DEVELOPMENT OF A MODEL FOR CALCULATING ENERGY EFFICIENCY IN STEEL FOUNDRIES

Siddhartha Biswas, Department of Materials Science & Engineering, Missouri S & T
Email: sbt65@mst.edu

Dr. Kent D. Peaslee, Professor, Department of Materials Science & Engineering, Missouri S & T
Email: kpeaslee@mst.edu

ABSTRACT
Improving energy efficiency has been a major concern for the steel foundries in recent times. To calculate energy efficiency and finding a user friendly way of determining options of improvements are the prime goals of this study. A spreadsheet model in Microsoft Excel is developed and will be provided to the steel foundries to evaluate their respective energy situation. On the basis of this evaluation, possible options for improving energy efficiency will be suggested and the effect of the changes will be monitored for further improvement of the model. The operating conditions and parameters are different in every steel foundry and this effort tries to take all of them into account. In this model, Statistical analysis of historical data and industrial measurements are used for the calculations and predictions. The statistical calculations were performed by using STATGRAPHICS commercial software.

1. INTRODUCTION
Steel is the most commonly used material in our day to day life. To remain in competition with other materials like plastics, composites, other metals, the cost of steel production needs to be reduced. Cost of energy has a major share in overall cost of steel production. And the energy cost is increasing every day. Energy production is also related to carbon dioxide emission. So using the energy efficiently is beneficial from both economic and environmental perspective. In an effort to understand the energy usage situation in US steel industry, in 2000, John Stubbles [1] studied the historical perspective and tried to find opportunities in increasing energy efficiency. In 2008, Kent Peaslee et al [2,3] studied the improvements in energy efficiency by means of industrial trials. To monitor and suggest ways for further improvements in energy efficiency, a bench mark was set to compare the energy situation in the future. To take the benchmarking process one step ahead, an excel spreadsheet model is designed and will be supplied to the foundries. To design the spreadsheet, the collected industrial data was analyzed statistically to find the important variables responsible for energy efficiency in the steel foundry. The principle obstacle to model such a spreadsheet is the fact that every steel foundry is different. The operating conditions and practices are different in each and every steel foundry. To account for all the variables, multi linear regression of all the variables was done to find the relationships. These relationships are compiled and used in the model to calculate the present energy efficiency and predict the impact of any change in practice in terms of savings. The aspects and assumptions of the model are given under section 2. The calculations and the variables used are described briefly under section 3. Concluding remarks are offered in section 5.

2. THE SPREADSHEET MODEL
The Spreadsheet model is the tip of an iceberg. All the industrial data collected over the last six years are at the base of that iceberg. These data are used to find relationship between different factors for various conditions. The calculations are done both for the induction furnaces and the electric arc furnaces (EAF). For example, Fig.1 and Fig.2 depicts relationship between power consumption and total power on time in EAF. The two conditions plotted here are cold start and hot start respectively. Cold start is the heat with cold refractory lining. The power consumption is relatively higher in this case as the lining needs to be soaked before heating the metal. All the subsequent heats are considered as hot start. Linear trend line was drawn using Microsoft Excel to find the relationships. Figure 3 shows that with increasing delay after one heat to next heat, the power consumption increases. This is due to the cooling of the furnace after the heat. The extra amount of energy is required to soak the furnace refractory wall. The red circled data points are considered as anomaly and thereby do not represent the bulk situation. These are discarded while modeling the spreadsheet.

Laboratory study of factors affecting energy consumption during melting in foundries is done at Missouri S & T foundry lab. Improving melting efficiency using new type of refractory materials developed at Missouri S & T was also studied [4]. Future industrial trials will be conducted to find out the usability of this refractory material in industrial scale.

The use of chemical energy or oxygen co-jet in addition to the electrical energy has the potential of reducing the energy consumption and increasing the energy efficiency. Figure 4 and 5 shows the improvements possible by using chemical energy and co-jet respectively. Industrial trial data with chemical energy and co-jet have been considered in the model and predictions can be made about the suitability of their usage in a steel foundry. In many cases better scheduling provides significant savings in energy as shown in the results. Which one of the above mentioned methods is suitable for a specific foundry can be determined by the model.
Figure 1: Relationship between Power Consumption and Power on Time for cold heats in Plant A.

\[
P_{\text{Consumption}} = 2.5891 \times \text{Power on Time} + 388.71 \\
R^2 = 0.2219
\]

Figure 2: Relationship between Power Consumption and Power on time for hot starts in Plant A.

\[
P_{\text{Consumption}} = 2.5891 \times \text{Power on Time} + 388.71 \\
R^2 = 0.2152
\]

Figure 3: Relationship between power consumption and delay time for plant A.

\[
P_{\text{Consumption}} = 0.2561 \times \text{Next power on delay Time} + 448.63 \\
R^2 = 0.0168
\]

Figure 4: Relationship between power consumption and tap to tap time with and without chemical energy (SiC) addition.

\[
y = 0.8941x + 322.81 \\
R^2 = 0.2937
\]

\[
y = 0.4481x + 389.27 \\
R^2 = 0.0646
\]
The variables that are considered for the model are – tap to
tap time (power on time + delay for the next heat time), energy
consumption, productivity, chemical energy, weight of metal
melted, slag practice etc. All these information was statistically
analyzed. Fruehan et al [5] calculated theoretical energy
perspective to produce steel. In their study, the energy values
have also been converted to Carbon dioxide emission in order
to indicate the potential for reduction in emissions of this
greenhouse gas. Theoretical thermodynamic calculations were
also done at Missouri S&T by using FACTSAGE 6.2 [6]. These
theoretical values for ideal conditions were compared with the
industrial data to calculate energy efficiency. Computational
Fluid Dynamics (CFD) modeling by ANSYS FLUENT 12.0
was also done to find out the effect of possible changes in
practice. Heat balance and components of heat losses were
analyzed using FLUENT and FACTSAGE. The relationship
calculated by above mentioned methods are compiled and used
for the model. Figure 6 shows the process flow chart used to
design the model.

2.1. Features of Spreadsheet
- Adaptable with different foundry practices
- User Friendly
- Suggest a to do list to improve energy efficiency
- Make predictions about effect of process improvements
- Calculate efficiency for current foundry practice
- Compare results with previously saved data

2.2. Assumptions
- The thermodynamic calculations are done under
equilibrium conditions
- While calculating relationships between variables,
values that are far off from normal are discarded as
they do not represent the regular practice.
- Effect of refractory lining is ignored in this model, but
will be included in future
- Temperature loss in metal transfer from furnace to the
molds are ignored

3. CALCULATIONS
The statistical analysis of the historical data was done by
STATGRAPHICS commercial software. Table 1 shows the list
of input values that are required to get the evaluation of the
recent condition of a steel foundry and for the prediction of
future improvements. To make this model suitable for specific
conditions and practices of a steel foundry, base data and
coefficient reflected by variables are calculated. These base
points are calculated from statistical analysis of historical data
and industrial trials. More variables will be added from future
trials. Microsoft Excel Solver add-in is used in the model for
the cost minimization calculation. Visual Basic for Applications
(VBA) will be used in future development of the model.

Table 1: Input variables used for the spreadsheet model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>We</td>
<td>Base electrical energy consumption, kWh/t</td>
</tr>
<tr>
<td>Ce</td>
<td>Cost kWh electrical energy, $/kWh</td>
</tr>
<tr>
<td>Cch1</td>
<td>Cost of chemical energy from oxifuel burner,$/kWh</td>
</tr>
<tr>
<td>Cch2</td>
<td>Cost of in-situ chemical energy,$/kWh</td>
</tr>
<tr>
<td>A1</td>
<td>Coefficient reflected by effect of Furnace load</td>
</tr>
<tr>
<td>X1</td>
<td>Relative Furnace load</td>
</tr>
<tr>
<td>A2</td>
<td>Coefficient reflected by effect of heat time</td>
</tr>
<tr>
<td>X2</td>
<td>Relative heat time</td>
</tr>
<tr>
<td>B1</td>
<td>Coefficient reflected by electrical energy decrease by using oxyfuel burner</td>
</tr>
<tr>
<td>B2</td>
<td>Coefficient reflected by electrical energy decrease by using in-situ chemical energy</td>
</tr>
<tr>
<td>Wch1</td>
<td>Oxyfuel burner energy, kWh/t</td>
</tr>
<tr>
<td>Wch2</td>
<td>In-situ chemical energy, kWh/t</td>
</tr>
</tbody>
</table>
4. RESULTS AND DISCUSSIONS

Missouri S & T received recent data to evaluate the current energy efficiency of melting and compared it with previous studies. The addition of SiC to the charge reduced the energy consumption by 7% and tap-to-tap time by 8% from the standard 2005 practice. Plant B’s current melting practice (no SiC) is more efficient than in 2005, reducing the overall energy by 5% and increasing productivity by 35%. The major improvement has been in scheduling with a significant reduction in the delay between tap and the next heat (50% reduction) and in melting time (20% reduction).

5. CONCLUSIONS

The Spreadsheet model is designed as a tool for the use of steel foundries. It will enable the steel foundries to have a better understanding of their energy usage and help them increase their energy efficiency and reduce the steel production cost. The improvement of the model is an ongoing process. More industrial trials will be done to validate the model.

6. ACKNOWLEDGMENTS

The author wishes to thank the support of the Intelligent Systems Center. The author also wishes to thank Steel Founders Society of America and the member companies that have provided support for this work. The author is also thankful to Dr. Simon Lekakh for his help and suggestions in making the model. This work is supported by the U.S. Department of Energy (DOE) assistance Award No. DE-FC36-04G014230, Energy Saving Melting and Revert Reduction Technology (“Energy SMART”) program, support does not constitute an endorsement by DOE of the views expressed is the article.

7. REFERENCES