapping temperature [°C]
G_E	Weight of all ferrous materials [t]	M_G	Specific burner gas [m³/t]
G_Z	Weight of slag formers [t]	M_L	Specific lance oxygen [m³/t]

The model assumes a linear dependency of the specific electrical energy demand from process parameters and input materials. The coefficients of equation (1) were determined by linear regression to process data of 14 different EAFs with tapping weights between 64 t and 147 t. The process data used for the statistical analysis were average data gathered between end 1990 and beginning of 1991 of all 14 furnaces as well as data from numerous heats of two of the 14 EAFs. All of the furnaces investigated operate on 100% scrap and are not using any form of scrap preheating.

After subsequent steps of development, Köhle[2] presented in 2002 the up to now final revision of the electrical energy demand model. The changes in comparison to the first model published in 2000 is the addition of coefficients taking the amount of charged DRI, HBI, hot metal and shredded scrap into account. In addition, coefficients related to the specific consumption of oxygen for post-combustion and related to energy losses were added in equation (2).

$$\frac{W_R}{kWh/t} = 375 + 400\left[\frac{G_E}{G_A} - 1\right] + 80\frac{G_{DRI/HBI}}{G_A} - 50\frac{G_{Shr}}{G_A} - 350\frac{G_{HM}}{G_A} + 1000\frac{G_Z}{G_A} + 0.3\left[\frac{T_A}{°C} - 1600\right] + 1.0\frac{t_S + t_N}{min} - 8.0\frac{M_G}{m^3/t} - 4.3\frac{M_L}{m^3/t} - 2.8\frac{M_N}{\frac{m^3}{t}} + NV\frac{W_V - W_{Vm}}{kWh/t} \quad (2)$$

with the additional values

G_{DRI}	Weight of DRI [t]	t_N	Power-off time [min]
G_{HBI}	Weight of HBI [t]	M_N	Specific oxygen for post-combustion [m³/t]
G_{Shr}	Weight of shredder [t]	W_V	energy losses (if measured)
G_{HM}	Weight of hot metal [t]	W_{Vm}	mean value of W_V
t_S	Power-on time [min]	NV	furnace specific factor (0.2 … 0.4)

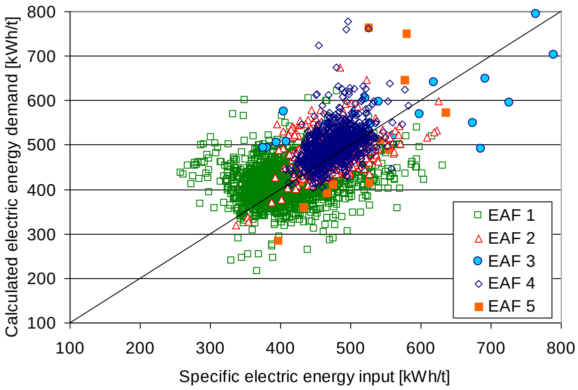

Fig. 1 Comparison of calculated electrical energy demand with real data from five EAFs in Europe, all charged with 100% steel scrap and alloys, partly high alloyed [3]

The application of the model by Kirschen et al.[3] to five European EAFs showed very good predictive capabilities of the model with regard to average values. For the prediction of the electrical energy demand of single heats on the other hand, the model is less suitable due to the high scatter visible in Fig. 1.

EAF SPECIFIC ENERGY DEMAND MODELS

Kirschen et al.[4] discuss the adaption of the Köhle model to specific furnaces as well as an entirely new furnace specific regression model in comparison to the Köhle model. They show results for an EAF charged with scrap, cold and hot DRI. Since the use of hot DRI is not included in the Köhle model, a completely new furnace specific model is created by a stepwise multiple linear regression. The model is based on available operational data. Therefore additional data not present in the Köhle model (e.g. metal yield, charged carbon, etc.) is used on the one hand side, while other data is not used because of missing relevance for the process (e.g. hot metal, shredder, etc.) or because of statistical insignificance for the model (e.g. tapping temperature). The model resulting from the stepwise multiple linear regression is given in equation (3).

$$\frac{W_R}{kWh/t} = -152.56 + 4.2146\frac{G_E}{t} - 5.0795\frac{G_A}{t} - 1.447\frac{G_{HDRI}}{t} - 1.3039\frac{G_{CDRI}}{t} - 1.9784\frac{G_{Scrap}}{t} + 3.0905\frac{G_A}{G_E} + 0.48352\frac{t_{ttt}}{min} + 4.8648\frac{t_S}{min} - 0.46807\frac{t_N}{min} - 0.31964\frac{t_{prep}}{min} - 0.0040591\frac{M_{O2}}{m^3} + 6.8737\frac{G_{chC}}{t} + 4.7919\frac{G_{injC}}{t} + 3.9598\frac{G_{Lime}}{t} + 1.3675\frac{G_{Dolo}}{t} + 3.8739\frac{P_{AVG}}{MW} \quad (3)$$

where W_R, G_E, G_A, t_S, t_N are the same process parameters as in equation (2), and:

G_{Scrap}	Weight of Scrap [t]	t_{ttt}	Tap-to-tap time [min]
G_{HDRI}	Weight of hot charged DRI [t]	t_{prep}	Preparation time [min]
G_{CDRI}	Weight of cold charged DRI [t]	M_{O2}	Total oxygen [m³]
G_{chC}	Weight of charge carbon [kg]	G_{Dolo}	Weight of dololime [kg]
G_{injC}	Weight of injected carbon fines [kg]	P_{AVG}	Average power [MW]
G_{injC}	Weight of injected carbon fines [kg]		

Fig. 2 shows results for the EAF calculated with the Köhle model and with the new regression model. While the R^2 value and the root mean squared error (RMSE) of the Köhle model is 0.31 and 74.4, respectively, the new regression model has R^2 and RMSE values of 0.96 and 10.7. Apart from the high accuracy also for single heats for this specific furnace, the stepwise multiple linear regression delivered additional information with regard to the statistical relevance of various process parameters to the electrical energy demand of the EAF.

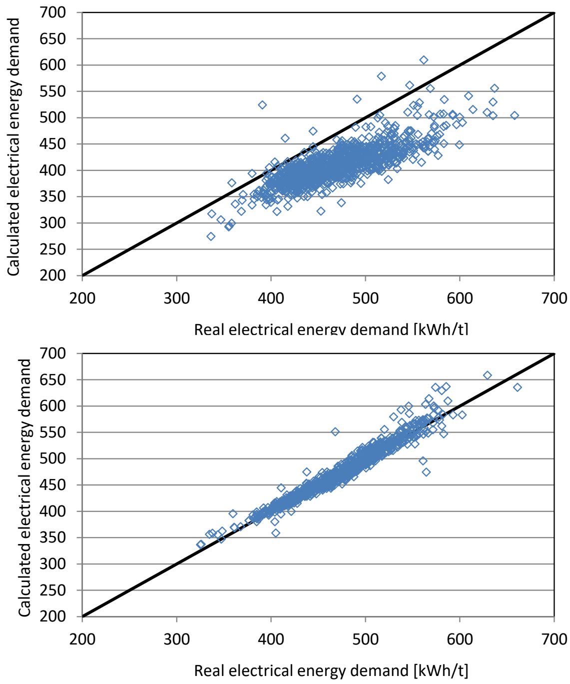

Fig. 2 Real specific electrical energy demand compared to the calculated values calculated with the Köhle model (top) and the new regression model (bottom) [4]

CONCLUSION AND OUTLOOK

An interesting application of the energy demand models, independent of their accuracy regarding single heats, is the comparison of production and/or trial campaigns at a furnace. Given that most of the influencing factors are unchanged or fluctuating in the usual range, differences in the electrical energy demand can become visible.

When an EAF specific energy demand model is created by statistical regression, it can also give interesting insights and starting points for further discussions and investigations just by looking at what process parameters have a statistically significant or insignificant influence on the electrical energy demand of the steelmaking process in the EAF.

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