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Effect of scale-up, design and process parameters on the productivity of ancient iron making process and recovery of iron in the product

C. B. SINGH*, R. N. GUPTA[1], A. K. VAISH[2] and B. N. ROY[3]
O.P. Jindal Institute of Technology, Raigarh - 496 109, India
[1]RVS, CET, Jamshedpur - 831007, India
[2]The M.S. University of Baroda, Vadodara - 390 001, India
[3]Metallurgical Engg. Deptt., BIT, Sindri, Dhanbad - 828 123, India

Abstract : Indian iron was famous in ancient times and it was exported to many countries throughout the world Though isolated pockets of iron making existed practically all over the country, yet there was no attempt of systematization and wider propagation. Recently an attempt has been made to establish proto-type furnace and scale it up with modifications in its design.The effect of scale -up.design and process parameters on the productivity of ancient iron making process and recovery of iron in the product has been discussed.

Keywords : Ancient iron, Proto-type, Scaled-up, Heat recovery, Productivity, Recovery of iron, Process parameters.

INTRODUCTION

Iron has been produced and used in India over 3000 years[1]. The technology of iron making has been handed over from one person to another within a limited group.Indian tribals and artisans produced quality iron prtoducts earlier than the developed countries, making use of local iron ores and wood charcoal. the travel records of Voysey[2], Buchman[3], Hadfield[4] and Varier[5] and a paper of Prof. Turner[6] clearly shows the supremacy of Indian iron and steel technology even in 18th century. Vaish et al.[7] have recently discussed the development of ancient iron making technology. The primitive iron making furnace used in age old process was about 80 cm. in height and built of ordinary clay with concave bottom. It comprised of a clay pipe as tuyere through a parabolic opening in the bottom of the furnace. Foot operated bellows were used for air blast. The fluid slag ($2FeO.SiO_2$) was removed intermittently through slag hole. After about 4 hour operation the lump of sponge iron luted with slag was removed with the help of tongs, A lot of entrapped slag was liquefied and forced out during heating and hammering. This clean mass of iron comprised of about 0.08-0.15%C, 0.02-0.05% Si, 0.02-0.03%S, 0.02-0.04% P and 0.001-0.006% Mn apart from about 3 to 7% slag as inclusions. It was extremely ductile and used for making a varieties of implements and decorative articles. The drawbacks with age old technology of iron making were critically reviewed and the design of the furnace was modified. The furnace was scaled - up accordingly in order to make the process more efficient, eco-friendly and economically viable for tribal artisans. The proto-type furnace (Bastar model) has been scaled-up to almost five times by increasing the height and diameter of furnace thereby increasing the productivity of the process and the recovery of iron in the product. The scaled-up process has enough scope for commercialization since the articles made out of its product have very good export potential.

**Corresponding Authors Email : cbsingh@opjit.edu.in*

SCALE-UP AND DESIGN OF PROTO-TYPE FURNACE

Initially the operation of primitive furnace for ancient iron making was studied in detail before establishing a proto-type furnace (Bastar model). The proto-type furnace was further scaled-up by (i) increasing the diameter of furnace at its neck region (d) as well as at the bottom of the hearth region (D) and (ii) increasing the shaft height of the furnace (H). The scale -up and design criteria were d/D ratio, H/D/2 ratio, shaft height(H),stack angle (θ) and volume of furnace (V) as shown in Table 1.The design of the tuyere and its location and type of the air blowing system and its design are to be suitably optimized so as to increase the productivity of the process. The proto type furnace(Bastar model) in operation is illustrated in Fig. 1, whereas the scaled-up furnace without and with heat recovery system are illustrated in Figs. 2 and 3 respectively.

Table 1 : Design parameters of proto-type furnace and scaled-up furnace without and with heat recovery system

Sl. No.	No. Type of furnace	Furnace cross section	Diameter of furnace at the neck region d (cm)	Diameter of furnace at the bottom of hearth region D (cm)	Height of furnace shaft H (cm)	d : D ratio	H/D/2 ratio	Stack angle θ (degrees)	Furnace volume V (m^3)	No. of tuyers	Temp. of air blast (^oC)	Exit gas flame Temp. (^oC)
1	Proto-type (Bastar model)	Circular	16	28	80	0.57	5.71	85	0.0309	One	Ambient Temp. 25-35	600-650
2	Scale-up without heat recovery system (Bastar Model)	Circular	28	48	127	0.58	5.29	84	0.14671	One	Ambient Temp. 25-35	500-550
3	Scale-up with heat recovery system (Bastar Model)	Circular	28	48	127	0.58	5.29	84	0.14671	Three	125	450-500

Fig. 1: A glimpse of proto- type furnace (Bastar model) in operation

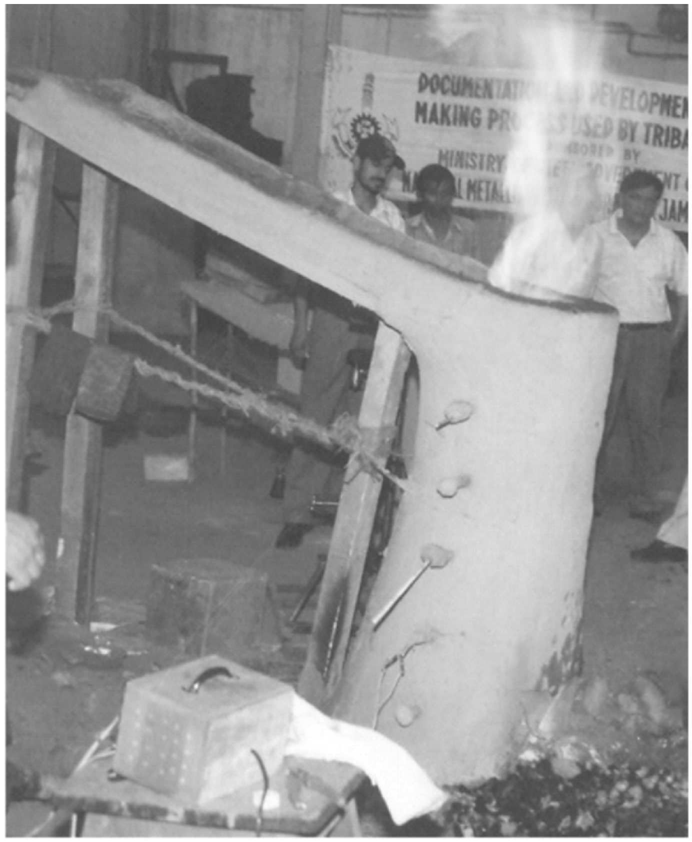

Fig. 2 : Scaled-up furnace (Bastar model) without heat recovery system in operation.

Fig. 3 : Scaled-up furnace (Bastar model) with heat recovery system in operation.

PROCESS PARAMETERS

The charge mix comprises of self fluxing iron ore and wood charcoal. The size of these raw materials ,their chemical analysis and mineralogy play specific role in the operation of iron making. The process of iron ore reduction and its smelting largely depends on (i) rate and continuity of air flow (ii) temperature in preheating, reduction and tuyere zone (iii) CO/CO_2 ratio (iv) size and size distribution of ore and reductant (v) ore to reductant ratio in the charge mix and (vi) total residence time in different zones of furnace.

EXPERIMENTAL

Charge materials

- The iron ore and Sal charcoal used in proto-type furnace is shown in Fig. 4 and their chemical analyses are given in Table 2 and Table3 respectively.
- The chemical analyses of two grades of Bastar iron ore and three types of wood charcoal used in proto-type furnace and scaled-up furnaces are given in Table 4 and Table 5 respectively.

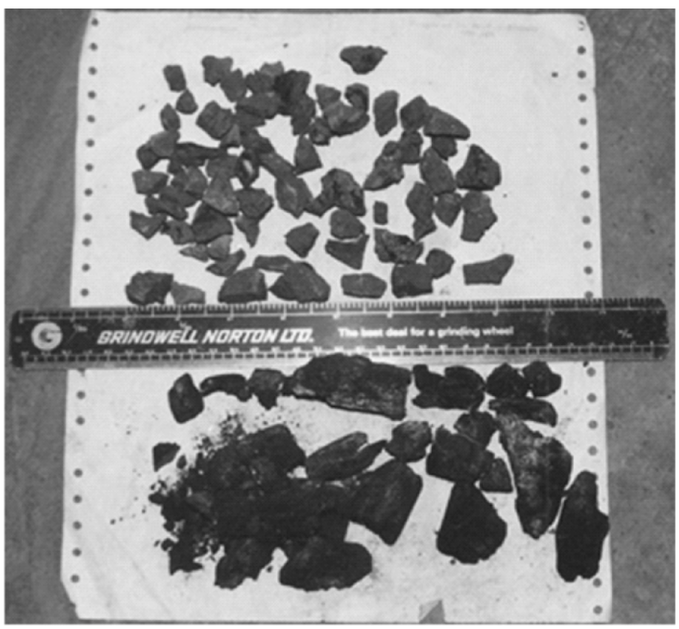

Fig. 4 : Bastar iron ore and Sal charcoal

Table 2 : Chemical analysis of iron ore from Bastar

Constituents	Bastar Ore
Fe (T) %	60.19
SiO_2 %	1.98
Al_2O_3 %	12.09
MnO %	Nf
S %	0.005
P %	Nf

Table 3 : Chemical analysis of Sal charcoal

Sample Particulars : (Air-dried basis) Proximate Analysis :	Sal wood charcoal
Moisture (M) %	5.6
Ash %	1.8
Volatile Matter (V.M.) %	20.7
Fixed Carbon (FC) %	71.9
Ultimate Analysis:	
Moisture %	5.60
Ash%	1.80
Carbon %	79.40
Hydrogen (cfm)%	2.69
Sulphur%	0.03
Nitrogen%	0.20
Oxygen (By diff)%	10.28
Total	100.00
C. V. (Kcal / kg)	7060

Table 4 : Chemical analysis of two grades of Bastar iron ore

Constituents (%)	Baster Ore I	Bastar Ore II
Fe (T)	63.13	60.19
SiO_2	1.55	1.98
Al_2O_3	7.04	12.09
MnO	0.056	Nf
S	0.236	0.005
P	0.54	Nf

Table 5 : Proximate analysis and ultimate analysis of wood charcoal of Sal, Eucalyptus and Acacia with their calorific values

Sl. No.	Sample Particulars Wood Charcoal	Wt. (Kg.)	Size (mm)	(Air dried basis)									
				Proximate Analysis				Ultimate Analysis					C.V. (K. cal/kg)
				M (%)	Ash (%)	VM (%)	FC (%)	C (%)	H (%)	S (%)	N (%)	O (%)	
1.	Sal	2.000	3-0	8.4	3.6	6.8	81.2	82.84	1.40	0.04	0.22	3.50	6900
2.	Eucalyptus	2.000	3-0	9.1	4.9	6.6	79.4	80.34	1.36	0.03	0.20	4.07	6720
3.	Acacia	2.000	3-0	9.3	3.3	6.2	81.2	81.85	1.13	0.02	0.24	4.16	7170

Proto-type furnace with usual rate of air blast

Experiments were conducted for iron making in proto-type furnace(Bastar model) making use of Bastar iron ore and charcoal prepared from Tamarind, Jamun and Mahua. The effect of different types of charcoal on the productivity of the process and recovery of iron in the product is shown in Table 6.

Proto-type furnace with increased rate of air blast

After a number of trials, proto-type furnace was upgraded with increased rate of air blast using lumps of two grades of Bastar iron ore and three types of wood charcoal namely Sal, Eucalyptus and Acacia. In this case the amounts of input and output materials were more than double than that of proto-type furnace with usual rate of air blast. Of course the duration of heat was increased from four hours to five and a half hours. The effect of different types of charcoal on the productivity of the process and recovery of iron in the product is shown in Table 7.

Scaled-up furnace without heat recovery system

The height of proto- type furnace (Bastar model) was increased for increasing the average residence time of reactants and the overall reduction of iron ore to metallic iron. As a result the flame temperature of the exit gas from the furnace came down from about 600 to 500^0C. Experiments were conducted making use of two grades of Bastar iron ore and three types of wood charcoal namely Sal, Eycalypus and Acacia.The effect of different types of charcoal on the productivity of the process and recovery of iron in the product is shown in Table 8.

Scaled-up furnace with heat recovery system

The volume of Bastar type furnace was increased to almost two times incorporating heat recovery system in order to improve its thermal efficiency apart from increasing the reduction of iron ore to metallic iron. Heat recovery system was designed to make use of the sensible heat of exit gases for increasing the temperature of air blast from ambient to 125^0C. This hot blast of air was blown into the furnace through three tuyers-fitted 120 degrees apart. As a result the flame temperature of the exit gas from the furnace came down from about 600 to 4500C or even less. Several experiments were conducted making use of two grades of Bastar iron ore and three types of wood charcoal namely Sal, Eycalypus and Acacia. The effect of different types of charcoal on the productivity of the process and recovery of iron in the product is shown in Table 8.

DISCUSSION

The productivity of the process and the recovery of iron in the product are influenced by scale-up, design and process parameters as follows:

Effect of different types of charcoal in proto-type furnace

The productivity of the process is maximum using Mahua charcoal and minimum while using Jamun charcoal. Likewise the recovery of iron in the product is maximum in the case of Mahua charcoal and minimum in the case of Jamun charcoal(Table 6).

Table 6 : Effect of different types of wood charcoal on the productivity and recovery of iron in proto-type furnace with usual rate of air blast

Sl. No.	Charge mix		Volume of furnace (m^3)	Duration of heat (hrs)	Wrought iron (kg)	Productivity ($kg/m^3/hr$)	Recovery of iron in in product (%)	Blowing of air into furnace (liters/ minute)
	Iron ore (kg)	Charcoal (kg)						
1	Bastar ore (5kg)	Sal (10kg)	0.0309	4	1.71	13.834	52.84	230
2	Bastar ore (5kg)	Tamarind (10 kg)	0.0309	4	1.63	13.187	50.37	230

3	Bastar ore (5kg)	Jamun (10kg)	0.0309	4	1.54	12.459	47.58	230
4	Bastar ore 5kg	Mahua (10kg)	0.0309	4	1.83	14.805	56.55	230

Effect of different types of charcoal in updated proto-type furnace

Both the productivity of the process and the recovery of iron in the product do not differ much with different types of charcoal in updated proto-type furnace. These are maximum using Acacia charcoal and minimum while using Sal charcoal(Table 7).

Table 7 : Effect of different types of wood charcoal on the productivity and recovery of iron in proto-type furnace with increased rate of air blast

Sl. No.	Charge mix		Volume of furnace (m^3)	Duration of heat (hrs)	Wrought iron (kg)	Productivity ($kg/m^3/hr$)	Recovery of iron in in product (%)	Blowing of air into furnace (liters/ minute)
	Iron ore (kg)	Charcoal (kg)						
1	Bastar ore I (11kg)	Sal (22kg)	0.0309	5.5	3.9	22.947	52.22	280
2	Bastar ore II (11kg)	Sal (22kg)	0.0309	5.5	3.7	21.771	51.97	280
3	Bastar ore I (11kg)	Eycalyptus (22kg)	0.0309	5.5	4.0	23.530	53.56	280
4	Bastar ore II (11kg)	Eucalyptus (22kg)	0.0309	5.5	3.85	22.650	54.07	280
5	Bastar ore I (11kg)	Acacia (22kg)	0.0309	5.5	4.15	24.410	55.57	280
6	Bastar ore II (11kg)	Acacia (22kg)	0.0309	5.5	3.90	22.940	54.78	280

Effect of increased rate of air blast in updated proto-type furnace

As a result of the increased rate of air blast from 230 liters/minute in proto type furnace to 280 liters/minute in updated proto-type furnace, the productivity of the process increased to almost one and a half times than that in usual proto-type furnace. However, the recovery of iron in the product is almost similar in both the cases (Tables 6 and 7).

Effect of scaled-up parameters

– As a result of scale-up,the productivity of the process increased significantly to almost one and a half times in scaled-up furnaces than that in usual proto-type furnace using Sal charcoal. Likewise the recovery of iron in the product is somewhat more in scaled -up furnaces than that in usual proto-type furnace using Sal charcoal (Tables 6 and 8).

– While comparing the performance in upgraded proto-type furnace and scaled -up furnaces, the productivity of the process using two grades of Bastar iron ore and three types of charcoal is almost similar but the recovery of iron in the product is considerably more in scaled -up furnaces than that in upgraded proto-type furnace (Tables 7 and 8).

Table 8 : Effect of different types of wood charcoal on the productivity and recovery of iron in scaled-up furnaces without as well as with heat recovery system

Sl. No.	Charge mix		Volume of furnace (m^3)	Duration of heat (hrs)	Wrought iron (kg)		Productivity ($kg/m^3/hr$)		Recovery of iron in product (%)	
	Iron ore (kg)	Charcoal (kg)			Scaled-up furnace without (hrs)	Scaled-up furnace with (hrs)	Scaled-up furnace without (hrs)	Scaled-up furnace with (hrs)	Scaled-up furnace without (hrs)	Scaled-up furnace with (hrs)
1	Bastar 0re I (36 kg)	Sal (72kg)	0.14671	4.5	12.83	13.93	19.433	21.099	51.37	57.0
2	Bastar 0re II (35kg)	Sal (70kg)	0.14671	4.5	13.40	14.30	20.29	21.66	57.88	63.12
3	Bastar 0re I (30kg)	Eycalyptus (60kg)	0.14671	4.5	11.85	13.25	17.94	20.06	56.93	65.06
4	Bastar 0re II (35kg)	Eycalyptus (70kg)	0.14671	4.5	13.15	15.80	19.91	24.84	56.80	69.75
5	Bastar 0re I (30kg)	Acacia (60kg)	0.14671	4.5	11.20	12.65	16.96	19.16	53.81	67.02
6	Bastar 0re II (35kg)	Acacia (70kg)	0.14671	4.5	14.10	15.85	21.35	24.00	60.86	69.97

Effect of design parameters in scaled up furnaces

While comparing the performance of scaled-up furnaces without heat recovery system and with heat recovery system along with three tuyers fitted 1200 apart using hot blast of air ,the productivity of the process is considerably more in scaled-up furnace with heat recovery system as can be clearly seen in Table 8. Thus the changes made in the design of scaled-up furnace by incorporating heat recovery system with hot blast of air using three tuyeres120 degrees apart show positive effect by increasing the productivity of process as well as recovery of iron in the product.

CONCLUSIONS

- The conventional costly Sal wood charcoal successfully replaced the charcoal made from Eucalyptus and Acacia which grow fast and are comparatively cheaper.
- The productivity of conventional furnace of ancient iron making can be increased significantly by substantial enhancement in the blast of air updating its performance.
- The scaled-up furnace alone has much higher productivity and increased iron content in its product .
- The scaled-up furnace with improved design of air blast system as well as heat recovery system has significant increase in the productivity of the process and the recovery of iron in the product.
- The scaled-up furnace with improved design can prove more economical for tribal artisans of our country.

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