Universidade Federal de Ouro Preto

Resolução CEPE N.º 1061

Aprova plano de trabalho de professores pesquisadores.

O **Conselho de Ensino, Pesquisa e Extensão da Universidade Federal de Ouro Preto,** no uso de suas atribuições legais,

Considerando a correspondência encaminhada pelo Chefe do Departamento de Engenharia Metalúrgica e de Materiais e pelo Coordenador da REDEMAT, datada de 29 de outubro de 1996,

R E S O L V E :

Aprovar o Plano de Trabalho a ser desenvolvido pelos Professores Pesquisadores Ahindra Ghosh e Niloy Nath, do Indian Institute of Technology-Kanpur/Índia, que fica fazendo parte integrante desta Resolução.

Ouro Preto, em 1º de novembro de 1996.

Prof. Renato Godinho Navarro
Presidente

ESCOLA DE MINAS
Praça Tiradentes, 20
CEP 35400-000 - Ouro Preto - Minas Gerais

REITORIA/UFOP
SOC
Recebida em
31 / 10 / 96

Ouro Preto, 29 de outubro de 1996.

Ilm^{0} Sr.
Prof. Renato Godinho Navarro
DD. Presidente do Conselho de Ensino, Pesquisa e Extensão da UFOP

Prezado Senhor,

Estamos enviando, em anexo, o projeto do Prof. Paulo Santos Assis a ser submetido à FAPEMIG para que tenhamos no período de 03.03.97 a 28.02.98, dois renomados pesquisadores do Indian Institute of Technology-Kanpur/India. Gostaríamos de lembrar a V.S^{a} que no contrato assinado ente o IIT-Kanpur e a UFOP, em fins de 1995, tal intercâmbio já era previsto. A FAPEMIG exige que o plano de trabalho seja aprovado e referendado pelo órgão competente da Instituição hospedeira.

Desta forma, acreditamos estar contribuindo significativamente para a consolidação de mais um curso de mestrado em nossa Universidade.

Atenciosamente,

Prof. Leonardo Barbosa Godefroid	Prof. Cristovam Paes de Oliveira
Chefe do DEMET	Coordenador da REDEMAT

1. Formulário 3.1-Apoio a capacitação de recursos humanos

1. Solicitante

Nome: Paulo Santos Assis

CPF: 130740246-15 Identidade: M-185373

Endereço residencial

Av. Riacho das Pedras 199

Jardim Riacho Telefone: 31 396 1429

CEP: 32241-320 Contagem/MG

Titulação máxima: Dr.-Eng.

2. Instituição

Universidade Federal de Ouro Preto

CGC:

Endereço:

Praça Tiradentes 20

Centro Telefone: 031 5591561

CEP 35400-000 Ouro Preto/MG

Representante legal: Prof. Renato Godinho Navarro

3. Dados pessoais

Nome: Niloy Kumar Nath/ Ahindra Ghosh

Endereço:

3.1 Niloy Nath: Av. dos Trabalhadores 420, Santa Cecília-CEP 27260-740 Volta Redonda-RJ (temporário)

3.2 Ahindra Ghosh: Indian Institute of Technology - Kanpur, 208016 - India

Titulação máxima: Niloy Nath - PhD, IIT Kanpur

Ahindra Ghosh - Pos-Dr., USA

4. Instituição onde será executado o plano de trabalho

Universidade Federal de Ouro Preto-Escola de Minas

Praça Tiradentes 20

Centro Fone: 031 559 1561

CEP 35400-000 Ouro Preto/MG

Representante legal: Prof. Renato Godinho Navarro

5. Plano de trabalho

T'titulo do projeto:

Simulação numérica e otimização de processos de extração pirometalúrgicos

Área de conhecimento: Sub-área de conhecimento:

3.03.00.00-2 3.03.02.00-5

Palavras-chave: Alto-forno, modelo, metalurgia extrativa

6. Resumo dos objetivos

1. Desenvolver modelos matemáticos na área de metalurgia extrativa, usando conceitos de simulação numérica;
2. Desenvolver simulações para implementação de modelos físicos de processos convencionais na siderurgia;
3. Desenvolver e implementar modelos físicos a frio e a quente de processos alternativos na produção de aço;
4. Apresentar conferências técnicas para alunos de graduação e mestrado da REDEMAT nas áreas de metalurgia extrativa;
5. Participar de seminários/congressos nacionais para exposição de contribuições técnicas relativas aos projetos desenvolvidos.

7. Período de execução

Início: 3.3.97 Término: 28.2.98

8. Recursos solicitados a FAPEMIG

a) Mensalidades: 24 (corresponde a 12 mensalidades por Pesquisador)

c) Passagem aérea: 02. Trecho 1: Kanpur/India-Ouro Preto-Kanpur. Trecho 2: Volta Redonda/RJ-Ouro Preto-Kanpur/India.

d) Seguro -saúde: 02. Valor total: R$ 1600,00

9. Recursos solicitados a outras fontes

-10. Datas e assinaturas:

Local e data

Ouro Preto, 01 de novembro de 1996

Prof. Renato Godinho Navarro-Reitor da UFOP

Prof. Dr. Paulo Santos Assis-Solicitante

11.1 PLANO DE TRABALHO A SER DESENVOLVIDO PELOS PROF. PESQUISADORES AHINDRA GHOSH E NILOY NATH

(RESUMO DO PLANO DE TRABALHO-INGLÊS)

WORK PLAN

1. TITLE

NUMERICAL SIMULATION AND OPTIMIZATION OF PYROMETALLURGICAL EXTRACTION PROCESSES

2. OBJECTIVE

The pyrometallurgical process of extraction involves high temperature and energy intensive operations. Pyrometallurgy is the most important route in terms of tonnage and scope of application for extraction and refining of metals, since at high temperature reaction kinetics becomes very fast giving rise to high productivity. Proper design and control of the process is necessary for efficiency and economy of the process, since the cost of energy or fuel is very high and it involves processing of large amount of materials.

For design and optimization of such process, various systematic steps are taken. The chemical reaction rates are obtained from the laboratory experiments and other parameters like heat of reaction, chemical equilibria, heat and mass transfer coefficient etc. are collected from literature data or experimentally determined.

Full scale numerical simulation of the process is done to evaluate the performance of the process. The optimum condition or parameters of the process can be evaluated by using various optimization techniques. The mathematical models are also used for process control during its operation.

Developing a mathematical model needs proper understanding of all the phenomena involved in the process. Small scale or Pilot plant experiments can be undertaken to match the experimental and simulated data, to verify the model.

Simultaneous experimental and numerical simulation helps in proper understanding and evaluation of the various phenomena and mechanisms involved in the process. It is important to stress that simulated and experimentally measured data are not alternatives, but most often pursued in a complementary fashion. Numerical simulation laboratory or pilot plant data and actual plant scale measurements are all ingredients of a successful program to obtain proper understanding of the process.

Most of the pyrometallurgical processes are very complex in nature and involves various physical and chemical phenomena. At present few typical pyrometallurgical processes are discussed in details for further study and industrial application for improving their efficiency and performance.

3. EXPERIMENTAL STUDY AND NUMERICAL SIMULATION ON REDUCTION ROAST IN PROCESS OF LATERITIC NICKELLIFERROUS ORE IN FIXED AND MOVING BED REACTORS

Economic extraction of nickel from the lateritic nickeliferrous ore found in India, Brazil and many other tropical regions of the world is gaining wide spread interest, since there is a limited resource of sulfide based nickel ore deposits, and the demand for this economically and strategically important metal is ever increasing.

The extraction process of nickel from lateritic ore involves energy intensive reduction process followed by leaching and electrowinning techniques to extract nickel, or smelting in electric furnace to obtain ferronickel. The overall economy of the process depends on the efficiency of the reduction process due to high cost of fuels like oil, coal or natural gas.

A comprehensive study of the process is done for the nickeliferrous ore found in India, starting from the single pellet reduetion kinetics study, to the final modeling of an industrial reduction roasting furnace like Multiple Hearth Furnace. The work can be subdivided into three parts:

· Ore characterization and single pellet reduction kinetics study.

· Computer simulation and experimental study of reduction in fixed bed reactors.

· Computer simulation of the reduction process in Multiple Hearth furnace.

3.1 Ore characterizativn and Single Pellet Reduction Kinetics study

The run of mines ore is characterized by using various technique like SEM, EDAX, DTA, X-ray diffraction, chemical analysis and BET surface area measurement.5. The ore contains a very high amount of iron oxide (54 wt.%) and small amount of nickel oxide (1.22 wt.%) and has a very high moisture content and complex mineralogy.

Single pellet reduction study is conducted in a thermogravimetric setup, to experimentally determine the kinetic parameters for both iron oxide and nickel oxide (1,2). Iron oxide reduction rate is directly calculated from the thermogravimetric readings while reduction rate of nickel is estimated by leaching and chemical analysis. The experimental data is analyzed by using the established gas solid reaction kinetic models like Grain model (3,4,5) and Two-layer model (6,7,8) with necessary modifications for nonisothermal reduction and effect of product gas formation. Furthermore a complex oxide reduction mechanism for nickel is also proposed considering the formation of $(Fe_{l-x}\ Ni_x)_2 0_3$ complex oxide, from the minerals like geothite present in the ore (1,9). According to this mechanism unlocked Ni0 formation takes place only after the partial reduction of this complex oxide to form wustite (Fe0) and nickel oxide (Ni0).

The macrostructure of the reducing pellet is then computationally simulated by using the two layer model to get a better insight of the reaction mechanism and visualization of the process (1,2).

3.2 Computer simulation and experimental study of reduction in fixed bed reactors

Under industrial conditions, packed bed of ore pellets are reduced by reducing gases, where gas flow or gas solid contact can take place in either of the two typical modes : (i) Gas flowing horizontally over the bed of ore pellets, as in Multiple Hearth Furnace and Rotary kiln; or (ii) Gas flowing vertically through the bed of ore pellets, as in Shaft furnace. Both the situations were considered in the present work.

Reduction under horizontal gas flow condition is experimentally studied in an enclosed box. A mathematical model is then developed to simulate the reduction process. The heat and mass transfer in the gaseous phase over the bed is dominated by convection; and inside the bed it is governed by diffusion. The computation involves steady state solution of the fluid flow field over the bed by using a stream function vorticity formulation and simultaneous transient state solution of (i) Solid phase thermal energy balance (ii) Gas phase thermal energy balance (iii) Gas phase mass or species balance and (iv) Solid phase mass or species balance equations. The experimental and simulated results showed reasonably good matching. The effect of parameters like gas velocity, pellet size etc. are also studied computationally.

Reduction under vertical gas flow condition is studied in a eylindrical reactor and a model is also developed for simulating the reduction process. Here both heat transfer and mass transfer inside the bed is dominated by forced convection. In this study the fluid flow field through a packed bed of pellets is calculated from a differential form of Ergun's equation (10), and void fraction variation in a packed bed of spheres in a cylindrical tube is taken from Benenati and Brosilow's work (11). The solution of the Ergun's equation in stream function form involving both the laminar and turbulent resistance terms (10) is done by using a semi-implicit technique. Previously solution of Ergun's equation was done either in the turbulent regimes (12,13) or in the laminar region which is equivalent to the Darcy's equation for creeping flow condition. The present solution technique is an improvement over the previous solution techniques as it can predict the flow field over the entire domain of laminar, intermediate and turbulent flow regions (1,14).

The solution procedure for heat transfer, mass transfer and reaction kinetics is similar to the procedure mentioned earlier.

3.3 Computer simulation of the reduction process in Multiple Hearth Furnace

Industrially reduction of this type of ore can be done in a rotary kiln, shaft furnace or multiple hearth furnace (MHF). Since the reduction process is very slow and good control of gas composition is necessary for efficient reduction, MHF is considered to be the most promising for this purpose. A model for the reduction process in MHF is therefore done (1,15) based on the specifications of a pilot plant used in RRL Bhubaneswar, India (16).

Finite difference method is used for the solution of cylindrical axi-symmetric (r-z) equations. The solution technique involves discritization by Crank-Nicholson scheme for time and first order upwinding for the eonvective terms. This model will help in optimizing the process parameters, scaleup of the furnace and finally for the process control of the furnace under operating conditions.

3.4 Results and Discussion

Considering the importance of nickel as a economically and strategically important metal, its extraction process is studied in details. Economic recovery of nickel from the low grade lateritic ore poses a considerable challenge for extractive metallurgy due to the energy intensive roasting operation involved in the process. The reduction mechanism of this type of ore is also not well esta□blished, and the reduction kinetics of nickel present in the ore varies considerably from the pure nickel oxide. To address these problems we have systematically studied the reduction roasting process of a typical low grade high iron containing nickel ore found in India. The procedure followed and the findings of the present investigation can be summa.rized as given below :

1. Single pellet reduction kinetics study with hydrogen was conducted in the range of 800 to 1000 K, in which the reduction roasting operation of this type of ores are generally conducted. The study showed good reducibility of 90 % or more for nickel at 900 K and l000 K, but 50 % or less at 800 K. For pure nickel oxide complete reduction takes place at well below 600 K.

2. The experimental results were analyzed by established gas solid reaction models to evaluate the kinetic parameters and to understand the mechanism of reduction. The results showed gradual decrease in the rate constant value with reduction time. This is explained to be due to the product gas formation and non-isothermal reduction.
3. It is known that nickel is present as solid solution with iron in the goethite phase of the nickel ore, and its reducibility is much less than the pure NiO. Due to this reason a complex oxide reduction mechanism is proposed.
4. Industrially reduction operations are conducted in roasting.furnaces with moving bed of ore pellets or briquetes. The reactant gas flow may be vertically through the bed as in shaft furnace or over the bed as in multiple hearth furnace and rotary kiln. To evaluate the reduction process under such conditions, fixed bed pellet reduction experiment.s were conducted for both the types of gas flow.
5. Quasi-steady state models were then developed for the fixed bed reduction conditions and matched with the experimental results to verify the models. The matching were found to be satisfactory considering the difficulties and limitations of experimental technique. The models were then used further to study the effect of some of the important parameters like pellet size, gas composition etc.
6. The experimental results were compared with the predictions made by the mixed oxide mechanism (which is used generally), and the proposed complex oxide mechanism. The predictions are similar for most of the cases, except for the conditions where reduction is less, and complete wustite formation has not

taken place. Under such conditions complex oxide mechanism for nickel reduction gave better results and so for the parametric study this mechanism is used.

7. The effect of water vapor on reducibility was found to be more significant at 900 K than at 1000 K, and due to this reason reduction kinetics under packed bed conditions is much faster at 1000 K than at 900 K.
8. An axisymmetric model for multiple hearth furnace was developed using quasisteady state formulation as used for the fixed bed reactor models. In the model each hearth is considered as a separate entity and output of one hearth is the input for the next hearth. By this method we can compute all the hearths together, or few selected hearths of importance.
9. MHF results showed gas solid heat transfer is quite fast, and high gas temperature is required to heat the ore bed.
10. Although Pure CO is not a very good reducing agent at the operating temperatures, but mixture of CO and H2 was found to be a good reducing agent with better selective reducibility of nickel than pure H2.
11. The MHF model can be easily scaled up for larger industrial furnaces, for nickel ore reduction; and it can also be adopted for other roasting systems provided the reaction kinetics of the system is known.

Based on the research work already done further work can be planned to develop similar models for *Rotary Kiln* and *Shaft Furnaces* used for nickel and ferro nickel production. Experimental study on the reduction kinetics of the ore is necessary to obtain the conditions for better selective reduction of nickel which will be helpful for efficient nickel extraction and high grade ferro- nickel production.

4. NUMERICAL SIMULATION AND OPTIMIZATION OF IRON ORE SINTERING PROCESS

The iron making process involves large scale pyrometallurgical operations like iron ore sintering and Blast furnace operation. The raw materials like iron ore, flux etc. are generally sintered before charging in the blast furnace for good permeability and strength against the high burden pressure inside the blast furnace.

Iron ore sintering is a complex process involving various physical and chemical phenomena like gas-solid heat and mass transfer, reaction kinetics, melting, agglomeration and solidification. The raw materials used for the sintering process can vary to a wide extent, and it often involves recycling of the poor quality sinter product. The hot gas produced during sintering can also be recirculated for better thermal efficiency and pollution control. Due to this large variation of input conditions and partial recirculation of the hot gas and sinter product, the quality of sinter is very difficult to predict. Furthermore, in order to cope up with the increasing fuel prices, the modern sintering plants tend to be increasingly fuel efficient. It is evident from the fact that during the last two decades coke breeze consumption in many sinter plants have decreased from 55 kg/t sinter to 45 kg/t sinter. Therefore, although sintering is a well established process, there is still enough potential for the improvement of its efficiency, and control of the product quality. Due to the complex nature of the process, mathematical modeling is seen as an important research tool capable of augmenting the information obtained from laboratory and plant trials.

A theoretical model for the iron ore sintering process have been developed (17). The process parameters for the model are taken from the previous work reported in literature (18,19). Despite formidable diffculties associated with the modeling work, as the exact mechanisms of several fundamental processes associated with iron ore sintering have defied analysis to date, the results showed a reasonable agreement with the various experimental result,s reported in the literature (19,20). The model presented here can be used to simulate both the static bed or pot tests carried out in laboratory and the actual moving bed condition used in the industrial sintering plants. This type of modeling study will help in identifying the optimum conditions for the sintering process and also for the process control during its operation.

4.1 Process Description

During the sintering process a mixture of iron ore, coke, limestone and water is charged on a moving strand to form a 30-60 mm thick bed. In the first few meters of the strand the charge is ignited by an ignition hood equipped with burners. The hot gas produced by the combustion of air and natural gas is sucked in through the charge material from the wind boxes placed below the grate. Combustion of coke begins in the top layers when the temperature reaches about 1000 K. This continues beyond the ignition hood where only cold air is sucked in, and a relatively narrow band of ignition zone moves down through the bed, while the strand moves forward. The strand speed is adjusted so that the combustion zone reaches the bottom of the bed and the process of sintering becomes complete at the discharge end. Part of the materials melt in the high temperature region known as the flame front where the temperature rises above 1400 K. This partial melting causes the particles to agglomerate together, to form a continuous porous sinter cake. Beyond the so called *burn through position,* where the flame front reaches the grate, the sinter is either cooled on the strand or directly discharged.

It is evident from the above discussions that the iron ore sintering process is a fine example of cross flow heat and mass exchanger. The physicochemical and thermal phenomena involved in the process are however both complex and numerous, and perhaps could be summarized as :

- Gas tlow through the porous sinter bed (i.e. through the wet sinter mix, dry zone and the sinter product).
- Gas-solid heat exchange.
- Drying of the wet micropellet and the consequent change in the bed permeability.
- The chemical reactions : dehydration, decarboration (removal of CO_2 from limestone), oxidation and reduction of iron oxides, coke combustion, formation of calcium ferrites and silicates.
- Melting and solidification.
- Agglomeration and change in texture to form the final product.

- Change in pellet size and porosity giving rise to a change in the bed permeability.

Its imperative to regulate the size and composition of the raw materials, in order to obtain a good quality sinter product. However, the amount of melting and the maximum temperature attained during the sintering process predominantly determines the sinter quality. The molten material produced by partial melting solidifies to form various mineral phases that bond the sintered structure together. The mineral phases present in the sinter are usually hematite, magnetite, calcium ferrite, and calcium silicates of various composition and morphology.

The sintering temperature also determines the texture of the product. A visually homogeneous texture necessitates a high sintering temperature of about 1700 K. At lower temperatures usually a heterogeneous texture is produced in which a significant amount of large ore particles remains unreacted. A heterogeneous texture consisting of relict porous hematite bonded by acicular calcium ferrites is reported to be optimal by Dawson (21).

The reducibility of primary hematite is very good while it is very poor for the glassy phase formed due to melting. The strength of the sinter product depends on the fraction melted and the type of bond formation. Below a critical amount of melting it remains loosely bound and brittle. The `Reduction Degradation Index, RDI' has received much attention recently. The phenomenon arises from the low temperature reduction of hematite at around 900 K, and it depends mainly on the mineralogy and the stn□cture of the sinter product which can be experimentally determined.

Among the other factors, the size distribution of the sinter feed varies by a wide extent and for the sintering process it is advantageous to have some particle size segregation in the bed i.e. an increase in mean particle size towards the bottom of the bed, and to have more coke breeze in the top half of the bed than in the bottom half (22).

4.2 Development of a Mathematical Model

The mathematical model presented here is capable of calculating the solid and gas temperatures and compositions at any specifc location of the sinter bed during its entire operation. To achieve this a dynamic model in two dimensional Cartesian coordinate system has been developed for the process, neglecting the variation in the transverse direction. The gas velocity through the bed is estimated from the Ergun's pressure drop equation by iterative method. All the other process variables are evaluated by solving the transient forms of the appropriate transport equations. The set of equations used for solving the process therefore consisted of:

1. Gas velocity profile in the sinter bed is by Ergun's pressure drop equation.
2. Solid phase thermal energy balance.
3. Gaseous phase thermal energy balance.
4. Solid phase mass or species balance.
5. Gaseous phase mass or species balance.

4.3 Experimental Verification

A limited number of pot tests were conducted in the pilot plant facility of National Steel Company of Brazil (CSN) located at Volta Redonda, RJ. Further experiments are planned to determine the optimum sinter quality and.the effect of process parameters. The simulation data were also tested against the data available in the literature (19).

4.4 Results and Discussion

Iron ore sintering involves processing of large amount of raw materials for preparing the burden material of the blast furnace. The quality of the sinter product is very important for the smooth operation and high productivity of blast furnace since it improves the permeability and reducibility of the burden material. The optimum sinter quality cari be determined experimentally. Numerical simulation of the process will then help in identifying the optimum operating conditions for thermal effciency and productivity. The salient features of the procedure followed and the results obtained are given below :

1. A two-dimensional dynamic model for the iron ore sintering process is developed involving most of the important process parameters and variables.

2. The simulation results reproduced the pilot plant and laboratory data from various sources with a reasonable accuracy.

3. Two melting temperature of 1250 K and 1450 K is considered for the solid. The maximum temperature reached in the combustion zone of sintering is about 10-20 K above the melting temperature. At high melting temperature the kinetics of sintering is faster and the thickness of the combustion zone is also higher. However the fraction melted due to sintering is higher for the lower melting temperature condition, since the solid has to be heated to a much lower temperature for melting.

4. The effect of coke, moisture and limestone content in the solid mix are studied computationally. The effect of oxygen concentration and gas velocity are also studied computationally.

5. Optimization techniques are applied to evaluate the gas velocity for maximum melting of solid in the bed. The optimum velocity is quite low initially in the top region (0.4-0.6 m/s), since higher velocity caused the bed to cool down without proper ignition. In the lower regions where the combustion zone is much larger higher gas velocity (1.5-1.5 m/s) is found to be optimum.

Further laboratory experiments are necessary to identify the important parameters and conditions for optimum sinter quality, considering all the important parameters like strength, reducibility and reduction degradation at 900 K. Interactive study of modeling and experimental work is also necessary to improve the thermal efficiency of the process.

5. NUMERICAL SIMULATION AND OPTIMIZATION OF BLAST FURNACE PROCESS

Blast furnace ironmaking is a very large and complex process. The understanding of the internal process and mechanism of blast furnace operation has improved in resent years due to various experimental work like sudden quenching and cutting through the vertical cross section of the blast furnace to observe the structure and composition of the solid inside the furnace. Numerical simulation of the process can further help in our understanding of the process to improve its fuel efficiency, productivity and quality of pig iron.

The BF can be divided into various zones like preheating zone, thermal reserve zone, füsion zone and the race way or tuyere zone. The gas composition and temperature vary smoothly over the vertical as well as the horizontal cross section of the furnace. The chemical processes are therefore continuous throughout the volume of the furnace.

The hot blast enters through the tuyeres at the bottom at a velocity of about 200-300 m/s and at a pressure of 2-4 atm pressure. Such a' high pressure is necessary to push the reducing gas through the solid burden and to overcome the high top pressure, if any. this create a raceway of 1-2 m in front of each tuyere which can be easily penetrated. The race way region is surrounded by lump coke, since all other raw materials are in molten condition at the high temperature region in the raceway. Liquid iron and slag percolate through this coke layers and collect in the hearth. The gases rising from the raceways heat up the descending coke, liquid slag and metal. During percolation any iron oxide (Fe0) remaining gets reduced and the metal gets saturated with carbon. Partial reduction of other oxides like sulfur, phosphorus, silicon, manganese etc. also occurs and makes the metal impure. Above this zone is the inverted `V' shaped fusion zone consisting of alternate layers of coke and other charge materials as developed by the charging sequence. In the fusion zone the ore, flux etc. melt and the permeability of the bed is only due to the alternate coke layers or `SLITS'. The gas flow therefore tends to become horizontal and coke quality must ensure this permeability in this region. As the charge melts in the fusion zone it trickles down the coke bed and the coke layer slowly becomes a part nf the active coke zone. The slag and metal while percolating the coke zone also absorbs the impurities present in the coke ash.

Almost all the phosphorus present in the raw materials goes in the metallic phase, and the sulfur partially goes to the metallic phase according to the composition of the slag phase. The sulfur content in the hot metal is low for basic slag containing higher concentration of CaO, $Mg0$ etc. The structure of the burden above the fusion zone is practically the same as is obtained in the stockline during charging. The reduction of iron in this region is mainly by the reducing gas i.e. by indirect reduction.

Most of the cost of raw materials used in blast furnace is due to the coke, since the high grade coal required for making metallurgical coke is not abundantly available in most of the countries. Therefore efforts are made to decrease the consumption of coke. Various methods are applied like injection of powdered coal, natural gas or oil from the tuyeres. Oxygen enrichment and high blast temperature is also used for this purpose. However coke consumption cannot be decreased below 300 kg/tHM since it is essential for the permeability in the fusion zone. Iron ore powder injection from the tuyeres is also done to improve the productivity of the furnace.

Development of a mathematical model for the blast furnace process is envisaged considering cylindrical axisymmetric condition. Since BF is a very complex process the computed results have to be first matched with the industrial results for model verification and parametric adjustments. The verified model then can be used for studying the effect of various important parameters and change in input conditions like fuel and iron ore injection, oxygen enrichment etc. Dynamic model for the process can be developed to study the response time for any change in input condition. This model can also be used for controlling the blast furnace process.

6. MERITS AND TECHNICAL FEASIBILITY

Pyrometallurgical processes generally involves large scale production involving high energy and fuel consumption. The pyrometallurgical processes are very complex in nature with fast operation kinetics. Since the cost of fuel is high, thermal efficiency and uniform product quality requires proper understanding of the process and efficient operation. Numerical simulation, experimental verification and deterrnination of the important parameters like reaction kinetics ete. will help in proper understanding of the various phenomena involved in the process. Gas velocity through the porous bed is very important for the pyrometallurgical systems discussed here. Generalized Ergun's equation in two dimension and axi-symmetric condition (10) can be used for this purpose. The solution procedure for the generalized Ergun's equation have been developed (14) which can be used for the numerical modeling. Most of the metallurgical vessels like blast furnace, MHF have cylindrical symmetry and mathematical modeling can be done by considering cylindrical axi-symmetric condition. Already a mathematical model for roasting of nickel ore in MHF have been developed, similar models can be developed for Rotary Kiln and Shaft Furnaces also. Experimental determination of the kinetic parameters of the various type of nickel ores used in industry can be done following similar procedures as discussed before (1,2). The simulated results and the industrial results can be matched and optimum operating conditions for nickel and ferro-nickel production can be proposed.

A dynamic model for iron ore sintering is developed, considering two dimensional Cartesian coordinate system. The simulated results were found to match reasonably well with the reported data and some experiments conducted in iSN laboratory (16). The conditions for optimum sinter quality can be determined from laboratory experiments. The model can then be used to evaluate the operating parameters for obtaining similar condition in the industrial sinter strands.

Development of a dynamic model for blast furnace in cylindrical axisymmetric coordinate system is envisaged to study the effect of various modi ications in the blast furnace like coal and fuel injection, iron ore injection etc. The generalized Ergun's equation (10) can be used to evaluate the gas velocity through the blast furnace. The measurement of important parameters inside the blast fiirnace is quite difficult inspite of the various developments in measurement techniques. The model verification can be mostly done by measuring the composition and temperature of the outlet gas from the top and outlet slag and hot metal from the bottom. The internal conditions and structure of the blast furnace can be compared with the information obtained from the cross section of the quenched blast furnace data available in literature (18).

7. REFERENCES

(1) N.K. Nath *: Reduction Roasting of Nickeliferrorrs ore in Multiple Hearth Funace* : Ph.D. Thesis; Indian Institute of Technology, Kanpur : 1995

(2) N.K. Nath, N. Chakraborti and R. Shekhar : *Selective reduction of Indian nickeliferrous ore: Single pellet experiments :* Scand. J. of Metal.: vol. 24 1995; PP 121-38

(3) H.Y. Sohn, J. Szekely : Chem. Eng. Sc.: 1972: 27: PP 763-78

(4) J. Szekely, C.I. Lin, H.Y. Sohn: Chem. Eng. Sc.: 1973: 28: PP 1975-89 (5) J. Szekely, A. Hastaoglu: Inst. Min.and Met.: Jun 1976: PP C78-87 (6) M. Ishida, C.Y. Wen : AIChE J: Mar 1968:14: 2: PP 311-17

(7) J.M. Ausman, C.C. Watson : Chem. Eng. Sc.:1962:17: PP 323-29

(8) Y·K· Rao : Unpublished I,ecture Notes. University of Washington, Seattle:1982

(9) N.K. Nath, N. Chakraborti and R. Shekhar : *Reduction of Indian nickeliferrous ore in a fixed bed reactor with horizontal gas flow over the bed:* Scand. J. of Metal. (Submitted for Pub.)

(10) I. Muchi, S. Asai, M. Kuwabara : Memoirs of the Faculty of Engineering: Nagoya University: 1987: 39: I: PP 92-99

(11) R.F. Benenati, C.B. Brosilow : AIChE J: Jul 1962: 8: 3: 359-6I
(12) V. Stanek, J. Szekely : AIChE J: Sep 1974: 20: 5: PP 974-80
(I3) J. Szekely, J.J. Poveromo : AIChE J: Jul 1975: 21: 4: PP 769-75 (14) N.K. Nath, N. Chakraborti and R. Shekhar : *Reduction of Indian nickeliferrorus ore* in *a fixed bed reactor with* gas *flowing vertically through the bed :* Scand. J. of Metal. (Submitted for Pub.)
(15) N.K. Nath, N. Chakraborti and R. Shekhar : *Mathematical modeling of reduction roasting process in multiple hearth furnace :* Scand. J. of Metal. (To be Submitted for Pub.)
(16) G.N. Banerjee, et al. Trans. Indian Inst. Met.: Feb 1994: 47: I: PP 21-26
(I7) N.K. Nath, A.J. Silva and N. Chakraborti : Dynamic Process *Modeling of Iron Ore Sintering* : Steel Research (Submitted for Pub.)
(18) Blast Furnace phenomena and Modelling : Committee on reaction within blast furnace, Joint society on iron and steel basic research. ; ISIJ, Elsevier Applied Science 1987, New York.
(19) M.J. Cumming and J.A. Thurlby : Ironmaking Steelmaking, 1990, Vol.I7, No.4, PP 245-54.
(20) F. Patisson, P.P. Bellot, D Ablitzer, E. Marliere, C. Duley and J.M. Steiler: Ironmaking and Steelmaking; 199I, Vol.I B, No.2, PP 89-95
(21) P.R. Dawson : Ironmaking and Steelmaking:1993, Vo1.20, No.2, PP 137-43.
(22) D.F. Ball, J. Dartnell, J. Davison, A Grieve, R Wild *: Agglomeration of Iron* Ores: U.M.I. Books on Demand : Ann Arbor, Michigan, 1994.

11.2 “Curricula-Vitae” dos Pesquisadores

11.2.1 Ahindra Ghosh
11.2.2 Niloy Nath

11.2.1 **Name**: AHINDRA GHOSH

Designation: Professor and Researcher

Address: Department of Metallurgical Engineering Indian Institute of Technology
KANPUR 208016, INDIA

Date of birth: August 25,1937

Educational Qualifications:

(i) Bachelor of Engineering (Metallurgical Engg.), Calcutta University, 1958

(ii)Doctor of Science(Sc.D.) in Metallurgy, Massachusetts Institute of Technology, U.S.A., 1963

Experience:

(i) Teaching, research at the Indian Institute of Technology, Kanpur from 1965 (i.e.more than 26 years)

(ii) Post-doctoral fellow at Ohio State University, USA, 1963 - 64

(iii) Visiting scientist at Imperial College,London,I973

(iv)Visiting Scientist at MIT,USA,1986

Research Interests :

(a)general

(i)Thermodynamics, Kinetics & Cold modelling of processes

(ii) Ironmaking and Steelmaking

(b) specific

(i) Reduction of iron ore by carbon, H_2, CO :(last 10 yrs)

(ii) Coke and char reactivity

(iii) Composite iron ore-coal pellet technology

(iv) Mixing and mass transfer in ladles

(v) Deoxidation of liquid steel

(vi) Ingot and continuous casting of steel

PUBLICATIONS

Books :

(1) Ahindra Ghosh and Hem Shanker Ray," Principles of Extractive Metallurgy",Ist edition,Indian Institute of Metals,Calcutta,l984; 2nd ed, 1991 Wiley Eastern Ltd. , New Delhi; approx.400 pages.

(2) Ahindra Ghosh,"Principles of Secondary Processing and Casting of Liquid Steel",Oxford & IBH Publishing Co.Pvt.Ltd.,New Delhi, 1990; 200 pg.

Papers:

About 60 research publications in standard reviewed journals;details enclosed

Unpublished Monographs (in typed & cvclostyled form)

(1)"Kinetics of Extractive Metallurgy",1976,approx.300 pages.

(2)"Momentum Transfer in Metallurgy",1983,approx.l25 pages. Conference Publications,Chapters in Books & Review Papers (mostly invited) list enclosed.

COURSES TAUGHT

(i) Metallurgical thermodynamics

(ii) Kinetics of extractive metallurgy

(iii) Heat, mass and momentum transfer

(iv) Ironmaking

(v) Steelmaking

(vi) Advanced chemical metallurgy

(vii) Process laboratories

RESEARCH & DEVELOPMENT ACTIVITIES

Guide 10 Ph.D.students, 23 Masters'students and many undergraduates

Handled 8 sponsored and consultancy projects

Carried out investigations in collaboration with steel plants in the area of deoxidation, ingot and continuous casting of steel

LIST OF PUBLICATIONS

(A) PAPERS PUBLISHED IN REVIEWED JOURNALS

1. R.N. Singh and A. Ghosh, "Reduction of Kemongundi iron ore in hydrogen", Ind. J. of Tech. , (1968), 334-7.
2. A. Ghosh, "Isobaric ternary phase diagrams for the molybdenum-carbon-oxygen system at 1600 K", J. Less Common Metals, (1969), 329-33.
3. A.Ghosh and T.B.King, "Kinetics of oxygen evolution at a platinum anode in lithium silicate melts", Trans. Met. Soc. AIME, Vo1.245, (1969), 145-52.
4. S.N.Basu and A.Ghosh, "Influence of porosity on the kinetics of reduction of hematite by hydrogen", JISI, (1970), 765-68.
5. A. Ghosh and G. R. St. Pierre, " Isobaric ternary phase diagrams in the iron-carbon-oxygen system", Ind. J. Tech., (1970), 79-81.
6. U.V. Choudary and A. Ghosh, "Thermodynamics of liquid copper-silver alloys by the solid electrolyte cell method" J. Electrochem. Soc. (New York), (1970), 1024-8.
7. P.K.Gairola, R.K.Tiwari and A.Ghosh, "Rate of dissolution of a vertical cylinder of nickel in liquid aluminum under free convective flow" Met. Trans., Vol.2, (1971), 2123-26.
8. P.J. Roychowdhury and A. Ghosh, "Thermodynamic measurements in liquid tin-silver alloys", Metallurgical Transactions, (1971), 2171-74.
9. S.K. Das and A. Ghosh, "Thermodynamic measurements in liquid lead-tin alloys Metallurgical Transactions, (1972), 803-6.
10. K.P.Jagannathan and A.Ghosh, "A thermodynamic study of molten Pb-Ag-Sn system", Met. Trans., Vol.4, (1973), 1577-83.
11. Anwar Ali, S.N. Basu and A. Ghosh, "Single pellet studies on reduction of some Indian iron ores", Trans. Ind. Inst. Metals, Vo1.26, (1973), 54-56.
12. K.P. Jagannathan and A. Ghosh, "Thermodynamic measurements in liquid copper-indium alloys", Trans. Ind. Inst. of Metals, Vol.27, (1974), 298-302.
13. V.N. Grover, K.P. Jagannathan and A. Ghosh, "A study of nitriding of ferrochrome", Trans. Ind. Inst. of Metals, Vol. 27, (1974), 331-35.
14. S.Basu and A.Ghosh, "A physico-chemical investigation on selective reduction of iron oxides in chromite", Met. Trans.B, Vol.6B, (1975), 441-51.
15. J.Kumar and A.Ghosh, "Gas absorption during pouring of a liquid metalsa cold model study", Trans. Ind. Inst. of Metals, Vo1.30, (1977), 39-44.
16. R.Mathur,M.S.Rao and A.Ghosh, "Kinetics of reduction of porous hematite pellets in mixtures of CO and H ",Trans.Ind.Inst.of Metals, Vo1.30, (1977), 45
17. M.C.Abraham and A.Ghosh,"Kinetics of reduction of iron oxide by carbon" Ironmaking and Steelmaking, Vol.6, (1979), 14-23.
18. A.K. Gokhale, A.K. Sengupta and A. Ghosh, "Investigations on carbothermic reduction of iron ore, Steel India, No.I, Vol.2, (1979), 36-42.
19. R.K. Verma, H.S. Ray and A. Ghosh, "Liquidus and solidus Temperatures of blast furnace slags with and without additives", Part-I: DTA measurement technique, Trans. Ind. Inst. of Metals, No.4, Vo1.32, (1979), 318-321.

20. R.K. Verma, H.S. Ray, A. Ghosh, R.N. Singh, S. Dharanipalan and S.K. Gupta, "Liquidus and solidus temperatures of blast furnace slag with and without additives", Part-II: Results and their significance to blast furnace operation under Indian conditions, Trans. Ind. Inst. of Metals, No.4, Vo1.32, (1979), 322-329.
21. R. Mathur, A. Ghosh and M. Someswar Rao, "Influence of some parameters on gas absorption during teeming - a water model study", Trans. Ind. Inst. of Metals, No.3, Vo1.33, (1980), 204-8.
22. N.B.Ballal and A.Ghosh," A water model study of bottom blown steelmaking process", Met. Trans. B, Vol.12B, (1981), 525-34.
23. S.R. Prabhakar and A. Ghosh, "Temperature drop during pouring of molten metal", Trans. Ind. Inst. of Metals, No.6, Vo1.34, (1981), *441-447.*
24. A. Ghosh and V. Naik, "Deoxidation of steel with Ca-Si-Al and Mg-Si-Al complex deoxidizer-a thermodynamic analysis" Tool & Alloy *Steels*, N°.7, Vol.I7, (1983), 239-44.
25. N.B. Ballal and A. Ghosh, "A kinetic analysis of oxygen absorption by sparks generated during rimming in ingot mould", Trans. Ind. Inst. of Metals, No.4 & 5, Vo1.36, (1983), 381-87.
26. S.K. Banerjee, T. Mukherjee and A. Ghosh, "Oxygen absorption during solidification of rimming steel ingots", Trans. Ind. Inst. of Metals, N°. 6, Vol. 36, (1983), 459-65
27. N.B.Ballal and A.Ghosh, "Mixing of concentric gas jets issuing vertically into a liquid", Met. Trans.B, Vol.ISB, (1984), 71-76.
28. A.Ghosh and P.N.Chaudhary, "An investigation of deoxidation of liquid steel by silicon and manganese", Trans. Ind. Inst. of Metals, Vo1.38, (1985), 31-42.
29. Brahma Deo, A.K.Bagaria and A.Ghosh, "Production of semikilled steels with controlled porosity - Part I: Computer simulation", Trans. Ind. Inst. of Metals, Vo1.38, (1985), 49-56.
30. D.Mazumdar and A.Ghosh,"Production of semikilled steels with controlled porosity - Part II : Experimental investigations", Ibid, 57-63.
31. H.N.Dharwadkar and A.Ghosh, "A cold model study on skin and blowhole formation with reference to solidification of steel", Met. Trans.B, Vol.17B, (1986), 553-64.
32. D.Ghosh, A.K.Ray and A.Ghosh, "Reduction of ferric oxide pellets with methane, Trans. ISIJ, Vo1, 26, (1986), 186-93.
33. A.Ghosh and G.V.R.Murty, "An assessment of thermodynamic parameters for deoxidation of molten iron by Cr,V,Al,Zr and Ti, Ibid,.629-37.
34. G.G.Krishnamurty, S.P.Mehrotra and A.Ghosh, "Experimental investigation of mixing phenomena in a gas-stirred liquid bath", Met. Trans.B, Vol.I9B, (1988), 839-50.
35. G.G.Krishnamurthy, A.Ghosh and S.P.Mehrotra, "Characterization of a twophase plume in gas-stirred liquid bath - a model study", Ibid, 885-92.
36. D. Bandyopadhyay, N. Chakraborti and A. Ghosh, "Re-evaluation of heat transfer effects in carbon gasification reaction", Steel Research, No.I2, Vo1.59, (1988), 537-541.

37. G.G.Krishnamurthy, A.Ghosh and S.P.Mehrotra, "Mathematical modelling of mixing phenomena in a gas-stirred liquid bath", Met. Trans.B, Vol.2OB (1989), 53-59.
38. S.K.Choudhary and A.Ghosh,"Study of coal char reactivity with reference to direct reduction processes", Trans. Ind. Inst. of Metals, Vol.42, (1989), 541-52.
39. D.Mazumdar, S.K.Kajani and A.Ghosh, "Mass transfer between solid and liquid in vessels agitated by bubble plume", Steel Research, Vol.6l, (1990),339-46.
40. Thomas Tharian K., A.L.Kundu, B.Deo and A.Ghosh, "A plant investigation on production of semikilled steel with controlled porosity", Trans.Ind. Inst. of Metals, Vol.43, (1990), 190-200.
41. D.Bandyopadhyaya, N.Chakraborti and A.Ghosh, "Heat and mass transfer limitations in gasification of carbon by carbon dioxide", Steel Research, Vo1.62, (1991), 143-51.
42. T.K.Roy, S.K.Choudhary and A.Ghosh, "A study of macrosegregation of continuously cast steel billets", Trans. Ind. Inst. of Metals, Vol.44, (1991), 215-22.
43. S.K. Choudhary and A. Ghosh, "A study of effect of mineral matter on coal char reactivity", Trans. Ind. Inst. of Metals, No.3, Vo1, 44, (1991), 209-14.
44. G.G. Krishna Murthy, A. Ghosh and S.P. Mehrotra, "Theoretical estimation of mixing parameters in a gas stirred liquid bath", Trans. Ind. Inst. of Metals, Vo1.44, (1991), 31-37.
45. R.K. Goyal and A. Ghosh,"Centreline segregation in continuously cast steel billets", Trans. Ind. Inst. of Metals, Vo1.45, (1992), 303-314.
46. P. Tiwari, D. Bandyopadhyay and A. Ghosh, "Kinetics of gasification of carbonand carbothermic reduction of iron oxide", Ironmaking and Steelmaking, Vol.l9, (1992), 464-68.
47. S.K. Choudhary,D. Mazumdar and A. Ghosh,"Mathematical modelling of heat transfer phenomena in continuous casting of steel", ISIJ International, Vo 1. 33, (1993), 764-774.
48. D. Bandyopadhyaya,N.Chakraborty and A. Ghosh,"Kinetics of reduction of iron oxide by carbon",Steel research, Vo1.64, (1993), 340-45.
49. S.K. Choudhary and A. Ghosh, "A study on morphology and macro-segregation in continuously cast steel billets", Vol.33, (1993), 764-74.
50. Sujoy K. Dutta and Ahindra Ghosh, "Kinetics of gaseous reduction of iron ore fines, ISIJ Int., No.II, Vo1.33, (1993), 168-73.
51. S.K. Dutta and A.Ghosh, "Study of non-isothermal reduction of iron ore-coal char composite pellets", Met.Trans B, No.I, Vol.25B, (1994), 16-26.
52. Kamlesh K. Singh and Ahindra Ghosh, "Carbonate capacities of Na_2O-SiO_2-B_2O_3 melts, ISIJ Int., No.2, Vo1.34, (1994), 150-154.
53. S.K. Dutta and A. Ghosh, "Evaluation of various cold bonding techniques for iron ore-coal/char composite pellets", Trans. Ind. Inst. of Metals , Vol.48, (1995), 1-13.

(B) SHORT RESEARCH PAPERS

1. A.Ghosh and G.R.St.Pierre, "Ternary phase diagrams for Si-C-0 system" , Trans. Met. Soc. AIME, Vo1.245, (1969), 2106-08.
2. A.K. Sengupta, K.P. Jagannathan and A. Ghosh, "Thermodynamic measurement in liquid copper-tin-alloys", Met. Trans.B, Vol.9B, (1978), 141-143.
3. A. Ghosh and S. Chakraborty, "On possibility of mixed control in kinetics of CO-$C0_2$ isotope exchange reaction on surfaces of oxide melts", Trans. Ind. Inst. of Metals, Vo1.42, (1989), 189-94.
4. S.K. Dutta and A. Ghosh, "A new method for measurement of degree of reduction in composite pellets of iron ore with carbonaceous matter", ISIJ Int. , No.10, Vo1.33, (1993), 1104-06.
5. T.K. Roy, R. Balasubramaniam and A. Ghosh, "Determination of oxygen and nitrogen diffusivities in titanium aluminides by subscale microhardness profiling", Scripta Materialia, Vol.34, (1996), 1425-1430.

(C) SCIENTIFIC REVIEWS

1. A. Ghosh, "Application of thermodynamics to deoxidation and ingot casting of steel", Tool & Alloy Steels, Vol.22, (1988), 383-91.
2. A. Ghosh, "Metallurgical education with special reference to India" METAL NEWS, No.4, Vo1.14, (1992), 8-14.
3. A. Ghosh, "Mini-steel plants - prospects and retrospect in India", Metallica, I.I.T. Kanpur, (1972).
4. A. Ghosh, "Role of interfaces in pyrometallurgical reactions", Trans. Ind. Inst. of Metals, Vo1.31, (1978), 1-11.
5. A. Ghosh, "Kinetics of steelmaking reactions and processes - an overview", Tool and Alloy Steels, Silver Jubilee, (1991), 65-74.
6. T.K. Roy, S.K. Choudhary and A. Ghosh, "Centreline segregation in continuous casting of steel", Tool & Alloy Steels, Vo1.26, (1992), 365=372.

(D) ARTICLES PUBLISHED IN SEMINARS, SYMPOSIA, CONFERENCES

1. K.P. Jagannathan and A. Ghosh, "Determination of activity in liquid metallic solutions", Silver Jubile Symposium, Indian Institute of Metals, (1972).
2. M.C. Abraham and A. Ghosh, "Kinetics of reduction of iron oxides and ores by carbon", Engineering World, Proc. of Conf. on Sponge Iron & its Conversion into Steel, held at NML, Feb. (1973).
3. N.B. Ballal and A. Ghosh, "Kinetics of decarburization reaction in L.D. Steelmaking", Proc. Symp. Surathkal, (1976), 241-62.
4. A.K. Bagaria, Brahma Deo and A. Ghosh, "Aspects of thermodynamics of deoxidation of molten steel with Mn, Si and A1", Intl. Symp. Proc. on `Modern Developments in Steelmaking', held at Jamshedpur, 16-18 Feb., (1981).
5. G.G: Krishan Murthy, A. Ghosh and S.P. Mehrotra, "Effect of plume geometry on recirculation flow rates in a gas injected vessel", Intl. Conf. Proc. on 'Progress in Metallurgical Research : Fundamental and Applied Aspects', eds. S.P. Mehrotra and T.R. Ramachandran, TataMcGraw Hill Publ. Co., New Delhi, (1986), 307-15.

6. G. G. Krishan Murthy, S. P. Mehrotra and A. Ghosh, "Mixing in a gas-injected vessel: some basic concepts and experimental measurements", 5th Int. Iron & Steel Congress, Proc. Process Tech., Vol.6, Iron & Steel Soc., Washington D.C., (1986), 401-07.
7. A. Ghosh, "Kinetic studies in process metallurgy", in Intl. Proc. on "Thermodynamic and Kinetics of Metallurgical Processes", eds. M.M. Rao K.P. Abraham, G.N.K. Iyenger and R.M. Mallya, Ind. Inst. of Metals, (1985), 161-184.
8. A. Ghosh, "Metallurgical education - some comments with specific reference to India", Preprints of Seminar on `Impact of changing needs of industry and R & D organizations on Metallurgical Education', held at B.H.U., March 20-21 (1987).
9. A. Ghosh, "Fundamentals of reduction of iron oxides", Proc. Workshop on Sponge Iron at Ranchi, (1988), 25-73.
10. A. Ghosh and S.K. Ajmani, "On evaluation of chemical rate constants for reduction of iron oxides by carbon", Proc. Symposium, IIT Kharagpur, (1989), 1-17.
11. A. Ghosh, "Review of secondary steelmaking principles", Preprints of Seminar on Secondary Steelmaking, Jamshedpur, (1989), 1-14.
12. A. Ghosh, "Fundamentals of vacuum degasssing systems", Int. Symp. on Quality steelmaking - emerging trends in the nineties', IIM, Ranchi', Nov (1991), 85-94.
13. A. Ghosh, "Physical chemistry of steelmaking - an appraisal of.current status", Indo - Russian bilateral symposium on `Emerging trends in process technology for iron and steel in the nineties', RDCIS, Ranchi, Oct (1992), 34-48.
14. A. Ghosh, "Fundamentals of productivity of smelting reduction processes", International Conference on Alternative Routes to Iron & Steel, Ind. Inst. Metals, Jamshedpur, (1996), 17-30.

(E) CHAPTERS CONTRIBUTED TO BOOKS

1. K.P. Jagannathan, S.K. Tiku, H.S. Ray, A. Ghosh and E.C. Subbarao, "Technological applications of solid electrolytes", Ch.6 of <u>Solid Electrolvtes</u> and <u>their Applications,</u> E.C.Subbarao ed., Plenum Press, New York, (1980).
2. A. Ghosh, "Cold modelling of high temperature metallurgical processes" Proc. Int.Conf. on Metal Sciences - The Emerging Frontiers, Varanasi, Nov (1977), 405-424.
3. A. Ghosh, "Chemical thermodynamics", in <u>Elements of Ceramic Science</u> Vol. I, D. Ganguly and S. Kumar ed., Indian Inst. of Ceramics, Calcutta, (1982), C 2.
4. Ahindra Ghosh, "Thermodynamics and kinetics of pyrometallurgy", in <u>Frontiers</u> in <u>Applied Chemistrv</u>, A.K. Biswas ed., Narosa Publishing House, New Delhi, (1988), Ch.2.
5. A. Ghosh, "Modelling of unit processes", in <u>Ouantitative Approaches in Processes Metallurgy</u>, A.K. Tripathi, P. Dutta and H.S. Ray eds., Allied Publishers Limited, New Delhi, (1995), Ch.I.

(F) BOOKS AUTHORED / EDITED

1. Ahindra Ghosh and Hem Shanker Ray," Principles of Extractive Metallurgy", Ist edition, Indian Institute of Metals, Calcutta, (1984), 2nd ed., Wiley Eastern Ltd., New Delhi, (1991), approx. 400 pages.
2. Ahindra Ghosh, "Principles of Secondary Processing and Casting of Liquid Steel", Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi,(1990), approx. 200 pages.
3. Pradip, Rakesh Kumar (Editors) and A. Ghosh (Managing Editor), "Selected Topics in Mineral Processing",Wiley Eastern Limited (Publishers), New Delhi, (1995), approx. 300 pages.

11.2.2 Dr. Niloy Kumar Nath

Name: Dr. Niloy Kumar Nath

UFF-EEIMVR, 420 Vila Santa Cecília
CEP: 27260-740,Volta Redonda, RJ, BRAZIL
E-Mail: nkn@metal.eeimvr.uff.br
Telephone: +55-243-44-4023 (office)
Fax: +55-243-44-5522

Father's name : Dr Nalini Kanta Nath

Permanent Address : No.1/A F'riend's Row
Santoshpur, Calcutta - 70775
Telephone : +91 033 472 4518

Date of birth: l6th April 1963

Education: Ph.D Indian Institute af Technology Kanpur 1995
M.Tech Indian.Institute of Technology, Kanpur 1989
B.Met.E Jadavpur University, India, 1987

Ph.D Thesis Title : "Reduction of Nickeliferrous ore in Multiple Hearth Furnace"

ALL DEGREES ARE IN METALLURGICAL ENGINEERING

Specialization: Process/Extractive Metallurgy with special emphasis on Mathematical Modelling and Computer simulation in UNIX and DOS environment.

Experience: 1996-present: Associated with UFF, Universidade Fedcral Fluminense, Brazil, and CSN, CNPq (National Steel Company and National Research Council of Brazil); Interactive research program with the University and the CSN Steel plant on : Dynamic Process rnodelling and optimization of Iron orc sinterization.

Languages Known: English, Portuguese, Bengali and Hindi

PUBLICATIONS

I. N.K.Nath, N Chakraborti and R Shekhar; Selective *reduction of Indian Nickeliferrousore: Single pellet experiments: Scandinavian Journal of Metallurgy: 1995,* 24: p 121-.38.

Submitted for publication:

2. N.K.Nath, N.Chakraborti and R Shekhar: *Reduction of Indian Nickeliferrous ore in a fixed bed reactor with horizontal gas flow over the bed: Scandinavian Journal of Metallurgy*

3 N.K.Nath, N.Chakraborti and R Shekhar: *Reduction of Indian Nickeliferrous ore in a fixed bed reactor with gas flowing vertically through the bed: Scandinavian Journal of Metallurgy*

4. N.K.Nath, N.Chakraborti and R Shekhar*: Mathematical modelling* of reduction roasting process in multiple hearth furnace: *Scandinavian Journal of Metallurgy*

To be submitted for publication

5. N. K. Nath, A.J.Silva and N.Chakraborti*: Dynamic* Process Modelling and Optmization for Iron Ore Sintering: Steel Research

CONFERENCE PRESENTATIONS

6. N.K.Nath, N.Chakraborti and R Shekhar: *Mathematical modelling* for selective reduction of nickeliferrous ore in a fixed bed reactor: 47th ATM of IIM, at Hyderabad, India, 1993

7. N.K.Nath, N.Chakraborti and R Shekhar: *Fixed bed pellet reduction under vertical gas flow conditions: 48th ATM of IIM, at Visakapatnam, India, 1994.*

8. N.K.Nath and A.J.da Silva: *Modelamento e otimização do processo de sinterização de minério de ferro. 51º. Congresso da ABM, Porto Alegre-RS, Brazil, Agosto de 1996.*