Melting behaviour of sponge iron in induction furnace

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Abstract

Sponge iron with its consistency of composition, lower content of tramp elements and particularly low phosphorus and of sulphur has drawn the attention of medium/large scale foundries for producing quality steel castings. It is one of the alternative charge materials to scrap in induction furnaces. National Metallurgical Laboratory has made an attempt to melt sponge iron in induction furnaces and optimize its melting behavour. It is possible to use continuous charging arrangements for melting of 100% sponge iron in induction furnace.

Introduction

Steel scrap is normally the feed stock for the production of steel in induction furnace. The scarcity of the scrap coupled with its varying composition and irregular size and supply is causing concern to the mini steel plants having induction furnaces. Thus, vagaries of the scrap market has given an impetus to sponge iron as one of the alternative charge materials to scrap. With deteriorating quality, fluctuating prices and non-availability of scrap, the sponge iron with its consistency of composition, lower content of tramp elements and particularly low phosphorus and sulphur has drawn the attention of medium/large scale foundries for producing quality casting.

Attempts have been made in the past [1-6] to develop the technique for producing steel by melting sponge iron in coreless induction furnace. Mostly attention was paid towards the study of effect of slag formation, lining corrosion and power consumption. In normal induction furnace operation, before the addition of DRI, a liquid pool is made. Due to low conductivity of slag, it cools and forms a hard crust on the top of the bath which hamper further feeding of DRI and its melting. This problem can be partly overcome by adopting a continuous charging method and intermittently deslagging [Fig.1]. Attempts have been made at NML to study the melting behaviour of sponge iron in induction furnace and to optimize the melting parameters for producing quality steel.

Experimental

Two varieties of sponge iron were melted in an induction furnace to investigate (i) isothermal dissolution behaviour of single particle in basic and acid slags and, (ii) the isothermal melting rate with different amounts of additions of sponge iron. Sponge iron used in these experiments was produced from two different processes namely, (i) coal based direct fired rotary kiln process at RDCIS (SAIL), Ranchi, and (ii) Coal based indirectly fired vertical retort furnace process developed at NML Jamshedpur. The chemical and physical properties of these two sponge iron used are shown in Tables-I, II and III. A medium frequency coreless induction furnace "Tocco" was used to investigate the melting behaviour of sponge iron. The experimental study included the melting behaviour of individual particles and bulk, effect of its density on the rate of melting and the variation of the melting rate of sponge iron in unit weight of molten pool at various temperatures. The melting of sponge iron in induction furnaces is beset with the difficulties of the requirement of a molten pool, and formation of slag of the gangue. The slag being electrically non-conductive, was melted only by the absorption of heat from the molten metal pool. Being much lighter, it remains on the top of the pool after forming a solid crust which prevents the sponge iron from coming in contact with the pool. The investigation was carried out to optimize the rate of charging of sponge iron in coreless induction furnace for continuous melting. From time to time slag was removed from the melt in order to facilitate the maximum amount of sponge iron to the melt. The molten pool always has a cover of slag, the isothermal dissolution behaviour of single particles was studied in basic and acid slags, whose compositions are mentioned in figures 5 & 6.

In the present investigation about 70 percent of the liquid metal was taken out from the furnace at each tap, leaving 30 percent as a pool of liquid metal to which DRI was added and slag was removed intermittently.

Experiments were conducted to optimize the rate of melting initially at 1300°C by varying the weight fraction of sponge charged to the molten pool. The first series of experiments were carried out with both the types of sponge iron as indicated above in high carbon molten pool at 1300°C. The results of this series of experiments performed with a pool weight of 7 kgs. As both the varieties of sponge iron exhibited identical pattern of melting rate , it was decided to continue further experiments with one type of sponge iron i.e. NML sponge iron at different temperatures. Further experiments were performed with a molten iron pool of 5 kg. at different temperatures and the effect of various weight fractions of sponge iron on melting rate was studied. The temperature of the molten pool was measured during the melting of sponge iron by optical pyrometer and also by using Pt/13% Pt/ Rh thermocouple.

Result and Discussion

(i) Particulate Melting Characteristic of sponge iron

The melting time of individual particle is found to be affected by the type of slag, size of the particle and its specific gravity. Figure-2 shows the average melting time with one standard deviation of NML sponge iron in basic slag at 1300°C while figure-3 shows the average melting time with one standard deviation of NML sponge iron as well as SAIL sponge iron in a acidic slag at 1300°C. It clearly indicates that the acidic slag facilitates melting, as melting time of NML sponge iron is reduced from 7.8 seconds in basic slag to 7.1. seconds in acidic slag. The average melting time of SAIL sponge iron is higher than that of NML sponge iron in acidic slag at 1300°C due to its wider variation in particle size as shown in Table-2. Figure-4 shows the regression of rate at melting upon the density of individual particle for both types of sponge iron at 1300°C. It clearly indicates the beneficial effect of higher density on the rate of melting of NML sponge iron. The essence of the particle wise experiments when viewed in the light of its physico-chemical characteristic suggest that for best results, the sponge iron should have close size range distribution, higher specific gravity and higher metallization (+92%). Melting in acidic slags is better than in basic slags.

(ii) Melting characteristic of Bulk Addition of Sponge Iron in Molten Pool

The rate of melting of sponge iron in a molten pool maintained at particular temperature is a function of the rate of excess energy input over its liquidus point and the particles available for being melted. From logical stand point, the maximum melting rate is the optimization of these two parameters. Figure-5 displays the variation of melting rate over a range of 0.05 to 0.25 weight fraction added at 1300°C for both types of sponge iron. The highest melting rate of 0.07 weight fraction/minute at 1300°C suggests that the rate of excess energy input to a melt weight of molten iron pool can assimilate 0.07 of its weight of sponge iron per minute. This forms the basis of continuous charging and melting sponge iron in a molten pool. Both the types of sponge iron exhibited similar trends. Further experiments were therefore carried out with the NML sponge iron at 1300, 1400, 1500 and 1600°C. Figures 6 and 7 show the experimental results which indicate that

(i) Melting rate increased steadily with increasing temperature of the pool at all additions.

(ii) The maximum melting rate is achieved at all temperature with the optimum adjustment of the superheat of the pool with the available sponge iron for melting

(iii) The melting rate maxima of 0.07, 0.14, 0.19 and 0.23 weight fraction sponge iron/minute achieved at 1300°C, 1400°C, 1500°C and 1600°C respectively indicate the possibility of continuous melting, while the charging rate does not exceed the above figures.

(iv) The maximum melting rate increases steadily till 1500°C and afterwards it slows down and becomes somewhat asymptotic beyond 1600°C. Figure-6 shows the variation of rate maxima with temperature.

Problems of Sponge Iron Melting in Induction Furnaces

For induction furnace melting, high metallized sponge iron with low gangue content is required. Low iron oxide content is important for safety as well as for energy consumption reasons. If a large quantity of low metallized sponge iron is introduced into a high carbon bath at a high tempeature, there is vigorous carbon boil. Such violent boil hampers the process operation and can be extremely dangerous. Even when sponge iron has high metallization, its feeding must be properly regulated to control the magnitude of the reaction. The upper line in figure-8 shows the relation of the amount of the iron oxide in the charged sponge iron as a function of the degree of metallization of sponge iron, while the lower line shows the amount of iron oxide joining the slag, expressed as percent of the charged sponge iron. It indicates that about 65 percent of the iron oxide is reduced in the induction furnace a long as deoxidizing conditions prevail. Figure-9 shows the effect of degree of metallisation on the energy consumption and clearly indicates that energy consumption increases with the decrease in metallisation. This lowers the capacity of the furnace, and, in addition requires the use of larger amount of carbon and ferro-silicon to meet the chemical specification.

Proposed Modifications for the Continuous charging and Melting of Sponge Iron in Induction Furnace

Arrangements for continuous melting however faces the difficulty of cooling of the slag and formation of crust. Therefore, arrangements were developed to overcome the difficulties of continuous melting of 100% sponge iron at NML. The induction furnace crucible was kept tilted to facilitate the withdrawal of slags during melting (Figure-10). The angle of tilting can be changed according to the volume of molten metal pool. Thus a total capacity of the induction furnace could be utilised without causing any problem. However, the slag characteristics Vs lining life of crucible, the suitable frequency for the desired contour of the top surface, the avoidance of crust formation of the slag are few of the points which require careful consideration before the adoption of induction furnace.

Conclusion

(1) The experience of melting sponge iron in induction furnaces infers that the best usage and melting of the sponge iron can be achieved if the particle size of the sponge iron is in close range and its metallization is + 90%. The density of its particle should be as high as possible.

(2) Even acidic slag facilitiates the melting of sponge iron.

(3) The melting rate increases with the rise in temperature. This requires careful control particularly for the rate of charging of sponge iron in the metallic pool.

(4) It is possible to use continuous charging arrangements for melting of 100% sponge iron in induction furnace by providing requisite modifications.

References

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Table-1 : Chemical Analysis of Sponge Iron

Constituents	Wt. % (SAIL)	Wt.% (NML)
Fe (Total)	87.98	90.72
Fe (Metal)	67.08	80.00
Metallization	76.24	88.18
Silica	2.40	3.04
Alumina	1.56	0.28
Sulphur	0.02	0.03
FeO (difference)	26.87	13.78

Table-2 : Size Analysis of Sponge Iron

Size	Wt. % (SAIL)	Wt.% (NML)
+ 25 mm	3.5	0.0
-25mm + 19 mm	8.8	0.0
-19 mm + 12.5 mm	37.5	5.1
-12.5 mm + 9 mm	43.7	56.2
-9mm + 6 mm	6.2	36.9
-6 mm	0.3	1.5

Table-3 : Bulk Density and Specific Gravity of Sponge Iron

	SAIL	NML
Bulk density tonne/m3 (ASTMC-29-60)	1.809	1.957
Average apparent specific gravity	5.710	5.700
Average true specific gravity	6.310	6.281
Porosity %	9.51	9.25

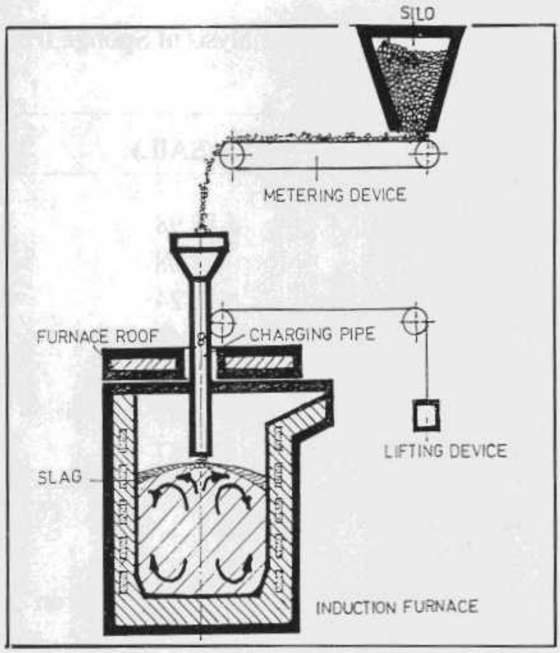

Fig.1 :Continuous charging method for direct reduced iron in to induction furnace

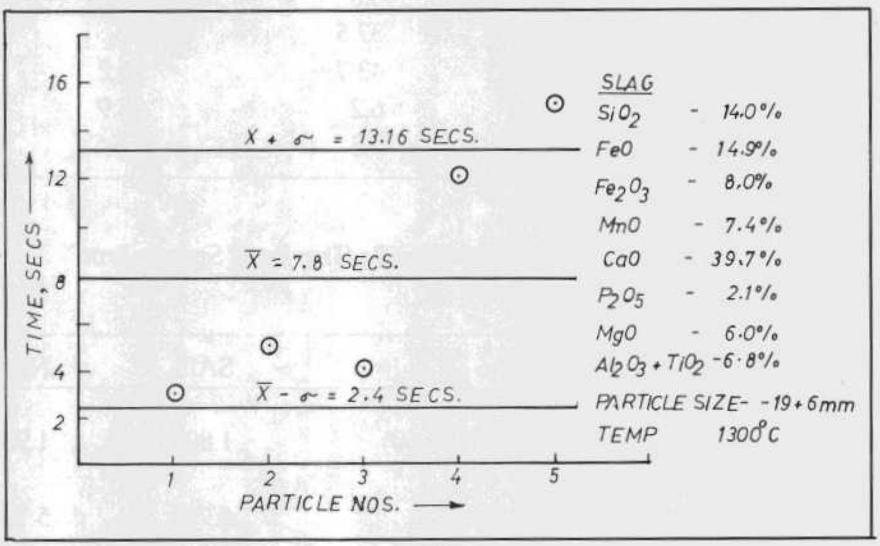

Fig.2 : Average melting time and standard deviations (σ) of NML sponge iron basic slag at 1300 ℃ in medium frequency foreless induction furnace

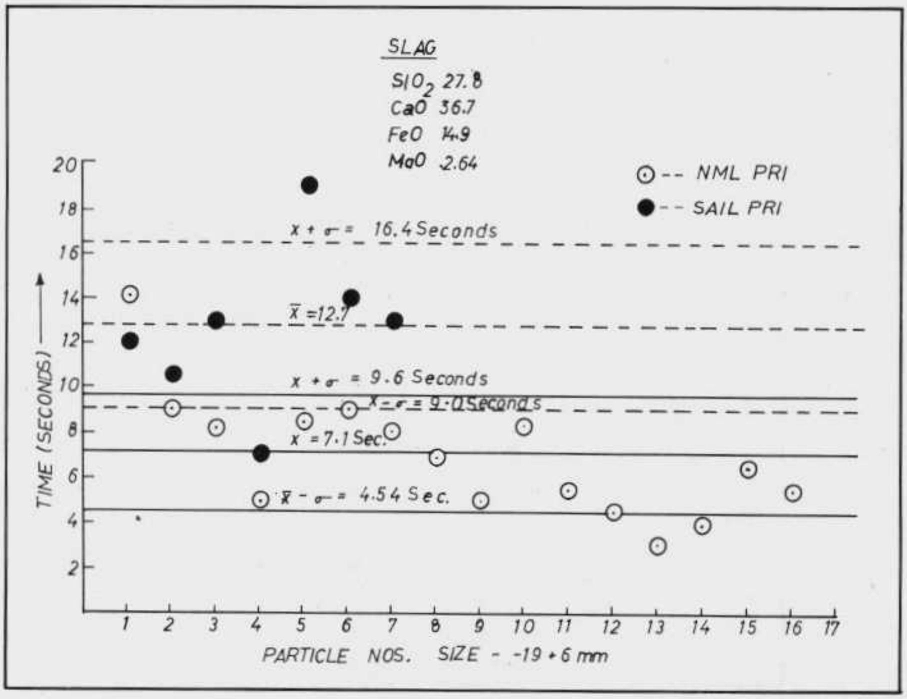

Fig.3 : Average melting time (x) and standard deviation of NML and SAIL sponge iron in acidic slag at 1300 ℃ in medium frequency coreless induction furnace

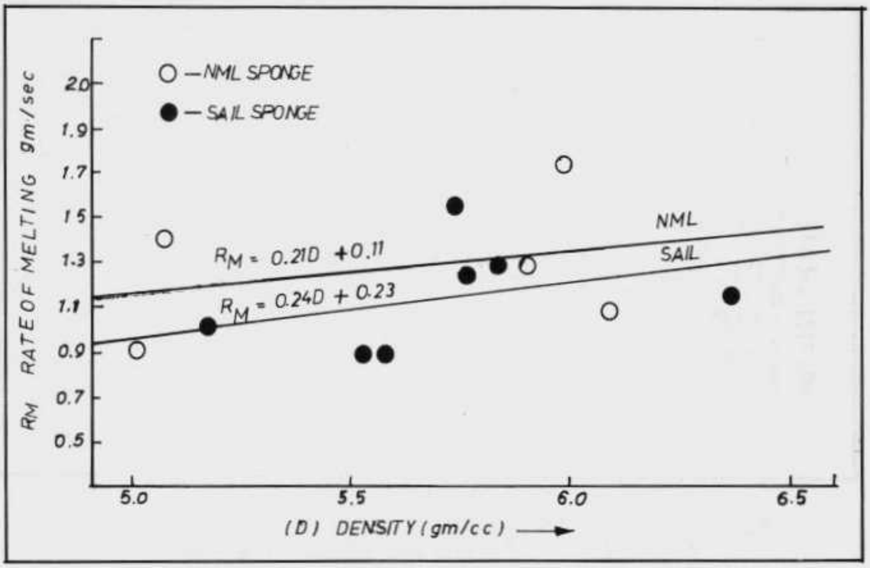

Fig.4 : Regression of rate of melting upon density in basic slag at 1300 ℃

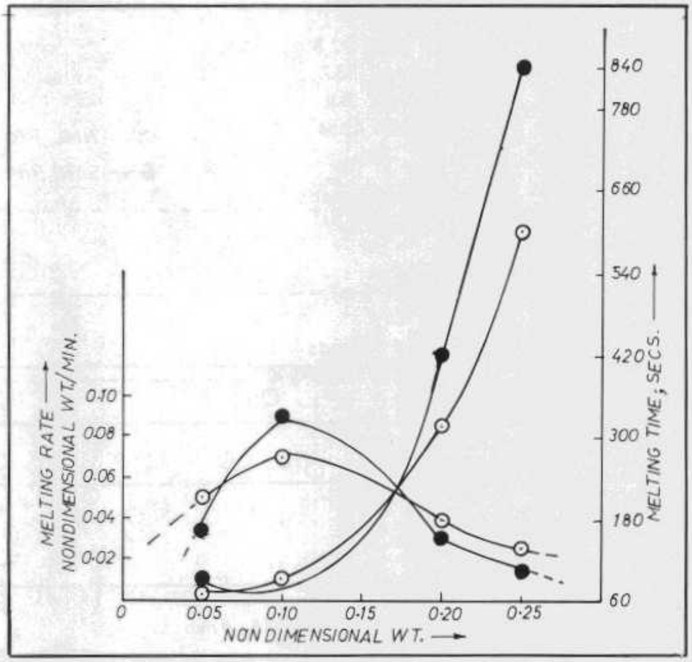

Fig.5: Optimisation of melting rate of sponge iron in molten iron (C-3.9, Si-1.7) 7.00 kg at 1300 ℃ in coreless induction furnace

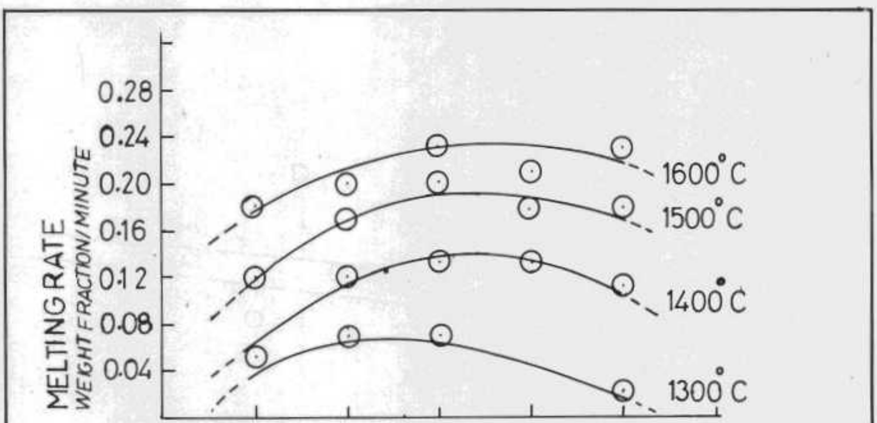

Fig.6 : Optimisation of melting rate of sponge iron in molten metal (C, 3.5 - 4.5, Si, 1.7-1.9) pool at different temperatures

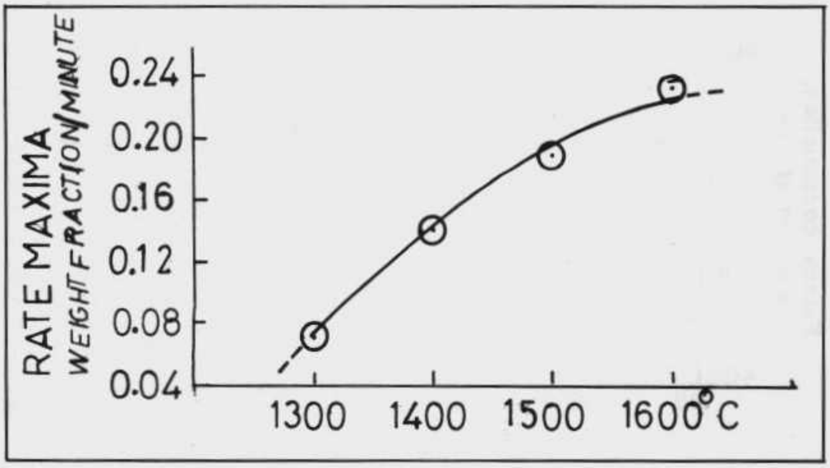

Fig.7 : Variation of the rate maxima with increasing tempeature of molten pool in induction furnace

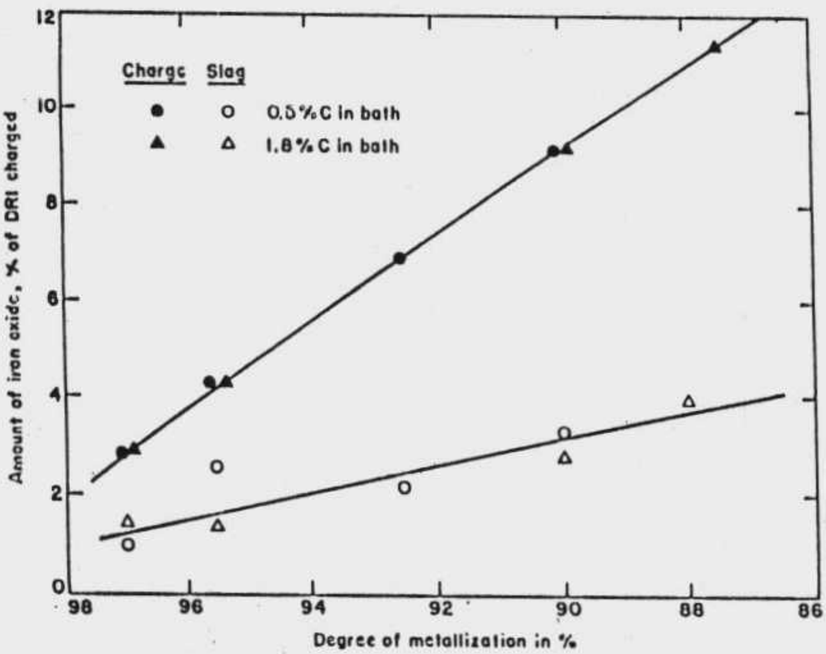

Fig.8 : Effect of the degree of metallization of DRI on the amount of the iron oxide in the charge and in the slag, expresed as %of the DRI charged

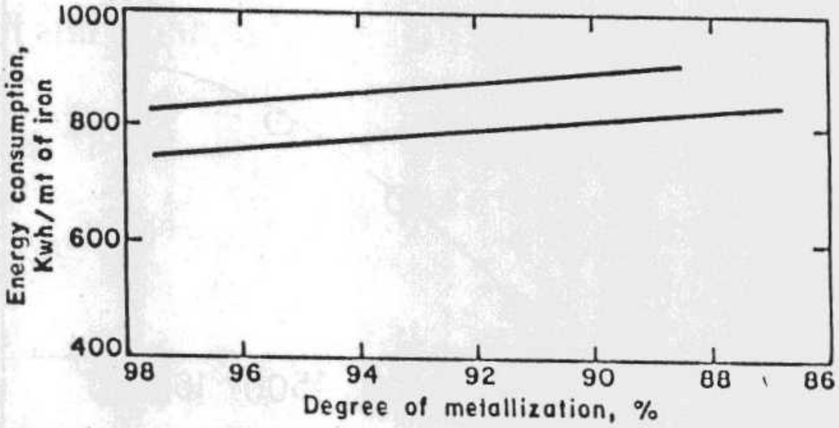

Fig. 9 : Effect of the degree of reduction of DRI on the energy consumption during batch melting in a coreless induction furnace

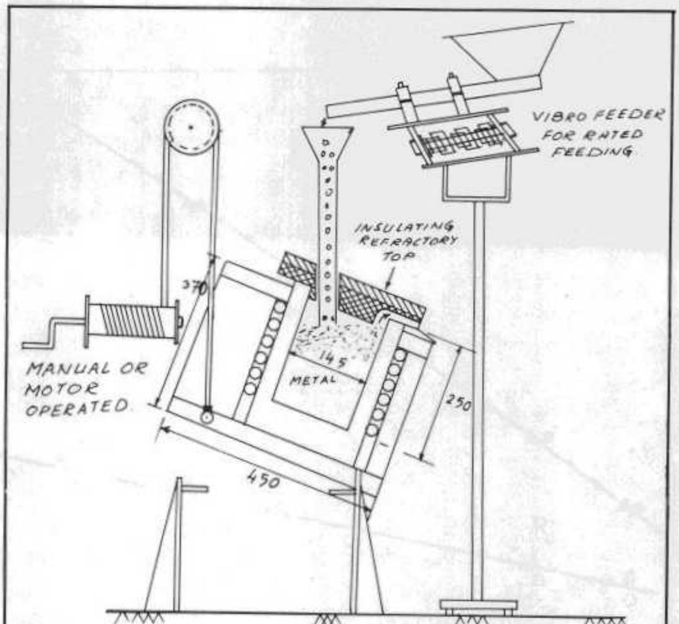

Fig.10 : Arrangements for continuous melting of sponge iron in induction furnace at NML