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ABSTRACT

Four courses in extractive metallurgy (Pyrometallurgy, Hydrometallurgy, Electrometallurgy; and Physical Chemistry of Iron and Steel) were prepared in a modular, self-paced format. Development of the course materials included: (1) preparation of course outlines by unit coordinators and advisory committees; (2) approval of course outlines (included in appendices) by task forces; (3) preparation and review of materials (including slide-tape programs) by coordinators and task forces; (4) use of materials by students in self-paced courses, as text materials for lecture classes, and as supplementary text materials; (5) revision based on student and instructor feedback; and (6) reuse by students. The course materials are for use at Montana College of Mineral Science and Technology as (1) text materials for lecture courses given at their once-a-year scheduled times; (2) self-paced courses for students who desire to take the courses at times other than the scheduled time; (3) self-paced courses for interested industry people who want to take courses while remaining on the job; and (4) self-paced deficiency courses for entering graduate students. Copies of the courses and slide-tape programs (which may be borrowed, reproduced, and returned) are available from the author. (Author/JN)

NSF/SED-80010

FINAL PROGRESS REPORT

SUBMITTED TO

NATIONAL SCIENCE FOUNDATION

HIGHER EDUCATION DIVISION

By

MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY

TITLE OF RESEARCH PROJECT

SELF-PACED TUTORIAL COURSES FOR MINERAL SCIENCE - METALLURGY DEPARTMENTS

NSF SED 75-04821

PRINCIPAL INVESTIGATOR

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PROFESSOR
DEPARTMENT OF METALLURGY - MINERAL PROCESSING

PERIOD COVERED: JULY, 1975 - AUGUST, 1980

SELF-PACED TUTORIAL COURSES FOR MINERAL SCIENCE - METALLURGY DEPARTMENTS

CONTENTS

1. SUMMARY

Four courses in extractive metallurgy have been prepared in a self-paced format. The courses are:

Unit Processes in Extractive Metallurgy: Pyrometallurgy
" " " " : Hydrometallurgy
" " " " : Electrometallurgy
Physical Chemistry of Iron & Steelmaking

The objectives of the study were to prepare the four courses, present them to students, and evaluate the response of their use in a self-paced format.

The results of the evaluation are that the courses can be effectively given in the self-paced format and that small departments can use the self-paced concept to expand their course offerings.

2. INTRODUCTION

A program to develop modular self-paced resource material in the area of extractive metallurgy was begun in July, 1975.

The goals of the project were

- to develop the appropriate course materials.
- to present the modular materials to students as:
  - a. self-paced courses
  - b. text materials for lecture courses
  - c. resource materials for supplementing present text material
- to evaluate the response to the materials when used in the above modes.

This study was supported by the National Science Foundation (NSF SED-7504821) and the metallurgical industry. Funding for the development and reproduction of the course materials, i.e., printed materials and tape-slide presentations, was provided by the National Science Foundation. The development of the resource material depicting actual plant practice and release of time and travel expenses for industrial participants serving on the task force development and review team were provided by various metallurgical companies.

The study was one of modular material development, student use, evaluation of results, i.e., it was a demonstration project to determine if self-paced course material could be effectively used in the minerals engineering area of study.

A task force of academic and industrial participants was organized to formulate the course outlines, to assist in the course material development, to review the material, and to assist in the evaluation of the use program. Members of the task force and their affiliation are listed in Table I.

TABLE I - Task Force Members

Dr. L. G. Twidwell
Montana College of Mineral Science and Technology

Dr. R. McClincy
Anaconda Copper Company

Dr. R. Johnson
Kennecott Copper Corporation (presently with Phelps-Dodge)

Dr. Dr. C. Smiernow
Drexel University (presently with University of Alabama)

Mr. C. Hanson
Anaconda Aluminum Company (presently retired)

Dr. L. Miller
University of Utah

Dr. H. Haung
Montana College of Mineral Science and Technology

Dr. Doug Robinson
Cominco (presently with University of Arizona)

Dr. T. J. O'Keefe
University of Missouri

Dr. A. H. Larson
Bunker Hill Company (presently with Gould, Inc.)

Mr. N. Plaks
Environmental Protection Agency

3 - Materials were to be prepared in extractive metallurgy. The specific courses included: Pyrometallurgy, Hydrometallurgy, Electrometallurgy, and Metallurgical Kinetics. A substitute course, Physical Chemistry of Iron and Steelmaking, replaced the Metallurgical Kinetics topic.

Course coordinators were selected for each course and an advisory team formed for each course. The unit coordinators and their advisory teams are listed in Table II.

TABLE II - Unit Coordinators and Advisory Teams

Unit Processes in Extractive Metallurgy - Pyrometallurgy

Unit Coordinator: Dr. L. G. Twidwell, Professor and Chairman to Metallurgy--Mineral Processing Department, Montana Tech

Advisory and Preparation Committee:

Dr. A. W. Schlechten, Alcoa Professor,
Colorado School of Mines (presently Professor Emeritus)

Dr. A. H. Larson, Research Manager,
Bunker Hill Company (presently Director of Process Development, Gould, Inc.)

Dr. T. McNulty, Research Director,
Anaconda Company (presently Vice-President, Kerr-McGee)

Dr. R. McClincy, Developmental Specialist,
Anaconda Copper Company

Dr. R. Johnson, Program Manager,
Kennecott Copper Company (presently Manager of Metallurgy, Phelps-Dodge Corporation)

Dr. G. Smiernow, Professor,
Drexel University (presently University of Alabama)

Mr. G. Hanson, Chief Metallurgist,
Anaconda Aluminum Company (presently retired)

Mr. D. McMillan, Project Supervisor,
Anaconda Aluminum Company

Dr. R. S. Rickard, Chief Metallurgist,
Earth Sciences, Inc.

Dr. S. Kallafalla, Research Manager,
U. S. Bureau of Mines

Unit Processes in Extractive Metallurgy - Hydrometallurgy

Unit Coordinators: Dr. J. Miller, Professor,
Mining, Metallurgy, Fuels Department
University of Utah

Dr. J. Herbst, Professor,
Mining, Metallurgy, Fuels Department
University of Utah

Dr. H. H. Haung was substituted as course coordinator in the fall, 1979.

Dr. H. H. Haung
Assistant Professor
Metallurgy - Mineral Processing Department
Montana Collage of Mineral Science
and Technology
Butte, Montana

Advisory and Preparation Committee:

Dr. L. G. Twidwell, Professor,
Montana Tech

Dr. M. C. Fuerstenau, Department Chairman,
South Dakota School of Mines

Dr. T. McNulty, Research Director,
Anaconda Copper Company (presently Vice President
Kerr-McGee)

Mr. A. O. Martel, Development Engineer,
St. Joseph Minerals Company

Dr. R. S. Rickard, Chief Metallurgist,
Earth Sciences, Inc.

Dr. M. E. Wadsworth, Department Chairman,
University of Utah

Dr. T. J. O'Keefe, Professor,
University of Missouri at Rolla

Also, Dr. J. D. Miller and Dr. J. Herbst served as advisors after Dr. Haung assumed the responsibilities as course coordinator.

Unit Processes in Extractive Metallurgy - Electrometallurgy

Unit Coordinator: Dr. T. J. O'Keefe, Professor
Metallurgy Department
University of Missouri

Advisory and Preparation Committee:

Dr. L. G. Twidwell, Professor,
Montana Tech

Dr. Paul Duby, Professor,
Columbia University

Mr. Alan Booth
American Metals Climax

Mr. Vic Ettel
International Nickel Company

Dr. Doug Robinson, Metallurgical Advisor
Cominco (presently, University of Arizona)

Physical Chemistry of Iron and Steelmaking

Unit Coordinator: Dr. L. G. Twidwell, Professor,
Chairman, Metallurgy - Mineral Processing
Department
Montana College of Mineral Science and Technology

Advisory and Preparation Committee

Mr. N. Plaks, Branch Chief,
E. P. A.

Mr. R. Hendricks, Program Manager,
E. P. A.

Dr. J. Clum, Professor,
University of Wisconsin

Dr. T. O'Keefe, Professor,
University of Missouri

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3. PROGRAM DEVELOPMENT AND TEST RESULTS

The development of course materials followed the sequence: development of a course outline by the unit coordinator and advisory committees, approval of the course outline by the task force, preparation of the materials, review of the materials by the project coordinator and the task force members, use of the materials by students, revision of the materials, and re-use by students.

It was noted at the start of the study (and later found to be emphasized by reviewer and user comments) that no single course would be appropriate and considered suitable by all potential users. An instructor must factor many considerations into his/her design of a course, e. g., a list of such considerations includes, but is not limited to, instructor background and training, curriculum design and emphasis (iron and steel versus non-ferrous, extractive versus physical or materials emphasis), the content of other related courses and the interrelationship between courses, prerequisite subject matter, style of coverage (descriptive or problem oriented), hours of credit, association with a laboratory course, etc. Therefore, the task force decision was to prepare the extractive metallurgy courses based on the following conditions:

- the courses would be junior level
- the prerequisites would include physical chemistry
- the courses would be designed based on a curriculum that emphasizes extractive metallurgy
- each course would be two semester hours of credit
- the courses would emphasize non-ferrous metallurgical processes

The preparation and results of using each course are described in the following sections.

UNIT PROCESSES IN EXTRACTIVE METALLURGY - PYROMETALLURGY

Unit Coordinator: Dr. L. G. Twidwell, Professor and Chairman,
Metallurgy-Mineral Processing Department,
Montana College of Mineral Science and Technology

The pyrometallurgy material was the first completed course and has been the most extensively used in the test program. The initial drafts used the concept that the self-paced resource material would be based on an available textbook (A textbook covering pyrometallurgical operations was not available. A general text "Principles of Extractive Metallurgy" by

T. Rosenquist, was available. This text covered a portion of the proposed topics; (but not by any means all of those selected by the advisory committee). The course material was later revised to be independent of textbook by Rosenquist. This change was necessary, because both student and instructor comments indicated that unnecessary confusion resulted from required readings from two sources in a back and forth manner.

The pyrometallurgy course is composed of five modules, thirty learning activities (each learning activity is material considered to be equivalent to 50 minutes of lecture material). This is the amount of material normally covered in a two-semester hour course.

The first four modules provide the student with coverage of unit operations in pyrometallurgy, i.e., 26 learning activities. The fifth module is a series of tape-slide presentations of actual plant practices to show the interrelationship between the previously described (in written text form) unit operations (4-8 learning activities of materials). The course materials include:

a. Four text modules in printed format (the course outline is presented in Appendix 1.):

   1. Pretreatment of Concentrates
   2. Smelting and Converting
   3. Reduction Processes
   4. Refining of Metallic Solutions

b. Eleven 35-mm slide-audio cassette tape programs on example pyrometallurgical processes

   1. Drying and Calcining

   2. Copper Production

      1) Conventional Reverberatory Smelting (Kennecott Copper Corporation)

      2) Mitsubishi Continuous Copper Smelting (Mitsubishi Copper Corporation)

      3) Noranda Continuous Copper Smelting (Noranda Copper Corporation)

   3. Lead Production
      (American Smelting & Refining Company)

   4. Zinc Production

      1) Vertical Retort Process
         (New Jersey Zinc Company)

      2) Lead-Zinc Blast Furnace
         (Imperial Smelting Processes Limited)

5. Titanium Production
   (Titanium Corporation of America)

6. Iron and Steel Production

   1) Iron Production
      (Inland Steel Company)

   2) Steel Production
      (Inland Steel Company and United States Steel Corporation)

7. Aluminum Production
   (Kaiser Aluminum and Chemical Corporation, Anaconda Aluminum Company, and Alcan Limited).

c. A sixteen millimeter movie on the Mitsubishi Process is available (not developed by this program, but Mitsubishi Metal Corporation has made the film available for use in this course).

Student input into the evaluation and revision of the course material is very important in the evolution of final course materials. Each instructor using the course material was (and is) provided module and course evaluation and comment forms that are filled out by the students. These forms are of a rather standard format. We have found that the students' comments are much more instructive if they are allowed to respond anonymously. (Example evaluation forms are presented in Appendix 2.)

The pyrometallurgy course has been presented to students majoring in metallurgical engineering and mineral processing engineering at the following places and times; table III.

TABLE III - Use of Pyrometallurgy Course Material

Place	Semester	Teaching Mode	Students
Montana Tech	Spring, 1977	Self-paced	13
	Spring, 1978	Optional: Lecture or Self-paced	9 (Self-paced) 6 (Lecture)
	Spring, 1979	Lecture - Materials used as text	8
	Spring, 1980	Optional: Lecture or Self-paced	2 (Self-paced) 11 (Lecture)
	Summer, 1980	Self-paced	2

Place	Semester	Teaching Mode	Students
Colorado School of Mines	Spring, 1977	Self-paced	63
University of Florida	Spring, 1978	Self-paced	14
Drexel	Spring, 1977	Lecture (Materials used as text)	9
	Spring, 1978	Lecture (Materials used as text)	12
	Spring, 1979	Lecture (Materials used as text)	12
University of Nevada	Fall, 1977	Lecture (Materials used as supplemental handouts)	10
North Carolina State University	Spring, 1979	Lecture (Materials used as text)	24
University of Missouri	Spring, 1978	Lecture (Materials used as supplemental handouts)	10
	Spring, 1979	Lecture (Materials used as supplemental handouts)	10

The Pyrometallurgy course has been presented at Montana Tech in several test modes: The entire class was required to take the course in the self-paced format (1977); the students selected either a lecture or self-paced format (1978&1980); the course was presented in the lecture format by a visiting instructor (1979); the students took the course at a time when it was not normally offered (summer, 1980)

The criteria for conducting the course in the self-paced format were:

1. Five modules were to be covered. Deadlines were established for completion of each module. Testing was not permitted beyond the established dates.

2. Instructor availability was assured during established hours, ie., designated hours for tutorial help were scheduled for three hours per week. However, a limit was not placed on the amount of tutorial time a student received.

3. Tests were given at the student's convenience. Tests were graded the same day they were taken. Re-examination was permitted twice, if necessary. The grade on the last test taken was the grade on the module. The average module grade was used as the basis for the final course grade.

4. Audio-visual materials were always available for student use.

A part of the collected data is presented in Table IV.

TABLE IV - Results of Student Use of the Pyrometallurgy Course: Montana Tech (Self-Paced Format)

Year	Module Number	Number of Learning Activities (L.A.)	Average Study Time Hours/Student	Average Study Time Hrs/Student/L.A.	Average Individual Tutorial Time Min./L.A.
1977	1	6	10.6	1.8	18
	2	7	16.0	2.3	5
	3	6	15.2	2.5	16
	4	7	16.5	2.3	5
1978	1	6	11.2	1.9	13
	2	7	14.6	2.1	4
	3	6	13.2	2.2	8
	4	7	13.8	2.3	4

These numbers give us a guide as to whether the length and difficulty of each learning activity was proper. We feel that two hours/learning activity is about the right length of input time. This would compare to one hour of in-class lecture and one hour of outside study for a conventional course. The average individual tutorial time should be a measure of either the difficulty of the material, i. e., more difficult material will require more tutorial help, or how well the material is written.

Three of the 1977 students declared in their course evaluation sheets that they would not take another self-paced course if they had the option. In answer to the question "what motivated your study," they all answered "deadlines for completion of each module." Six of the students stated they would elect to take other courses in the self-paced format and would recommend the course to their peers. Their answer to the motivation question was "an interest in the major field of study." Four of the students left the question on taking other self-paced courses unanswered.

The course was offered again in the spring, 1978. The students were allowed to choose the self-paced format or lecture format. We hoped to gain information as to whether choice would effect performance. The students were given the choice of switching from the self-paced mode to lecture mode at any time if they so desired. None did so. Nine of fifteen students chose the self-paced technique. As seen in Table IV a significant difference in hours of study or tutorial time between the forced self-paced class and the elected self-paced class is not noted, except for module 3. The class grade average for both groups was "B".

One of the major advantages of having courses in a self-paced format is that the course can be given at any time, not just in a specific semester. We allowed two students to take the self-paced course in the summer, 1980. Data was not collected on study or tutorial time, but the students comments clearly showed the course a success. One student received a grade of "A"; the other a "C".

The pyrometallurgy course materials were also used at Colorado School of Mines in the spring, 1977. The course is an elective course in the metallurgical engineering curriculum. Two professors and three graduate students were assigned to the course. The three graduate students were the main source of tutorial assistance. Sixty-three students were enrolled.

The criteria established for the course was somewhat different than that used at Montana Tech.

1. All students were required to take the course in the self-paced format. Each student was assigned a graduate student for tutorial help.

2. Module completion deadlines were not established.

3. Special periods for tutoring were established, but attendance at help sessions was not required.

4. Tests were given at designated times, e.g., Friday of each week, tests would be retaken a week later.

5. Attendance at special lectures was required. The C.S.M. course was a three semester hour course, whereas the self-paced materials were designed for a two semester-hour course.

A partial summary of results are presented in Table V.

TABLE V - Results of Student Use of the Pyrometallurgy Course: Colorado School of Mines

Module Number	Average Study Time (Hrs/Student)	(Hrs/Student/L.A.)	Average Individual Tutorial Time Minutes/L.A.
1	13.6	2.3	17
2	10.5	1.8	7
3	10.9	1.6	11
4	-	-	-

The results are about the same as obtained at Montana Tech with respect to hours/learning activity, i.e., about 2. Tutorial help is similar in trend, i.e., longer for modules 1 and 3 than for 2.

There was a majority of students who objected to their being required to take the course in the self-paced format. After completing module 3, a decision was made by the C.S.M. course faculty to allow the students to choose the mode of instruction in which they would finish the course. The reasons for this (as expressed by the faculty presenting the course) were:

1. One of the course instructors is a well recognized speaker who motivates and stimulates students interest. Students felt they could learn better from his lectures than from their own coverage of the material, especially since their tutorial help was given by graduate students. The instructor attracts students into his courses and some of the students expressed that they felt cheated by not having more contact with him. The students did not know they were registering for a self-paced course.

2. Dissatisfaction of the students with the format of presentation.

3. Lack of deadlines to motivate some students to cover the material rapidly enough. Some fell way behind in the course.

4. Lack of effective use of tutorial assistance.

5. Lack of previous training and use by the instructors in self-paced course management.

Ten of the sixty-three students chose to finish the course in the self-paced format.

The instructors' comments to the task force were:

1. The textbook is much too brief in its coverage of several important areas of pyrometallurgy. The module text material is good for use by the students as a supplemental aid in expanding and explaining the text.

2. Self-paced instruction requires instructor training and experience to be successful.

3. Deadlines must be required for completion of each module in order to force some students to complete the course.

4. Some lectures are needed periodically to cover those topics in which the student is asked to solve problems.

The developed materials were also used at Drexel University, the University of Nevada, the University of Missouri and North Carolina State University to support lecture type courses. Their feedback was also very helpful in revising the course materials.

We have found that the development of the materials for the self-paced format has been much more time-consuming than anticipated, because the courses could not be linked to a presently available text.

Our conclusions are that

1. Modular materials in specialized areas are very useful as supplemental resource materials for students in lecture format classes.

2. A self-paced course in pyrometallurgy is certainly possible and acceptable, but students must know what they are getting into and tutorial help must be readily accessible and encouraging.

3. The use of tape-slide programs illustrating actual processing steps and equipment are well accepted and important to students in a course such as pyrometallurgy.

We suspect that very few courses in extractive metallurgy (available for national distribution) will be prepared in the self-paced format, because of several factors:

1. The preparation of such courses are very time consuming and costly.

2. Each instructor has his own ideas on course content which may differ considerably from that of the author's.

3. Each instructor knows the general knowledge level of his particular class. A self-paced course may be too advanced, too simple, too theoretical, or too practical for his particular class.

We do feel that it is important to develop resource materials in the extractive metallurgy area. Modularized materials, whether they are printed materials, tapes, slides, films, video-tapes, can be a great help to a teacher in assembling his course presentations.

Unit Processes in Extractive Metallurgy - Electrometallurgy

Unit Coordinator: Dr. T. J. O'Keefe
Professor of Metallurgical Engineering
Metallurgy Department
University of Missouri at Rolla
Rolla, Missouri

The course materials have been developed and peer reviewed. A textbook is not available that covers this material. Therefore, the developed materials should be welcomed as resource materials by those instructors teaching this subject matter.

The electrometallurgy course is composed of six modules, twenty-five learning activities. The first three modules provides the student with fundamental information on electrochemical phenomena. The last three modules concentrate on applications to electrometallurgical systems. An outline is presented in Appendix 3.

Tape-slide programs were not prepared for this course. However, liberal use of photographs, sketches and figures is made.

The electrometallurgy course materials were not completely prepared until the spring, 1980. Much of the material was completed (except for the module on Thermodynamics and Solution Chemistry) a year earlier. That material that was available was used both at Montana Tech and University of Missouri as supplemental handout material (spring, 1978, 1979, 1980). The course material will be used this spring (1981) in its completed and reproduced form at both colleges. The text materials will also be used for a short course to be presented by Dr. T. J. O'Keefe, (University of Missouri) and Dr. D. Robinson (University of Arizona) in December, 1980.

THE PHYSICAL CHEMISTRY OF IRON AND STEELMAKING

Unit Coordinator: Dr. L. G. Twidwell
Professor and Chairman
Metallurgy - Mineral Processing Department
Montana College of Mineral Science and Technology

The course material has been developed and peer reviewed. An Excellent text book is available, "Physical Chemistry of Iron and Steel Manufacture," by C. Bodsworth and H. B. Bell. This text, however, is considered advanced material, appropriate for graduate students who have had an introductory course in iron and steelmaking. It does not contain sufficient information in certain areas, e.g., refractories, ferroalloys, environmental concerns.

The iron and steelmaking course is a three semester hour course instead of two, as are all the other self-paced courses. It consists of six modules, twenty-six learning activities. Some of the learning activities exceed the normal one-hour study time requirement specified earlier. A course outline is presented in Appendix 4.

The principal investigator of this study spent one year with the Environmental Protection Agency, Metallurgical Processes Branch, Industrial Processes Division, Research Triangle Park, Raleigh, N. C., in 1979-1980. A portion of the leave period was spent completing the Iron and Steelmaking Course. The course material has been used for only one semester (spring, 1980).

It was used as text material for a lecture mode class (seven students). It has been used in the self-paced format by students during the past summer. Some revision of content is expected to be necessary as more students use the course and supply comments.

UNIT PROCESS IN EXTRACTIVE METALLURGY - HYDROMETALLURGY

Unit Coordinator: Dr. H. H. Haung
Metallurgy - Mineral Processing Department
Montana College of Mineral Science and Technology

The hydrometallurgy course development was initially assigned to Dr. J. Miller and Dr. J. Herbst. However, the course development was reassigned to Dr. Haung (a former post-doctoral student of Miller and Wadsworth at the University of Utah) in the Fall, 1979. The course materials were completed at the end of the spring semester, 1980. The materials have been peer reviewed and are now ready for student use. A course outline is presented in Appendix 5.

The hydrometallurgy course consists of seven modules, thirty-seven learning activities. Although the course was planned to be a two-credit hour course, the reviewers comments (and the coordinators agree) suggest that the material is in reality closer to four credits of materials. The hydrometallurgy course material will be used as text material this semester (Fall, 1980) at Montana Tech by 24 students. The results of their use will help to properly specify the appropriate credit hour designation.

4. CONCLUSIONS

The original conceptional goal of this project was to find a means whereby a small faculty in a specialty department, such as the metallurgy-mineral processing department at Montana Tech, could become more productive. More productive is used here to mean that a larger number of courses could be offered by the same number of faculty members. The term productive, is not used here to mean that a given course could be given more effectively to more students.

The self-paced course concept appeared to offer the possibility of attaining the stated goal. It is the opinion of the principal investigators that the concept is valid and applicable to our situation at Montana Tech. In our situation the courses will be used:

1. as text materials for lecture courses given at their once-a-year scheduled times.

2. as self-paced courses for students who desire to take the courses at times other than the scheduled time. This includes the possibility of a student taking courses during the summer.

3. as self-paced courses for interested industry people who want to take the courses while remaining on the job.

4. as self-paced deficiency courses for entering graduate students.

There are a number of considerations that one should be aware of concerning the developed materials. These considerations, I believe, greatly hinder wide-spread use of the prepared materials:

1. The courses are upper-level technology-based courses. They are not like basic engineering, math or chemistry courses that present relatively unchanging (or at least slowly changing) concepts. New technological development (forced by energy needs, mineral shortages, environmental regulations) in the areas of pyrometallurgy and hydrometallurgy are occurring at unforeseen rates. Updating of course material is, therefore, required yearly or, at least, by-yearly.

   Prepared materials can be rapidly outdated. An example of this is the pyrometallurgy material. This material was completed in essentially its present form in June, 1977. A large body of new information is now available that is presented to our students as supplements to the prepared course materials.

   It is important that NSF continue and be encouraged in its efforts to develop more realistic information distribution systems than the present traditional printed text material system.

2. The educational emphasis of a department greatly influences what courses and the content of its courses.

   The development of appropriate interrelationships between courses requires a careful and coordinated design of each course. It is, therefore, very unlikely that departments that have accomplished proper curriculum design will be able to use an entire package of material prepared elsewhere. Perhaps, they could use portions of the materials prepared during this project. This argument, then, is the basis for our recommendation that the developed materials be made available for review, but be supplied on a limited basis only. Those portions that the individual instructor wants to use then can be reproduced by that instructor from the supplied material.

5. DISTRIBUTION PLAN

The proposed distribution plan for the four self-paced courses is based on the following:

1. Each metallurgy or material science department has a specific emphasis in their program. Most U. S. departments emphasize the materials areas, e.g., only sixteen of eighty-five departments emphasize extractive metallurgy.

2. Each department has (or should have) developed appropriate interrelationships between courses that requires a careful and coordinated design of each course within that department. This means, of course, that a course within one metallurgy department does not necessarily fit the needs of a similarly titled course in another metallurgy department.

3. Individual instructors design their courses based on their educational background and experiences. Each sees the needs somewhat differently because of that and because they are aware of the limitations and strong points of their individual students.

There are not funds in the NSF project to support reproduction of the developed materials. The college has provided the funds for reproducing 200 copies of each course. These funds must be recovered by the college. Further reproduction expenses are not budgeted. The distribution plan is based on the previous conclusion that some instructors may want to use a portion of the developed material, but probably will want to pick and choose what they want for their students.

The distribution plan includes:

1. A letter to announce the availability of the four courses to all metallurgy-material science engineering departments. The list will include all those departments specified in its Metallurgy/Materials Education Yearbook, Edition 19, May, 1980, published by the American Society of Metals.

2. The sale of the 200 copies on a first-come [illegible] a cost not to exceed the cost of reproduction, a book [illegible] handling fee,

and a shipping cost. The place of purchase will be the Montana Tech Bookstore. The purchaser may reproduce that portion of the material of interest to his/her students. Note, however, that a portion of the materials are reproduced from other sources by written permission. Permission for further reproduction of those materials must be obtained by the individuals who wish to copy the material.

3. Those who order the pyrometallurgy material will be sent copies of the scripts for each type slide program. Then, upon request, a set of the slides will be provided that can be reproduced and the originals returned to the principle investigator. Three sets are available to be sent out for further reproduction.

APPENDIX 1. PYROMETALLURGY COURSE OUTLINE

UNIT PROCESSES IN EXTRACTIVE METALLURGY-PYROMETALLURGY

Course Outline *

Module 1

PRETREATMENT OF CONCENTRATES

1.1 Drying and Calcining
  1. Drying Processes
  2. Calcining — *Learning Activity 1*

1.2 Roasting Processes
  1. Purpose
  2. Thermodynamic Basis — *Learning Activity 2,3*
  3. Roaster Types & Industrial Systems
  4. Environmental Considerations — *Learning Activity 4,5*

1.3 Agglomerating Processes
  1. Purpose
  2. Agglomerating Systems — *Learning Activity 6*
     1. Sintering
     2. Pelletizing
     3. Nodulizing
     4. Briquetting

Module 2

SMELTING AND CONVERTING PROCESSES

2.1 Smelting
  1. Slag-Matte Formation
     1. Thermodynamic Basis
     2. Slag Function — *Learning Activity 1*
  2. Smelting Processes
     1. Reverberatory
     2. Electric
     3. Flash — *Learning Activity 2*

2.2 Converting
  1. Purpose and Thermodynamic Basis
  2. Converting Operation — *Learning Activity 3,4*

2.3 Continuous Copper Smelting and Converting
  1. Proposed Processes — *Learning Activity 5*
  2. Commercial Processes
     1. Noranda
     2. Mitsubishi
     3. Top Blown Rotary Converter

2.4 Energy Considerations — *Learning Activity 6, 7*

Module 3

REDUCTION PROCESSES

3.1 Thermodynamics of Oxide Reduction
  1. Equilibrium Pressure of Oxygen
  2. Free Energy - Temperature Diagrams — *Learning Activity 1,2*

3.2 Blast Furnaces
  1. General Characteristics
  2. Iron Blast Furnace — *Learning Activity 3*
  3. Lead Blast Furnace — *Learning Activity 4*
  4. Lead-Zinc Blast Furnace — *Learning Activity 5*

3.3 Electrothermic Reduction — *Learning Activity 6*

Module 4

REFINING PROCESSES FOR METALLIC SOLUTIONS

4.1 Metal-Slag Processes
  1. Slag
    1. Blast Furnace Slags
    2. Ferrous Slags — *Learning Activity 1*
  2. Impurity Oxidation
    1. Steelmaking Reactions
    2. Nonferrous Metal Purification — *Learning Activity 2*
  3. Deoxidation Reactions

4.2 Metal-Metal, Metal-Compound Processes
  1. Decreased Solubility
  2. Immiscibility
  3. Reagent Addition
  4. Selective Volatilization — *Learning Activity 3, 4*

4.3 Metal-Gas, Metal-Vapor Processes
  1. Vacuum Refining — *Learning Activity 5*
  2. Inert Gas Flushing
  3. Halide Evolution — *Learning Activity 6*
  4. Carbonyl — *Learning Activity 7*

Module 5

INTERRELATIONSHIP BETWEEN UNIT PROCESSES: EXAMPLE PYROMETALLURGICAL PROCESS

5.1 Iron
  1. Blast Furnace
  2. Refining of Liquid Steel

5.2 Copper
1. Conventional Process
    1. Reverberatory
    2. Flash

2. Continuous
    1. Noranda
    2. Mitsubishi

5.3 Lead and Zinc
1. Lead Blast Furnace
2. Zinc Vertical Retort
3. Imperial Smelting Furnace

5.4 Aluminum

5.5 Titanium

*Each module is sub-divided into learning units approximately 50 minutes in length.

The student will be given a test following each module. He must score well on this test or be required to review the material and retake another test before he can advance to the next module.

Each module will include a set of printed notes and audio-visual aids (tape-slide, films, video tapes, etc.).

APPENDIX 2. USER UNSTRUCTION AND EVALUATION FORMS

1. Course Management Instruction (Attached Form).
2. Evaluation Forms
    1. Student Information Form
    2. Module Information Form
    3. Final Evaluation Comments

COURSE MANAGEMENT

The course in pyrometallurgy is a two credit (semester) hour course. It is made up of five modules, i.e., groups of learning activities. Each learning activity is the material that a lecturer could cover in one hour. There are 24 learning activities in the first four modules. These are presentations on unit processes and background material required to understand unit processes.

A normal two hour course contains about 32-34 class periods. In this course there are 24 learning activities and about ten one-hour industry presentations.

Course management is an important part of the self-paced format. Tutorial interaction between instructor and student is to be encouraged. At present we are allowing a great deal of flexibility in how the materials are used and presented. We know that if you simply give the students the materials and let them go study on their own completely, the learning experience will probably be a failure. We do know the following from the experiences of others:

1. There must be a deadline for completion of each module. If not, students push the materials aside thinking they can cram and do it all near the end of the semester. The students must have time goals and if they don't stick with the goals they should be asked to withdraw from the class.

2. There must be specific scheduled times when the instructor is available for individual consultation. Students should be encouraged to use this contact time.

3. Audio-visual materials should be readily available; preferably used in a room designed for that purpose. The students can't take the tape-slide presentations home. We cannot supply enough copies to allow this.

4. The student must cover the text material before they cover the other material. Otherwise, they are not going to be able to follow the presentations.

5. Students should be encouraged to study and work problems together.

6. Testing can take several forms and the instructor must decide what is proper for his class.

COURSE EVALUATION DATA

Student Information

Please answer the following questions by filling in the appropriate blanks. This data will be returned to Montana Tech for statistical evaluation and will not in any way affect your grade in this course. It is information to be used only for course evaluation.

1. My cumulative grade point average at the beginning of this semester was ------------------------------------ ________
2. The number of credits I am taking this semester is ________.
3. My age is -- ________.

For each of the following items, place an X in the appropriate blank.

4. For me this course is ------------Required____ Elective____.
5. I am ---------------------------- Male______ Female______.
6. My major is: Chemistry____ Engineering____ English____ Geology____.
   History______ Mathematics_____ Other_________.
7. The grade I expect in this course is: A___ B___ C___ D____
   F___ PASS____
8. I am a: Freshman ____ Sophomore ____ Junior ____ Senior ____
   Graduate ____

COURSE EVALUATION DATA

Module Information

Module 1

Student Number ______.

1. When did you complete the test for this module? ______________.
2. What was your grade? ______________.
3. Did you retake the test? ______________.
4. Estimate the amount of time you spent to cover the material __________ hours.
5. Did you study alone? __________.
6. Estimate the amount of time you used tutorial help __________ hrs.
7. Do you have any suggestions or comments on the subject material covered in this module?

COURSE EVALUATION DATA

Final Evaluation Comments

Student Number ____________

1. When did you complete the course? ______________________
2. What was your grade? ____________
3. Compare this course with other engineering courses you have taken (circle the appropriate number):
   a. interest level

      least interesting 1 2 3 4 5 most interesting
   b. difficulty

      easiest 1 2 3 4 5 most difficult
   c. time consuming

      least time required 1 2 3 4 5 most time required
4. Would you recommend this course to other students? _________.
5. Estimate the average number of hours per week you spent studying for this course. ____________
6. For two hours of credit, was the time required about right?

   too little 1 2 3 4 5 too much
7. Rate your learning in this course against all other courses you have taken in college so far.

   least 1 2 3 4 5 most
   a. What motivated your study?

   b. What deterred your study?

8. Would you take another course in the self-paced format?

____
yes or no

9. General Comments.

APPENDIX 3. ELECTROMETALLURGY COURSE OUTLINE

UNIT PROCESSES IN EXTRACTIVE METALLURGY-ELECTROMETALLURGY

Course Outline

Module 1

BASIC CONCEPTS

1.1 Introduction — *Learning Activity 1*
1. Reaction Types
2. Essentials for Electrochemical Reactions
3. Conductors
4. Units, Definition, Terms

1.2 Electrochemical Cells — *Learning Activity 2*
1. Cell Types
2. Cell Conventions
   1. Galvanic
   2. Electrolytic
3. Faraday's Law

1.3 Materials Aspects of Electrometallurgy — *Learning Activity 3*
1. Introduction
2. Engineering Requirements of Materials
3. Structure

Module 2

THERMODYNAMICS AND SOLUTION CHEMISTRY

2.1 Thermodynamics — *Learning Activity 1*
1. Introduction
2. Reversible Electrode Potentials
3. Chemical Equilibria
4. Electrode Potential
5. Cell Reactions
6. Guidelines and Rules for Cell Reactions
7. Concentration Cells
8. Electrode Potentials--Sign Conversion

2.2 Thermodynamic Equilibrium Diagrams — *Learning Activity 2*
1. Introduction
2. Classes of Reactions
3. Construction of Pourbaix Diagrams
4. Conventions for Writing Reactions
5. Sample Calculations
6. Reference Electrodes
7. Activity and Activity Coefficients
8. Ionic Solutions
9. Solutions Near Electrode Surfaces

2.3 Solution Chemistry: Ionic Conduction — *Learning Activity 3*
1. Resistivity and Conductivity
2. Ionic Migration and Transport Numbers
3. Ionic Mobility and Diffusion Coefficient
4. Measurement of Electrolytic Conductance

2.4 Solution Chemistry: Theory of Electrolytic Conductance — *Learning Activity 4*
1. "Classical" Theory of Dissociation
2. Debye-Hückel-Onsager Theory

Module 3

KINETICS

3.1 Polarization of Solid Electrodes — *Learning Activity 1*
1. What is Polarization?
2. Polarization Curves and Their Measurement
3. Irreversible Character of Polarization
4. Different Types of Polarization

3.2 Mass Transfer Polarization — *Learning Activity 2*
1. Transport of Ions by Migration
2. Transport of Ions by Diffusion
3. Transport of Ions by Convection
4. Polarization Caused by Slow Mass Transfer
5. Metallurgical Examples

3.3 Convective Mass Transfer — *Learning Activity 3*
1. Natural Convection
2. Forced Convection
3. Enhanced Convection in Electrowinning

3.4 Charge Transfer Polarization — *Learning Activity 4*
1. Model
2. Equations
3. Metal Deposition
4. H_2 Discharge on Metals
5. O_2 Discharging Electrode
6. Cl_2 Discharging Electrode

3.5 Electrocrystallization — *Learning Activity 5*
1. Electrode Potential
2. Current Density
3. Temperature and Ion Concentration
4. Acidity
5. Mechanical Factors
6. Metal Substrate

Module 4

INDUSTRIAL PRACTICES I--EXTRACTION

4.1 Plant Equipment — *Learning Activity 1*
1. Primary Considerations
2. Electrical Equipment
3. Mechanical Equipment
4. Electrolytic Solutions

4.2 Electrorefining — *Learning Activity 2*
1. Purpose of Process
2. Electrochemistry
3. Considerations in the Design of Equipment

4.3 Practical Electrorefining Processes — *Learning Activity 3*
1. Principal Impurities
2. Major Objectives
3. The Role and Control of Addition Agents
4. Special Cell Design
5. Size and Cost of Commercial Operations

4.4 Electrowinning — *Learning Activity 4*
1. Purpose
2. Cathodic Process
3. Anodic Process
4. Solution Mixing
5. Control of Acid Mist
6. Problems of Heat Generation

4.5 Practical Electrowinning Processes — *Learning Activity 5*
1. Metal Recovery and Size of Operations
2. Chemistry and Electrochemistry of the Zinc Cell
3. Cathode Materials
4. Anode Materials
5. Cell Design Consideration

4.6 Cementation — *Learning Activity 6*
1. Introduction
2. General Aspects
3. Cementation Reaction Mechanism
4. Kinetic Aspects of Cementation Reactions
5. Deposit Effects
6. Influence of Impurities on Cementation Kinetics
7. Outline of a Typical Laboratory Cementation Study
8. Plant Methods and Equipment

4.7 References

Module 5

Corrosion of Metals

5.1 Corrosion Principles — *Learning Activity 1*
1. Introduction
2. Electrochemistry
3. Thermodynamics
4. Corrosion Rates

5.2 Forms of Corrosion — *Learning Activity 2*
1. Uniform
2. Galvanic
3. Crevice
4. Erosion
5. Pitting
6. Intergranular
7. Selective Leaching
8. Stress Corrosion

5.3 Effects of Certain Variables in Corrosion — *Learning Activity 3*
1. Calculated Corrosion Rates
2. Mixed Potential - Applications
3. Influencing Factors

5.4 Mineral Acid Environments — *Learning Activity 4*
1. Introduction
2. Sulfuric Acid
3. Nitric Acid
4. Hydrochloric Acid

5.5 References

Module 6

Industrial Practices II--Electroplating and Finishing

6.1 Substrate Preparation and Selection of Coatings — *Learning Activity 1*
1. Introduction
2. Preparation of Surfaces
3. Selection and Types of Coatings

6.2 Characteristics of Plated Surfaces and Their Evaluation — *Learning Activity 2*
1. Coherent Deposits
2. Uniform Deposits
3. Electrolyte Quality Testing

6.3 Metal Plating Systems — *Learning Activity 3*
1. Aqueous Plating Baths
2. Complex Ions in Electroplating
3. Strike Solutions
4. Common Electroplating Systems

APPENDIX-4. PHYSICAL CHEMISTRY OF IRON AND STEELMAKING COURSE OUTLINE

PHYSICAL CHEMISTRY OF IRON AND STEELMAKING

Course Outline *

Module 1

PHYSICAL CHEMISTRY OF REDUCTION PROCESSES

1.1 Review of Thermodynamics
  1. Thermodynamic Terms and Definitions — *Learning Activity 1*
  2. First Law of Thermodynamics
     1. Energy
     2. Enthalpy
     3. Heat Capacity
  3. Thermophysics
  4. Thermochemistry — *Learning Activity 2*
     1. Heat of Formation
     2. Heat of Reaction
     3. Temperature Effects
  5. Second and Third Laws of Thermodynamics
     1. Second Law
     2. Third Law
     3. Entropy Change with Physical State
     4. Entropy Change with Chemical State
  6. Free Energy — *Learning Activity 3*
     1. Definition and Derivation
     2. Chemical Changes
     3. Temperature Effects

1.2 Application of Thermodynamics to the Reduction Process — *Learning Activity 4*
  1. Free Energy Diagrams
  2. Reaction Spontaneity
  3. Fe - O + C Phase Equilibria

1.3 Physical Chemical Considerations in the Blast Furnace — *Learning Activity 5*
  1. Boudouard Reaction
  2. The Blast Furnace

1.4 List of References and Data Compilations

Module 2

PHYSICAL CHEMISTRY OF LIQUID IRON AND STEEL

2.1 Thermodynamic Properties of Metallic Solutions: Theory — *Learning Activity 1*
  1. Ideal Solutions
  2. Real Solutions
  3. Change in Standard State
  4. Solution Interactions

2.2 Refining Reactions in Liquid Steel Solutions — *Learning Activity 2*
1. Carbon Removal
    1. Thermodynamics
    2. Carbon Boil
2. Hydrogen and Nitrogen Removal — *Learning Activity 3*
    1. Hydrogen
    2. Nitrogen
    3. Special Techniques
3. Deoxidation — *Learning Activity 4*
    1. Solid Deoxidants
    2. Inert Gas Flushing
4. Desulfurization
    1. Thermodynamic Properties
    2. Special Removal Techniques
        1. Sulfur Containing Gases
        2. Sulfide Formation

2.3 Summary of Refining Processes — *Learning Activity 5*
1. Basic Oxygen Process
    1. Top Blown Process
    2. Bottom Blown Process
2. Electric Furnace Process — *Learning Activity 6*
    1. Chromium Stainless Steel
    2. Argon Refining of Chromium Steel

2.4 References

2.5 Appendix: Interaction Coefficients for Steels

Module 3

PHYSICAL CHEMISTRY OF SLAGS AND REFRACTORIES

3.1 General Role of Slags

3.2 Physical Chemical Considerations — *Learning Activity 1*
1. Blast Furnace Slags
2. Steel Refining Slags
    1. Basic Electric Furnace Slags — *Learning Activity 2*
        1. Sulfur
        2. Phosphorus
    2. Basic Oxygen Steelmaking Slags — *Learning Activity 3*
        1. Phosphorus
        2. Sulfur
        3. Oxygen

3.3 Refractories — *Learning Activity 4*
1. Refractory Development
    1. Acid Refractories
    2. Basic Refractories
2. Refractories for the Steel Industry — *Learning Activity 5*
    1. Coke Ovens
    2. Blast Furnace
    3. Refining Vessels

1. Electric Arc
2. AOD
3. BOP
4. Q-BOP
4. Others

3.4 Slag-Refractory Interactions — *Learning Activity 6*
1. Blast Furnace
2. Refining Slags
1. Magnesia Refractories
2. Chrome Refractories
3. BOP — *Learning Activity 7*
1. Slag - Refractory
2. Economics

3.5 References

Module 4

SELECTED TOPICS: PART I

PELLETIZING, SINTERING, COLD BOND AGGLOMERATION

4.1 Pelletizing — *Learning Activity 1*
1. Green Pelletizing
1. Fundamentals
2. Drum Versus Disc Processes
2. Indurating
1. Fundamentals
2. Equipment

4.2 Sintering — *Learning Activity 2*
1. Introduction
2. Sintering Characteristics
3. Briquetting

4.3 Cold Bond Agglomeration — *Learning Activity 3*
1. Carbonate Bond Process
2. Cement Bond Processes
3. Hydrothermal Processes

4.4 References

Module 5

SELECTED TOPICS: PART II

DIRECT REDUCTION, CONTINUOUS STEELMAKING, OXYGEN PRODUCTION

5.1 Direct Reduction Ironmaking — *Learning Activity 1*
1. Introduction
2. Gas Reduction
1. Fixed-Bed Processes

2. Fluidized-Bed Processes
3. Solid Reduction
4. Product Sizes

5.2 Continuous Steelmaking — *Learning Activity 2*
1. Spray Process
2. Continuous Refining in a Metal Bath

5.3 Oxygen in Steelmaking — *Learning Activity 3*
1. Uses in Steelmaking
2. Oxygen Production

Module 6

SELECTED TOPICS: PART III

FERROALLOY PRODUCTION

6.1 Ferroalloys and Their Uses — *Learning Activity 1*
1. Ferroalloy Products
2. Ferroalloy Uses in the Steel Industry

6.2 Ferroalloy Production
1. Production Methods
   1. Thermodynamics
      1. Ferromanganese
      2. Ferrosilicon
2. Furnace Types

6.3 Ferroalloy Emission Control — *Learning Activity 2*
1. Air Emissions
2. Water Pollution
3. Solid Wastes
4. Organic Emissions

6.4 References

APPENDIX 5. HYDROMETALLURGY COURSE OUTLINE

UNIT PROCESSES IN EXTRACTIVE METALLURGY-HYDROMETALLURGY

Course Outline

Module 1

FUNDAMENTALS - SOLUTION CHEMISTRY

1.1 Introduction — *Learning Activity 1*
1. Liquid State
2. Structure and Properties of Aqueous Solutions
3. Stability Relations
4. Reaction Types

1.2 Activity - Concentration Relationships — *Learning Activity 2*
1. Definition of Standard State
2. Mean Ionic Activity - Individual Ionic Activity
3. Estimating Ionic Activity Coefficients

1.3 Complex Equilibria — *Learning Activity 3*
1. Complex Ions
2. Stability Constants
3. Distribution of Species
4. Computer Program for Solution Equilibrium Calculations — *Learning Activity 4*

1.4 Oxidation-Reduction Reactions — *Learning Activity 5, 6*
1. Convention
2. Electrochemical Phase Diagrams
3. Appendix

Module 2

FUNDAMENTALS - MASS TRANSFER AND REACTION KINETICS

2.1 Introduction — *Learning Activity 1*
1. Classification of Reactions
2. Definition of Reaction Rate

2.2 Homogeneous Kinetics
1. Law of Mass Action and Rate Law
2. Theories of Rate Constant
3. Catalysis — *Learning Activity 2*
4. Reaction Order from Batch Reactor Data
5. Suggested Readings

2.3 Heterogeneous Kinetics — *Learning Activity 3*
1. Reaction Steps and the Rate Controlling Step
2. Transport Within Phases
3. Kinetics of Adsorption Reactions
4. Reaction of the Interface — *Learning Activity 4*

Module 3

LEACHING SYSTEMS FUNDAMENTALS

4. Suspension of Solid in a Stirred Tank
5. Mass Transfer to Particles in Agitation Tanks

4. References

3.5 Reactor Design — *Learning Activity 4*

1. Types of Reactors
2. Design Parameters
   1. Review of the Kinetics of Fluid Particle Reaction
   2. Concentration of the Lixiviant
3. Modeling and Design for Continuous Leaching Systems - J. A. Herbst
   1. Symbols and Notations
   2. Description of Governing Equations
   3. Results from Computer Simulation
   4. Design Work Sheet and Example
4. References

Module 4

PHASE SEPARATION

4.1 Thickening — *Learning Activity 1*

1. Introduction
2. How a Continuous Thickener Functions
3. Elements of a Thickener
4. Some Factors that Size Continuous Thickener Basins
5. Practical Mill Design Considerations for Thickeners
6. Major Factors Influencing Thickener Design

4.2 Filtering — *Learning Activity 2*

1. Introduction
2. Types of Continuous Filters
3. Applied Theory of Continuous Filtration
4. Applied Thoery Use in Predicting Full Scale Results

Module 5

LEACHING OF METALS; OXIDES AND SULFIDES

5.1 Overview — *Learning Activity 1*

1. Introduction
2. Leaching Methods and Equipment
3. Thermodynamics of Leaching Reactors
4. Leaching Kinetics
5. References

5.2 Leaching of Metals — *Learning Activity 2*

1. Gold Cyanidation
    1. Chemistry and Mechanism of Cyanide Leaching of Gold
    2. Gold Cyanidation Practice
    3. Conventional Gold Cyanidation
    4. Carbon Adsorption and Desorption Process
    5. Electrowinning
    6. Cyanide Heap Leaching of Gold Ore
    7. Cortez Heap Leach Cyanidation
2. Leaching of Metallic Copper
    1. Chemistry
    2. Practice
3. References

5.3 Leaching of Oxides — *Learning Activity 3, 4*

1. Thermodynamics and Kinetics
2. Leaching of Uranium Oxides
    1. Hydrometallurgical Process for Uranium Oxides
    2. Acid Leaching of Uranium Oxides
    3. Carbonate Leaching of Uranium Oxides
3. Leaching of Bauxite--Bayer Process
4. Leaching of Nickel Oxides
    1. General Considerations
    2. Direct Sulfuric Acid Leach
    3. Reductive Roasting/Ammoniacal Leaching
    4. Sulfidization Process
5. Leaching of Ocean Manganese Nodules
    1. General Considerations
    2. Kennecott Cuprion Process
6. Leaching of Copper Oxide
    1. Leaching Methods
    2. In-situ Leaching
    3. Dump Leaching
    4. Heap Leaching
    5. Vat Leaching
    6. Agitation Leaching
7. References

5.4 Leaching of Sulfides — *Learning Activity 5*

1. Introduction
    1. Thermodynamics
    2. Kinetics
2. Leaching of Nickel and Cobalt Sulfide Minerals
    1. Ammonia Oxidation Leaching of Ni-Co Sulfides
    2. Acid Leaching of Nickel and Cobalt Sulfides
    3. Leaching of Copper-Nickel Matte

3. Leaching of Copper Sulfides-Fundamental Studies — *Learning Activity 6*
   1. Sulfuric Acid Leach
   2. Ammonia-Oxygen Leach
   3. Ferric Chloride Leach
   4. Nitric Acid Leach
   5. Cyanide Leach
   6. Microbiological Leach — *Learning Activity 7*
   7. Electrochemical
4. Leaching of Copper Sulfide-Processes — *Learning Activity 8*
   1. Roast-Leach-Electrowin Process
   2. Ammonia Leach Processes
   3. Ferric Chloride Leach Processes
   4. Acid Leach Processes
5. Leaching of Other Sulfides
   1. Roast Leach Process for Zinc Sulfide
   2. Direct Leaching of Zinc Sulfide
6. References

Module 6

SOLUTION CONCENTRATION AND PURIFICATION

6.1 Solvent Extraction — *Learning Activity 1*
   1. Introduction
   2. Characterization of Extraction Reaction
   3. Extraction Chemistry — *Learning Activity 2*
   4. Solvent Extraction Systems — *Learning Activity 3*

6.2 Ion Exchange — *Learning Activity 4*
   1. Introduction
   2. General Principles
      1. Chemical Composition and Structure of Resins
      2. Selectivity of Ion Exchanger
      3. Kinetics of Ion Exchange Reaction
   3. Hydrometallurgical Applications — *Learning Activity 5*
      1. Uranium Extraction--Chemistry of Adsorption and Elution
      2. Uranium Ion Exchange--Processes and Equipment
      3. Extraction of Other Metals
      4. Separation of Metal Ions

Module 7

METAL RECOVERY

7.1 Gaseous Reduction in Aqueous Solution — *Learning Activity 1*
   1. Hydrogen Gas Reduction
   2. Other Gases.

7.2 Cementation — *Learning Activity 2*

1. Introduction
2. Theory
3. Initial Concentration
4. Temperature
5. Summary

7.3 Electrolysis — *Learning Activity 3*
1. Introduction
2. Sample Calculations
3. Electrowinning of Copper — *Learning Activity 4*
    1. Electrowinning Reactions
    2. Cell Voltage and Energy Consumption
    3. Cathode Current Efficiency: Interfering Iron Reactions
    4. Purity of Cathode: Behavior of Electrolyte Impurities
    5. Electrowinning Tankhouse Practice
    6. Special Problems of Solvent Extraction Electrolytes
    7. Recent Improvement in Electrowinning Procedure
    8. Summary

7.4 Electrowinning Plant Practice — *Learning Activity 5*
1. Purpose of Process
2. The Cathodic Process
3. The Anodic Process
4. Solution Mixing
5. Control of Acid Mist
6. Problems of Heat Generation
7. Metal Recovery and Size of Operations
8. Chemistry and Electrochemistry of the Zinc Cell
9. Cathode Materials
10. Anode Materials
11. Cell Design Considerations