CHAPTER 7
SUMMARY AND CONCLUSIONS

7.1 Summary of Studies

With increasing demand of iron and steel world wide and depleting reserves of the coking coal as well as growing restriction on the use of coke as reducing agent due to environmental and economic factors, there has been an increased interest for the implementation of new ironmaking technologies with less capital investment. For the past hundred years, blast furnace (BF) has played a major role in producing hot metal because of their high efficiency, mass production and high degree of gas utilization. Presently, blast furnace contributes over 90 percent (pct) of the world's iron production and the rest coming from direct reduced iron (DRI) plants, mini blast furnaces (MBF), Corex, Ausmelt, HI-smelt etc.

Natural gas-based processes such as Midrex and HyL are relatively proven technologies with a combined market share of 90 pct for direct reduced iron (DRI) / hot briquetted iron (HBI). These processes can only be used where natural gas is relatively inexpensive. Quality related issues like low metallization and high gangue content, particularly in coal based DRI, needs to be addressed. Yet another issue is the environmental emission and waste disposal.

The dominance of BF technology, however, has been subject to close scrutiny owing to some inherent limitations in the process. In view of scarce availability and high cost of coke/coking coal, requirement of lumpy iron ore or agglomerated fines, sinter and coke oven plant, high investment cost for furnace and auxiliary equipment, sophisticated process control systems, additional facilities to arrest pollution, huge investment etc, the newly developed smelting reduction technologies like Corex, Fines, Ausmelt, HI-smelt etc for production of hot metal are gathering attention.

India is fortunate to have large reserves of high grade iron ores and is the fourth largest iron ore producing country in the world. The reserves of hematite and magnetite ores are

12.91 and 10.68 billion tonnes (Bt) respectively. However, over 60 percent (pct) of its total production are fines including concentrates. Of the total hematite reserves about 34 pct (4326 Mt) is fines. Indian iron ore deposits, being soft and friable in nature, contain quite a good amount of superfines (-200 mesh) rich in iron content (65 pct and above) and low gangue content known as blue dust. An estimated reserve of blue dust in India is around 418 Mt, which is about 3 pct of the total hematite ore reserves. Due to limited agglomeration capacity, indigenous utilization of iron ore fines is limited and therefore, substantial portion, nearly 80 pct of total, is exported. Besides, there are problems of utilization of tailings. India has reasonable coal reserves, more than 240 billion tonnes (Bt). Out of this, mineable are only 93 Bt. The coking coal, useful for blast furnace iron making, is around 17 Bt (18.3 pct) only, whereas the non-coking coal is 76.0 Bt (81.7 pct). Enormous amount of coal fines and coke breezes are generated during coal mining and coking of coal respectively.

Utilization of these fines for extracting metal is of vital concern for resource conservation and pollution control. These fine concentrates can not be processed in DRI reactors such as Midrex, HyL, Rotary hearth and Rotary kiln. Heat hardening or induration of the agglomerates is costly and emits CO_2 and other pollutants. In order to utilize these fines efficiently and economically, a novel concept of cold bonding technique has been developed. In the cold bonding concept, the fines of iron bearing oxides and carbonaceous materials are mixed with suitable binder and optimum quantity of moisture. The mixture is then pelletized into balls of appropriate size and the pellets are hardened due to the physico-chemical changes of the binder in ambient conditions or at slightly elevated temperature (400 to 500 K).

The term composite pellet is being employed here to mean pellet containing mixture of fines of iron bearing oxide and carbonaceous material (coal/coke/char) which has been imparted sufficient green strength for subsequent handling by cold bonding technique. Cold bonded iron ore-coal/coke composite pellets are very promising feed materials in smelting reduction processes because of utilization of cheaper resource, very fast reduction due to intimate contact between reductant and oxide particles, reduction in energy consumption, their uniform size and convenient form, consistent product quality, promising prospect for iron making at small scale with higher production rate and pollution control.

Non-coking coal based iron making technology has special relevance for country like India. In fact, the need to make non-coking coal based iron making units economically viable has resulted in the development of smelting reduction (SR) processes. The concept of SR process of iron ore was initiated in 1970s. The SR process involving both reduction and smelting, is very similar to the blast furnace, in which all the reactions take pace in a single reactor. Most of the smelting reduction processes involve the removal of oxygen from iron ore in the solid state followed by further removal of remaining oxygen in liquid phase reduction reactions. The SR process exploits faster reduction kinetics at high temperature due to enlarged specific contact area between reactants in a dispersed phase and increased mass transport rates due to convection and thereby improves productivity. The process make use of non-coking coal in a broad range of composition and accept a wide range of materials including iron ore fines, plant wastes or inferior grade ore directly. Their process control is relatively simple and they work out economically at small-scale operation catering to varying demands of the market. The process is environmentally acceptable. Some of the upcoming SR processes are Corex, Finex, Romelt, HIsmelt, Ausmelt, DIOS, AISI-DOE, Redsmelt, Fastmet, Iron Dynamics, ITmk3, Kawasaki Star Process etc. Amongst these SR processes, Corex has already been established at commercial scale and Romelt is in advanced stage of commercialization.

Smelting reduction processes of liquid ironmaking are drawing considerable attention because these processes are currently being developed as an alternative to BF ironmaking with the following objectives:

i) to utilize low grade solid fuels and ore fines,
ii) to produce hot metal at lower capital investment and production costs,
iii) to reduce emissions and pollutants during conversion of coal to coke,
iv) to achieve flexibility regarding input of raw materials and selection of operating parameters, and
v) to install small hot metal production units to meet fluctuating market demand and increase production in small steps of capital investment.

From the literature review, it is clear that composite pellets have been successfully produced, tested and found suitable for use as feed material in cupola, rotary kiln and even in blast furnace. ITmk3 process uses composite pellets to produce almost pure pig iron nuggets. However, it has not yet picked up commercially in a significant way. Local conditions, future trends and developments are going to dictate economics. Review on kinetics and reduction mechanism of composite pellets indicates that the reaction mechanism in composite pellet is very complex because of the participation of many phases, gases and occurrence of several reactions simultaneously and not yet fairly understood.

Review of smelting reduction processes / technologies indicates that not much work is done on fundamental studies on reduction smelting of iron ore-coal composite pellets. There have been a few investigations reported in the literature on smelting reduction of iron oxides in contact with Fe-C melts (mostly in slag phase) under various operating conditions. However, fundamental studies on smelting reduction of iron ore-coal composite pellets in liquid metal bath are not available in published literature. Looking into the above aspect, the following **objectives** have been set for the present investigation.

i) To prepare composite pellets using various binders by cold bonding techniques in the laboratory and evaluate their properties; this would be a contribution towards development of suitable binder for cold bonding technology.

ii) Fundamental investigation on reduction smelting of iron ore-coal composite pellets in liquid metal bath, including auxiliary studies as back-up investigations with emphasis on kinetics.

An attempt is made to develop a mathematical formulation for mass balance in smelting reduction process. A comprehensive review of different methods, used by investigators in past, for measurement of degree of reduction in composite pellets was done. An empirical relation developed by Wang *et al* was modified to calculate the degree of reduction for composite pellets.

To achieve the set objectives, the overall programme consisted of four parts:

i) Characterization of raw materials and evaluation of performance of binders for cold bonding of composite pellets,
ii) Devolatilization of coal and non-isothermal reduction of iron ore-coal composite pellets using TG/DTA,
iii) Fundamental studies on reduction smelting of iron ore-coal composite pellets in liquid melt, and
iv) Bulk dissolution of composite pellets in molten bath and iron recovery including mass balance calculations.

Therefore, from a fundamental point of view, it was decided to carry out the preparation and testing of iron ore-coal composite briquettes / pellets, non-isothermal reduction of iron ore-coal composite pellets using simultaneous thermal analyzer and investigation on reduction smelting of composite pellets in liquid metal bath, including auxiliary studies as back-up investigations with emphasis on kinetics, for better understanding of reduction behaviour of composite pellets.

The following raw materials were selected and procured for the present study:

Iron ore : Tata Steel, Jamshedpur (Source: Noamundi mines, Jharkhand)

Coal : i) Jharia mines, Dhanbad, Jharkhand, and
ii) Bhilai Steel Plant, Bhilai, Madhya Pradesh

Binders : i) Lime : Procured from local market (laboratory reagent grade)
ii) Dextrose : Procured from local market (laboratory reagent grade)
iii) Molasses : Procured from local foundry, Vadodara
iv) Sodium polyacrylate (SPA): Available at department laboratory

Charging material : Cast iron scrap (procured from local market)

Chemical analysis of iron ore was done using Energy Dispersive X-ray Fluorescence (XRF) Spectrometer. Potassium dichromate method (volumetric) was used to determine the total iron (Fe_{tot}) content in the iron oxide (Fe_2O_3). The proximate analyses of coals were done according to the standard method. Coal ash analysis was done using XRF Spectrometer.

The Scanning Electron Microscopic (SEM) examination of iron ore, coal and lime powders was carried out using JEOL SEM (Model: JSM-5610 LV) coupled with Oxford Energy Dispersive Analytical X-ray (EDAX) system. The iron ore powder sample showed the presence of mostly spheroidal shaped particles. Coal powder sample from Jharia mines showed the presence of mostly irregular shaped particles. However, some particles are nearly spherical in shape. Coal powder sample from Bhilai Steel Plant showed the presence of mostly irregular shaped particle but some particles appear to have flaky morphology. A wide variation in particle size was observed. Lime powder sample showed the presence of both irregular and spheroidal shaped particles. Variation in particle size was observed minimum. SEM examination of fractured surface of oven dried composite pellets evinced the distribution of iron ore, coal and lime particles reasonably uniform.

To select the proper binder, cylindrical shaped briquettes (diameter 9.70-9.75 mm and height 13-14 mm) were prepared and tested. It was observed that the highest compressive strength of 357 N/briquette was obtained for briquettes prepared using 10 pct slaked lime and 5 pct dextrose as binder and 6 minutes of CO_2 gas exposure. Similarly, the highest drop strength (84 Nos.) and lowest shatter index value (0.44 pct) were obtained for briquettes prepared using slaked lime plus dextrose as binder and 6 minutes of CO_2 gas exposure.

Therefore, iron ore-coal composite pellets were prepared using slaked lime plus dextrose as binder with Fe_{tot}/C_{fix} ratios of 2.50, 3.11, 3.50 and 4.0 and tested for physical and mechanical properties. Variation in compressive strength was observed mostly by ±15 pct of the average value. For ACP (coal from Jharia mines) pellets, the maximum and minimum strengths of 330 and 212 N/pellet were obtained for Fe_{tot}/C_{fix} ratio of 4.0 and 2.5 respectively. Similarly, for BCP (coal from Bhilai Steel Plant) pellets, the maximum and minimum strengths of 362 and 240 N/pellet were obtained for Fe_{tot}/C_{fix} ratio of 4.0 and 2.5 respectively. With increase in Fe_{tot}/C_{fix} ratio in composite pellet, the strength improved. It was observed that with increase in Fe_{tot}/C_{fix} ratio the porosity of pellet decreased. With increase in porosity both the compressive and drop strengths decreased.

Pyrolysis (TG-DTA) of coals were carried out in SEIKO TG-DTA-32 Simultaneous Thermal Analyzer in platinum crucible (Make: SII, SEIKO Instruments, Japan) in the temperature range of 298 to 1273 K at a heating rate of 15 K/min. Alpha alumina was used as reference material. The atmosphere inside the furnace chamber was maintained inert by flowing argon gas at 300 cc/min. Same instrument was used for non-isothermal reduction (TG-DTA) studies of iron ore-coal composite pellets subjected to a maximum temperature of 1473 K at a heating rate of 10 K/min in inert atmosphere.

Coal pyrolysis result, for coal sample from Jharia mines, showed that below 536.3 K, the coal loses its moisture, between 536.3 and 956.8 K, the weight loss is significant because of tar and volatile release and above 956.8 K, the weight loss is small as only gases are released. Similar trend was observed for coal sample from Bhilai Steel Plant but with different amounts of weight loss which is due to high volatile matter content.

TG-DTA results for iron ore-coal composite pellets showed that the sample loses weight in multi-stages. The total weight loss represents the weight loss due to the loss of oxygen present in iron oxide and carbon and volatiles present in coal. The initial weight loss (about 1 pct) up to 450 K is due to the loss of moisture. Between 450 and 1050 K, the weight loss (about 14 pct) is significantly due to the release of coal volatiles and reduction of iron oxide by hydrogen mainly. Between 1050 and 1360 K, the rapid weight loss (15-20 pct) is due to the dominant role of CO in the reduction of iron oxide at high temperature. The degree of reduction will go further up if the reduction temperature is kept higher (up to 1500 K).

Smelting reduction of iron ore-coal composite pellets was carried out in a laboratory induction furnace to investigate the reduction kinetics and dissolution behaviour of composite pellets in liquid metal bath. For reduction kinetic studies, the pellets of known weight were tied with tungsten wire. The samples were initially preheated for 2 minutes and then immersed in liquid metal bath maintained at a temperature of 1723 ± 10 K for 10, 20, 30, 40 and 50 seconds. After immersing the samples for predetermined period of time, the samples were quickly taken out and transferred to the desiccator to prevent oxidation. The weight loss of each sample was measured using electronic balance. Both fraction of reduction and rate of reduction were calculated.

To study the dissolution behaviour of composite pellets in liquid metal bath, a single pellet was thrown in the metal bath and visually observed that how the pellet dissolved in the metal bath and the time period for complete dissolution was noted. This was repeated several times. Few partially dissolved pellets were collected for scanning electron microscopic examination. Several heats were taken to observe the bulk dissolution of composite pellets in liquid metal bath and recovery of iron (yield) was calculated. The chemical analysis of metal samples of castings was carried out by Optical Emission Spectrometer (OES). For precise analysis of carbon and sulphur, the samples were analyzed by LECO carbon-sulphur analyzer.

SEM examination of fractured surface of the dry pellets was carried out to observe the distribution of iron ore, coal and lime particles in the agglomerate. Reduced pellets were examined for microstructural observation to understand the reduction kinetics and process mechanism. SEM photomicrographs of reduced pellets revealed a diffused reaction front, cluster of whiskers of iron, sintered structure and surface cracks. The tunnel like appearance on the surface indicates the continuous evolution of gas which is due to the presence of high volatiles in coal. The X-ray diffraction (XRD) test was carried out to identify the phases present in reduced pellet. XRD results revealed that the reduction occurred topochemically, i.e., stage wise, e.g., $Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe$.

The salient findings from studies on non-isothermal reduction of composite pellets by TG-DTA and smelting reduction composite pellets in liquid metal bath in an induction furnace and other auxiliary studies like SEM and XRD are presented as conclusions.

In summary, the present investigation has demonstrated smelting reduction of composite pellets in an induction furnace a feasible alternative route to produce hot metal. The investigation on kinetics and dissolution behaviour of composite pellets in liquid metal bath gave insight for fundamental and fair understanding of the reduction behaviour of iron ore-coal composite pellets. The metal, produced in smelting reduction, has reasonable iron yield of 95 to 97.5 pct. The present studies also demonstrate an effective way of utilization of cheaper resources (fines and superfines of iron ore and coal) for extracting metal which is of vital concern for resource conservation and pollution control.

Using cold bonding technique, composite pellets of sufficient green strength were produced. This is a contribution towards development of suitable binder for cold bonding technology.

7.2 Conclusions

1. The compressive strength value of 357 N/briquette was obtained for briquette prepared by slaked lime and dextrose as binder. The highest drop strength as well as lowest shatter index values was obtained for briquettes prepared by same binder combination.
2. The compressive strength values of 362 and 330 N/pellet were obtained for BCP (Bhilai coal) and ACP (Jharia coal) pellets (Fe_{tot}/C_{fix} ratio at 4.0) respectively. This is due to the presence of higher amount of iron ore, binder and lower amount of coal in BCP pellets than ACP pellets.
3. It was observed that the compressive strength values of both ACP and BCP pellets increased with increasing Fe_{tot}/C_{fix} ratio. This may be attributed to the higher amount of iron ore as well as binder present in pellets.
4. It was observed that porosity of both ACP and BCP pellets decreased with increasing Fe_{tot}/C_{fix} ratio. This is attributed to the increasing amount of iron ore vis-a- vis decreasing amount of coal in pellets with increasing Fe_{tot}/C_{fix} ratio.
5. Porosity of BCP pellets were found lower than ACP pellets for the same Fe_{tot}/C_{fix} ratio. This is due to present of higher amount of iron ore as well as lower amount of coal in BCP pellets than ACP pellets.
6. The compressive strength of BCP pellets were found higher than ACP pellets for corresponding Fe_{tot}/C_{fix} ratio which may be attributed to the relatively higher amount of binder as well as low porosity.
7. It was also observed that with increase in porosity both the compressive and drop strengths decreased.
8. During pyrolysis of Jharia coal, total weight loss (13.66 pct) was slightly lower than that of the volatile matters content (15.65 pct) of coal as obtained in proximate analysis. This is due to incomplete removal of volatiles as the overall pyrolysis temperature (1115.6 K) was low.

9. During pyrolysis of Bhilai coal, total weight loss (28.46 pct) was slightly higher than that of the volatile matters content (27 pct) of coal as obtained in proximate analysis. This is due to the loss of moisture, which may be present in pellet, during pyrolysis.
10. For ACP1 pellet, the initial weight loss (1.45 pct of sample weight) up to 429.7 K was due to the loss of moisture. Between 429.7 and 1052.6 K, the weight loss was 13.91 pct of the initial weight, which was significantly due to the release of coal volatiles and reduction of iron oxide by hydrogen mainly. In the temperature range of 1052.6 and 1361.3 K, the TG curve shows very rapid weight loss (14.48 pct of the initial weight), which is due to the dominant role of CO in the reduction of iron oxide at high temperature. Similar trend was observed for BCP1 pellet but with different amount of weight loss which was due to the coal having low ash and high volatile matter content.
11. The fraction of reduction for pellet was increased with time of heating and rise in temperature. Initially the fraction of reduction was very low which may be due to the release of volatiles, which is very slow process. But later on the fraction of reduction increased with time, which may be attributed to the faster gas-solid reactions at high temperature.
12. It was observed that with increase in Fe_{tot}/C_{fix} ratio, the degree of reduction decreased which is attributed to the lesser amount of reductant present in pellets as well as decrease of porosity of the pellets.
13. It was observed that with increase in porosity the degree of reduction also increased which is attributed to larger inner surface area available for reduction. Reduction is greatly facilitated by the access of reductant, which is available into the interior of the pellet.
14. For pellets of identical Fe_{tot}/C_{fix} ratio, it was observed that BCP pellet (coal with high volatile matters) resulted in both higher degree of reduction. This is due to more release of reducing gases (i.e., H_2 and CO).
15. The quantum of volatiles released at different temperature during reduction of pellet take part in reduction reactions and therefore, it is more appropriate to use Eq. (3.81) to calculate the degree of reduction for composite pellets than that of Eqs. (3.76).

16. The rate of reduction increases with increase in temperature. The rate of reduction curves can be divided into three segments. Initially rate of reaction is very fast due to rapid release of moisture. After that rate becomes very slow, more or less constant that is due to devolatilization of coal. Finally rate of reduction is again increased with temperature due to rapid gas-solid reactions.
17. The computed values of activation energy (E) obtained are in the range of 0.86 to 8.82 and 12.37 to 38.32 kJ/mol for initial and later stage of reduction respectively.
18. For 16-17 mm diameter pellets, the time require for complete dissolution, in fully immersed condition, in liquid metal bath was observed to be 83-90 seconds. That means dissolution rate of composite pellet is very fast. Hence, production rate will be faster.
19. It was observed that the weight loss of pellets immersed for 10 seconds in liquid metal bath was higher than the amount of volatiles present in pellets. For 20, 30 and 40 seconds of immersion in liquid metal bath, the weight loss of pellets was found much higher than the amount of volatiles present in pellets. This indicates that the volatiles present in the pellet released within 10 seconds of the immersion of pellet into the liquid metal bath due to very high temperature.
20. The reduction of pellet in liquid metal bath, at the initial stage proceeded relatively slower, at the intermediate stage much faster and at the final stage again becomes slower (for BCP pellet). This is due to the release of volatile matters from the pellet as well as incubation period at the earlier stage. In the intermediate stage, gaseous diffusion through the porous solid (due to release of volatiles from the composites) and finally the fraction of reduction decreases due to sintering and densification of product particles.
21. It was also observed that the fraction of reduction increases with decrease of Fe_{tot}/C_{fix} ratio. It is obvious that by decreasing Fe_{tot}/C_{fix} ratio, the carbon present in composite pellet increases, i.e., more reductant present in pellet and hence more reduction takes place.
22. It was observed that initially, the reduction rate is very fast for both ACP and BCP pellets and later on the rate decreases with time. This is due to the release of volatiles at a time from the composite pellet, which causes rapid gas-solid reactions.

Sintering and densification of product particles occur due to very high temperature, hence the rate of reduction decreases due to poor diffusivity of gases and slower diffusion of carbon at the final stage.

23. The degree of reduction varied in the range of 68-87 pct for ACP (coal from Jharia mines) pellets for 40 seconds and 73-92 pct for BCP (coal from Bhilai steel plant) pellets for 40 seconds. This indicates that Bhilai coal having high volatiles resulted in higher degree of reduction.
24. For BCP pellets immersed in liquid melt for 50 seconds, the degree of reduction varied in the range of 80-98 pct. This indicates that the reduction of pellet continues even after 40 seconds and increased with time.
25. It was found that up to 30 seconds, there are some effects of volatile matters on reduction of composite pellet but after 40 seconds, that effect is negligible.
26. It was observed that with increase in Fe_{tot}/C_{fix} ratio the iron yield decreases. This is due to the lower carbon content in pellets which leads to incomplete reduction of iron oxides.
27. It was observed that with increase in Fe_{tot}/C_{fix} ratio the slag weight decreases. With increase in Fe_{tot}/C_{fix} ratio in composite pellet, the percentage of coal decreases and thereby the amount of ash content goes down. This leads to the decrease in slag weight.
28. For the same Fe_{tot}/C_{fix} ratio of composite pellet, the quantity of slag produced is more with ACP pellets than that for BCP pellets. This is due to the higher ash content in coal from Jharia mines that is used for making ACP pellets.
29. It was found that the carbon content decreased in all heats except H1 and H5 where ACP1 and BCP1 pellets were used respectively. In both these pellets, the Fe_{tot}/C_{fix} ratio is low (2.5), which refers to more carbon than the stoichiometric (Fe_{tot}/C_{fix} = 3.11). The excess carbon in these composite pellets went into the melt resulting in carburization of the melt according to the reaction : $\mathbf{C_{(s)} = C_{(carburized)}}$. Therefore, the carbon content of the product increased. In other heats, the carbon content is either equal to or less than the stoichiometric (theoretically required for complete reduction of iron oxide) and therefore, the carbon from the melt takes part into reduction of

iron oxide. Further, the lower carbon content in product may be due to the dilution of carbon as more Fe is coming from reduction of iron oxides of composite pellets.

30. It was observed that the silicon, manganese and sulphur content decreased in all heats due to their dilution in the melt. The tramp elements like chromium, nickel and copper (except molybdenum) decreased in all heats which is attributed to the dilution of these elements occurred during heat. As the content of tramp elements goes down, the quality of the product improves.
31. Phosphorous content increased in all heats, which is attributed to the phosphorous coming from the iron ore of composite pellets. With increase in Fe_{tot}/C_{fix} ratio, the iron ore content in composite pellets also increases and that is why phosphorous content in melt also increased.
32. Since dissolution rate of composite pellet is very fast, so production rate will be faster. The quality of the product will be also improved by charging composite pellets as feed material.
33. SEM photomicrographs of reduced pellets revealed a diffused reaction front, cluster of whiskers of iron, sintered structure and surface cracks. The tunnel like appearance on the surface indicates the continuous evolution of gas which is due to the presence of high volatiles in coal. XRD and SEM observations of educed pellets indicate that the reduction occurred topochemically, i.e., stage wise, e.g., $Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe$.
34. It is possible to charge composite pellets as feed material in *Smelting Reduction Process* to get faster production, even in the form of steel.

7.3 Suggestions for Further Work

1. TG-DTA of composite pellet was carried out at a single heating rate of 10 ^{O}C/min only. To know the effect of heating rate on reduction behaviour, it should be carried out at different heating rates with larger variation in heating rate.
2. During TG-DTA of composite pellets, the highest temperature obtained was 1361 K and the reduction remained incomplete. Hence, study may be carried out at further higher temperature to assess the maximum extent of reduction.

3. Kinetic study of smelting reduction of iron ore-coal composite pellets was carried out in an induction furnace in liquid metal bath at a temperature of 1723 ± 10 K. To calculate the activation energy and to know more about the reduction and dissolution behaviour, study is required to be carried out at different temperatures with longer period of pellet immersion in the liquid melt than that in present study.
4. The iron ore-coal composite pellets produced in present study have good dry strength but swelling behaviour and strength after reduction were not studied. Such specific investigations are essential for better understanding of the pellet properties and their behaviour in reduction/smelting furnaces.
5. Economic evaluation of the smelting reduction of composite pellets by conducting trials at pilot plant level is required for commercialization in future.
6. Pellets may be made in bulk in large size disc pelletizer and trials in large capacity furnace is required to know the operational difficulties and the problems associated with bulk dissolution of pellets.
7. Economic evaluation of cost of the cold bonding would help in selection of binder combination and pellet making procedure from the data of present study and future trials.
8. By adding composite pellets in melt, it is possible to get steel directly by controlling the Fe_{tot}/C_{fix} ratio in composite pellet. Since dissolution rate of composite pellet is very fast, after complete dissolution of composites, oxygen lancing can be done to the liquid bath to control carbon and phosphorous in the bath and desulphurization can be carried out in the ladle.
9. By proper heat balance calculation, it is possible to design the reactor to get steel directly by continuous charging of composite pellets.