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Design of Experimentation for Cupola Furnace

Hemant R. Bhagat [1], Dr.V.G.Arajpure [2]

[1] *Research scholar, B.D,C.O.Engg. Wardha, (M.S)*
[2] *Principal & Research Guide, Godawari Engineering College, Jalgaon*

Abstract – *Design of Experimentation (DOE) is planning process in a research study to meet specific objectives. The proper planning of an experiment is very much important consideration in order to achieve the research objectives clearly and efficiently with the right type of data and appropriate sample size.*

The evolution of melting process of cupola is a complex phenomenon. There are many factors affecting the performance of melting. In this chapter the attempt is made to present the adopted design of experimentation in detail and to generate design data in the form of evolving experimental data-based models [56] for various dependent/ response variables of melting process of cupola by carrying out field data-based data collection.

INTRODUCTION

Philosophy of A Field Data Based Model

Adoption of basic laws of mechanics could be applied for correlation of various dependent and independent parameters of melting process of cupola in theoretical approach. A theoretical approach can be adopted in a case if known logic can be applied correlating the various dependent and independent parameters of the system. Though qualitatively, the relationship between dependent and independent variables could be known based on available literature data, the generalized quantitative relationship may not be known sometimes due to complexity of phenomenon.

The kinematics of transmission of solid metal to molten metal in cupola is a complex phenomenon. Hence the formulation of quantitative relation based on logic is not possible in case of such a complex phenomenon. On account of no possibility of formulation of theoretical model i.e. logic-based model, only alternative is left to formulate experimental data-based model. This reason cause to adopt an experimental approach to establish the field data-based model. Hence it is proposed to formulate such model in this investigation.

Hilbert Schenk Jr. has suggested a methodology of experimentation to formulate the field data-based models for prediction of behavior of such complex phenomenon as like in melting process. The same approach is adopted in the present research which is stepwise explained below:

(i) Identification of dependent, independent and extraneous variables affecting the phenomenon.
(ii) Reduction of variables by dimensional analysis.
(iii) Deciding the test planning comprising of determination of test envelope, test points and test sequence of experimental plan.
(iv) Design of an experimental set up.
(v) Executing the experimental plan i.e. experimentation.
(vi) Purification of experimental data.
(vii) Formulation of experimental data-based models.
(viii) Reliability of models.
(ix) Optimization of models.
(x) ANN Simulation of models.

System, Causes, Effects and Extraneous Variables

It is well known that any activity occurs because of four essential parameters /sub systems /issues namely System, Causes, Effects and Extraneous Variables .This is illustrated by one activity of gardening .For example, a gardener is performing a digging operation in a garden . This activity is realized by arranging

(a) **System**:This is a specific spot in a garden with naturally available environment conditions of humidity, air circulation, ambient temperature etc.
(b) **Causes**:These are the issues which are actuating the system)which sets the system in action.
(c) **Effect**:These are the responses of the execution of an activity.

(d) **Extraneous Variables**:These are the Factors / Parameters /Causes which do influence the performance of the activity but which cannot be measured .This are at times abstract.

Process ofField data-based data collection

Design of experiment involves following steps:

a) Based on the known qualitative physical characteristics of the phenomenon, identifying the independent and dependent variables which affect the phenomenon. And establishing the dimensional equations for molten metal process in cupola. The experimentation becomes time consuming, tedious and costly if system involves large number of independent variables. So, with the help of dimensional analysis one can reduce the number of variables and hence these reduced number of dimensional equations are the targeted form of mathematical models.
b) Test planning consists of deciding test envelope, test sequence and plan of experimentation for the set of deduced dimensional equations.

It is necessary to evolve the physical design of experimental set up in setting up the test points, adjusting the test sequence, execution of proposed experimental plan, noting down the responses and provision for necessary instrumentation for deducing the relation of dependent pi terms of the dimensional equation in terms of independent pi terms. Experimental set up is designed in such a way that it can accommodate the ranges of independent and dependent variables within the proposed test envelope of experimental plan. After noting down the responses and obtained dimensional relations of dependent pi terms of dimensional equations, the exact mathematical model can be formed within the specified test envelope.

Identification of Variables in Phenomenon

In a very general sense, the term variable is used to describe any physical quantity that undergoes change and ultimately affect the phenomenon under research investigation. The physical quantity is termed as an independent variable if it can be changed without affecting the other quantities and the physical quantity is termed as dependent variables or response variable if it can be changed by variation of one or more number of parameters. If a physical quantity affects our experimental test and if it is changing in random and uncontrolled manner, then it is called extraneous variable. The various dependent variables and independent variables involved in the phenomenon of metal melting process of cupola are described in following tables.

Table of Dependent Variables

Sr. No.	Name of variable
1	Carbon Equivalent
2	Carbon Content
3	Silicon Content
4	Slag at outlet
5	Wood at outlet
6	Pure Pig Iron outlet
7	Cast Iron Scrap Outlet
8	Coke at outlet
9	Waste In front of Cupola
10	Number of Actual Charging required
11	Strength of Material
12	Hardness of Material

Table of Independent Variables

Sr. No.	Name of variable
1	Internal Diameter of Cupola
2	Melting Capacity of Cupola
3	Temperature of Spout
4	Input raw Pig Iron
5	Input Cast Iron Scrap
6	Foundry Return
7	Chura
8	Choke
9	Lime Stone
10	Silicon
11	Manganese
12	Pouring Temperature
13	Liquid Temperature
14	Solid Temperature
15	Acceleration due to gravity

Reduction of Variables using Dimensional Analysis

The given test can be made compact in the operating plan without loss in control on the phenomenon by several methods. The Buckingham's pi theorem is the best known and most powerful tool. Therefore, in this research, Buckingham's pi theorem [56] is preferred and used to perform dimensional analysis of the phenomenon to reduce the variables. Dimensional analysis is an extremely useful mathematical technique used in reduction of variables by forming non-dimensional groups of the variables which are called as pi (π)terms. Deducing the dimensional equation for a phenomenon reduces number of independent variables pi terms in the experiment. The exact mathematical form of this dimensional equation is the targeted model. Thus, this method of dimensional analysis provides a systematic experimental planning and permits the presentation of results in more useful and concise format. Table 5.3 shows various dependent and independent variables involved in the phenomenon with their symbols, units, dimensions, nomenclature and nature.

Formation of pi (π) terms for all Dependent and Independent Variables affecting the phenomenon (Application of Buckingham's Π- Theorem method of Dimensional Analysis)

Formation of pi (π) terms for independent variables

The process of dimensional analysis is followed step by step as explained below:

The Carbon Equivalent, %CEis function of Internal Diameter of Cupoladci, Melting Capacity of Cupola (Mc), Temperature of Spout (Tsp), Input raw Pig Iron (PIip), Input Cast Iron Scrap (CISip), Foundry Return (FRi),Chura(Ch), Choke (Ck), Lime Stone (LS), Silicon (Si), Manganese (Mg),Pouring Temperature (TP), Liquid Temperature (TL), Solid Temperature (TS) and Acceleration due to gravity **(g)**

%CE= f (dci, Mc, Tsp, PIip,CISip, FR, Ch, Ck, Ls,Si, Mg, TP, TL, TS, g) ….. (5.1)

Or, f_1 (dci, Mc, Tsp, PIip,CISip, FR, Ch, Ck, Ls,Si, Mg, TP, TL, TS, g)= 0 ….. (5.2)

Dci, Mc, g and Tsp are considered as the repeating variables (i.e. m = 4)

Total no. of independent variables = n = 15

No. of Π terms = n – m = 15 - 4= 11

$\Pi_{D1} = f_1 (\Pi_1, \Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6, \Pi_7, \Pi_8, \Pi_9, \Pi_{10}, \Pi_{11}) = 0$….. (5.3)

First Π term:

$\Pi_1 = (dci)^{a}{}_1(Mc)^{b}{}_1(g)^{c}{}_1(Tsp)^{d}{}_1 PIip$

$(M)^0(L)^0(T)^0(\theta)^0 = (L)^{a}{}_1(MT^{-1})^{b}{}_1 (LT^{-2})^{c}{}_1(\theta)^{d1}M$

The values of a_1, b_1 ,c_1 and d_1 are computed by equating the powers of M, L ,T &θ on both sides as given below :

For 'M'	For 'L'	For 'T'	For 'θ'
M→0 = b9 **b9= 0**	L→0 =a9+ c9 **a9 = 0**	T→ 0 = - b9 – 2c9 **c9=0**	θ→ 0 = d_9+1 **d_9=-1**

Substituting the values of a9, b9and c9 in the eq. of Π_1 term, we have:

$\Pi_9 = (dci)^0(Mc)^0(g)^0(Tsp)^{-1}Tp$

$$\pi_9 = \left(\frac{TP}{Tsp}\right) \text{................(5.12)}$$

Similarly,

$$\pi_{10} = \left(\frac{TL}{Tsp}\right) \ldots\ldots (4.13)$$

$$\pi_{11} = \left(\frac{TS}{Tsp}\right) \text{..........(5.14)}$$

Thus total eleven pi terms are found out for independent variables which are given in following table 5.4:

Table 5.4 Pi terms for independent variables

pi terms	pi terms equations
π_1	$\pi_1 = \left(\frac{PIip}{Mc}\right)\sqrt{\frac{g}{dci}}$
π_2	$\pi_2 = \left(\frac{CISip}{Mc}\right)\sqrt{\frac{g}{dci}}$
π_3	$\pi_3 = \left(\frac{FRi}{Mc}\right)\sqrt{\frac{g}{dci}}$
π_4	$\pi_4 = \left(\frac{Ch}{Mc}\right)\sqrt{\frac{g}{dci}}$
π_5	$\pi_5 = \left(\frac{Cki}{Mc}\right)\sqrt{\frac{g}{dci}}$
π_6	$\pi_6 = \left(\frac{Ls}{Mc}\right)\sqrt{\frac{g}{dci}}$
π_7	$\pi_7 = \left(\frac{Si}{Mc}\right)\sqrt{\frac{g}{dci}}$
π_8	$\pi_8 = \left(\frac{Mg}{Mc}\right)\sqrt{\frac{g}{dci}}$
π_9	$\pi_9 = \left(\frac{TP}{Tsp}\right)$
π_{10}	$\pi_{10} = \left(\frac{TL}{Tsp}\right)$
π_{11}	$\pi_{11} = \left(\frac{TS}{Tsp}\right)$

CONCLUSION

We have taken the live problems of Cupola furnace in industry .The groups of independent variables which may influence the metal melting process operation phenomenon are identified as Related to Cupola Specifications Related to phase transformation Temperature The parameters which are constant during the experiment were recorded first. The field experiment was planned to record the Carbon Equivalent, Carbon Content, Silicon Content, Slag at outlet, Wood at outlet, Pure Pig Iron outlet, Cast Iron Scrap Outlet, Coke at outlet, Waste In front of Cupola, In design of experimentations to solve the problems the dependent and independent variables are reduced to the extent possible. Ultimately output of Number of Actual

Charging required, Strength of output Material and Hardness of output Material for the metal melting operation successfully recorded.

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