DIRECT REDUCED IRON: AN ADVANTAGEOUS CHARGE MATERIAL FOR INDUCTION FURNACES

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Abstract Industrial and experimental induction furnaces are used for melting various types of iron ingots, returned scraps and DRI sponge pellets to produce high purity cast - iron and steel heats. The lowest consumption of electrical energy determined for continuous feeding operation is 0.3 KWH/Kg for the production of cast - iron in a 1.5 - ton industial furnace and 0.45 KWH/Kg for the production of steel in a 25 - Kg experimental furnace. The optimum feeding rate for lowest energy consumption is 12.5 grams per second for continuous feeding of DRI in a 25 - Kg induction furnace. Similar measurements show that the optimum size of the DRI pellets is around 7 milimeters.

چکیده کوره‌های القایی صنعتی و آزمایشگاهی برای ذوب کردن انواع مختلف شمشهای آهنی، قراضه‌های برگشتی و پلتهای آهن احیاء مستقیم شده به منظور تولید چدن و فولاد مذاب با درجه خلوص بالا مورد استفاده قرار گرفته است. حداقل میزان مصرف انرژی الکتریکی در حالت بار کردن پیوسته برابر با ۰/۳ کیلو وات ساعت بر کیلوگرم برای تولید چدن در کوره صنعتی ۱/۵ تنی و ۰/۴۵ کیلو وات ساعت بر کیلوگرم برای تولید فولاد در کوره آزمایشگاهی ۲۵ کیلوگرمی به دست آمد. اپتیموم سرعت بار کردن برای دستیابی به کمترین میزان مصرف انژری ۱۲/۵ گرم در ثانیه در حالت بار کردن پیوسته آهن احیاء مستقیم شده در کوره القایی ۲۵ کیلوگرمی به دست آمد. اندازه گیری مشابه نشان می‌دهد که اندازه اپتیموم پلتهای آهن احیاء مستقیم حدود ۷ میلی‌متر است.

INTRODUCTION

It has been more than three decades since Direct Reduced Iron (DRI) was introduced as an alternative charge material for electric melting processes. Although extensive investigations have been carried out on the melting of this material in electric arc furnaces (EAF) [1 - 8], the amount of work done on feeding DRI into an electric induction furnace (EIF) is very limited [9 - 11]. In this paper, the results of the studies carried out on the performance of DRI sponge iron pellets in the EIF under various circumstances are described. The main objective of this work is to find alternative ways for substituting DRI pellets for other raw materials such as sorrel metals, steel scraps and pig - iron ingots usually used in cast iron shops.

The DRI melting process is considerably influenced by the physical, chemical and thermal specifications of the charged material [5, 6]. Some of these specifications are shape, size, density, chemical analysis and the degree of metallization. Other parameters such as the method of charging, the type of furnace, the temperature of bath, the chemical composition of molten phases and the flow of fluid inside furnace and around the particles are also of appreciable importance, [12 - 14].

Considerable information is needed about the chemical and thermal mechanisms that control the melting process of the DRI particles in the EIF in order to predict their optimum feeding conditions. Therefore a number of experiments are designed to obtain the information necessary for characterizing the behavior of the sponge iron (SI) particles in an electric induction bath. The results are used for modeling DRI electric induction melting. The mathematically predicted data are compared with the experimental results.

MODELING

The feeding of the DRI materials to the uncovered center of the crowned iron surface (Figure 1) creates a unique chance for the SI pellets to exchange heat and mass directly with the molten metallic phase. Because of the smaller density of the SI pellets they float on the surface of the iron melt before they can completely melt. A relatively large volume of gas can be produced as a result of the reduction reactions between carbon and oxygen during heating and melting of each pellet. The volume of the gases evolved is a function of both the temperature and the rate of rise of temperature. A typical example studied earlier by the auther is shown in Figure 2. The volume of the gases evolved from the DRI pellet is determined from this curve.

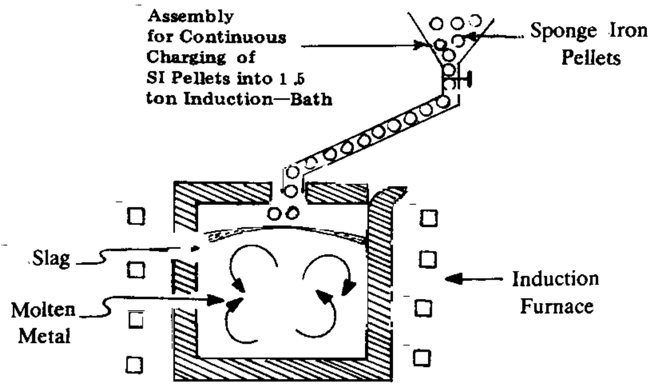

Figure 1. Continuous charging of granular materials into the induction bath.

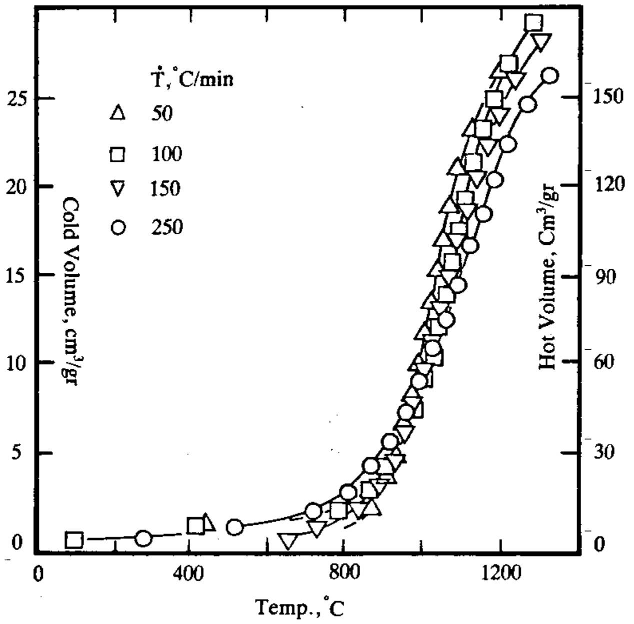

Figure 2. Distribution of the gases evolved from DRI samples. %O= 2.01, %C= 1.06 [16].

Experimental evidence shows that the amount of agitation produced at the surface of the liquid is enough to expel the floating solid or liquid islands away from the external surface of the gassing pellet, except that the rate of charging is so much as not to allow the particle to retain its surrounding domain. A highly active DRI pellet with a relatively low metallization degree and high carbon content can, therefore, be assumed to behave like an isolated gassing particle floating on the surface of the liquid melt. The whole heating and melting process can take no more than a few seconds for such a case (Figure 3).

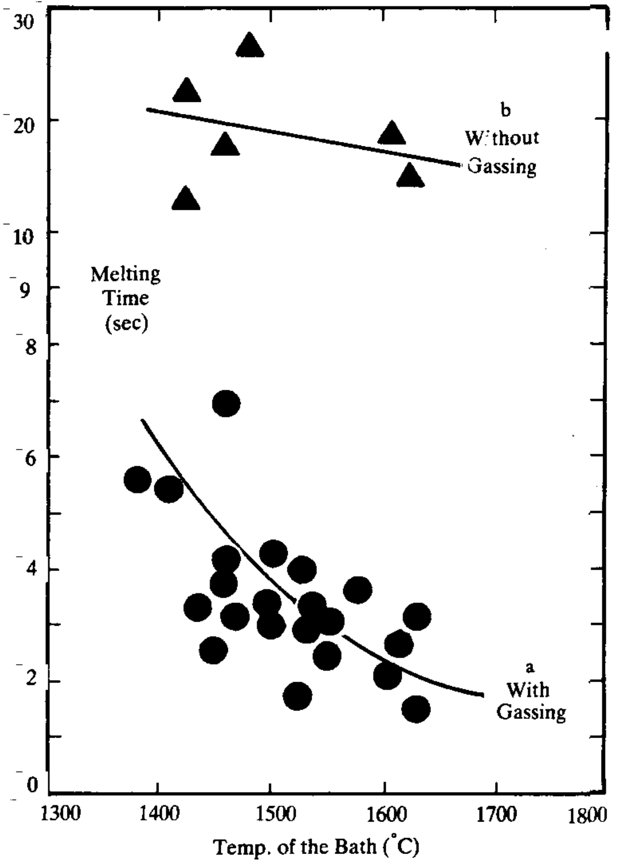

Figure 3. Melting time of a) 92.5% metallized, highly gassing and b) 97% metallized low-gassing DRI pellets charged onto the surface of liquid iron melt. Other Characteristics of the pellets are given in Table 3.

In the case of the highly metallized low-gassing DRI particles, the melting time is distinctively high for two reasons. The first is that these particles are easily surrounded with nearly insulating molten oxides exerting out from them and/or by slags gathered around the internal side of the walls of the crucible. The second reason is that they do not produce any substantial surface turbulence due to the gassing effects. A comparison is made in Figure 3 of the melting time of a number of gassing and non-gassing DRI pellets.

The calculations on the average melting time of the DRI pellets are based on the mathematical model used in Reference 5. However modifications are made for 1) the on- surface melting of the floating DRI pellets, 2) the direct contact between the DRI pellets and the iron melt and 3) the mechanisms for transfer of heat to the DRI pellets floating on the surface of the hot iron phase.

Kolomogoroff's theory of isotropic turbulence is applied to calculate the rate of transfer of heat to the gassing solid pellets. A correlation similar to that used for the melting of spherical solid particles in a liquid slag phase [5] is used to describe the effects of agitations due to gas evolution (Equation 1), except that the rate of dissipation of energy is estimated through a different procedure based on the new conditions:

$$Nu = 2 + 0.83\,Ko^{0.62}Pr^{0.36} \qquad (1)$$

Nu, Ko and Pr are the Nusselt, Kolomogoroff and Prandtl numbers indicating the behavior of the system as related to the transfer of heat, dissipation of energy and transfer of momentum, respectively. The rate of dissipation of energy is calculated from the reversible expansive work done by the evolving gas:

$$E_d = f_s \; {}_{V_p}^{V_g^{\infty}} P_a . dV = f_s P_a \,(V_g^{\infty} - V_p) \simeq f_s\, P_a\, V^a{}_g \frac{T_{\infty}}{T_a} \qquad (2)$$

E_d is the amount of energy dissipated, f_s is the fraction of work done on the liquid phase, P_a is the atmospheric pressure, V_p is the volume of the DRI pellet, V_g^{∞} and V^a_g are the total volumes of gas measured at the liquid and ambient temperatures, respectively, T is the temperature of the liquid phase and T_{∞} is the ambient temperature. The assumption is made that the gases are ideal and have a total volume initially equal to that of the pellet and finally equal to that when released to the air. The former is not, of course, considerable when compared with the latter.

The rate of dissipation of energy can, therefore, be obtained from the following expression:

$$\varepsilon = f_s P_a \dot{V}^a{}_g T_{\infty} / T_a \qquad (3)$$

$\dot{V}^a{}_g$ is the rate of evolution of gas measured at ambient temperature. The quantity f_s is assumed equal to the volume fraction of the pellet submerged in the iron phase. This quantity is calculated from the buoyancy forces acting on the pellet:

$$f_s = \frac{\rho_p}{\rho_m} \qquad (4)$$

ρ_p and ρ_m are the densities of the DRI pellet and the iron phase.

If the rate of feeding is so great that the DRI pellets may thermally interact with each other, the following correlation can then be used for calculation of the rate of transfer of heat into them:

$$Nu = 2 + 0.26\,Ko^{0.50}Pr^{0.33} \qquad (5)$$

Equations 1 and 5 are utilized for estimation of the rate of transmission of heat from turbulent eddies contacting with the DRI sufrace. The area of this surface can be estimated from the submerged fraction f_s:

$$A_c \simeq 4\pi r^2 f_s \qquad (6)$$

A_c is the area of contact and R is the radius of the DRI pellet.

Evolution of gas is not the only mechanism influencing the rate of heating of the DRI pellets. Magnetic stirring does, for example, help this process, too. But the amount of its effect is relatively small because the difference between the velocity of the DRI pellets and that of the liquid iron phase is, at least, initially negligible. This is due to the small density of the DRI pellets which does not allow them move with a different velocity than that of the liquid melt.

The total amount of heat required for melting a unit mass of the DRI pellets is a function of their chemical composition and the melting rate. The effect of the chemical composition is due to the differences in the specific heats of the materials and reactions (Tables 1 and 2). The effect of the melting rate is principally on the heat losses from the electric heating system. The heating efficiency, η, can be calculated from the theoretical and measured heat effects. The applied definition is as follows:

$$\eta = \left(\frac{\Delta H_C}{\Delta H_M}\right) 100 \qquad (7)$$

in which ΔH_C and ΔH_M are the calculated and measured heat values, respectively.

DRI CHARACTERISTICS

The studies are carried out with DRI sponge pellets made at the Ahwas Steel Complex. The compression strength of the pellets is 1.704 MPa, their abrasion index is 5.34 percent minus 0.5 mm and their tumbler index is 77.03 percent plus 6.3 mm according to the standard used at the Ahwaz Steel Complex. These numbers are determined after 15 impacts of a 14 Kg weight dropped from a 43 cm height over the pellets contained in a cylinder of 7.5 cm diameter and 5 cm

Table 1. Thermal Data Used in Calculations [17].

No.	Substance	$\Delta H^{\circ}_{1873-298}$ $(\frac{KJ}{mole})$*
1	$CaO.2Al_2O_3$	(748)
2	$3CaO.SiO_2$	(627)
3	$2CaO.SiO_2$	(473)
4	$CaO.MgO.SiO_2$	(465)
5	$2MgO.SiO_2$	(376)
6	$Al_2O_3.SiO_2$	(343)
7	SiO_2	116.4
8	Al_2O_3	301.0
9	CaO	162.0
	MgO	154.5
11	$Fe_{0.947}O$	122.5
12	Fe	77.3
13	Pig Iron	(61.6)
	EIF Steel	(79.5)
15	Sponge Iron	(91.4)

* Figures in parentheses are calculated from other data.

Table 2. Enthalpies of Reactions Taking Place During Heating of DRI Pellets Evaluated from the Information Given in Reference 17.

No.	Reaction	Enthalpy Change*
1	$1.1\text{"FeO"}_{(s)}+Fe_3C_{(s)}\rightarrow 4.05Fe_{(s)}+0.9CO_{(g)}+0.1CO_{2(g)}$	5.72 (J/Cm^3)
2	$1.1\text{"FeO"}_{(s)}+\underline{C}\rightarrow 1.05Fe_{(s)}+0.9CO_{(g)}+0.1CO_{2(g)}$	5.64 (J/Cm^3)
3	$Fe_3C_{(s)}\rightarrow 3Fe_{(s)}+\underline{C}$	-5.14 (J/g_{Fe_3C})
4	$\text{"FeO"}_{(s)}+C_{(Gr)}\rightarrow Fe_{(l)}+CO_{(g)}$	5.34 (J/Cm^3)
5	$C_{(Gr)}\rightarrow \underline{C}$	1.78 (KJ/g_c)
6	$2CaO_{(s)}+SiO_{2(s)}\rightarrow 2CaO.SiO_{2(s)}$	-2.18 (KJ/g_{SiO_2})

*The data are for the range of stability of phases and materials and cubic centimeter of cold gases.

height. The apparent density of the pellets is 2.9 grams per cubic centimeter and their porosity is around 60 percent [9].

The chemical characteristics of the fused SI pellets are determined by melting 150 grams of DRI samples in an alumina crucible heated in a resistance furnace. The molten phases formed in the crucible are then separated, weighed and analyzed [9]. The results given in Table 3 indicate that around 8.9 percent of SI goes into the slag. It is, however, obvious that with a higher carbon content the quantity of the slag would be less (This is the case with the molten bath used for production of ductile iron illustrated in Table 7).

Although the initial amounts of carbon and oxygen present in SI are generally balanced,as a result of the oxidizing conditions of the furnace during the melting process, a portion of FeO is transferred into the slag. If the carbon content of the molten metal is sufficient for reduction of the total amount of FeO of the slag, not only is the slag volume diminished, but the recovery of the metal can also be increased.

Chemical analysis of the produced iron shows that SI is a suitable material for the production of various ferro-alloys with precisely controlled analysis. According to the data given in Table 3, the melting product of the SI is a relatively pure material without any undesirable trace elements. Hence, it can be concluded that SI can be favorably used for the production of special steels which are usually constrained with very small amounts of impurities used for electrical purposes and low carbon maraging steels, for example, can be produced by melting SI materials, too. These

Table 3. Properties of the Slag and Metal Phases Produced by Melting 150 grams of the Ahwaz Sponge Iron Samples.

Material	Chemical Analysis (Weight Percent)												Weight		Other Properties	
	C	Si	S	P	Ni	Fe Total	SiO_2	Al_2O_3	CaO	MgO	MnO	P_2O_5	Grams	Percent		
Sponge Iron	1.6	—	0.002	—	—	92.1	1.6	+ TiO_2 1.04	0.29	0.32	0.077	0.042	150	100	Degree Metallization 92.55	Reduced Iron 85.24
	Total 93.70						Total 3.37									
Slag	—	—	—	—	—	18.4	41.11	26.5	2.52	3.45	—	—	13	8.9	$B=\frac{CaO + MgO}{SiO_2}$ 0.145	
Iron	0.005	0.006	0.003	0.012	0.025		——						132.5	88.4	$HV_{10}(KgF/mm^2)$ 115	

applications, in addition to the use of the SI pellets in the production of nodular cast iron, can be of great significance in the iron melting industry.

EXPERIMENTS AND RESULTS

Quantitative studies can be made of the effects of (a) the size of the induction bath, (b) the type of the charge material, (c) the method of charging, (d) the rate of feeding and, (e) the size of the SI pellets on the chemical composition of the hot metal, rate of melting and electrical energy consumption. In this study, two types of experimental and commercial induction systems with respective capacities of 25 and 1500 Kilograms are used. The refractory lining of the former is made of magnesite and the latter is made of silica. The results are descirbed.

Experiments with a 25-Kg Induction Furnace: The SI pellets are divided into different sets according to their size distribution. Samples weighing 500 grams from each set are continuously fed into a molten bath with the chemical composition similar to that given in Figure 4. The experimental set-up is illustrated in Figure 5. The apparent melting time of the SI pellets is measured by the direct visual method. The consumption of the electricity is measured by the meter of the furnace. The results are given in Table 4. The initial temperature of the bath is the same in all experiments. Due to the small ratio of the weight of the samples to that of the bath, relatively small changes in the chemical composition of the bath is obtained (Figure 4).

In order to determine the effect of the method of charging on the heating and melting process, 1 Kg of SI pellets is charged firstly in a batch process and secondly through a continuous feeding operation into the induction bath of Figure 5 .The melting time and the energy consumption are determined for several experiments. The average of the results are illustrated in Table 5.

The effects of the feeding rate on the melting time of the SI pellets and on the electric energy consumption is studied by the continuous charging of 1 Kg SI pellets into the induction bath of Figure 5 at different rates. The starting temperature of the tests is kept the same (1550°C). Other conditions such as the inlet electric power of the furnace are also nearly unchanged. The results are given in Table 6.

Experiments with 1.5- ton Electric Induction Furnace: 1100 Kilo-grams of hot metal is produced by melting various iron ingots and casting scraps. The chemical analysis of the molten bath is given in Figure 6. A mixture made of 400 Kg SI and 8 Kg granular graphite is continuously fed into the melt. The continuous charging is done by the assembly shown in Figure 1. The crowned surface of the bath facilitated the direct charging of the SI pellets to the clean metallic surface of the bath. The slag is pushed toward the crucible walls. Because of their relatively small density, the SI pellets are carried by the stirring liquid metal towards the walls and underneath the slag phase. This is the place where they reside for the remainder of their lives. The highly active gassing DRI pellets persist, however, in an oscillatory motion until they totally melt away.

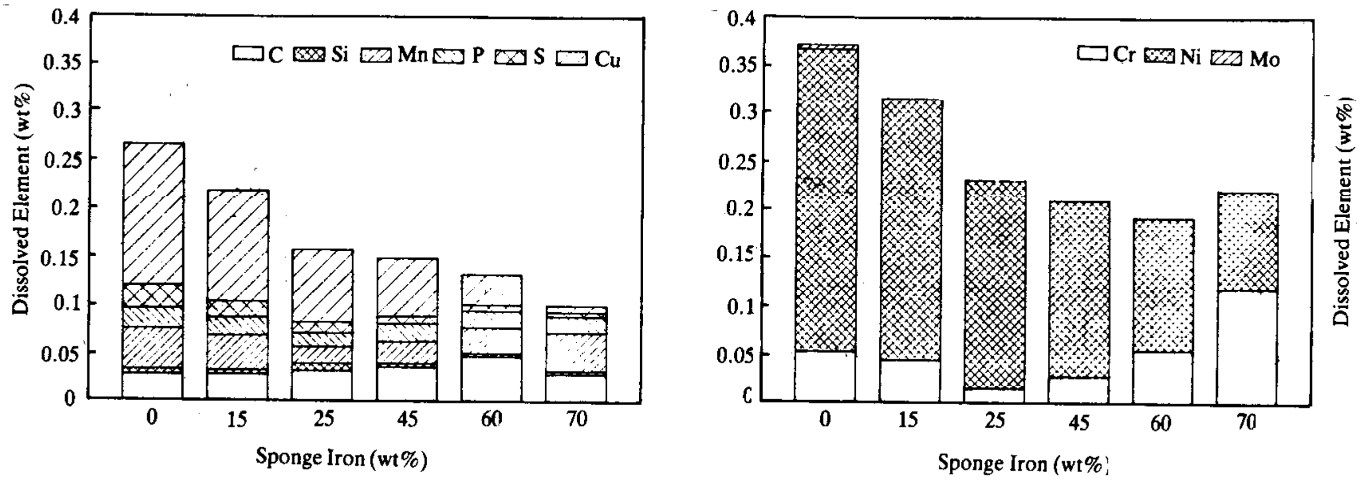

Figure 4. Chemical analysis of the hot metal produced by adding different percentages of sponge iron into a molten induction bath.

Table 4. Effect of the size of pellets on the time and energy required for melting 500 grams of SI in 25- Kg experimental induction furnace.

Size(mm)	Melting Time(sec)	Electrical Energy Consumption (KWH)	Heating Efficiency (%)
<1	60	0.360	53
1.8	56	0.270	70
3.4	40	0.198	96
5	35.5	0.194	98
8	54.5	0.293	65
8.5	37	0.191	99
10	53.5	0.266	71
15	100	0.513	37
mixture of all Sizes	57	0.302	63

Table 5. Effect of the feeding method on the melting time and energy consumption in 25-Kg induction furnace.

Feeding Method	Melting Time for 1 Kg SI Pellets (sec)	Energy Consumption (KWH/Kg)	Heating Efficiency (%)
Batch	202	1.134	34
Continuous	82	0.45	84

At the end of the melting process, 18 Kilograms of ferrosilicon (75% purity) is added to the bath in order to correct the silicon content of the bath. Similar experiments are carried out with higher proportions of sponge iron pellets. The results show that the contents of the impurities can be reduced as a result of the dilution of the molten iron with the relatively clean SI materials (Figure 6).

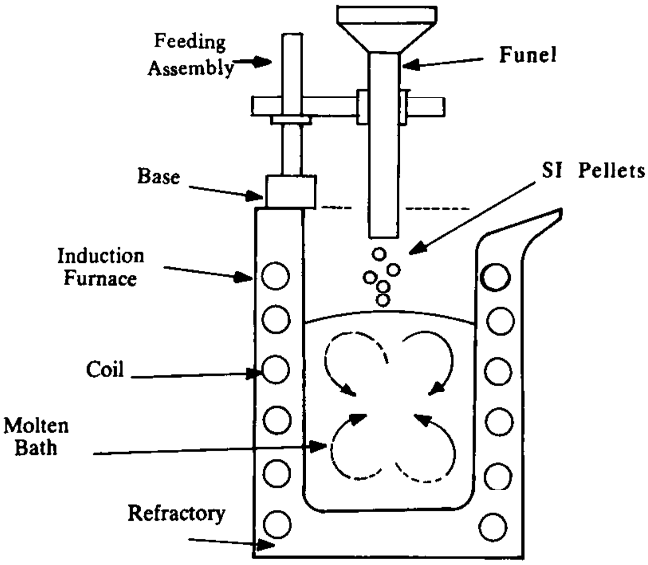

Figure 5. Continuous feeding of SI into 25- Kg electric induction bath.

Table 6. Effect of feeding rate of the SI pellets on the melting time and electrical energy consumption in 25- Kg induction furnace.

Test No.	Feeding Rate (gr/sec)	Melting Time (sec)	Energy Consumption (KWH/Kg)	Heating Efficiency (%)
1	22.22	99	0.522	73
2	21.27	67	0.333	114*
3	16.39	90	0.486	78
4	14.92	90	0.486	78
5	14.70	82	0.459	83
6	14.08	89	0.504	75
7	12.50	90	0.360	106*
8	11.90	132	0.666	57
9	11.11	92	0.504	75
10	10.10	99	0.522	73
11	9.90	101	0.531	72
12	8.85	146	0.72	53
13	7.75	183	1.053	36
14	6.62	216	0.882	43
15	6.58	182	0.792	48
16	6.29	178	1.008	38
17	5.78	202	1.134	34
18	5.55	211	1	38

*Excess heat may be due to the oxidation of elements.

DISCUSSION

The contents of the trace elements in the SI pellets are relatively small. The addition of these materials to the charge of the induction furnace has, therefore, the effect of lowering the contents of the impurities contained in the hot metal existing in the bath. This effect for 25- Kg and 1.5 - ton induction furnaces is compared in Figure 7. The reduction of some of the elements, such as S and P in both furnaces is especially beneficial as a result of the elimination of the refining processes.

The effect of both the type of the charge material and

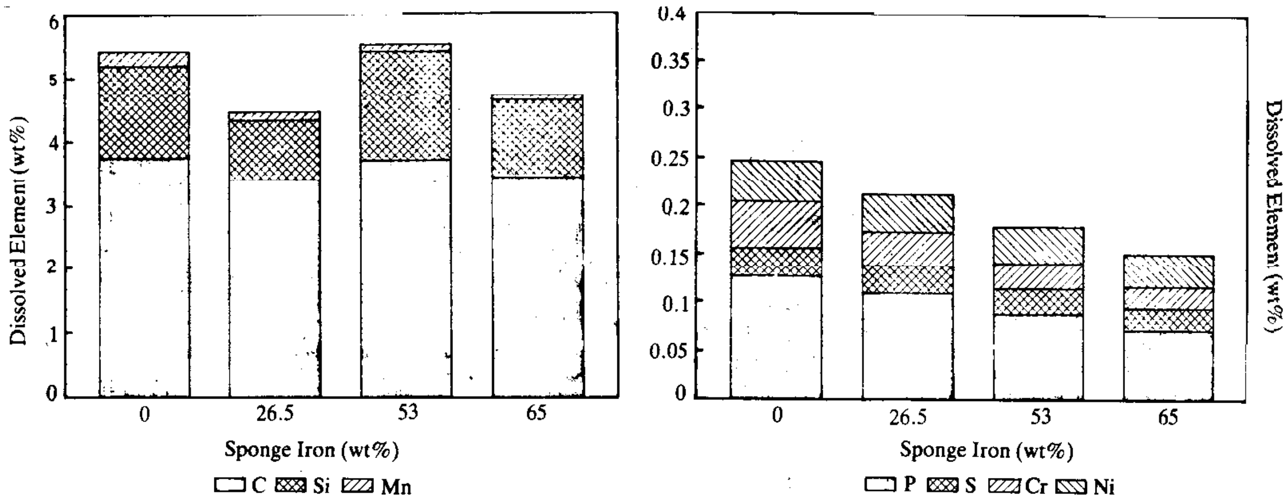

Figure 6. Chemical analysis of the hot metal produced by adding different ratios of SI material to the 1.5- ton molten iron bath

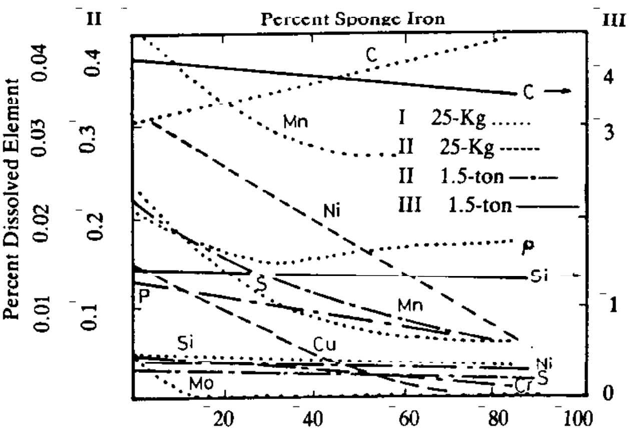

Figure 7. Effect of addition of SI pellets on the chemical analyses of the molten metal (a) 1.5- ton and (b) 25- Kg core less electric induction furnaces.

the method of feeding on the rate of melting, weight percent of the slag produced and the consumption of the electric energy is summarized in Table 7. As is indicated in the table, the melting rate of the charge material is reduced when SI pellets are fed instead of iron ingots and returned scrap into the hot bath. The melting rate, however, improves when the continuous charging is practiced instead of the batch process. These changes can be due to several inter- relating effects:

a) The thermal conductivity of the SI pellets is much lower than that of the metallic ingots and scraps, thus they can be heated up much slower than the latter.

b) The density of the SI pellets is smaller than that of the molten metal, hence they float over the surface of the bath. Floatation of the SI pellets results in a partial surface contact and a relatively small heating rate.

c) The batch feeding operation enhances the interactions between cold solid particles and causes the formation of relatively slow melting islands floating on the surface of the hot metal.

d) The continuous feeding operation can result in reduction of solid- solid contacts and improvement of the liquid- solid heat effects. This process can especially result in enhancement of the melting rate, when the SI pellets are directly charged into the slag- free central part of the surface of the metallic phase (Figure 1).

The weight percent of the slag produced is also a function of the type of the charging material. The iron ingots and returned scraps are nearly slag- free materials, whereas, the SI pellets contain at least 8 percent of slagging materials (Table 3). Part of the slag can, however, be reduced and returned to the metallic phase. The data listed in Table 7 indicate that the higher contact between the molten metal and the solid particles can result in a lower amount of slag as is the case for the continuous SI feeding operation.

The experimental data summarized in Table 7 also indicate that the consumption of the electrical energy is at its least value when the sponge pellets are continuously charged into the melt. These results can be considered in good agreement with the previous data, if the smoother operation of the furnace during the continuous feeding of the pellets is being paid enough consideration.

The experimantal results, in general, indicate that the SI pellets are advantageous materials for the

Table 7. Effect of the type of charge material on the rate of melting, electrical energy consumption and the amount of slag produced in 1.5- ton induction furnace.

Experiment	Materials Charged into the hot melt	Method of Charging	Rate of Melting (kg/min)	Weight of Slag Produced (Percent)	Consumption of Electricity (KWH/Kg)	Heating Efficiency (%)
1	Russian Ingot and Returned Scrap	Batch	22.0	3.0	0.4	73
2	Sponge Iron Pellets	Batch	11.2	7.5	0.48	60
3	Sponge Iron Pellets	Continuous	18.0	5.3	0.3	97

production of cast- iron and steel, especially when utilized in continuous feeding operations into the coreless induction furnaces. A more advanced technique seems to lend itself to a continuous process composed of charging, melting, deslagging and tapping stages. Such a continuous process, if technologically is proved to be feasible, can help us to diminish the size of the coreless induction bath and enhance the production rate. Application of the dynamic systems analysis and optimization techniques can help one to obtain the best design with the least expenditures.

The effect of the rate of feeding on the time and energy required for melting one Kilo-gram of SI pellets charged in a continuous way into the 25- Kg induction bath of Figure 5 is illustrated in Figure 8. The data show that the melting time and the energy consumption can both be reduced in increasing the rate of feeding of the sponge pellets into the induction bath. These results indicate that if the induction power can be sufficient enough to provide and maintain the temperature of the bath at the required level, the greatest use can be made of the capacity of the furnace by continuous feeding at the maximum possible rate. In Table 8, a comparison is made of the effect of the furnace size and the charging method on the melting time, energy consumption and the heating efficiency of the system.

Effect of the size of particles on the time and energy required for continuous melting of 500 grams of SI pellets into a 25- Kg induction bath, shown in Figure 9, indicates that the optimum size of the pellets for obtaining minimal values for the melting time and energy consumption is around 7 mm. This figure depends on the conditions prevailing the motion of heat and fluid in the bath. These conditions are functions, clearly, of the systems used for heating and the materials charged into them.

Through increasing the rate of feeding of the DRI pellets, a considerable amount of turbulence can be produced at the surface of the molten phase (Equations 2 and 3). A violently stirred liquid phase is capable of heating solid particles with a higher rate. If the rate of feeding does not exceed an extremum where the multi-pellet interactions start to prevail, the most desirable condition for a continuous feeding operation can be obtained. The fractional concentration of the DRI at the surface of the liquid melt is an important factor here. For very tiny DRI pellets, for instance, the fractional concentration is so great that the multi-pellet interactions can result in a relatively small melting rate (Figure 9). To resolve such complexities which are adherent to the system, utilization must be made of the theoretical and experimental evidences through the application of the thermophysical data available to predict the behavior of the system under various circumstances and to obtain the optimum feeding conditions.

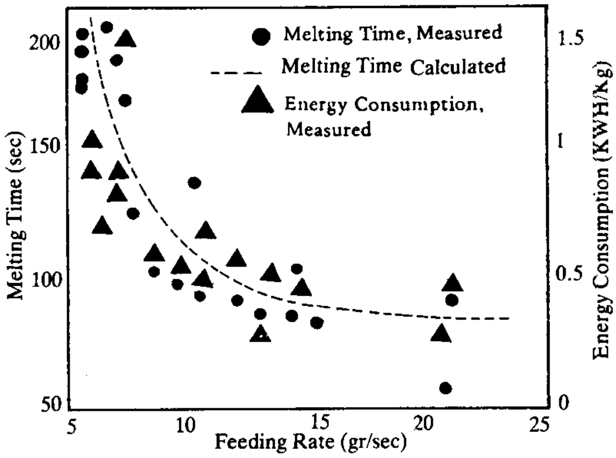

Figure 8. Effect of rate of feeding on the time and energy required for continuous melting of one Kilo-gram of SI pellets into the 25- Kg induction bath of Figures 4 and 5.

Table 8. Comparrison of the Operation Characteristics of the melting systems.

EIF SI	25 — Kg		1.5 — ton	
	Continuous	Batch	Continuous	Batch
Bath Condition	T=1550°C, C=0.030%		T=1420°C, C=3.75%	
Melting Time (sec/Kg)	82	202	(3.33)	(5.36)
Energy Consumption (KWH/Kg)	0.45	1.134	0.3	0.48
Heating Efficiency (%)	84	34	96	60

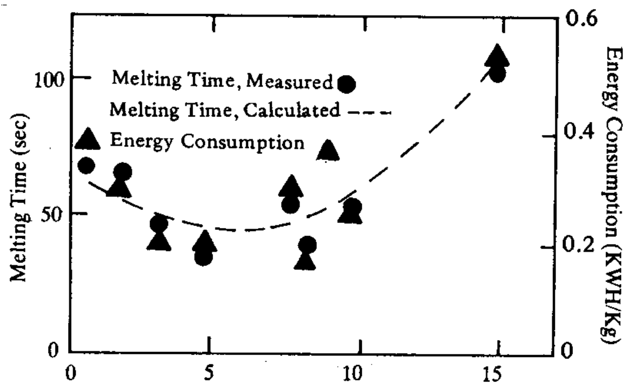

Figure 9. Effect of size of SI pellets on the time and energy required for continuous melting of 500 grams SI pellets in 25- Kg induction furnace.

CONCLUSIONS

Continuous feeding of sponge iron pellets into the electric induction furnace is a convenient way of producing high quality cast - iron and steel. The diminision of the contents of the undesirable trace elements as a result of the utilization of the DRI materials, can provide the iron- maker with a relatively clean bath that does not need subsequent purifying processes.

The minimum amounts of the electric energy consumption and the cold materials melting time can be achieved with the continuous charging of SI pellets directly into the hot bath with optimal rates of input of electric power and feeding materials. The maximum capacity could be used with the equipment, if the melting system and SI characteristics can be designed carefully.

Although the formation of around 6 percent slag at the top of the furnace is a matter of little concern, the advantages obtained in the utilization of the SI materials especially in a continuous feeding operation can easily cover this unavoidable deficiency.

The Kolomogoroff's theory of isotropic turbulence as indicated by Equations 1 to 5 can be utilized to explain the behavior of the multi- pellet DRI melting system shown in Figures 8 and 9. Any increase in the rate of feeding of the sponge iron pellets can result in an enhancement in the rate of melting provided that:

1) A uniform distribution of the DRI materials can be achieved through a well- controlled continuous feeding technique.

2) The energy dissipation due to the gassing process be well suited to produce the maximum amount of turbulence.

3) The rate of feeding does not exceed the maximum permissible amount for a non- interacting multi- pellet operation.

4) The size of the DRI pellets is so sellected to keep the surface density of the sponge pellets for the maximum conversion of the dissipated energies to the local turbulence.

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