National Institute of Technology, Tiruchirappalli – 620 015

Department of Metallurgical and Materials Engineering

Course MT 303 Iron Making and Steel Making (IMSM)

Lecture Plan and Related Details

Core Course for B. Tech. (MME) – V Semester – 2008 Version

Acad. Yr. 2008 – 2009 ODD SEMESTER

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Proposed Slot: C (Mon. 3, Tues. 2, Wed. 1, Fri. 2) – four times a week
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PREFACE

I had drafted and displayed an outline for the course on IMSM, offered in 2007. It was a small beginning. I had been motivated by some very systematic and useful display of technical information, with an orientation towards the students, in the internet, like:

MIT – open course ware of Prof. Adam Powell IV, on Transport Phenomena in Materials Engineering

MIT – open course ware of Prof. W. Craig Carter, on Thermodynamics of Materials

IISc – site of Prof. T. A. Abinandanan, on Metallurgical Thermodynamics

The above three are well conceived and well delivered courses / structured information, laced with limericks and haiku also. (Will students of IMSM 2008 contribute poems, apart from bricks and bouquets?) My effort, here, aims at providing a single consolidated file with information related to my course on IMSM (2008). The material displayed for IMSM 2007 got lot of encouragement and criticism. Some excerpts, here:

(Check with me, if you want the complete communication.)

1. A Professor from an NIT: “…. Good effort; class room lectures should be supplemented by lectures by experts from the steel industry….“ (Sir, I am yet to arrange for lectures by industrial experts; and shall try this year.)

2. An executive from an engineering company: “…. Brought in transparency in course content and expectations; should include pictures and videos, so that students can appreciate the process….“ (Sir, I have identified web based sources where pictures and videos are available; and am alerting my students about the sources; and am using some pictures and videos this year.)

3. A Professor from an IIT: “….impressed with the course content; you can use the recent version of MST to present nice slides to the class….“ (Sir, I intend to try this option in IMSM 2008.)

Hope the student would find the information presented here convenient, useful and motivating.

New faculty entering the realms of process metallurgy (“an endangered species”!) may find this a convenient starting point. I am very grateful to Prof. V. Sivan, MME, for his critical observations; and for his grace in handing over courses on IMSM to me, for teaching the future generations.
OBJECTIVES

1. To become familiar with iron making and steel making
2. To become conversant with the role of thermodynamics and kinetics in IMSM
3. To get a feel for what is happening in the steel industry

Hidden agenda – The student, at the end of this course, will be in a position to think of process metallurgy and steel industry – with due respect and some interest. The student should become aware that a career in metallurgy could be interesting and rewarding.

ORIGIN OF THIS COURSE

This course is derived from three earlier courses in the B. Tech. (Met. Engg.) curriculum. The changes had been initiated during 1999 – 2000. The courses on (i) Fuels, Refractories and Furnace technology, (ii) Production of Iron, (iii) Production of Steel have been consolidated and made into a single course. Some topics on Refractories were then incorporated in a new course on Ceramic Materials. Some topics on Fuels were then incorporated in a course on Mineral Processing. Essentially, this IMSM course is equivalent to 2.5 courses of earlier days. This course on IMSM was operated, for a few years, as a 5-credit one semester course (BMT 502) (4 Lectures and 1 Tutorial per week). The course has now (vide 2006 regulations) been compressed further into a 4-credit one semester course (3 Lectures and 1 Tutorial per week). The course contents are rather voluminous, but not tough at all!

This redesign of the course has occurred during a period when the fortunes of the steel industry have been improving. However, in terms of student training, no major omissions have been noticed. During the last three years, it appears that - more than 5 students per batch (UG MME batch size of about 30 students) have been getting placed (on campus) in the steel industry.
**PRE-REQUISITES**
The present academic regulations of NITT do not provide for explicit listing of pre-requisites. However, the students study this course in the Fifth Semester and would have already completed courses such as Mineral Processing, Metallurgical Thermodynamics and Transport Phenomena. [As a teacher, I would insist on “questioning the unquestionable” (borrowing the words of a leading personality) as the important pre-requisite!]

**INDICATIVE SYLLABUS**
(Vide MME syllabus booklet circulated in MME Board of Studies Meeting of 2008)
(equivalent to five “units”)

Classification of furnaces; different kinds of furnaces; heat balance, energy conservation and energy audit; parts, construction and design aspects of blast furnace (B/F), ancillary equipment; blast furnace instrumentation

Blast furnace reactions; partitioning of solute elements between the metal and the slag; reactions in blast furnace; blast furnace slags; mass balance and heat balance calculations

Blast furnace operations; B/F irregularities and remedial measures, B/F refractories and causes of failure, modern trends in B/F technology; overview of direct reduction processes, electric smelting; production of DRI (HBI/Sponge iron)

Review of traditional steel making; thermodynamics of steelmaking; air/O₂ impurity interaction, slag metal interaction; foaming slag; removal of S and P; de-oxidizers, refining, alloying

Open hearth furnace; Bessemer converter; bottom blown and top blown processes; slag practices and sequencing; LD, VD, AOD and VOD; ladle metallurgy and injection metallurgy; electric arc furnace and DRI usage; ingot casting and continuous casting; energy, environmental and quality considerations
Suggested TEXT BOOKS and some comments

- easy to read; good number of examples; some information needs to be corrected;

- widely used set of books; good deal of metallurgical discussion;

- easy to read; widely used in India; lot of descriptive information;

- easy to read; widely used in India; lot of descriptive information;

Text books cited (above) essentially to help the average and below average students.

Every student of this course should read “Making, Shaping and Treating of Steels” (MST) – a classic and voluminous source. Revised editions are available. I hope to get the recent version of MST, with CD, this year. Strongly recommended by faculty of IIT – BBY.

The student would find very useful and interesting information in the website steeluniversity.org. This site has got simulation features also, to give the user a real feel for the processes. Some of you should try the international on-line competition in this site. I appreciate the efforts made by Tilak Bhattacharjee and team in Nov. 2007. We should win a prize, this year.

I intend to provide excerpts from (a) “Fundamentals of Steelmaking Metallurgy”, authored by B Deo and R Boom (esp. information on slags); and (b) Tata Search, 1998 (sort of case – studies); as supplementary information, for this year’s course. I shall also provide you bits of information from my ongoing research in process metallurgy. I will also share with you some of my observations from plants I have visited / interacted with in India and in the USA – stepping beyond the textbooks.

Well, I do use unconventional sources (for a teacher of metallurgy!) – including The Economic Times, “Business Maharajas” of Gita Piramal, for providing commercially relevant bits of information and some anecdotes! We are interested in the thermodynamics and kinetics of
IMSM, but should also understand how these are “applied” in the shop floor!! You should know how metallurgical knowledge and expertise translate into money!!! The steel industry is doing very well, now. Strike the iron when it is hot. (an understatement for a metallurgist)

**APPROACH**

**Delivery:** Approx. **44 Lectures and 9 Tutorials**
Active participation in class encouraged.

**Emphasis:** Whither steel?; Comments on the steel industry
Role of thermodynamics and kinetics in IMSM
Efforts to improve quality and productivity
Efforts to reduce energy consumption; and efforts to reduce pollution
Recent technological developments related to IMSM

Plant Visit, *subject to other constraints* (Visited VSP with an earlier batch)
*(Prefer to schedule plant visit after completing about 60% of course contents)*
All students are expected to come for the plant visit; and attendance will be recorded.

**Assessment:** Vide Institute Norms (UG);
Continuous Assessment – 50 marks; and Semester Exam – 50 marks;
Cycle Tests 20 + 20; (Topics to be announced in class); Assignments 10;
(NIL choice in question paper, vide 2006 regulations)
(Test dates and Exam date vide due circulars from the Academic Office)
*(Exploring the possibility of having one on-line test)*
Grading on relative basis, subject to prevailing guidelines;
Anyway, the final grades will only be proposed by me; and need to be approved by the Performance Analysis Committee.
**INDICATIVE PATTERN FOR TESTS and EXAM** (to be discussed in the class)

**First Cycle Test:**
- Short answer questions 10 marks
- Numerical problems / Analytical questions 10 marks

**Second Cycle Test:**  **Exploring online test**

**Semester Exam:**
- Descriptive Questions 40 marks
- Numerical problems / Analytical questions 60 marks

**PROPOSED SEQUENCE OF LECTURES**

1. Introduction to the Course and related details
2. Whither Steel? Steel Vs other engineering materials; status of the steel industry
3. Two-hour presentation on IMSM (**Tues. July 22, 4 pm, CSG**) (using web based sources)
4. (as above) (incl. sequence of operations, Indian scenario, global scenario)
5. Role of thermodynamics and transport phenomena in IMSM
6. Historical Evolutions in Technologies related to IMSM
7. Introduction to Furnaces; related energetics; refractories
8. Discussion on (some) specific furnaces
10. Introduction to Iron making (IM)
11. Design / Constructional features of Blast Furnaces
12. Blast Furnace – Auxiliary Equipment, including gas cleaning; and instrumentation
14. Ore, Flux, Coke, Air, Hot Metal, Slag and Flue Gas; Reduction Reactions (ref. Tutorial 2)
15. Blast Furnace – Burden preparation
16. Discussion on Blast Furnace Reduction reactions
17. (IM) Partitioning of Solute Elements between metal and slag - I
18. (IM) Partitioning of Solute Elements between metal and slag – II (ref. Tutorial 3)
19. Treatment of Hot Metal; Utilization of blast furnace Slags
20. Charging Sequence in Blast Furnace operations
21. Operational Irregularities and remedial measures, in Blast furnaces
22. Banking In, Banking Out and related practices
23. Modern trends in Blast Furnace Technology; alternate routes of iron making
24. Direct Reduction of Iron – I
25. Direct Reduction of Iron – II
26. Thermodynamic and Kinetic Aspects of Steel making (SM) – an overview
27. Hot Metal, Scrap, Flux, Oxygen, Liquid Steel, Slag and Flue Gas (ref. Tutorial 4)
28. Different Processes – Thomas, Bessemer, Open Hearth, Oxy. / LD, EAF, EOF
29. Overview of Oxidation Reactions in SM; Acid SM Vs Basic SM; BOF Vs EAF
30. (SM) Carbon – Oxygen Reaction
31. (SM) Oxidation of Si, Mn, P (ref. Tutorials 5,6)
32. Need for further processing of Liquid Steel – Generic discussion
33. Deoxidation, Degassing, Refining, Alloying treatments; Slag practices
34. Electric Steel Making – Discussion on Grades, Energy, Cost and Time (ref. Tutorial 7)
35. Recent Developments in Electric Arc Furnace (EAF) based production
36. Ladle Metallurgy; VD, VOD, AOD; Injection Metallurgy
37. Casting of Liquid Steel – Overview; Multiple Options; Ingot Casting
38. Continuous Casting (CC) – Mould, Geometry, Machine, Productivity
39. Role of Mould Powders in CC of Steels
40. Improvements in CC – B/O Detection, Flow Control Devices and High Speed Casting
   (ref. Tutorial 8)
41. Quality and Energy Considerations in IMSM
42. Environmental Aspects related to the Steel Industry; Utilization of wastes; Emission
   control and emission trading (ref. Tutorial 9)
43. One hour presentation on IMSM using web based sources
44. Emerging Technologies; Process Modeling; Market Trends; Concluding Remarks

**PROPOSED SEQUENCE OF TUTORIALS**
1. Heat balance and Thermal Efficiency calculations in furnaces (ref. lecture 9)
2. Mass balance calculations for blast furnace – emphasis on **scale of operations** (ref. L 14)
3. Thermodynamics of Iron making (ref. L 18)
5. Thermodynamics of Steel making (ref. L 31)
6. Phase Diagrams for Slags / Fluxes / Refractories (ref. L 31)
7. Mass Balance / heat balance calculations related to EAF operations (ref. L 34)
8. Calculations for Heat Flow / Fluid Flow / Productivity in Continuous Casting (ref. L 40)
9. Calculations related to Cost / Energy / Environment in IMSM (ref. L 42)

ASSIGNMENT QUESTIONS
Assignment no. 1: Due Monday, Aug. 18, 2008
1. Explain, with the help of a neat sketch, the construction and the operation of any one furnace used for melting. Provide indicative design or process calculations related to the cited furnace.
2. Explain, briefly, the testing of refractories.

Assignment no. 2: Due Monday, Sept. 29, 2008
1. Look into the web site of any one Indian steel plant. Describe, briefly, their production route. Describe, in detail, any one special technical aspect of the cited plant. (For example, the plant may have the largest blast furnace in the country. In such case, what are the advantages, in terms of productivity?) (For example, the plant may have EOF in place of conventional Oxygen steel making. In such cases, what are the advantages, in terms of energy consumption?)
2. Explain, in detail, the critical role of DRI in the Indian scenario. Describe, briefly, the process parameters associated with the production of DRI.

Assignment no. 3: Due Friday, Oct. 24, 2008
1. Describe, in detail, a binary / ternary phase diagram related to fluxes / slags / refractories.
2. Describe, in detail, any one process development initiative (improved technology / radically new technology) related to IMSM – with emphasis on how the understanding of thermodynamics / kinetics had contributed to the cited development.
Sample QUESTION PAPERS from PREVIOUS YEARS (with some comments)

Included, here, are (for IMSM):
Final exam (end-semester examination) question papers from the last five academic years;
Cycle test (mid-semester examination) question papers from one academic year.

The question papers have been collated to give an idea to the student about the expectations of the teacher, with respect to pedagogy and academic assessment. Further, students who fail in the course (and then take a “supplementary / arrears examination”) would find this a convenient reference while preparing for the supplementary exam (normally held in later semester/s). In general, the question paper for supplementary examination (if set for such candidates alone) will be less rigorous than usual.

Please note that the question papers would be in tune with the then prevailing academic regulations / syllabi. Many of the questions are fairly simple and conventional. Sufficient number of simple / straightforward questions would be included, so that even the weak student has an opportunity to “clear” the course. One would also find a few questions which necessitate reasonable analytical / problem-solving skills. The open – ended / analytical questions often help in differentiating between the average students and the superior students.

The question paper could, of course, be made more innovative and interesting – in the coming years.
BMT 502 IRON AND STEEL MAKING

Duration 3 hours

Max. Marks 70

Part A. 10 x 2 = 20 marks
Distinguish between the following pairs, in 4 -5 sentences each:

1. Recuperator and Regenerator
2. Pig Iron and Cast Iron
3. Direct Reduction and Indirect Reduction
4. Self – fluxed sinter and Super – fluxed sinter
5. Blowing In and Blowing Out
6. Acidic Refractories and Basic Refractories
7. Open Hearth Steel making and Oxygen Steel making
8. EAF and EOF
9. Carbon Steel and Alloy Steel
10. Class I and Class II ferroalloys

Part B. Answer one full question from each unit. 5 x 10 = 50 marks

Unit I
1. (a) Write short notes on Pig Casting Machine. (3)
   (b) Describe, in detail, the construction and operation of induction furnace. (7)
2. (a) Write short notes on Blast Furnace Instrumentation. (3)
   (b) Describe, in detail, the cleaning of blast furnace gas. (7)
Unit II
3.  (a) Write short notes on the Utilization of blast furnace slags. (3)
    (b) Describe, in detail, the conditions favourable for dephosphorization. (7)

4.  (a) Write short notes on Solution Loss Reaction. (3)
    (b) Discuss, in detail, the significance of thermodynamics in blast furnace operations. (7)

Unit III
5.  (a) Write short notes on Blast Furnace Refractories. (3)
    (b) Describe, in detail, the principle and practice of fuel injection. (7)

6.  (a) Write short notes on DRI. (3)
    (b) Describe, in detail, sintering OR pelletization. (7)

Unit IV
7.  (a) Write short notes on the principle of deoxidation. (3)
    (b) Steel (0.2%C, 0.2%Mn) is being made in an LD converter. The metallic charge consists of hot metal (4%C, 1%Si, 1%Mn, 0.3%P) and scrap in the ratio 4:1. Lime containing 2%Silica and 3%Magnesia is added as flux. Lance Oxygen of purity 99.5% is used. 2% of total Fe input is lost to the slag phase with the ratio of ferrous to ferric ions in the slag as 1:1. Partial pressures of CO and CO$_2$ are equal in the flue gas. The slag has about 50% CaO. Efficiency of oxygen utilization may be taken as 90%.

Calculate the following, per tonne of steel:
- Weights of hot metal and scrap to be charged
- Volume of Oxygen required in m$^3$ (STP) (7)
8. (a) Write short notes on the significance of Sievert’s Law in steelmaking. (3)

(b) Indicate the typical compositions for any three of the following:
Reducing slag in EAF operation; Open hearth steel making slag; LD converter slag;
Synthetic slag for refining; continuous casting mould powder;
AND Indicate the locations of any three of the above in a C – A – S ternary diagram. (4)

(c) A 100 Tonne ladle of steel at 1600°C contains 0.03 wt% Oxygen. Explain how you would calculate the amount of pure Aluminium to be added, for reducing the Oxygen content of the steel to 0.001 wt%. Assume Henrian behaviour for both Oxygen and Aluminium and assume that equilibrium conditions are reached. (3)

Unit V
9. (a) Expand the following abbreviations: LF, AOD, VD. (3)

(b) Molten steel at 1600°C is being held in a ladle. Assume that the depth of molten steel is 2 metres. The steel contains inclusions of size $10^{-6}$ m and $10^{-4}$ m, with about 50% of each. Plant personnel would like to know whether some / all of these inclusions can be removed during secondary treatment / continuous casting. What are the options available? Discuss, the same, qualitatively and quantitatively. Reasonable assumptions for production parameters / physical properties permitted. (7)

10. (a) Differentiate between ingot casting, continuous casting and strip casting. (3)

(b) Consider the case of a steel plant which has been in operation for the past 10 years. Key statistics about the plant are as follows:

<table>
<thead>
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<th>Plant capacity (installed)</th>
<th>2.4 million Tonnes of liquid steel per annum</th>
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<tbody>
<tr>
<td>Plant Production (2002 – 2003)</td>
<td>2.7 million Tonnes of liquid steel (1 year)</td>
</tr>
<tr>
<td>Grades Produced</td>
<td>Carbon steels, esp. low Carbon</td>
</tr>
<tr>
<td>Iron making</td>
<td>4 blast furnaces</td>
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</table>
Steel making 4 LD converters  
Con. Casting 2 slab casters (1.5 m/min)  
Salable Product HRC

The plant has decided to improve quality by installing secondary treatment facilities and productivity by installing a thin slab caster (about 4.5 m/min). Answer the following questions, with indicative calculations, wherever appropriate:

# How could the plant produce more than the installed capacity?  
# Which are the secondary treatments suitable for this plant?  
# What will be the effect of the proposed changes on the refractory consumption?  
# Why should the casting speed be increased?  
# Will there be any change in the number of passes / steps in the hot rolling mill?  

Note: For all numerical problems:
@ Reasonable assumptions may be made for production parameters and physical properties, if the values are NOT given.  
@ Clark’s tables may be used for values such as atomic weight.  
@ Composition is given in weight percent unless indicated otherwise.  
@ Credit will be given more for the approach than for the precise numerical answer.
Part A.  
Distinguish between the technical terms given in the following pairs, in 4 -5 sentences each:
1. Cupola and blast furnace
2. Arc furnace and induction furnace
3. Flux and slag
4. Iron and steel
5. Pig iron and DRI
6. Direct reduction and indirect reduction
7. Impurity and alloying element (in steels)
8. Bessemer converter and Thomas converter
9. Flat product and long product
10. AOD and VOD

Part B.  Answer one full question from each unit.  
Unit I
1. [a] Draw, neatly, the open hearth furnace.  Label the important parts / regions.  Description is NOT required.  
   (3)
(b) An Indian power plant is considering the usage of the following coals, on an obviously, long term and large scale basis. Indicate, with simple calculations, how you would rate the different coals, for the proposed application. Partial information is provided on the compositions of the four samples being considered:

Coal A: Moisture 3%, Ash 17%, Volatile Matter 46%, Carbon 83%;
Coal B: Moisture 2%, Ash 27%, Volatile Matter 28%, Carbon 73%;
Coal C: Moisture 2%, Ash 22%, Volatile Matter 35%, Carbon 78%;
Coal D: Moisture 1%, Ash 20%, Volatile Matter 40%, Carbon 80%;  

2.  
   [a] Draw, neatly, the hot blast cupola. Label the important parts / regions. Description is NOT required.  
   
   [b] Consider the case of an LD converter, of capacity 150 Tonnes, which uses normally up to 3% of cold scrap in the metallic charge. The exhaust gases from the converter are leaving at about 1000°C. There is a proposal to preheat the scrap and to increase the scrap level in the metallic charge. Answer the following questions using indicative calculations.

   * How would you determine the excess heat available for preheating the scrap?  
   [2]

   * How does the use of preheated scrap influence the Oxygen consumption?  
   [3]

   * Will all the heat from the converter gas be used for preheating?  
   [2]

Unit II

3. Describe, in detail, the thermodynamic aspects of blast furnace iron making.

4.  
   (a) Indicate the typical compositions of:
   iron ore, coal, hot metal and blast furnace slag.  
   [4]

   (b) Discuss, in detail, any two reactions in iron making.  
   [6]

Unit III

5. Describe, in detail, any two developments in blast furnace operations.
6. Write short notes (about 150 words each):
   [a] Pillaring       [b] High top pressure
   [c] HBI            [d] Dwight Lloyd Sintering machine

Unit IV
7. [a] What is “Swedish iron”? [1]
   [b] What are Calcium Aluminate slags used for? [1]
   [c] What is “Semi-killed steel”? [1]
   [d] Why are ferro-alloys used in steelmaking? [1]
   [e] Why is degassing carried out? What is the role of vacuum in degassing? [6]

8. [a] Describe, briefly, the factors influencing the choice of deoxidizers. [3]
   [b] How does the composition of hot metal influence the steel making process? [3]
   [c] Comment, briefly, on the advantages and limitations of Oxygen steel making process. [4]

Unit V
9. [a] Draw, neatly, the converter / furnace used for any one Oxygen steel making process other than the LD converter. [3]
   [b] Consider the following shop floor problem:
       “The number of re-blown heats has been suddenly increasing”.
       Indicate how you would proceed to solve the problem. [3]
   [c] Consider the following shop floor scenario:
       “There has been a problem in the blast furnace shop due to which hot metal output will be reduced by 20 to 30%, for the next three months. The plant has to modify the charge combination. The output from the converter shop should be maintained at the existing level. DRI and scrap could be considered. The cost of hot metal may be assumed to be Rs.7,200/- per tonne, DRI to be Rs.10,200/- per tonne and scrap to be Rs.8,200/- per tonne.”
Indicate, with simple techno – economic calculations / criteria, how you would optimize the charge going into the converter. [4]

10. [a] What is a “breakout”? [1]
[b] What is a “dummy bar”? [1]
[c] What is “EOF”? [1]
[d] What is an “oscillation mark”? [1]
[e] Consider the following complaint from a customer, purchasing HRC for downstream processing:
“The incidence of inclusions / inclusion related defects in the finished product has been suddenly increasing”. Indicate, how you would identify the possible cause(s) for the said problem. [6]

Note: For all numerical problems:
@ Reasonable assumptions may be made for production parameters and physical properties, if the values are NOT given.
@ Clark’s tables (provided by the invigilator) may be used for constants / values such as atomic weight.
@ Composition is given in weight percent, unless indicated otherwise.
@ Technical insight and logical approach are expected.
This question paper has been set along the guidelines prescribed by the CoE and covers the entire syllabus. Part A questions should be answered briefly. In the case of numerical problems/analytical problems involving numerical calculations, substantial weightage will be given for the logic as well as the analysis. In case of numerical problems, the students may assume reasonable values for properties/parameters. The assumptions need not be precise, but should fairly reflect the real values.

**Part A.**

10 x 2 = 20 marks

Distinguish between the technical terms given in the following pairs, in 2-3 sentences each:

1. Energy conservation and energy audit
2. Batch type furnace and continuous type furnace
3. Ore and gangue
4. Carbon steel and alloy steel
5. Scrap and DRI
6. Tuyere and bustle pipe
7. Low carbon ferro-alloy and high carbon ferro-alloy
8. LD and EOF
9. Slab and bloom (precise numbers NOT essential)

10. Degassing and deoxidation

**Part B.** Answer one full question from each unit.  

5 x 10 = 50 marks

**Unit I**

1. Describe, in detail, the construction and operation of any one metallurgical furnace NOT normally used in an integrated steel plant. (eg., do NOT choose blast furnace.)

2. [a] Describe, briefly, why modern furnaces are designed for operation with more than one type of fuel.  

[b] A ferrous foundry wants to set up a furnace for heat treatment of castings – with an estimated operational temperature of 1000°C max. and throughput of about 5 Tonnes per day. The foundry operates in three shifts and produces cast products of weight range approximately 50 grams to 500 grams. Many of the products are, reportedly, sensitive to chemical composition at the surface. Explain how you would choose a furnace for the above requirement. What kind of precautions should be taken with the fuel / heating system? (Precise and elaborate design of the furnace is NOT expected.)  

**Unit II**

3. Describe, in detail, the specific reactions taking place in any two distinct regions of the blast furnace.

4. (a) Why do steel plants normally try to control the Sulphur level in the hot metal itself, rather than in the liquid steel?  

(3)
(b) Consider a blast furnace producing 2000 Tonnes of hot metal per day. Given your understanding of the blast furnace reactions, operations, raw materials and products, estimate:

# the quantity of raw material to be charged into the furnace, per hour
# the quantity of hot metal output, per tapping operation
# the quantity of blast furnace slag generated, per year
# the typical production output, from its intended life.

Clues: eg., Raw material charged includes ore, coke and flux
Tapping is done at pre-defined instants
Slag generated is, say, 400 Kg per tonne of hot metal
The blast furnace is expected to operate for “long time”.

Unit III

5. Describe, in detail, any four operational irregularities and the corresponding remedial measures, in blast furnace operation.

6. (a) Why are the steel plants carrying out “sintering” operation? Why are the plants trying to enhance the percent sinter in the burden?  
(b) Explain, in detail, why the Indian steel industry is very interested in the commercial production of sponge iron, rather than being dependent solely on the blast furnace route?
(c) Name any two Indian companies producing sponge iron.

Unit IV

7. Describe, in detail, any two reactions in oxygen steel making.

8. (a) Describe, briefly, how the properties / quality of “source of iron” influences the selection of steel making process.
An integrated steel plant has been operating with 100% hot metal, for the production of low carbon steel, via LD converter. The plant wants to move to other combinations such as

- 90% hot metal and 10% procured scrap
- 90% hot metal and 10% internal scrap
- 90% hot metal and 10% DRI.

Discuss, the advantages and limitations of each of these options – preferably, with simple numerical calculations. The analysis could be with emphasis on energetics as well as steel quality.

Unit V

9. Describe, in detail, the recent developments in EAF design / operations.

10. [a] Read the following statements carefully and comment on the validity of the statements:

# Steel making does not consume any energy.
# Continuous casting process is continuous within each heat.
# The total oxygen in killed steel is zero.

(b) Many types of waste materials (solid / liquid / gaseous) are generated in steel plant operations. There is a need to utilize these waste materials – either within the plant or elsewhere. Give any three examples for utilization within the plant. (3) Some plants are trying to use oxide wastes from one process in another process, or even in the same process. How is this possible? (4)
1. (a) What is “shatter index”?  
(b) What is a “regenerator”?  
(c) What is a “down comer”?  
(d) List any two specific types of heat losses.  
(e) What is “flue gas”?  
(f) What is “coking coal”?  
(g) Consider a blast furnace having the following dimensions:
   
<table>
<thead>
<tr>
<th>Section</th>
<th>Diameter ID</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearth</td>
<td>8.5 m</td>
<td>3.25 m</td>
</tr>
<tr>
<td>Bosh</td>
<td>9.5 m</td>
<td>3.5 m</td>
</tr>
<tr>
<td>Throat</td>
<td>6.0 m</td>
<td>19.0 m</td>
</tr>
</tbody>
</table>
   
   The slopes / variations in dimensions within each section may be ignored. 
   
   The productivity of the blast furnace may be taken as 2.0 T / m$^3$/ day. 
   
   Estimate the daily output from this blast furnace.  
   
   If the furnace has a coke rate of 650 Kg, estimate the amount of coke to be charged per hour into the furnace.  
   
   Estimate the slag generated per year from this furnace, assuming the slag generation per tonne of hot metal to be 0.50 Tonnes.
2. (a) Define “direct reduction”.  
(b) What is a “mixer”?  
(c) What is “external desulphurization”?  
(d) Define “basicity”.  
(e) Describe, in detail, any one reaction in the blast furnace.  

3. (a) What is “sponge iron”?  
(b) What is “electric smelting”?  
(c) What is “banking”?  
(d) What is “hanging”?  
(e) Define “degree of metallization”.  
(f) Describe, in detail, any one process for the production of sponge iron.  

4. (a) What is a “reducing slag”?  
(b) What is “Carbon boil”?  
(c) What is a “sub-lance”?  
(d) What is “combined blowing”?  
(e) What is “stream degassing”?  
(f) At 1600°C, liquid solutions of MnO in FeO and Mn in Fe are approximately ideal. Determine the weight percent concentration of Mn in iron which is in equilibrium with an oxide melt (slag) containing 0.30 mole fraction of MnO and 0.70 mole fraction of FeO, at this temperature.  

The $\Delta G^\circ$ values for the formation of FeO (Liq.) and MnO (Liq.) are (-55,620 + 10.83 T) Cal and (-84,700 + 14.5 T) Cal respectively. The atomic weights of Mn and Fe may be taken as 54.94 and 55.85 respectively. (Source: Bodsworth and Appleton)  

5. (a) What is “AOD”?  
(b) What is “sequence casting”?  
(c) What is “metallurgical length”?  
(d) Excerpts from the log sheet of a steel plant producing high – speed steel, via electric steel making, are given below: (adapted from Tupkary)
Furnace size 5.0 T

HSS specification  C 0.85, Mn 0.30, Si 0.30, P 0.025 max., S 0.025 max.,
                  W 6.10, Mo 5.00, V 2.00, Cr 4.15 (wt %)

Charge material  2800 Kg HSS revert and 1240 Kg SAE 52100 revert

SAE 52100 specification  C 1.00, Mn 0.35, Si 0.30, P 0.025 max., S 0.025 max., Cr 1.50

0625 hours  Power ON
0845, 0930, 1015, 1040 hours  slag off
1055 hours  alloying additions incl. 165 Kg Fe-V, 55 Kg Fe-Cr
1130 hours  alloying additions, in smaller quantities
1135 hours  Furnace Tapped

Explain the following aspects / observations: 6

#  Cr additions are done in the later stage of the process.
#  About 5 Kg of coke powder was added during this heat.
#  The slags, at different stages of this heat, were observed to have different colours.

(e) Explain, in detail, the generation of solid wastes in integrated steel plant operations.
Indicate, briefly, the disposal of such solid wastes. (6 + 2) 8
1. (a) What is a “recuperator”?  
(b) What is “ESP”, in the context of gas cleaning?  
(c) The analysis of coal used in a boiler trial is as follows:  
82 weight % Carbon, 6 % Hydrogen, 4 % Oxygen and 8 % ash.  
(i) Estimate the theoretical minimum air required for combustion of one Kg of coal.  
(ii) If the actual air supplied is 18 Kg per Kg of coal and if only 80% of Carbon undergoes complete combustion, estimate the weight of flue gas generated.  
(iii) What is the advantage associated with “excess air”? What is the disadvantage (if any) associated with “excess air”?  
(Molecular weights of CO, CO$_2$, N$_2$ may be taken as 28, 44 and 28 respectively.)  
(Adapted from O. P. Gupta)

2. (a) What is “External Desiliconization”?  
(b) What are the sources of Sulphur in blast furnace operations?  
(c) Describe, in detail, the Sulphur reaction in the blast furnace.

3. (a) What is “HBI”?  
(b) What is “PCI”?
(c) Describe, in detail, any three operational difficulties (irregularities) encountered in blast furnace operations, along with the corresponding remedial measures.

4. (a) What is “basic steel making”?  
(b) What is “Continuous Steel making”?  
(c) A steel plant has encountered two problems related to the quality of liquid steel. The first problem is that – about 3% of the heats are returned from the caster, on account of Phosphorous (exceeding specification). The second problem is that – customers are complaining about inclusions (exceeding specification), in the cast and rolled product. Describe, in detail, how you would analyze the problems; and what kind of further modifications / solutions you would suggest to reduce the problems.

5. (a) What is “strip casting”?  
(b) What are the typical difficulties in utilizing 100% of all solid wastes and 100% of all liquid wastes within the steel plant itself?  
(c) Consider a steel plant with following operational details:

<table>
<thead>
<tr>
<th>Product Grade</th>
<th>90% of production is LCAK, with limited range of Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Size</td>
<td>125 Tonnes</td>
</tr>
<tr>
<td>Con. Casting m/c</td>
<td>Multiple machines; each with four strands</td>
</tr>
<tr>
<td>Cast Product</td>
<td>Blooms, 300 mm square</td>
</tr>
<tr>
<td>Casting operation</td>
<td>Two heats in sequence</td>
</tr>
</tbody>
</table>

The caster personnel have been told that the casting speed can not exceed 1.2 m/min.

(i) Assume reasonable casting speed and calculate the casting duration (per heat).  
(ii) If the plant wants to move towards sequence casting with five heats in sequence, what are the precautions to be taken (or modifications needed)?  
(iii) Suppose the plant is suddenly finding a market for some grades of Carbon steel, where the maximum gas content can be only about half of what the plant is presently achieving. What are the precautions to be taken (or modifications needed)?
1. Why are metallurgical furnaces often operated at high temperatures? 1
2. What is an ORSAT apparatus? 1
3. What is a Parallel Flow Recuperator? 1
4. Indicate the typical calorific value for any one solid fuel. 1
5. Name any one shaft type furnace. 1
6. What is the “total heat” in flue gas made up of? 1
7. Explain, with a neat sketch, the construction of a cupola. 4
8. Coal with a C.V. of 7100 Kcal / Kg has 0.78 C, 0.05 H₂, 0.08 O₂, 0.02 S, 0.02 N₂ and balance ash. This coal is burnt in a furnace with 50% excess air. Assume air inlet to be at 15°C and flue gas to be at 325°C. Assume Cp of air to be 0.24 and that of the dry combustion products to be 0.25. Assume that 700 Kcal is carried away by every Kg of moisture in the flue gas. ESTIMATE THE PROPORTION OF HEAT CARRIED AWAY BY THE FLUE GASES. Make reasonable assumptions if further data / conditions are required. 5
1. What is Swedish Iron? 1
2. What is Coke Rate? 1
3. What is a Tuyere? 1
4. Indicate the typical composition of iron ore. 1
5. What is Pillaring? 1
6. State the Direct and Indirect Reduction reactions. 1
7. Describe, briefly, the Sulphur reaction in iron making. 3
8. A blast furnace is operated with iron ore containing 88% Fe$_2$O$_3$, 3.5% SiO$_2$, 4% Al$_2$O$_3$, 0.6% P$_2$O$_5$ and rest moisture. 800 Kg of coke, having 72.5% C, 15% SiO$_2$, 7.8% Al$_2$O$_3$, 2.1% FeS and rest Fe$_2$O$_3$, is being used for producing one tonne of molten pig iron. 1435 Kg of iron ore is being used for producing one tonne of molten pig iron. The slag produced has basicity value of 1.2 and Al$_2$O$_3$ content of 18%. Reasonable assumptions permitted, for the flux composition.

(a) If the plant is able to get coke of superior quality – say half the present Sulphur content and about 75% C, what will be the nature of changes in the burden and in the hot metal? Assume that the slag does not contain any iron oxide.

(b) If, with the new coke, there is a change in the flux used resulting in a slag having 2% FeO, what will be the nature of changes in the S content of the hot metal?

(c) If the FeO content of the slag becomes 25%, will the plant operation be affected in any way?

Discuss, the above possibilities, with indicative numerical calculations / graphs. 6

(The emphasis is on comprehension and analysis, rather than a precise answer.)
BMT 502 IRON AND STEEL MAKING

Duration 60 minutes   Answer ALL questions   Max. Marks 15

(a) What is “Sponge Iron”? 1
(b) What is “Oxygen Steelmaking”? 1
(c) What is an Electric Arc Furnace used for? 1
(d) What is a “Low shaft furnace”? 1
(e) What is “Cementation Process”? 1
(f) What is “Acid steel making”? 1
(g) Differentiate between deoxidation and degassing. 1
(h) Describe, in detail, any one direct reduction process. 5
(i) Describe, briefly, any one reaction in steel making. 3

SRS Sept. 18, 2003
STUDENT PERFORMANCE (RECENT BATCHES) IN IMSM:
(With input from official results released by the O/o Dean (Academic))

Term: Acad. Year 2006 – 2007: ODD Semester
Class: B. Tech. (MME) – V Semester (Batch graduating in 2008)
(Referred to as the “2004” batch, in NITT parlance)
Class Strength: 30
Average GPA of this MME class, in the semester cited: 7.39 (scale of 10)
Distribution of grades in BMT 502 IMSM (5-credit course):
S (10 points) 6
A 2
B 8
C 3
D 5
E (5 points) 3
F (failure) 3

The following students performed well and earned S grade: Chandrasekaran Yazhini, G Hariprasad, Gaurav Garg, Karthik Kumar H, Rannesh L and V Vinod.
STUDENT PERFORMANCE (RECENT BATCHES) IN IMSM:
(With input from official results released by the O/o Dean (Academic))

Term: Acad. Year 2007 – 2008: ODD Semester
Class: B. Tech. (MME) – V Semester (Batch graduating in 2009)
(Referred to as the “2005” batch, in NITT parlance)

Class Strength: 27

Average mark of this MME class, as cited by MIS: 65 out of 100 (before revaluation)
Number of changes made during revaluation: one only
Range of marks, for students who passed this course: 42 to 83, out of 100

Distribution of grades (after revaluation) in BMT 502 IMSM (4-credit course):

S (10 points) 6 students (with marks 80 and above)
A 1
B 14
C 2
D 1 (with 54 marks)
E (5 points) 1
F (failure) 2

Total number of students 27

The following students performed well and earned S grade: P. Sudarshan, J. Ramesh, S. Kameshwaran, Suman Saurabh, Tilak Bhattacharjee and S. Vivek.

Tilak Bhattacharjee enthusiastically attended ALL sessions for this course (100% attendance).
Quality Targets / Metrics for IMSM 2008:

1. I (the teacher) intend to start all sessions by the stipulated time; and, I will NOT start any session beyond five minute delay (reasonable under local circumstances). In case I anticipate some delay, I will keep the class representative informed. In case I do not show up within ten minutes from the stipulated starting time, the class representative may record the class attendance (and submit the same to me, later); and the students may adjourn. Further, the fact may be brought to the attention of the department office.

2. I may be away, on official duty, for a maximum of about 10% of the scheduled classes. In such instances, advance information will be provided to the class.

3. Students are expected to attend all sessions, though some relaxation is given in the Institute rules on attendance requirements. Eligibility for appearing in the examination will be in tune with the Institute rules on attendance requirements. Any student absent for two or more “consecutive lectures” should have the courtesy to explain the absence, before attending further lectures.

4. I understand that, on some occasions, some students may be entering the class late by up to five minutes w.r.t. scheduled starting time. In such cases, the students can just walk into the class without seeking my permission. However, on a few occasions, latecomers will be denied entry into the class - if they tend to exploit / stretch this concession.

5. One special session - after each cycle test – will be conducted specifically for the “below average” students.

6. Maximum number of special classes (outside the four cited slots) – eight only.

7. NIL copying for assignments (though we had often excused this, in the past!).

8. Student Feedback I – format and contents designed by me – to be collected from the class during the second week of the semester; and, to be discussed with the class in the third week of the semester.

9. Student Feedback II – format and contents designed by me – to be collected from the class by the seventh week of the semester; and, to be discussed with the class by the eighth week of the semester.
10. Students are expected to offer their “collective feedback” during the Class Committee meetings, so that some of the difficulties could be addressed. Students are also expected to provide quantitative feedback, at the end of the semester (feedback collected by the Academic Office) – so that the course / related activities could be improved for the next batch of students.

11. I hope that at least half the class will be motivated to take elective/s in process metallurgy, such as process modeling.

12. Actual performance (vs. cited targets) to be made available in the (course) website, for the next batch.

CONCLUDING REMARKS

I have provided an outline of the course as well as my philosophy behind this course. Hope the students would interact during this semester and make this course increasingly beneficial.

SUGGESTIONS FOR IMPROVEMENT ARE WELCOME. Thanks.

ACKNOWLEDGEMENTS

It is my pleasure to thank my students, colleagues and peers – for their help, encouragement and professional criticism. I thank the following individuals, in this indicative list:

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3. Sri. R. Easwaran, Addl. GM (Quality), BHEL, Trichy
4. Sri. S. Chakraborty, Asst. GM (R&D), Vizag Steel Plant
5. Prof. Mangala Sunder Krishnan, Chemistry, IIT Madras
6. Prof. N.B. Ballal, MME, IIT Bombay
7. Sri. Pradeep K., CSG, NIT Trichy

Raman

July 18, 2008

raman@nitt.edu