STATE OF THE ART
AND
FUTURE DIRECTIONS IN SOLVENT EXTRACTION

PROCEEDINGS OF
THE SECOND INTERNATIONAL
SOLVENT EXTRACTION WORKSHOP '2000

OCT. 10 - 13, 2000
BANFF, ALBERTA, CANADA

Organized and Chaired by Dr. Gordon M. Ritcey

Sponsored by the International Committee for Solvent Extraction (ICSE)

Session Chairmen:

Don Ibana, Curtin University of Technology, Kalgoorlie, W.A., Australia
Bruce Monzyk, Battelle, Columbus, Ohio, United States
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CONTENTS

FORWARD

The following is a summary of the Solvent Extraction Workshop'2000 which was held October 10-13, 2000 in Banff, Alberta, Canada. The Workshop, which was the second such meeting, was again sponsored by the International Solvent Extraction Committee (ISEC). The workshop, which was by invitation, covered all aspects of the solvent extraction process,

This SX Workshop was held 3 years after the initial workshop, and again about half-way between the previous International Solvent Extraction Conference (ISEC) in Barcelona, ISEC"99, and the next meeting, in Capetown, South Africa, ISEC '2002. The purpose was to bring together many of the experts in solvent extraction to identify and to discuss the various problem areas in this unit process. The recommendations would provide the many researchers throughout the world with good project ideas that could result in significant reductions in capital and operating costs of solvent extraction plants. Because of the success of the first meeting in 1997 in Banff, both the technical aspects as well as the venue, it was decided to again return to Banff in 2000.

Again, this workshop was planned not as the usual, formal, conference, but instead was styled after the very successful and informal Gordon Research Conferences that have been held in the USA on various aspects of chemistry and engineering.

The list of possible invited experts for such a workshop was assembled by members of ICSE, and if some have been overlooked, it was not intentional. If the workshop was to be successful, the total attendees would be limited to about 75.

It was hoped that the invited specialists would recognize that participation would be useful to the solvent extraction community in general, as well as an opportunity to personally benefit from the meetings. Invites included those from chemistry, chemical engineering, process design, engineering contractors, and operating plants. As in the first workshop, it was anticipated that the Solvent Extraction Workshop'2000 "experts" in the areas of R & D, engineering and applications would:

1) critically review the individual areas of concern in the consideration of solvent extraction from R&D to its industrial scale-up to plant processing;

2) provide a closer interaction between chemistry-engineering-process development-plant design and construction then is possible in the usual, large international meetings;

3) improve the communication between the R&D scientists and engineers and the engineering contractors to optimize the design of future solvent extraction operations;

4) transfer the conclusions of this meeting to ISEC ‘99, thus providing some guidance to future R&D and plant design; and,

5) would provide a document for wide circulation amongst practitioners, possibly by publishing in “Hydrometallurgy”.

The meetings took place over a 4-day period, although the first day, Tuesday, was really to arrive and meet each other socially at a reception.

The format comprised an informal technical session in the morning, followed by lunch and then break for the afternoon. This permitted the attendees to visit the area for sightseeing, or participate in sporting activities of their choice. Following dinner, the evening sessions commenced.

On Wednesday, the first part of the morning was devoted to the introduction of the workshop, the concerns as identified by the first workshop participants, and those numerous items of concern were then prioritized into smaller lists for the individual workshop sessions to consider for discussion. The subsequent group workshops that morning and evening, Thursday and Friday morning dealt further with the list of concerns in more detail. The workshop closed late Friday afternoon with the summary presentations by the groups to the total workshop meeting.

Like any technical meeting, there were a number of invites who were unable to attend due to other commitments, illness prior to the meeting, and also some who were assigned other responsibilities in their respective organizations. -- all, which was indeed unfortunate. However, those that did attend were rewarded, I believe, in the useful discussions that resulted with their participation. The venue of the Banff Centre was perfect, and the sunny days that week in the mountains was glorious.

Gordon M. Ritcey, SX Workshop '2000 Chairman

PROGRAM

Tues. Oct 10

Check-in at Professional Development Centre (the Main Lodge building)
1500 - 1630 Registration, Max Bell Building, Foyer
1700 - 1830 Reception, Max Bell Building, Foyer
Dinner

Wed Oct 11

0830 Opening Remarks - Max Bell Building (Room 252)
0900 Workshop sessions (Rooms 251, 252, 253)
1030 Break - Coffee / Tea
1100 Workshop sessions
1215 - 1330 Lunch - main dining room, Donald Cameron Hall

Afternoon Free

1730 - 1900 Dinner
1900 Workshop sessions
2030 Break - Coffee / Tea
2100 Close of sessions

Thurs Oct 12

0900 Workshop sessions
1030 Break - Coffee / Tea
1100 Workshop sessions
1215 - 1330 Lunch

Afternoon Free

1730 - 1900 Dinner
1900 Workshop sessions
2030 Break - Coffee / Tea
2100 Close of sessions

Fri Oct 13

0900 Workshop sessions
1030 Break -Coffee / Tea
1100 Workshop sessions
1215 - 1330 Lunch
1330 Wrap-up session

This Final Session will be held immediately following lunch, instead of in the evening. This will give those that depart later on Wednesday the opportunity to participate, This session will be devoted to summary presentations of the individual work groups.

1500 Break
1630 Close of Workshop

OPENING REMARKS

Dr. Gordon Ritcey

Good morning ladies & gentlemen, and welcome to Banff and the Solvent Extraction Workshop'2000. I am pleased to see so many old friends, as well as a few others who I have met for the first time, but have known of them through their contributions to solvent extraction.

This is the second workshop on the integrated aspects of solvent extraction--from the basic studies, in chemistry and chemical engineering, through process design, piloting, and then engineering and plant design, scale-up and operation.

The initial workshop, held just 3 years ago here at this same venue proved very successful, and the recommendation at that time by the participants was to hold such workshops periodically.

The initial workshop in 1997 was under the sponsorship of the International Solvent Extraction Committee, as is this workshop. The idea was to hold such a "think-tank" type of meeting mid-way between the International Solvent Extraction Conferences (ISEC'S) with invited "experts" for the purpose to identify gaps in the process technology and to determine areas where further R & D would be required in order to ultimately provide for optimum plant performance in new and existing SX plants..

The Banff venue choice appeared to have been a good one in 1997, so again Banff was selected for this meeting. I hope that for those who are in Banff for the first time, as well as others who have had the opportunity to visit before, that you will enjoy the beautiful scenery the area offers. You will have an opportunity to explore the area in the free afternoons today and tomorrow.

The registration of about 45 is well short of the 73 in the first workshop. This number includes 16 participants that attended the first workshop. The decrease in registration for the second workshop has been due to a number of invitees who have not been able to participate because of conflict with other events, together with necessary cancellations by others who had been transferred to other projects, such as engineering projects, pilot plants or plant start-ups., as well as health reasons.

A wide spectrum of expertise and background are here, representing 10 countries. The smaller group may prove better than a larger group in the discussions. We shall know in a few days! I would hope that everyone participates in the discussions in order to obtain the most benefits from the valuable interaction in the workshops.

Solvent extraction begins as studies and investigations of the fundamentals of chemistry and chemical engineering, with the objective of transferring the accumulated scientific data to an applied science, as an industrial unit operation for the recovery of many substances. A number of disciplines and stages in the application of the data to the subsequent engineering design and construction will contribute to a cost-effective operation.

The **objectives** of this workshop are similar to the initial workshop:

1) to **address and critique** the various areas of the SX process, including:

  a) fundamental research in chemistry & chemical engineering

  b) flowsheet development (chemistry, chemical engineering, metallurgy) through to piloting to obtain preliminary design and cost data

  c) engineering design, control, plant design and plant construction

  d) plant operation (problems and solutions)

2) to **determine where there are gaps or flaws in our knowledge** so that:

  a) additional fundamental research projects would be identified and carried out;

  b) possibly some on-going fundamental research may be identified as not generally applicable to improving the process in the long term;

  c) identify where improved chemistry, extractants, contactors and control could be developed or improved to enhance the overall operation and economics in the process and plant design; and,

  d) an improved understanding and communication between chemists-engineers-engineering companies will result in improved plant operations, thus reducing the many costly operating problems of plants.

So how are we to achieve the objectives?

A number of "concerns" were identified in the first workshop. Only a few of those were actually addressed in the time available in that workshop. These are cited in the proceedings of that workshop. Thus we have a basis and background from which to begin our discussions in this present workshop.

For those who did not attend the first workshop, the workshop is informal and hopefully more like a "think tank", but still with some structure.

As in the first workshop, I have divided the grouping into chemistry, chemical engineering, and process & plant design and operation. You will notice that each of the 3 workshop sessions is comprised of a number of specific items to address--but is not necessarily limited to those subjects. Undoubtedly, many of you will have some additional questions which might be addressed--and this should be encouraged. However, try to cite those areas for discussion in the appropriate time in the sessions.

Each session will require a “facilitator or motivator” chairperson to maintain continuity throughout the sessions. These persons are best selected by each group. The actual sessions will therefore be **guided** from one subject to the next by the co-chairpersons. In any session at any time there will always be some with more experience in that subject area than the others, and would therefore lead the debates and discussion on that subject. As in any "think tank" type of meeting, the questions and answers gradually will arrive at a point where the "feeding on one another" has provided some real information and perhaps, even conclusions.

Of course in this 3-day meeting we can't expect to solve all the problems, or determine all the gaps requiring further research. But we can continue from the first workshop, and at the same time gain valuable information in the subject of interest.

To achieve the objectives of defining R&D needs we must have some conclusions. So that is why there are 3 chairpersons to ensure that the final conclusions on each subject area of their session are noted.

As you are probably well aware , we meet in the individual workshop sessions today and tomorrow in the morning until 12 noon, with a coffee / tea break midway. Following lunch, the afternoon is free for leisure activities. After dinner, we reconvene at 7 pm and terminate at 9 pm. Again there is a break midway.

On Friday, we have the morning sessions but there is no evening sessions. Instead, there is an afternoon session. In this plenary, or wrap-up session, we meet as a total group in the auditorium. Representatives from each of the 3 workshop groups will present a summary to the total participants of the workshops.

So that is the mechanism of the workshop. The small discussion sessions will take place in 2 other meeting rooms, in addition to this room. The rooms are set-up as classroom style and can accommodate from 20-35 each.

As I only have a general idea of expressed individual interests, it is difficult to assign rooms ahead of schedule. Also, because of the broad interests of many, I will spend a few minutes to review the concerns expressed by the participants in the first workshop. In addition, I have summarized possible points for discussion by the 3 groups, based on these concerns, as well from suggestions from others here and as a result of my own observations.

GENERAL WORKSHOP CONCERNS/RECOMMENDATIONS (1997)

The following concerns were identified at the beginning of the 1997 SX Workshop as Concerns where more information was required. This list was used in the Workshop discussions to select topical areas for the separate discussions. by the smaller groups. Because many of the items listed were not discussed, only some selected by each group, the list was again used as a reference point to the discussions, together with the conclusions of the SX Workshop '97.

CHEMISTRY

what are the main restrictions on reagents imposed by the plant operations, that is the chemists designing the process must be aware of problems that may result from the mineralogy of the ores or the process variables required.

need a reagent for co extraction at about pH 1.5, so as to eliminate the acid neutralization. a higher cost reagent may be acceptable as the metal being recovered is of higher value.

research is required on reagent degradation, the causes and mechanisms occurring.

speciation studies are required on all solutions throughout the process, not, just the solvent extraction process, if the plant operations are to be optimized; again this requires time, particular expertise and funding. Universities can be an asset in this area.

understanding the process as regards the fundamental chemistry levels vs real operation and the problems, both the organic and the aqueous phases must be considered, as there are changes in the kinetics, viscosity and physical aspects as loading occurs.

analyses:
- frequency of sampling (on-line vs. off-line)
- modern instruments vs. old "wet" techniques

is there a better way to treat fouled organics other than by clay treatment, which is expensive as well as little understood as to functionality and may not always be completely satisfactory.

CHEMICAL ENGINEERING

requirement for more sophisticated design models of equipment, eg. columns

modelling / simulation
- a) can it help in the plant design?
- b) possible use in the total plant system

there appears to be a lack of data on the thermodynamics in concentrated solutions, as most basic work has been performed and published on dilute solutions, but funding is required.

application of columns to metals such as copper--will depend on the kinetics; can the rates be increased?

Design

Use real solutions for design; difficult to relate from one plant to another and so the physical characteristics as well as the chemical will differ. Also, once the plant is in operation, the performance may differ compared to the bench and pilot plant data due to perhaps the accumulation of surfactants. Thus the typical plant solution should be used.

the SX process operation is dynamic and changing continually in physical and chemical compositions (including surfactants) during the plant life, compared to the original process design based on a static sampling.

dependence of design on the aqueous media, eg. $S0_4^{2-}$, Cl^-, NH_4^+ as regards reagent degradation, contactor choice, physical dynamics, final products, economics, etc.

fundamentals of chloride leaching systems, or other novel systems could be considered.

piloting usually performed using mixer settlers, from which data is taken for scale-up; however the mixer settler used will be quite different in design from the eventual plant. Very little interest on other possible contactors, such as columns, where the piloting would be performed on a similar engineered design as the final plant.

piloting should be considered in the full context of the total (metallurgical) flowsheet so that leaching is really part of the pilot plant.

interfacing the upstream / downstream compatibility together with the economics and the environmental impacts is important.

Operation

- # what information is required by the operator in order to operate the process in the most efficient manner.

- # how much data has to be provided to the design engineers and how long should a pilot plant be run, and what data are really required.

- # guidelines are required regarding entrainment (Physical & chemical), the causes and the effect of tip speed, shear, etc. on organic entrainment as well as aqueous entrainment.

- # there is a need for sensors that are robust to the process.

- # start-up problems, as seen by the designers, operators, engineers; good partnerships are necessary between the engineering company who built the plant and the operator regarding the plant performance. Plants should be designed to be easy to start-up and have easy access to all areas and be "operator friendly".

- # linking of 2 SX circuits can pose different, and often, difficult problems (Mo/Cu, Ni/Co, Co/Cu, Cu/U); more work is required in prediction and design in the pilot through to plant operations rather than discover the problem after the plant has been in operation.

- # do we have all the necessary plant data and process monitoring requirements throughout the plant and operation?

- # reagents conservation should be considered by recycle of waste streams where possible, but recognizing the role of minor impurities and the possible effects on the mechanical aspects (rubber liners), or of the metallurgy.

- # analyses of components / impurities / entrainment by on-line must be considered; also includes solubility of organic components as well as the degradation of organic components of the solvent mixture.

- # sampling, and the concern with integrity of the samples, which can vary over time, etc; realistic samples are required.

- # precipitation / crystallization from either one or both phases can occur during the plant operation, such as the basic nickel sulphates in the ammoniacal systems.

diluents / modifiers effects, not only on the mass transfer and physical aspects, but also the effects of possible additives to the diluent due to possible changes in the legislation (limit addition of aromatic); no reliable analytical methods exist.

revision of design parameters in light of "recent" knowledge regarding better design of the process; which are the real parameters?

organic removal from aqueous phases: consider equipment, reagent "cleaning", and regeneration; what is the effect on the economics? Better methods have to be devised.

GENERAL

SX-EW is considered as "known technology" by many operators, but not by all the industry.

communication between different groups (both ways) are required.

SX is considered by the banking society as "exotic". Together with bad publicity, funding for major projects becomes difficult, as the financial houses do not understand the SX processes.

SX vs. environment, where SX is perceived as an environmental risk because of the general public understanding and the "green process technology" which would eliminate the use of solvents.

safety/health concerns include the removal of the word "solvents" from processing. education; and improved public relations are required. Biodegradability and toxicity must be addressed. Do we need better methods and equipment for entrainment?

deficiency of published information (eg.,handbooks) that could address issues, as compared to most publications which may be little more than literature reviews --eg., such as a small book for the operators of pilot plants and plants.

differential funding (R&D vs. pilot). The research funding is usually easier to obtain.

generic funding for research is practised by such as AMIRA (Australia)., MIRO (UK-Europe), Copper Research Association (USA), Separation Processes (UK), NRC (Canada), and others which should be identified.

considerable information and data are available in the literature, mostly from academia, which needs to be "translated to the plants" so as to be more useful.

novel applications of SX include catalysis and the production of powders with defined size and other qualities.

CONCERNS FOR DISCUSSION AT SX WORKSHOP '2000

The following areas were selected as possible topics for discussion in the 3 workshops in SX Workshop '2000. Naturally, in the 3-days available, only certain of the topics were covered, and these are summarized later in the Proceedings.

CHEMISTRY

- Reagents - new and old
- Extractants, diluents, modifiers
- Tailor-making
- Sequential extraction (2 separate extractants)
- Performance prediction
- Synergistic mixtures
- Microemulsions / micelles
- Interfacial reactions
- Solvent impregnated resins
- Reactivity / reagent break-down; regeneration / solvent treatment
- Sampling and analyses and techniques
- Performance relative to chemistry of aqueous and organic phases (synthetic vs real)

CHEMICAL ENGINEERING

- Contactors-design, pros-cons
- Interfacial phenomena
- Dispersion / coalescence and phase continuity
- Modelling and control of process
- Sampling and analyses
- Modelling and simulation
- Verification on continuous circuit
- Contactors / simulation / drop models
  - coalescence, drop break up
  - small scale experiments
  - pilot scale columns / mixer settlers
  - slow kinetics vs. column choice
- Data base

PROCESS DESIGN AND DEVELOPMENT

Factors in design
- aqueous medium
- contactor choice
- physical dynamics
- final products
- environment, economics, etc

Mass transfer And equilibrium data - (kinetics estimation and modelling
Scaling from stirred vessel / lewis cell / rising droplet / venturi tube
Physical - chemical aspects
- emulsions and cruds

Sulphate /chloride / alkaline options
Waste treatment (mills, plating etc)
- metals and toxic materials

Process Controls
Solvent Losses
Types:
- solubility,
- evaporation,
- cruds,
- entrainment

Recovery methods
Bench-pilot-plant design including research, engineering, contactors
"Rules of thumb " in process design and their relevance
Standardized test procedures
New processes
Treatment of laterite alkaline leach solutions for Ni-Co recovery
- alternate routes

PLANT DESIGN / SCALE-UP / PLANT OPERATION

- # Concerns in scale-up
- # Bench-pilot data-- engineering to plant
- # Basic process data information required by engineering & guarantees to client
- # Some problems in scale-up to plant
- # Tech / economic decisions in design
- # Dispersion - coalescence - solvent losses and solutions to problems
- # Problems & solutions in linking 2 circuits; eg. Ni-Co; Cu-U
- # Pros - cons of ammoniacal extraction
- # Pros - cons of chloride extraction
- # Pros - cons of sulphate extraction and chlorides strip for sequential extraction eg. Co-Ni
- # Problems in large plants; eg Cu, Ni, Co, U
- # Sampling & analyses; sensing and control (throughout entire plant)
- # Environment and reagent recycle
- # Comparison and critique of new laterite Ni plants

Acid

- sequential recovery of Co and Ni
- Co recovery followed by H2 reduction of Ni
- Co + Ni recovery, HCl stripping and SX of Co

Alkaline

- acid leach and alkaline precipitation of Co + Ni from acid
- leach of precipitate with alkali; SX of Ni; acidification of raffinate and SX of Co
- alkaline leach + sulphide precipitation
  (re-solution in acid; S of Co - Ni)

- # The future of SX plants--what are the main areas that require improvement?
  eg. design, scale-up, solvent treatment, safety, environment, energy use, CAPEX, OPEX, etc.

WORKSHOP ’2000 SUMMARIES

CHEMISTRY GROUP

Prepared by Dr. Don Ibana

1.0 REAGENTS AND DILUENTS

There is a need to understand solvent degradation in plants particularly the effect of NO^{3-}, causes of oxidation, and role of phase modifiers.

An extensive, coherent review of organic degradation in plant conditions including underlying chemistry principles would be useful.

Apply fundamental understanding of degradation to design of next generation extractants and predictive models of degradation

There is a need for systems that permit higher metal loading, better kinetics, better coalescence, and more selective reagents (e.g. for rare earth metals; Co from Mn, Cu, Zn; Zn from Fe).

Speciation studies in real solutions, e.g. aggregation, how chemistry changes with chemical conditions, would be useful.

There is a need for a review of solvent losses and regeneration.

Synergism has some uses.

2.0 CRUD / THIRD-PHASE FORMATION

Identify first steps in crud formation in plant conditions.

Understand relative role of solids, surfactants and biologically derived materials in crud formation.

Understand this phenomenon from operational point of view.

Develop predictive models of crud and third-phase formation.

3.0 INTERFACIAL PHENOMENA

Kinetics (mechanism, methods, and data interpretation) remains a controversial topic and a better understanding is needed.

Explore use of kinetics to enhance selectivity and improve process / plant design.

There is a need to understand chemical influences in coalescence.

4.0 ENVIRONMENTAL

Develop biodegradable / environmentally benign extractants and diluents.

Develop new methods, i.e. alternatives to incineration, for organic waste treatment.

Investigate toxicology of extractant / diluent combination.

Improved approaches to solvent recovery (eg supercritical fluid) would be useful.

5.0 NOVEL CONFIGURATIONS

- # Novel configurations will not replace SX but may expand capabilities of SX.
- # There is a growing importance for techniques with decreasing emission limits
- # Electrostatically - assisted SX & membrane - assisted SX may find industrial applications in hydrometallurgy.
- # Other novel techniques such as supercritical fluid (SCF), extraction chromatography, micellar-enhanced ultra-filtration, ligand-modified MEUF, liquid membranes may find special applications.

6.0 ANALYSIS AND MONITORING

- # A reliable method of monitoring total organic content (TOC) is needed.
- # Understanding the fundamentals of ion transfer in sensors is necessary..
- # Develop real-time monitoring for concentrations of phase modifier, extractant concentration, solvent regeneration, solvent losses (soluble / entrained)
- # Sensors are needed.

CHEMICAL ENGINEERING GROUP

Prepared by: Dr. Bruce Monzyk

1.0 SCOPE OF DISCUSSIONS

Contractors- design considerations

Interfacial Phenomena

Dispersion / coalescence and phase continuity

Modeling and control of process
- sampling and analyses
- modeling and simulation
- verification on continuous circuits

Contactors / simulation / drop models
- (coalescence, drop break-up),
- small scale experiments
- pilot scale columns / mixer-settlers
- slow kinetics vs. column choice

Database
- thermodynamics – equilibrium constants, T dependence, diffusivities, partition coefficient
- kinetics – chemical reaction rate constants, mechanisms, temperature effects, by-products, diffusivities
- fluid dynamics
- physical properties: viscosities, densities
- impurity and solids formation effects chemical engineering – results (needs)

2.0 CHEMICAL ENGINEERING - RESULTS (NEEDS)

The 1997 List was found to represent an excellent list of needs by the attendees at the 2000 session as well

It was agreed that good physical/chemical mathematical models exist, but are under-utilized

Need for user friendly software and graphics to more rapidly illustrate the value of the calculated results of the models and to allow more interactive use by those less skilled, and / or have less time with mathematics and are involved in the physical application end of the technology

Droplet Size Needs (models usually require this as an input parameter)
- droplet size needs is seen as a stumbling block to use of models
- can the need for droplet size be omitted? – suggested research programs
- can drop size be made easier to measure?
- can drop size be calculated directly, eg. from "first principles"
- might be able to use an empirical method to determine dropsize once a system is found, calibrated and published – more research project needs. Can such a system be tied into an expert system so that it can be unique for each use?

The session generated 12 ideas for mass transfer/kinetics work and 16 ideas for design model work.

3.0 CHEMICAL ENGINEERING SESSION DETAILS

Design Models

expect that long term work needed for model improvements

needs to be in a form to sell the work

a venturi tube / drop riser device was suggested for mass transport measurement

two approaches,
- empirical
- fundamental

pilot plants have been too large
- minimize column diameter
- reduces test program cost substantially
- include any recycle loops
- do chemistry on a small scale, then screen possible equipment types

Mixer-settlers are easy to design; other contactors often are more difficult because they must be designed on sound chemical engineering principles.

Models are already available, just underutilized

It is often difficult to generate lab data to feed into models (to design pilot plants). e.g. drop size is difficult to calculate theoretically. Therefore it may be easier (faster, cheaper) to go quickly to a small pilot plant (e.g. equipment determines droplet size, esp. for columns).

Hartland method allows comparison of columns

Propose that plants use plant data to " test" models – another area for research

Need to include solvent degradation into models – area for new research

Most models still need to be tested on a full commercial scale

Models need to be converted to useful software form so they can gain wide spread use

However, models still have a problem with low interfacial systems or for certain packings (e.g. ceramic raschig rings). This is due to 1 equation approach (in the Hartland model). Solution is to break up into a set of equations – another research need (in software form for ease of use)

Need CFD codes in model software so it can handle two phase flows.

There appears to be a need to get ride of droplet size requirement for modeling (dropsize changes with chemistry changes, column size, column design, etc). This would be a very valuable advance – another research need).

There is a deficiency in general of the physics and chemistry understanding of droplet formation / coalescence – more research needs.

CFD codes still are incapable of solving problems of >1 drop ! They now use 100x100x100 elements. Need 1000x1000x1000. (Note that 1 element is < 100 nm). – another research need.

Flow sheeting / steady state calculations are well known, solved and are used.

4.0 MASS TRANSFER / KINETICS FOR MULTI-COMPONENT SYSTEMS

Current list is again well written and a good summary for this section.

Contaminant effects stands alone.

Prediction of crowding amount needed – rates and equilibrium –" fractional extraction approach", i.e. high purity on both ends of the column, i.e. scrubber cascade cases , e.g. phosphoric acid, sulfolane, rare earths, with effect of iron loading. The key need here is for standardized systems.

Caution – physical properties at mid column can be much different that at the ends. Density differences can go to zero!

Zn-DEHPA is such a standard system but few actual plants exist at a commercial scale. A requirement to consider for a standard would be a multi-component system, esp. at high concentrations.

Cu/Fe separation with oxime extractants is also a potential standard system , and the system is wide spread commercially. There is a lot of data available on this system with pure and actual process streams. Understanding is good and well documented. There is a big effect of scrubbing.

Ni/Co separation is another potential standard system but is strongly dependent on starting point. This system is may be "a ways off" for being a standard.

Multi-component diffusivity measurements are a problem because the bimodal curve / two phase region is wide (narrow is desired for precise measurements)

Diffusivities are very time consuming to measure. Therefore very few are available – research need. Especially for commercial systems (at high concentration,- outside of Debye-Huckel theory).

Interfacial surface tension is very difficult to predict, especially with T and P effects (e.g. liquid CO_2 system).

PROCESS DESIGN AND DEVELOPMENT

Prepared by: J. Dean Thibault, P.Eng.

1.0 PROCESS CONTROL, SAMPLING, ANALYSIS AND ON-LINE SENSING

1.1 Organic Monitoring

Analytical methods, used to monitor the effective loading / efficiency of the organic, are not readily available for operators. In most cases, the degradation of organics by oxidation or "poisons" in the pregnant solutions is not fully understood and is site specific.

If degradation of the organic is a continuous limitation to the operation of a solvent extraction circuit, methods to regenerate or remove degradation products are not readily available for operations. Organic regeneration may be cost prohibitive depending on the cost of organic and / or metallurgical performance.

Operators have developed unique quality control measures to monitor the efficiency of the organic. Bench scale loading and kinetic data are quantified over the life time of the organic. This method provides a general indication of organic degradation but is not representative of plant performance.

1.2 On-Line Analysis

Operators are using on-line analysis systems to measure metal concentrations in pregnant solutions. With the use of integrated control systems and measurement of solution flowrates, the optimum organic loading is controlled. The actual measurement of metal concentrations in the organic phase is an ideal control parameter and on-line instruments for organic phase analytical are not available.

On-line analysis is generally not required to operate solvent extraction circuits. However, for complex extractions where the overall efficiency is dependent on tight control of process variables (such as pH changes in each stage, phase continuity, specific ion concentration), specialized on-line instrumentation is required.

On-line monitoring of organic concentrations in aqueous streams is necessary to prevent carry-over in hybrid solvent extraction systems. Most solvent extraction circuits do not employ on-line organic analysis and the reliability of organic monitoring has not been proven.

1.3 Real Time Analysis

Real time analysis is generally performed by process engineers in charge of solvent extraction operations. However, the use of on-line analysis (continuous monitoring and trending) of analytical parameters is capital intensive and may not be accepted by management. The economic offset for continuous on-line analysis is the cost of technicians and the reduction in production or product quality.

Real time analysis may be justified as a valuable tool for operations however, in addition to the hardware, there is a definite need for interpretation of analytical results. The use of real time analysis is not considered a viable operating tool if processing supervisors / engineers do not have time to correlate trends with process efficiency. However, with predictable interpretation of real time analysis as a function of process variables, real time analysis provides a foundation for the development of expert system control.

1.4 Control System

Most solvent extraction circuits are designed to operate with simplified control systems. Hydraulic design of solvent extraction equipment does not require highly integrated control of flow. A majority of the control philosophy is based on monitoring; both status of equipment (On/Off) and analog indication (such as pH, reagent tank levels).

2.0 PROBLEMS IN LARGE PLANTS

2.1 Publications

Limited information has been published on the commissioning and operation of solvent extraction systems. As a result, there is a limited knowledge base with respect to new plant design.

Design engineering firms generally do not follow up on plant operations which require redesign. Therefore, plants are designed under similar practise with genetic design omissions; impacting on plant metallurgy, availability, etc.

Documentation of both design criteria and operating experience has an impact on plant engineering expertise. In most cases, engineering firms or equipment vendors retain this expertise to remain competitive. As a result, operating data for plant or equipment installations are not published.

2.2 Plant Engineering

The engineering of solvent extraction facilities over the last few decades has been very competitive. Engineering firms and operators are not willing to accept new technology or technical risk. Also, large operations with multi-metal production flowsheets are designed with highly integrated unit operations which have increased the complexity of plant design. In some cases, new technologies are required to comply with the operating criteria of highly integrated / complex flowsheets.

For large operations, new technologies or new flowsheets take time to accept. There is not an incentive for engineering firms to utilize new technology for plant design, nor are operators willing to raise the extra capital required to support technological risk.

The selection and sizing of solvent extraction equipment is the major technological risk of large plant design. The reliability and performance of solvent extraction circuits are based on scale-up from pilot programs. In the case of vendor supplied equipment (with specialized design parameters), the engineering firm has limited scale-up know-how and the performance data are not based on integrated flowsheet-pilot plant testing. Therefore, the supply of commercially proven solvent extraction equipment is the basis for plant performance and guarantees.

In addition to solvent extraction equipment, the selection of materials for construction has a major impact on plant cost and engineering practise. In some cases, plants are designed with limited consideration of materials and replacement costs during commissioning. There are cost benefits to assure control of material selection during design and installation.

2.3 Operations

Operators of large plants are concerned about the reliability and predictability of solvent extraction circuits. In most cases, the mechanical reliability is not an issue and control of process chemistry will depend on operating experience. Large plants are not considered operator friendly if changes go undetected or if changes in process variables are made and the impact on process efficiency remains unknown. The large inventory of organic is generally less forgiving in large plants.

The excessive formation of crud has an impact on plant efficiency and operating cost. In some cases, plants are not designed to handle the volume of crud, and the loss of organic with crud has an impact on the operating cost. Measures to deal with crud on a regular basis are generally not available to operators. Therefore, crud formation in large quantities has an environmental impact.

Large plants with hybrid circuits (both chlorides and sulfates) or more than one organic system (eg. alklylphosphate and carboxylic acid) require cost effective unit operations to prevent cross-contamination. Flotation is generally used for recovery of residual organic and the efficiency remains questionable. Cost effective organic recovery systems are required to improve on plant efficiency and maintain environmental compliance.

Large plants require extra capital for fire protection systems. Investment and insurance firms have set standards and codes for fire protection systems.

2.4 Novel Process Equipment

A mechanism is required to integrate new or novel process equipment into large plants. Engineering firms have limited know-how on scale-up of novel process equipment and are reluctant to guarantee overall process performance. Under most EPCM contracts, the process performance guarantee requires proven process equipment.

In some cases, the equipment vendor will run demonstration trials and provide equipment performance guarantees. However, engineering firms require definitive design data on scale-up and performance efficiency under alternative loads; which is generally not available.

Operating companies need to take the risk with novel process equipment. Equipment vendors need to install prototype equipment and demonstrate the net benefits to operators. Often, new equipment is installed and process performance data are not published.

Use of column technology was acknowledged as a novel system which has limited installations in large plants. It is reported that column installation costs may be a fraction of conventional mixer settler systems. It is believed that columns are not readily accepted and installed because operators have a mind-set that they do not want to be the first. The success of column installations appears to be with operators who have worked directly with vendors on pilot scale development through to commercial installation.

3.0 BENCH SCALE AND PILOT TESTING

3.1 General Requirements / Scope

- The amount of testing required for flowsheet development and the sizing of the solvent extraction equipment will depend on the relative design experience. Some engineering firms have designed various copper circuits and very little pilot testing is required. However, limited information is available on metals such as indium, antimony, etc. and extensive piloting may be required. The extent of the pilot program or work scope will depend on the specific metal and matrix of the feedstock.

- For commercial development of a solvent extraction flowsheet, "cost-effective testing" is always a requirement. There is an optimum balance of technical risk, schedule and cost. The reality of test programs is the limited time and budget for flowsheet development.

- The availability of feedstock may also limit the scope of a test program. With large changes in the feedstock composition (resulting from a large variation in ore or the purchase of feedstock from alternative sources), the objectives of the program need to address the primary reason for testing.

- The proficiency of the test program is based highly on the communication between the engineering firm and the test facility. In most cases, the engineering firm is not directly involved with day-to-day test objectives. Test standards or protocols are difficult to establish because each project has different objectives. To improve on technology transfer, direct supervision of test programs is required by engineering firms.

3.2 Testing Approach

- Bench scale test programs are generally designed to assess organic selectivity as a function of process variables such as acidity, temperature, chloride concentrations, etc. Based on the assessment of selectivity, additional bench scale testing may be conducted to quantify organic loading, isotherm / equilibrium data, reaction and disengagement rates.
- Pilot testing or continuous flow of the organic and aqueous phase is conducted to confirm chemistry, number of stages and effects of recycle.

- Alternative flowsheet configurations are generally tested to confirm stage integration, effects of organic / aqueous ratios, phase continuity, etc. Tests are completed to assure a stabilized flowsheet.

Equipment specific tests are conducted with optional contactor-phase separation equipment. Parameters for scale-up are generally defined as a function of equipment performance.

Depending on the degree of technical risk, a test program may include a detailed assessment of independent variables and the relative impact on flowsheet efficiency or product quality. Independent variables which are considered important to maintaining operations include the following:

? formation of crud and assessment of chemical / physical parameters which influence crud formation.

? use of water which represents process water and / or recycle of water possibly with humic acids, etc.

? solution doping with contaminants or poisons which may build-up within the circuit.

3.3 Duration and Size of Pilot Testing

The scope of work for a pilot program is generally limited by the availability of feedstock and budget. Operators favour the operation of pilot systems to assess the impact of feedstock variability on process parameters; in addition to scale-up parameters. Therefore, detailed planning of pilot programs are evident with close scrutiny of objectives.

The size of the pilot system for the design of commercial facilities is determined by the availability of equipment and design experience at the test facility. As a general rule, systems sized for 1.0 to 10.0 l/min aqueous flow are used to assess process chemistry, confirm number of stages and overall selectivity. Design data used to scale-up process equipment requires pilot equipment sized for 20 to 40 l/min aqueous flow.

The technical viability of a flowsheet will depend on organic selection and dependent variables. These parameters are generally quantified by bench scale tests prior to pilot programs. Subsequent pilot test programs will include an assessment of the organics reliability as a function of “organic cycles”. The duration and size of the pilot system will dictate the number of organic cycles; generally ranging from 20 to 400.

3.4 Physical Parameters

- Pilot tests are conducted on prototype solvent extraction equipment to quantify physical parameters such as reaction kinetics as a function of mixing intensity, residence time distribution and liquid / liquid separation (disengagement) rates.
- Equipment vendors have test protocols which are equipment specific. Scale-up of equipment from these protocols are considered proprietary to the vendor and are used to develop performance guarantees.
- Materials of construction are also confirmed with prototype testing.

3.5 Computer Models

- Computer models are available for prediction of performance as a function of process parameters. Although computer models do not accurately predict mass transfer, drop size distribution, etc., the models are generally useful to screen variables. Pilot plant data are required to confirm model predictions.
- The fundamental problem with computer models is that variable input is based on clean / ideal solutions. It is recognized that there is a need for improved correlation for real solutions to simulated in-plant systems.
- There is a demand for computer models to assist with design and operations. However, commercially available models for tailor design flowsheets are not readily available. General requirements for models include:
  - in-plant optimization - general trends of process variables.
  - assessment of off-design conditions to simulate process upsets.
  - operator training.
  - evolution of expert system control.

4.0 TECHNICAL / ECONOMIC DECISIONS IN DESIGN

4.1 Design Criteria

Pilot programs are conducted to quantify process variables, which are generally frozen as the design criteria for commercial design of the solvent extraction facility. Changes to design parameters such as feedstock composition, product specifications and environment compliance, will have an impact on the optimum selection of process variables. Therefore, the efficiency of the design is dependent on the qualification of design parameters and process variables.

The design criteria provides a mechanism to transfer data from testing / pilot plant programs to commercial design. Therefore, test facilities as well as engineering firms should provide input to the design criteria. To improve on design data transfer through the various stages of process development, the process design criteria should define an integrated flowsheet (rather than solvent extraction as a stand alone unit operation) based on the following factors.

A) Characterization of feedstock; including the variation of impurities and the subsequent impact on unit operations (both upstream and downstream to solvent extraction).

B) Characterization of process water which best represents commercial operations. In some cases, the quality of recycle water has an impact on organic management.

C) Identification of all process variables which impact on selectivity, throughput, metal recovery / purity, etc. (ie: variables having an impact on the technical and economic viability of the integrated flowsheet) should be identified by both design and test facility engineers prior to pilot testing. The test program should be defined to quantify the process variables and is documented by both design and test facility teams.

D) Characterization of solid, liquid and gas streams; which may have an impact on the environment. Environmental, Health / Safety and Regulatory standards should be defined and factors which impact on environmental compliance should be identified.

E) Quantify product specifications (as well as feedstock compositions which may have an impact on product specifications).

F) Quantify materials of construction for each process stream.

4.2 Equipment and Capital Costs

Capital cost requirements are generally based on solvent extraction equipment as a "stand alone" unit operation. There is a need to consider capital cost as a fully integrated flowsheet; to include considerations for solids removal, organic loss / inventory, quality of water, etc.

Clarification of solvent extraction feed solutions was identified as a high capital investment relative to solvent extraction equipment. In most cases, less than 20 ppm total suspended solids is required to maintain solvent extraction operations (preventing crud formation, solids sand out in settlers, etc.). Design of solvent extraction systems capable of handling solids and elimination of clarification equipment requires further review.

The initial charge for organic (organic inventory) is a major start-up expenditure and operators are well aware of replacement costs in the event of contamination / poisoned organic. Measures to reduce organic inventory or optimize on the settler volume remains a concern to operators.

Compliance with environmental regulations has increased capital costs for recovery of entrained organic in aqueous streams and in vapour phase.

Solvent extraction circuits operating at elevated temperatures or with high chloride contents require specialized materials of construction, increasing the cost of equipment.

Impurities having non-selective characteristics in the primary solvent extraction circuit are separated by the addition of a secondary solvent extraction circuit or alternative separation unit operations (such as ion exchange). In addition to the extra cost for impurity selective separation, additional process equipment is required to prevent organic carryover or cross contamination.

4.3 Operating Costs

The loss of organic by entrainment or formation of crud was identified as a major operating cost. Conventional recovery methods and measures to reduce organic oxidation are not considered effective. Costs to maintain the organic inventory are considered significant by operators.

Cost effective methods to treat the organic for reuse have not been established at most operations. The organic loss may result from oxidation-degradation of the extractant and / or entrainment with reagents in process water (such as surfactants). In some cases, clay treatment will not work. Clay separation is a low-cost alternative but the life of clay is limited. In the case of high oxidation degradation of the extractant, clay consumption and the related disposal costs are high.

5.0 ENVIRONMENT, REAGENT RECOVERY AND WASTE TREATMENT

5.1 Organic Loss Assessment

A detailed breakdown of organic loss was not available for discussion. In general, most operators do not have information or detailed accounting of organic loss. It has been estimated that the loss of organic from copper circuits is defined as follows:

? 50% of total organic loss by entrainment in aqueous phase (loss to environment and or downstream unit operations).

? 25% of total organic loss by evaporation in off-gas systems; usually to the atmosphere or to off-gas scrubber systems.

? 25% of total organic loss to crud; which is recovered and disposed of within a landfill.

Organic loss by evaporation may be higher in high temperature circuits and there is a need to improve on off-gas monitoring and accountability of organic loss. In some cases, the organic loss results in high mist carryover in ventilation systems.

Operator wash-down to sumps accounts for high organic loss; which may be controlled by the operating staff. In most cases, the design of sump systems does not include oil skimming or recovery unit operations to reclaim the organic.

Organic loss by crud formation is attributed to a limited understanding of process chemistry and preventative measures. The direct cause for crud formation will vary with each installation. Therefore, standard preventative measures are not prevalent and each case is unique.

5.2 Organic Recovery Options

- # Novel technologies for organic recovery have not been recognized. The standard methods of organic recovery for new solvent extraction installations were identified as follows.

  A) Primary Recovery: alternative design of settlers to increase settling area and optimization of coalescence rates.

  B) Secondary Recovery: use of "after-settlers" and washing of aqueous streams with diluent. For high organic loadings, flotation columns are commonly used.

  C) Tertiary Recovery: use of coalescers and carbon bed filters. Steam strip or carbon regeneration (using methanol) on site is not common. Operators comment that carbon columns are satisfactory but require close monitoring of breakthrough.

- # To reduce volatile organic carbon, closed systems are required with off-gas and ventilation scrubber systems. Petrochemical industries have developed unit operations; which may be suitable for volatile loss.
- # Bentonite clays are commonly used for crud treatment. Alternative methods such as biotreatment have not been commercialized for solvent extraction applications.
- # Membrane systems are under development using hydrophobic tube membrane filters to replace secondary and tertiary recovery systems. Although these units are not installed in commercial solvent extraction systems, pilot systems have indicated the following advantages:

  A) In excess of 99% removal of entrained organic on a continuous basis. There is no need for continuous backwash and monitoring of breakthrough.

  B) Organic is suitable for reuse. The use of reagents or subsequent disposal of media is not required.

  C) High removal efficiency is required for hybrid organic systems and operation of electrowinning cells. The use of hydrogen peroxide to destroy residual organic is not required.

6.0 MULTIPLE SOLVENT EXTRACTION CIRCUITS

6.1 Linking of Two or more Organic Circuits

To avoid cross contamination of two or more solvent extraction circuits with non-compatible extractants, a diluent wash on the raffinate is required. To maintain operations using a diluent wash, close monitoring of the extractant and diluent mass balance is required.

Scrubbing of the loaded strip solution with fresh organic is required to prevent organic carry over in nickel circuits. Columns have been successfully piloted using a fixed bed of diluent for scrubbing operations.

In nickel circuits, the use of certain activated carbon may remove nickel. Jameson flotation cells have been used to recover organic concentrations up to 0.2%. The overall efficiency of flotation was not discussed but is considered the best available technology for commercial installations.

6.2 Ammonium, Sulfate and Chloride Systems

Hybrid systems are commonly used to improve on selectivity and a limited number of hybrid solvent extraction circuits are used commercially. The efficiency of these circuits is dependent on the degree of washing between stages.

In addition to carry-over, materials of construction and compatibility issues require close scrutiny. Design of the entire circuit for compatibility in the event of carry over has significant cost implications.

7.0 EDUCATION OF OPERATORS AND PROCESS ENGINEERS

7.1 Literature

For junior and experienced engineers, there is a lack of publications, text books, etc. on the design and operation of solvent extraction facilities. A significant amount of literature has been published on copper solvent extraction operations and general design data. Various engineering firms have developed design experience and know-how on copper solvent extraction circuits. However, the transfer of copper solvent extraction design for use on other metals is not applicable. A need for design and operating practise documentation for different plants is required to improve on plant efficiency.

There is a general consensus that innovative designs or novel equipment used in solvent extraction circuits is not documented. Novel equipment is introduced in various publications but detailed data on chemical-mechanical performance efficiency is not readily available. Advantages of novel concepts are not documented to spur the interest of both designers and operators.

7.2 Training Medium

Computer models are considered to be an excellent training tool for both operators and process engineers. Models are also used to review alternative flowsheet configurations. Process simulation models for hydrometallurgical and solvent extraction plants are presently not used because of limited availability for tailored flowsheets.

Self-training software is available, or has been developed at various operations for self-pace training of operators. This training program has been integrated with pay schedules (based on the level of competency) and is considered successful.

8.0 FUTURE OF SOLVENT EXTRACTION PLANT DESIGN AND OPERATION

8.1 Expert Systems

Solvent extraction operations are considered fairly stable. However, the efficiency of separation may be optimized with use of an expert system (combination of computer modelling of process variables and process control). In the case of complex ores where the metallurgy is not monitored on a continuous basis, expert systems are definitely a requirement for optimum plant efficiency.

Expert systems are not commonly used for hydrometallurgical operations and have limited commercial experience. The technical viability of expert system control of solvent extraction circuits is based on the following:

? on-line analysis and the ability to monitor the concentration of various components (anions and cations) within the pregnant leach solution and various intermediate streams.

? prior to development of computer models, the impact of process variables on the efficiency of the plant should be quantified and scale-up from bench scale to plant data quantified.

? on large circuits with large holding capacities, “lag times” need to be determined for advanced control of a change in process conditions.

? maturity of computer model development with respect to simulation of the solvent extraction circuit.

? flow control which may not be possible with some systems designed to operate with dynamic hydraulics of the layout and mixer / pump configuration.

? operations experience with changes in process loads, trending of data, etc. and understanding of process control philosophy.

The development of expert systems is limited as a result of "mining industry" mentality. Operations generally are lean on instrumentation or automation control is eliminated at the design stage. General reasons for management rejection of expert systems includes:

? process design and operating disciplines have not quantified the economics or justified improved return on investment.

? product quality control issues are not generally focussed on problems with solvent extraction.

? design engineers and/or equipment vendors have limited information to recommend or attempt to include expert systems as an integral part of a performance guarantee.

8.2 Analytical / Speciation Analysis

Identification of species which impact on the overall efficiency of solvent extraction circuits is a common problem to solvent extraction operators. Contaminants such as chromium, iron and arsenic have different oxidation states and accurate methods are not available to operators. Centres of excellence, such as universities with long turnaround time, are generally required. Therefore, analytical techniques are required; not only to identify specific species but to assist operators with plant control.

There is also a limited understanding of solution chemistry and control of species having a direct impact on solvent extraction efficiency. Solution characteristics such as Eh-pH relationships will control species and this relationship is generally not defined. Development of techniques to "modify and condition" aqueous solutions prior to solvent extraction is recognized as a concept to improve on solvent extraction efficiency.

8.3 Environmental Issues

The use of solvent extraction for refining of specific metals has prevailed over pyrometallurgical techniques because of environmental issues. However, the environmental impact of solvent extraction is dependent on control of heavy metals and wastewater management. Technological improvements are required to maintain a closed-loop process water system and fixation of heavy metals.

Compliance with environmental guidelines has an influence on the design or modifications to solvent extraction plants. The need to comply with hazardous waste protocols has also increased demand for the treatment of waste residues using solvent extraction methods.

Trends in solvent extraction design based on compliance with environmental protocols, include:

? multi-circuit design has evolved for multi product circuits. Production has also evolved to recover metals from feedstock to eliminate environmental impact. Economics of environment impact are justification for by-product metal recovery.

? add-on solvent extraction circuits are under development for the treatment of smelter residues and furnace dust.

For multi-metal separation (as required for the treatment of waste streams), there is a need to integrate ion exchange and solvent extraction technologies to improve on selectivity of the flowsheet. Development of highly integrated flowsheets is required to improve on commercial viability of waste stream recovery systems.

8.4 Columns

Various companies have developed and commercially operated columns in pharmaceutical and organic chemical industries. The limited commercial experience using columns for metal separation is a result of limited documentation of commercial advantages. In some cases (high mass transfer or high solution flow), the use of a mixer settler is considered an advantage over columns. However, general advantages of column technology were noted as follows:

? operating and capital cost for complete installation may be up to 50% of conventional mixer settler systems.

? columns may eliminate the need for optimum clarification of leach solutions.

? crud may be easier to deal with.

? columns may be more efficient relative to overall separation, when more than three stages are required.

? reduction in solvent inventory; high phases ratios are possible without recycle of the minor phase.

? capability to control pH along the column.

? ease for operation at elevated temperatures.

? ease to add on stages.

? lower maintenance with respect to mechanical parts.

? system hydraulics (pumping) and mixing are not integrated.

? entrainment in columns may be slightly less and coalescers may be integrated with column operation.

Application of column technology in the uranium industry has been commercial for over twenty years. General operating and design experience in the more recent column installations are summarized as:

? flowsheets need to be frozen and well defined before entering column test programs.

? pilot development is generally done using 100 mm diameter columns. Data are used for scale-up to 2.5 m diameter columns.

? pilot units are required for training of operators and continuous monitoring of operation.

Extended test programs are reported in progress for optimum nickel-cobalt separation. Optimum column selection, mixing requirements and capacity of columns are under review.

CLOSING REMARKS

Following the presentation of the conclusions from each of the 3 work groups, there was a discussion as to what had been achieved., and what should be considered for future meetings.

One of the striking points was the somewhat similar conclusions in several areas of concern that all 3 groups were in agreement. Also, the understanding and appreciation by the Chemical Engineering group of the concerns pertaining to process and plant design, saw the former group join the latter group early in the Workshop. Applications of the chemical engineering to the process design and equipment selection are necessary in regard to plant design and optimum operation.
In relation to the next such Workshop, we should go to a Gordon Conference style, that is have one group with perhaps one plenary lecture or presentation to lead off each session into a particular area.

We need to identify priorities on issues that are developed. Sharing of data is a problem, particularly failures and some mechanism of facilitating this could be developed.

There was a discussion on a consortium for research across the solvent extraction community of the AMIRA/Mintek type.

We need to develop further the solvent extraction website and link it to existing websites maintained by the Universities of Bradford and Osaka. (This is an area in which the International Solvent Extraction Committee should be involved, and will be considered by that committee).

There was some discussion as to whether a Fractionation Research Institute or a Separation Process Science Group or similar organization would be effective in the solvent extraction area.

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QUESTIONNAIRE / COMMENTS

The following are ratings and comments as received from the questionnaire. Note that because the questionnaire was not distributed until the wrap-up session, all comments were not received due to the early departure of many due to travel arrangements. Thus the numbers shown represent only about 60% of the participants.

RATING OF WORKSHOP RELATIVE TO MY REQUIREMENTS

	%
Useful and informative	89
Interesting	11
Waste of time	0

PARTICIPATION IN DISCUSSIONS

I participated frequently in the discussions	43
I participated occasionally in the discussions	52
I participated very little in the discussions	5

WOULD YOU ATTEND A SUBSEQUENT WORKSHOP?

No	7	Yes	93

WORKSHOP PROGRAM AND FORMAT

I like the idea of evening sessions with the afternoon free	100
I prefer to have the evenings free	0

I think the duration of the workshop was:

Suitable	96
Too long	0
Too short	4

MY IDEAL NUMBER FOR SUCH A WORKSHOP

	<50	50	75	85	100
%	6	25	39	6	24

CONTENT OF WORKSHOP

Are keynote papers required?

	No	Uncertain	Yes (few selected)
%	4	12	84

The areas discussed were necessary 98

VENUE AND FACILITIES

	EXCELLENT	GOOD	POOR
WORKSHOPS	35	65	
Meals	70	30	
Recreation	80	20	
Location	83	17	
ACCOMMODATION	45	55	

MEALS

For such a group, the meals buffet package was ideal 92

I would prefer to plan and order my meals 8

Do you think a special dinner is required?	Yes	5
	No	95

Was the reception adequate :	In length	Yes	100
	In content	Yes	100

SOCIAL ACTIVITIES

In a future workshop I would:

- be interested in planned activities (eg. tours, hiking, fishing, rafting, etc)
30

- not be interested in planned activities, but would prefer
to organize my own activities 70

OBSERVATIONS / COMMENTS / SUGGESTIONS

The following comments were provided by the participants, and should be considered when organizing the next event.

GENERAL

- an excellent workshop

- the workshop was informative and the possibility for networking was of great value

- the workshop was an excellent way of establishing contacts and exchanging information

- the bringing together of all aspects of the technology was particularly valuable and will help maintain efforts focussed, eg. on precious resources

- the meeting is a good opportunity to learn from other SX experts, primarily in separation fields different than my own. It is also a good opportunity to learn about opportunities for new research or industry needs and develop new contacts.

- many thanks for organizing such a great event

PUBLICITY OF WORKSHOP

- publicize the workshop more extensively to boost attendance

VENUE

- the location and duration of the workshop was ideal

- Banff is a marvelous location for such a meeting. Undoubtedly however, Canada has a number of equally marvelous alternative locations. Perhaps future meetings could be held in one of those locations, for example, Quebec City, east coast / west coast

- Banff is an excellent site. However, next time it could be held elsewhere in Canada, but, like Banff, far from a city

RECEPTION

- # as several participants arrived late (after the Reception had closed), perhaps the reception should be held at a later hour

SPECIAL DINNER

- # it may be good idea to have a special dinner, included in the registration fee

- # a special dinner could foster some additional interaction amongst the participants

WORKSHOP AND FORMAT

- # the workshop format was improved over that of 1997 (less formal, smaller, and no keynote papers

- # the format was suitable and the separation into chemistry, chemical engineering, and design / operations was understandable, and necessary at this stage
- # the participation in the workshop discussions was better than in 1997 meeting.

- # prior to the final session it would be helpful to have one or two additional opportunities to bring the whole group together.
- # perhaps a slightly more structured format would be more suitable, a format that instigates real issues, debates and approaches for further development.

- # operate a little more closely to a Gordon Conference format with provocative, cutting edge speakers–perhaps 1 per session.

- # the list of topics should have been distributed to all participants prior to the first session to facilitate prioritizing of the subjects for discussion.

- # in the chemistry group, a couple of discussion items were chosen which in fact did not interest more than 2-3 participants. We should have a mechanism to avoid that.

- # the meeting has now reached a point where we need to focus better, and concentrate on 2-3 topics for each meeting, and then zero in on what we want in those areas, and producing recommendations for those involved in process development and plant design.

require a better mechanism to transfer the results and areas which require further R&D to those that can work on the problems, perhaps through the International Committee, or through setting up a strong group, or through the involvement of national agencies, eg. MITEC, MIRO, AMIRA, etc.

perhaps spread throughout the schedule, time for individuals to make brief (5-10 minutes) presentations of current problems and approaches to solutions.

less focus on requirements for academic research.

presentation of specific problems.

for presentations / reporting use pc / laptop directly to simplify presentations.

PARTICIPANTS

more plant operations personnel at the meeting would have been beneficial as they could express their views on where research could be directed.

more participants from other industries using solvent extraction, such as food, pharmaceuticals.

need an input from the major Cu companies.

invite more younger people.

SUBJECT AREAS

cover other metal industries, e.g. PM’s, Zn, Cu, rare earths.

application of SX in new economy industries, eg. biotechnology.