NEW TECHNOLOGY AND APPROACHES IN REAGENT DEVELOPMENT AND APPLICATIONS IN THE PROCESSING OF BASE AND PRECIOUS METALS AND INDUSTRIAL MINERALS

- D. R. Nagaraj PhD
  Cytec Industries Inc. - 1937 West Main St; Stamford, CT 06877;
  email: d.r.nagaraj@cytec.com

- S. A. Ravishankar PhD
  Cytec Industries Inc. - 1937 West Main St; Stamford, CT 06877;
  email: s.a.ravishankar@cytec.com

- Ricardo Capanema;
  Cytec do Brasil Ltda - Rua Tomé de Souza, 557 / 1102, BH-MG – CEP: 30140-130
  Email: ricardo.capanema@cytec.com

RESUMO
Na última década, nossos esforços estiveram focados em desenvolver conceitos e uma lógica racional para novas abordagens e tecnologias no desenvolvimento e otimização de reagentes no processamento de metais básicos e preciosos e minerais industriais. Estes esforços, resultaram em novos sistemas químicos para recuperação de metais básicos e preciosos por flotação, e uma nova tecnologia baseada em nano partículas no processamento de minerais industriais. Outro importante resultado é o desenvolvimento de um completo procedimento chamado Flotation Matrix™100 para facilitar a implementação de uma abordagem holística na seleção de reagentes e otimização da flotação. Essa alternativa se mostrava necessária frente à abordagem tradicional que é basicamente reducionista e incremental. Os elementos críticos do Flotation Matrix™100 incluem uma base de dados de reagentes de flotação e suas aplicações, ferramentas para quantificar as necessidades do processo, um software especializado para seleção de reagentes e protocolos e ferramentas estatísticas para avaliação de reagentes em laboratório e boas práticas necessárias para uma bem sucedida implementação em escala industrial. Exemplos serão apresentados para destacar a aplicação dos novos reagentes e tecnologias mencionadas acima.

PALAVRAS CHAVE: Inovação, flotação, metais básicos e preciosos; avaliação reagentes, novas tecnologias, minerais industriais.

ABSTRACT
Over the past decade or so, our efforts have focused on developing the rationale and concepts for new approaches and technologies in reagent development and optimization in the processing of base and precious metals and industrial minerals. These efforts have resulted in new reagents for base and precious metals recovery in flotation, and the new nanoparticle-based technology in industrial minerals processing. Another major outcome is in the development of a comprehensive program called Flotation Matrix™100 to facilitate the implementation of a holistic approach to reagent selection and optimization in flotation. This is a much needed alternative to the traditional approach to reagent optimization which is mostly reductionistic and incremental. The critical elements of Flotation Matrix™100 include a web-based, searchable knowledge base for flotation reagents and their applications; tools to quantify plant needs; expert system reagent selection software; and protocols and statistical tools for laboratory and plant best practices needed for successful implementation in the plant. An overview will be given using examples to highlight the application of the new reagents and technology.

KEY-WORDS: Innovation, flotation, basic and precious metals, reagents evaluation, new technologies, industrial minerals.
1. INTRODUCTION

The chronology of development of flotation reagents of industrial relevance during the past 100 years is divided by Booth and Freyberger (1962) into two distinct periods (or phases): oil flotation (1860–1920) and chemical flotation (1921–present). A closer scrutiny would suggest three distinct periods (see Table 1), the first being still oil flotation. The second period might be characterized as discovery and expansion (1921–1950), and the third period as the rational, targeted design (1951–present).

Table 1 – Three important periods in flotation reagent development

<table>
<thead>
<tr>
<th>Period</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Days to 1920</td>
<td>Oils, oleic acid, soaps, CuSO₄, SO₂, lime, soda ash, cresylic acids, aliphatic alcohols, aldehydes, ketones, esters, pine oils</td>
<td></td>
</tr>
<tr>
<td>1921–1950: Discovery and Expansion Phase (use of chemicals developed in other industries; e.g., rubber, textile, tanning)</td>
<td>Collectors: Chelating agents, dithiocarbamate, dithiophosphate, fatty acids/amines, guanidines, hydroxamate, imidazolines, mercaptans, mercaptobenzothiazole, petroleum sulfonates, primary amines, sulfosuccinates, thiocarbanilide, trithiocarbanilides, xanthate, xanthogen formate. Modifiers: Dextrin, dyes, lignin, polyphosphate, sodium cyanide, sodium silicate, sodium sulfide, starch, tannin, zinc sulfate</td>
<td></td>
</tr>
<tr>
<td>1951–present: Rational, Targeted Design (either designed for or developed for targeted use in flotation applications)</td>
<td>Collectors: Alkoxycarbonyl thionocarbamate, alkoxycarbonyl thiourea, allyl thionocarbamates, dialkyl thionocarbamates, dithiophosphates, hydroxamates, monothiophosphate, monothiophosphinates, phosphonic acids, sulfosuccinamates, xanthate esters. Frothers: Polypropylene glycols and ethers, triethoxybutane. Modifiers: Synthetic functionalized polymeric modifiers, modified polysaccharides, carboxymethylcellulose, guar, polyacrylates, zinc cyanide</td>
<td></td>
</tr>
</tbody>
</table>

Source: Nagaraj 2003

In the early days of flotation, large quantities of fatty and oily materials, up to 10% to 20% of the weight of the ore, were used as a means of separating the value components from gangue minerals in ore pulps. Later, various gases replaced these large quantities of oil as a buoyant and separating medium, decreasing oil requirements to less than 1% of the weight of the ore. With this reduction in oil consumption, inherent differences in frothing and collecting power of various oils were noted (Booth and Freyberger 1962). Several important modifiers such as lime, sulfur dioxide (SO₂), sodium carbonate, and copper sulfate (CuSO₄) were used to enhance separations.

The year 1921 marked the beginning of a major revolution in flotation reagents that set the stage for the next 80 years or so. A trend was established toward reagents of definite chemical composition by the use of certain types of small organic molecules and oils containing sulfur (either naturally or by direct sulfurization). Several major patents appeared (e.g., Perkins 1921; Vivian 1921) which taught that small, water-soluble molecules could be used as collectors instead of large amounts of oil. This trend continued by the later application of N- and S-containing compounds such as naphthylamines, diamino benzene, toluidines, thiocarbanilides, and several other organic complexing (or chelating) agents for sulfide mineral flotation. Their consumption was low (0.1 to 0.5 lb/t). This was followed by differential flotation using sodium cyanide (NaCN) and the discovery of xanthates, dithiophosphates, dithiocarbamates, mercaptobenzothiazole, and amines (for nonsulfides). It is important to note that the majority of chemicals used for flotation in the period from 1921 to 1950 were developed in other industries (e.g., rubber, textile, tanning). During the third period, 1951–present, the trend began for developing reagents specifically targeted for flotation application rather than merely evaluating chemicals developed for other industries (see Table 1 for examples). Modern chemical flotation is built on this foundation and it has undergone significant refinement to bring much-needed, rational, scientific rigor from developments in organic, polymer, and coordination chemistry. The ideal goal is the development of mineral-targeted, high-performance reagents that not only provide improved value recoveries and selective separation, but also provide the platform to extend flotation technique to a much greater variety of mineral and nonmineral systems and to nonflotation separations.

Our aim in this paper is to critically analyze the development and use of flotation reagents in presenting a state-of-the-art view of flotation reagents, to identify pitfalls and gaps in art and science, and to critically analyze research focus and

---

1 This is an approximate date used for convenience, the shift occurred sometime in the early 1950s.
approach. A conscious choice has been made to provide an overview of flotation reagents from an industry perspective rather than to repeat information that already exists in the literature with regard to historical, theoretical, and fundamental aspects. The emphasis will be on plant practice which would necessarily mean a "top-down" or "total system" (holistic) view; that is, need- or mineral-centric rather than reagent-centric.

2. CRITICAL ANALYSIS OF THE STATUS OF FLOTATION REAGENTS

2.1. Collectors

It is well established that the main function of the collector is to impart sufficient hydrophobicity to the mineral surface so that the probability of bubble-mineral attachment is increased. It is also well established that a collector molecule accomplishes this function by adsorbing on the mineral surface. Collector adsorption and the consequent development of hydrophobicity on the mineral surface does not guarantee the desired flotation outcome, for flotation is a probabilistic (or rather, pseudo-probabilistic) process.

A perusal of flotation literature on chemical aspects in the past 100 years would indicate that collectors have been accorded paramount importance and close attention at the expense of modifiers and frothers. From the perspective of the flotation plant's overall goals of maximizing recovery, grade, and profitability, such importance to collector alone is rather distorted and reductionistic. Collectors do play a critical role in providing a part of the solution and are necessary but not sufficient.

In terms of research, in sulfide flotation there is still a preoccupation with the study of interactions between xanthates (80 years after their introduction) and sulfide minerals, and elucidation of the mechanisms (more importantly, electrochemical interactions). Other collectors have received little attention, which is in stark contrast to plant practice. There is much redundancy in these studies and their findings, to the point where such research has become irrelevant to the plant metallurgists and reagent developers who moved beyond xanthates many decades ago; for example, xanthate is not the primary collector in the vast majority of copper plants which make up the bulk of sulfide flotation. Even in operations where selectivity is not critical, additional collectors are invariably used to augment performance deficiencies of xanthate.

A similar vein would be the vast number of reductionistic electrochemical studies conducted over the past four decades. We cannot deny that these studies have helped in terms of gaining a better understanding of the sulfide flotation systems, but they have not had the revolutionary impact that was claimed of them time and again for plant practice. If the focus had been on the real total system, applied research would certainly have produced the necessary knowledge base to implement concepts in the plant. Indeed, the occasional limited, applied studies have already identified the pitfalls in terms of measurement, interpretation, and control of pulp potentials. The only practical method of control is using chemicals (reagents and various gases) that participate not only in electrochemical reactions but also in many chemical reactions. The numerous misconceptions surrounding pulp potentials have accentuated the problem (Nagaraj 2000b).

The landscape is either the same or even worse in nonsulfide flotation where the obsessive focus is on the interactions between fatty acid or dodecylamine on selected minerals.

Many of the classical problems in flotation that were recognized in the first half-century of flotation—for example, effect of water chemistry, slime coatings, recovery of coarse and fine particles, difficult mineral separations—have yet to be solved and have received relatively little attention. Even in fundamental studies related to such problems, the tendency has been to focus on xanthates and fatty acids rather than to consider alternatives that may possess certain inherently advantageous properties.

2.2. Modifiers

Unlike collectors, discussion of modifiers is limited in the literature, although, selective flotation is made possible by use of a large number of modifiers. Their importance is in direct relation to complexity of mineralogy. Sutherland and Wark (1955) noted that "depressants have made possible the excellent results of selective flotation. Nevertheless, being difficult to control, they cause the metallurgist more worry than any other single class of flotation reagent." This observation is valid even today.

The chemistry of modifiers in flotation pulps is quite complex in comparison to that of collectors, and it is more complex in nonsulfide systems than it is in sulfide systems. Modifiers can affect multiple factors simultaneously in flotation pulps and, therefore, have multiple functions. (Details of predominant functions of various modifiers are found
in works by Eigeles [1977] and Chander [1988]). For example, addition of lime in a copper circuit can have the following effects: pH modification (and the resultant changes in interfacial chemistry, solubility of minerals, changes in water chemistry), depression of pyrite, formation of colloidal calcium sulfate precipitate and its adsorption on sulfide minerals, modification of froth characteristics and viscosity of pulp, modification of collector adsorption, precipitation of multivalent metal ions as hydroxides, removal of slime coatings from sulfides, dispersion and depression of certain gangue minerals, and reduction in grinding media wear. Thus, depending upon the type, modifiers can change pH, pulp potential (E_p), composition of the aqueous phase, and surface composition of the minerals and bubbles. They can affect properties of all three interfaces. They are also known to affect dispersion and rise-velocity of bubbles. The same modifier in different circuits could produce very different flotation outcomes, or different modifiers used for pH control in a circuit can have very different results at the same pH.

Difficulties arise in the laboratory investigation of all aspects of the action of modifiers. Many of the complex effects of modifiers are evident only in real flotation pulps where the variability in mineralogy and operating conditions has a significant impact and is virtually impossible to simulate in the laboratory. Thus, effects observed in model systems used in laboratory investigation can be quite misleading.

2.3. Frother and Frothing

The froth phase in flotation is probably the most neglected phase in flotation research in stark contrast to its importance, particularly in view of the disproportionate amount of research that has been conducted on collectors. This is not surprising, however unjustified, given the complexity of the three-phase froths that comprise a variety of mineral species and aqueous phase species (See Figure 1 for a schematic representation of the froth phase composition).

![Froth Phase Diagram]

Figure 1. The complexity of the three-phase froths (A, B, C, etc represents major species in recycled water; C1, C2 and C3 three different collector types; similar to frothers, F, and modifiers, M)

Fundamental studies conducted over the decades to characterize and understand froths and frothing have tended to be mostly reductionistic; for example: study of froths and foams in the absence of solids or using unrepresentative model solids; studies that focus on equilibrium and dynamic surface tension at the liquid/gas interface; methods for evaluation and ranking of frothers, such as froth column tests and dynamic frothability in the absence of solids and other reagents (collectors, modifiers) and under idealized conditions; or studying collector–frother interactions, often in the absence of solids. Extensive studies have been conducted on the role of surface tension of frothers in two-phase foam/froth systems. In fact, some of the earliest surface tension measurements date back to the early period of flotation. Given that only two major classes of frothers: Alcohols and Polyclycols / Glycol Ethers; with a limited number of members in each class, are used in plants, and that the literature is replete with surface tension measurements in the absence of solids, continued measurements will probably not reveal any new information. Although these studies have illuminated on some fundamental concepts pertaining to froths and foams, they have had, unfortunately, little impact on control or
manipulation of froth phase in a plant or on frother selection for a given application. As a result, frother selection and froth phase management are still dependent upon empirical testing, trial and error, visual observation in the plant, and reliance on qualitative descriptors: watery or dry; stability; persistence; and others; and not on surface tension, solubility, bubble size, and so forth. More recently, froth cameras have replaced the experienced eye of the traditional operator.

A system much closer to the plant froth phase is a simulated three-phase system (solid/liquid/gas) in the laboratory. In these systems, it has been clearly demonstrated that a mere change in collector, either to a different class or to a different homologue in the same class, can have dramatic synergistic or antagonistic effects on froth characteristics. In extreme cases, the heavily mineralized froths can become very dry and flow with difficulty (e.g., see Sheridan et al. 2002). Such effects can be linked to hydrophobicity of the solids in the froth phase, but literature is scarce in this aspect. The last extensive study was by Dippenaar, Harris, and Nicol (1978). Froth rheology in the three-phase system is recognized to be important, but again, literature is scarce. Much of the practical pertaining to interactions between flotation reagents reside as proprietary information in the research and development (R&D) laboratories of reagent developers and are inaccessible. It is clear that a rule-dictated knowledge base does exist in the industry, but this is qualitative, specific to a system and conditions, and does not relate back to fundamental concepts; therefore, the feedback information is unable or inadequate to facilitate product development and application.

2.4. New Cytec’s Reagents and Technologies

Based on the challenges of the industry, Cytec has developed new technologies (presented in Table 2) to meet specific industries needs.

Table 2. New Cytec’s Reagents for Specific Industries Needs

<table>
<thead>
<tr>
<th>New Technology</th>
<th>Application</th>
<th>Industry need</th>
</tr>
</thead>
<tbody>
<tr>
<td>MaxGold®</td>
<td>Collector</td>
<td>- Enhance Au recovery in Primary and Cu-Au ores; - Improve recovery of Metallics; - Improve total sulfide recovery in primary Au ores</td>
</tr>
<tr>
<td>AERO® XD 5002</td>
<td>Collector</td>
<td>- Improve recovery of Cu and Mo, with low lime consumption; - Greener alternative than AERO® 5460 and AERO® 5415</td>
</tr>
<tr>
<td>AERO MX-3016</td>
<td>Collector</td>
<td>- New collector for improving Mo recovery</td>
</tr>
<tr>
<td>NanoSep®</td>
<td>Magnetic separation enhancer</td>
<td>- Magnet reagents can be designed to remove non-magnetic impurities thereby extending the process capability and flexibility to more difficult ore bodies. - Potential uses in the Kaolin, carbonate and phosphate industries.</td>
</tr>
</tbody>
</table>

3. REAGENT SELECTION AND OPTIMIZATION – TRADITIONAL REDUCTIONIST X EXPANDED HOLISTIC PROCEDURE (CYTEC’S FLOTATION MATRIX 100)

3.1. Traditional reductionist process

In the 1920s and 1930s, the number of commercially used flotation reagents was relatively small, and reagent selection for a given application was relatively straightforward. As the number and diversity of commercially available flotation reagents steadily increased to meet the ever-increasing technical and economic challenges, reagent selection became gradually more complicated. Four other factors have made the situation more acute:

- The obsessive research focus on “old” reagents (e.g., xanthate, fatty acid, cyanide) meant that the chemistry and applications knowledge for all other reagents remained woefully inadequate in the published literature.
- Science did not keep pace with technology; the increasing emphasis on reductionistic research over the decades meant a widening gap between research and practice.
- Application knowledge developed by in-house research in the chemical companies remained largely inaccessible in
Consequently, at present, the process of reagent selection and optimization can be characterized as rather informal, reductionistic, and frequently based on extension of personal experience from one mineral system or plant to another, gut feeling, anecdotes, and myths (Nagaraj and Bruce 2003; Nagaraj 2005). There is no recognized “standard” practice, and the informal process is fraught with pitfalls.

For a given separation, at first glance the pool of reagent classes—and homologues within each class—available for selection appears to be large and bewildering. This is partly the result of the evolutionary nature of reagent development over the decades. But more importantly, given the complexity of the flotation system, a particular reagent class or a specific homologue just happens to produce the optimum results for the separation and ore type in question. General guidelines are available for reagent selection in the form of an accumulated knowledge base in reagent developers’ handbooks and product literature (e.g., the Mining Chemicals Handbook [Cytec 2002]). This serves to narrow the selection for a given application; however, the metallurgist must still use additional filters to refine the selection to a manageable level in order to move to the laboratory testing phase. Historically, this stage of reagent selection has tended to be reductionistic and informal. Problems in complex systems invariably have multiple solutions, each with its degree of desirability. Even an arbitrary process of reagent selection will provide a solution to a plant’s problem. However, such a solution may not be sufficiently robust, that is, the selected reagent will have a narrow, unoptimized window of performance—and may only be a temporary fix—and its nonrobustness may not even be discovered for a long time, given the significant routine variability in plant performance. This approach is very costly in the long run and adds little to our knowledge base.

3.2. An Expanded Holistic Process – Cytec’s Floatation Matrix 100

In order to develop a robust solution to a problem in the plant, and to increase value or profitability in the operation, a holistic or total system approach is necessary. The schematic representation (shown in Figure 2) presents an expanded holistic view of the flotation system, with particular importance to reagent selection and optimization and depicting additional triangles and trade-offs. The expanded view of chemical factors reveals the flotation reagent triangle interacting with mineralogy (ore types). The resulting tetrahedron forms the basis for reagent selection and evaluation, in combination with triangles depicted for best practices, plant needs, and knowledge base—all emphasizing trade-offs.

Source: Nagaraj 2005

Figure 2. Expanded holistic view of the flotation system in reagent selection and optimization.

“Reagent optimization” has many connotations. To the mill operators, for example, it may mean working with the reagent currently in use to find conditions (e.g., dosages, addition points) that provide optimum performance with respect to certain targeted metallurgical goals (e.g., improved recovery/grade, or cost-effectiveness). Or it may mean searching the market for an alternative reagent that provides performance better than the one currently in use. To the chemical supplier, it may mean modification of existing, or designing new, structures to provide reagents that perform
better (for a given application, e.g., copper flotation) than currently marketed reagents, not just in any particular mill but across all mills in the industry. The ultimate goal is a robust solution to the needs of the dynamic plant system with all its variability. Although laboratory testing is an integral part of the process of optimization, its goal is merely to identify potential solutions, problems, and benefits.

A rational, holistic process is necessary in order to implement the total system approach described in Figure 2. Such a process comprising four critical phases is schematically represented in Figure 3. Although these four phases proceed in a logical sequence, they are indeed highly iterative. The discovery/definition phase provides all the necessary information for reagent selection and sets the objectives, goals and success criteria. The reagent selection phase, then, begins with preliminary screening of available reagents using knowledge base and expertise of the reagent developer to arrive at a subset of reagents that meet the requirements established in the discovery/definition phase. The selected reagents can then be screened in the laboratory by an iterative process. Historically, the preliminary screening phase has been rather simplistic, as it involved merely selecting representative candidates from several different families, and essentially ignoring other important reagents in the circuit and operational variables. Thus, if the objective is to screen collectors for a given separation, the candidate products might be a set of representative collectors from several families, keeping all other reagents and conditions constant. The assumption in this one-reagent-at-a-time approach is that reagents perform independently of one another and independent of the operating conditions.

Factors grouped under constraints in Table 3 are relatively straightforward to deal with in the reagent selection process, but they can often have an overriding impact on reagent selection. For example, a reagent selected on the basis of its superior metallurgical performance can still be rejected because its odor is objectionable, or it was not registered for use in the country where the plant is located, or it might be perceived to present environmental problems, or its unit price is perceived to be unacceptable though the overall treatment cost would have been significantly lower. Technical factors (see Table 3) present the greatest challenge in reagent selection, because many of these are difficult to assess fully in the preliminary reagent screening phase prior to laboratory evaluation. Consequently, a combination of available knowledge base and empirical diagnostic laboratory testing is used in an iterative process to assess the impact of the technical factors in reagent selection. The objective is to reduce the number of potential reagents and conditions that need to be evaluated in the laboratory. A holistic approach using highly efficient experimental designs and rigorous data analysis will greatly facilitate the reagent selection process and the chances of arriving at a robust solution rapidly.
Table 3—Important factors that dictate reagent selection and trade-off

<table>
<thead>
<tr>
<th>Technical Factors</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reagent Chemistry</td>
<td>Reagent tox registrations</td>
</tr>
<tr>
<td>Ore Types, mineralogy, mineral chemistry</td>
<td>Handling</td>
</tr>
<tr>
<td>Frothing characteristics</td>
<td>Logistics</td>
</tr>
<tr>
<td>Water chemistry and gangue minerals</td>
<td>Toxicity and environmental issues</td>
</tr>
<tr>
<td>Stability (both short and long term)</td>
<td>Odor</td>
</tr>
<tr>
<td>Particle size distribution</td>
<td>Manufacture</td>
</tr>
<tr>
<td>Downstream effects</td>
<td>Cost</td>
</tr>
<tr>
<td>Co-value minerals recovery</td>
<td>Strategic fit</td>
</tr>
<tr>
<td>Plant circuit, process conditions, plant constraints</td>
<td>Compatibility with other reagents</td>
</tr>
</tbody>
</table>

Recently, a rule-based expert system reagent selector was developed by Cytec Industries (Franzidis 2005). This is the first of its kind and is part of a comprehensive package, called Flotation Matrix 100, that is designed to incorporate all the elements of the holistic approach, namely, definition of mineralogy and plant needs, reagent selection, and laboratory and plant best practices. The available performance knowledge base and published literature follows the order: collectors >> modifiers > frothers. Thus, collector selection is easier than that of modifiers and frothers. General guidelines are, however, available for all three classes of reagents, and these form the basis of narrowing the selection to a given application (Cytec 2002).

4. CONCLUDING REMARKS

The industry need is to improve the efficiency of plant operation with a special emphasis on value recovery in the most profitable manner. Solutions to this overarching need lie in the total system or holistic approach, first for the whole operation comprising geology, mine, comminution, concentrating units, and downstream operations. The focus next would be within an individual unit operation, without losing sight of interlinks between unit operations, and incorporating the physical, chemical, and operating factors simultaneously rather than optimizing one factor at a time. There is also a need to recognize that reagent chemistry is one of approximately 20 factors that dictate reagent selection and optimization. Thus, a holistic approach is necessary to incorporate all the factors and to view reagents in terms of a flotation reagent triangle. In flotation unit operation, the choice of a reagent is critical, but the current default mode is selection of traditional workhorses (e.g., xanthate in sulfide flotation, fatty acid or amine in nonsulfide flotation) without a total system approach and irrespective of the need and mineralogy. This is essentially a status quo and fails to exploit the advantages and benefits offered by other chemistries.

In this context, the industry must clearly communicate the need, not merely state the problem. When the need is clearly defined, research focus efforts will be targeted toward the need rather than reconfirming the stated problem. Therefore, the focus should really be mineralogy driven in order to truly meet the industry needs; the appropriate reagents and conditions would then follow. This is the top-down approach that is needed for both research and practice. The industry will be better served by taking this “big picture view” and by making a commitment to support and direct relevant research.

5. BIBLIOGRAPHY