IETE Journal of Research

ISSN: 0377-2063 (Print) 0974-780X (Online) Journal homepage: http://www.tandfonline.com/loi/tijr20

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To cite this article: P N Mishra, S K Kak & S C Srivastava (2001) An Expert System for LD Steel Making, IETE Journal of Research, 47:1-2, 85-89, DOI: 10.1080/03772063.2001.11416207

To link to this article: https://doi.org/10.1080/03772063.2001.11416207

Published online: 26 Mar 2015.

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IETE Journal of Research
Vol 47, Nos 1&2, January-April 2001, pp 85-89

An Expert System for LD Steel Making

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LD process of stealmaking accounts for 70% of steel production throughout the world. Due to various constraints like the complexity of LD process; variation in quantity, quality and grade of input materials; varying operating conditions, random parameters and their values; the interventions of an expert and skilled operator is necessary to tackle the complex situation. To overcome this, there exists, a need of a system, which does not only possess the process control capabilities, but also emulates operator's expertise in terms of his knowledge and skill. Such a system has been developed named "Expert Steelmaker". The paper discusses the "Expert Steelmaker" which can presently be used in an advisory mode by the LD steelmaking operator.

Indexing terms: Expert system, LD steelmaking, Process control, Charge calculations, Materials and energy balance.

LD process of steelmaking accounts for 70% of steel production throughout the world. Due to various constraints like the complexity of LD process; variation in quantity, quality & grade of input materials; varying operating conditions, random parameters & their values; the interventions of an expert and skilled operator is necessary to tackle the complex situation. To overcome this, there exists a need of a system which does not only posses the process control capabilities as discussed else where [1] but also emulates operator's expertise in terms of his knowledge and skill. We have developed such a system, named "Expert Steelmaker". No expert system tools have been used for building our "Expert Steelmaker" but, it has been developed using Prolog language only.

A few other expert systems for LD steelmaking have been reported in the literature. One such system is LD-ES which was built using an expert system support tool named FACOMESHELL [2]. The ESHELL runs on UTILISP, a dialect of LISP. It uses fuzzy logic for some of its knowledge representation. Another expert system combined with a mathematical model for BOF process control has been reported by T Yoshida *et al* [3]. This system applies a rule based reasoning technique to improve the output of presently available mathematical models and uses fuzzy reasoning to estimate in furnace reactions. Further, using an expert system, a one man operation of blowing has been established [4].

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Since engineering problem solving is not entirely symbolic and sophisticated numerical computation need to be performed to determine physical system parameters, a knowledge based system in that problem solving environment needs to be integrated with computational procedures for successful application. Sunderam *et al* [5] has proposed organisation of numeric computation using a task structure vocabulary and demonstrated its potential as a viable tool for integration of numerical methods with knowledge based systems. However, our prolog based ES does the computation as well as symbolic processing.

The paper discusses the "Expert Steelmaker" which can presently be used in an advisory mode by the LD steelmaking operator.

TOWARDS BUILDING AN EXPERT COMPUTER SYSTEM

The most important step in building such a system is knowledge acquisition followed by its representation for machine use and Interpretation. After building knowledge base, inference engine and user Interface are created so that inferences are drawn and made available to the outside user.

The first step in acquiring the process knowledge is the identification of an expert or group of experts. It has been pointed out by Mittal and Dyn [6] that multiple expert consultation is beneficial than basing the system on the knowledge of a single expert; further the expert should be always a practicing one. We also arrived at the same conclusion independently and have, therefore, chosen multiple experts for the codification of knowledge to be used by our system. These experts have been working in industry, in the area of LD steelmaking for more than a decade. Also, these persons are considered as experts by their colleagues.

Various expert operators of leading steel plants of India have been interviewed in various phases to acquire the operational knowledge; these, however; showed area of commonality and some regions of conflict in their expertise which had then to be resolved by crosschecking and observing the process.

The knowledge thus acquired had to be suitability represented with the help of a high level computer language. The evolution of certain high level languages for Artificial Intelligence has resulted in standard languages like LISP, ADA, PROLOG etc. IBM PC compatible turbo-Prolog has been used by us for the development of our expert system. It has been earlier demonstrated by Veronica Dahl [7] that logic programming can be used as a representation of knowledge for both database knowledge as well as procedural knowledge.

In the development process of this expert system we have used the knowledge available in the references [8,9] extensively in addition to the knowledge elicited from experts from iron and steel industry. Modular programming has been used for realizing the expert system. An important feature introduced is a timer module that runs in background so as to remind the operator about different actions to be taken during a particular heat cycle.

The aim and scope of "Expert Steelmaker"

The aim of designing this Expert Steelmaker was to develop an adviser to an operator for complete heat cycle of an LD furnace. It has to achieve the following:

(*a*) To calculate the amount of materials needed to make a desired quality and quantity of steel. These materials are hot metal, steelscrap, burnt lime, burnt dolomite, oxygen etc.

(*b*) To optimize the process under various defined constraints and

(*c*) To guide the operator through the complete heat cycle specifying actions to be taken in response to feedback given interactively by the operators.

Our approach to achieve these aims is through knowledge based reasoning, dynamic process modeling and interactive operator's response evaluation. Rules have been formulated on the basis of knowledge acquired from experts and existing literature on LD steelmaking. The declarative and procedural knowledge thus obtained have both been represented in Prolog.

Blow control strategies for LD process control have widely been used throughout the world, where in, blowing control is dependent on the operator's observation of the process. If the heat becomes too wild and sloppy, appropriate action is taken on the lance height or oxygen blowing rate. Sometime materials additions are also done. We have adopted a similar strategy in our expert system.

Various methods for automatic blowing control of BOF using computers have been employed since 1960. These control methods are classified into two types:

(*a*) Static control in which the necessary amount of oxygen and that of the coolant are fixed before blowing by statistical or theoretical analysis of data on mass balance and heat balance.

(*b*) Semi dynamic control in which the carbon content in the molten steel is estimated and controlled to the aim value by analysis and information derived from the exhaust gas. However, the controllability of these methods is limited and not always satisfactory in achieving the composition and temperature at the end of blowing. A combination of static control and dynamic control have been proposed earlier [10,11]. Optimal control for LD converter process have also been reported [12]. Even then operator is a necessary element in controlling the process.

Our system with static control coupled with blow control strategy in the form of knowledge base (KB) evolves into an optimal dynamic control for the LD process of steelmaking.

KNOWLEDGE BASED CHARGE CALCULATION

The knowledge based charge calculation module is the heart of the Expert Steelmaker. It accepts input parameters in the following syntactical format using standard notation of elements and compounds to be provided by the operator of the LD furnace.

Composition of hot metal: Al %, C %, Fe %, Mn %, P %, S%, Si %, other %,

Composition of steel scrap Al %, C %, Fe%, Mn %, P %, S%, Si%, other %.

Composition of gray iron: Al %, C %, Fe %, Mn%, P %, S %, Si %, other %.

Composition of silicon carbide: SiC %, SiO_2 %, Al_2O_3 %, other %.

Composition of calcium carbide: CaC_2 %, CaS %, CaO % other %.

Composition of iron ore: CaO %, FeO %, Fe_2O_3 %, MgO %, MnO %, P_2O_5 %, SiO_2 %, Al_2O_3 %, other %.

Composition of ferro-silicon: SiC %, Fe %, other %.

Composition of burnt lime: CaO %, MgO %, SiO_2, Fe_2O_3 %, Al_2O_3 %, other %, LOI %.

Composition of burnt dolomite: CaO %, MgO %, SiO_2%, Fe_2O_3 %, Al_2O_3 %, other %, LOI.

Composition of steel to be made C %, O %.

Tonnage oxygen O_2 %, by volume, N_2 plus Ar %, by volume.

Element distribution (% of weight charged):

% of C oxidized to CO, % of C oxidized to CO_2.

% of total Mn to steel, % of total Mn to slag.

% of total P to steel, % of total P to slag.

% of total S to steel, % of total S to slag.

% of total Fe oxidized to Fe_2O_2 fume.

Composition of slag (weight ratios) - CaO/SiO_2, MgO/SiO_2, Fe_2O_3/SiO_2.

The output information provided by the charge modules are:

- weight of hot metal,
- weight of steelscrap (or any two combination of materials like hotmetal, steelscrap, gray iron, ferrosilicon, silicon carbide and calcium carbide),
- weight of burnt lime to be added,
- weight of burnt dolomite to be added, and
- weight of tonnage oxygen to be blown

for a ton of steel of desired composition at the desired temperature.

This module works in conjunction with the knowledge base such that if the desired composition of steel to be made is known in terms of grade of steel to be made, it automatically assumes the composition of steel to be made. Additionally, KB has a range of values for all input informations. Whenever, the operator exceeds the limit of the range for an input, while inputting the informations, the system prompts him to recheck. If the operator confirms, KB will update the range of the corresponding input information for future use, giving it learning capability. Otherwise it understands it as a mistake and asks the operator to re-enter the correct value. If the operator is ignorant about the particular input information's value, the knowledge module assume the value based on its latest knowledge of that information.

The charge calculation module has a grade sub module which stores all the composition range for different grades of steel, which are most often produced by a particular steel plant. However, this sub module can be updated for any new type of grade of steel to be produced by dynamically interacting with the knowledge module.

GUIDANCE AND EXPLANATION FOR THE OPERATOR

The expert system (ES) guides the operator of LD furnace through the complete process cycle after outputting the quantity of materials required for the desired heat. It is an interactive process, in the sense that the expert system advises the action to be taken by the operator, waits for his response and then goes to the next action. After estimated time of oxygen blow, it tells that heat is ready to be tapped.

Basic explanation capabilities like answers to what and why type of questions have also been incorporated into the system to make it user friendly. An example is given below:

Operator	What (softblow)
ES	Softblow means keep lance height at more than 2.5 m
Operator	Why (softblow)
ES	Softblow because dc-dt is between 48-60.

RESULTS AND DISCUSSION

To validate and test the charge calculation module, material and energy balance for a few typical cases have been undertaken using data samples from ref [8]. The results are in agreement with the corresponding material and energy values [8] and are given in Table 1. Charge calculation also seem to be reasonable though they have not been practically verified. The response of ES to various input conditions have been evaluated and found satisfactory.

CONCLUSION

An advisory expert system has been developed for LD process steel making which undertakes charge calculation intelligently and guides interactively the operator of LD process for a complete cycle till the heat is ready to be tapped. The system does not use any ES shell and is implemented using Prolog language which has been used for representing declarative and procedural knowledge: timing and mathematical calculation. The system should be quite useful for the Steel Industry. Similar technique may be used in other advisory mode process control application where material and energy balance are important and operator interaction with the process is a necessity. By providing suitable hardware and software interface, the system can be used for on line process control application also.

TABLE 1 Material balance and heat effect at selected temperatures for six cases

Case-I

	Values as per Ref. (8) (kg)	Values as per our expert system (kg)
INPUT ITEMS		
Hot metal	1000	1000
Burnt lime	63	63
Burnt dolomite	20	19.6
99.5% Oxygen	86	85.6
TOTAL INPUT	1169	1168.2
OUTPUT ITEMS		
Steel	912	912.1
Slag	141	140.49
Gas & Fume	116	115.56
TOTAL OUTPUT	1169	1168.15
Heat effect	−131 MCal	−132 MCal

Case-IV

	Values as per Ref. (8) (kg)	Values as per our expert system (kg)
INPUT ITEMS		
Steel Crap	1000	1000
Burnt lime	0	0
Burnt dolomite	0	0
99.5% Oxygen	3	3.36
TOTAL INPUT	1003	1003.36
OUTPUT ITEMS		
Steel	981	981
Slag	13	13.3
Gas & Fume	9	8.69
TOTAL OUTPUT	1003	1002.99
Heat effect	315 MCal	315 MCal

Case-II

	(kg)	(kg)
INPUT ITEMS		
Gray Iron Scrap	1000	1000
Burnt lime	158	157.5
Burnt dolomite	49	49
99.5% Oxygen	92	91.92
TOTAL INPUT	1299	1298.42
OUTPUT ITEMS		
Steel	877	876.6
Slag	340	339.5
Gas & Fume	82	82.1
TOTAL OUTPUT	1299	1298.2
Heat effect	122 MCal	120.5 MCal

Case-V

	(kg)	(kg)
INPUT ITEMS		
Iron Ore	1000	1000
Burnt lime	149	149.1
Burnt dolomite	33	33.38
99.5% Oxygen	−265	−265.2
TOTAL INPUT	917	917.28
OUTPUT ITEMS		
Steel	599	599.3
Slag	313	312.9
Gas & Fume	5	4.8
TOTAL OUTPUT	917	917
Heat effect	148 MCal	148 MCal

Case-III

	(kg)	(kg)
INPUT ITEMS		
Calcium carbide	1000	1000
Burnt lime	−937	−936.5
Burnt dolomite	12	12.1
99.5% Oxygen	655	656.19
TOTAL INPUT	730	731.79
OUTPUT ITEMS		
Steel	14	14
Slag	−32	−31.6
Gas & Fume	748	748.3
TOTAL OUTPUT	730	730.7
Heat effect	−232 MCal	−230 MCal

Case-VI

	(kg)	(kg)
INPUT ITEMS		
Silicon carbide	1000	1000
Burnt lime	5298	5297.9
Burnt dolomite	1648	1648.5
99.5% Oxygen	1900	1900
TOTAL INPUT	9846	9846.4
OUTPUT ITEMS		
Steel	−2081	−2081
Slag	11070	11072
Gas & Fume	857	857
TOTAL OUTPUT	9846	9848
Heat effect	−242 MCal	−380 MCal

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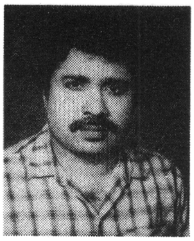
AUTHOR



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