Biosorption technology: starting up an enterprise

B. Volesky* and G. Naja

BV-Sorbex, Inc. and Department of Chemical Engineering,
McGill University, 3610 University Street,
Montreal, Quebec H3A 2B2, Canada
Fax +1-514-3986678
E-mail: boya.volesky@mcgill.ca E-mail: ghinwa.naja@mcgill.ca
*Corresponding author

Abstract: Research into biosorption elucidated the principles of this effective process for water decontamination. While it seems that this technology could hardly have any competition, the process has not been applied as yet and several commercialisation attempts have not been successful. As solid capitalisation is required for innovative process ventures, partnership approach is perhaps advisable. While mining companies appear to be excellent 'clients', each is invariably concerned with having its own environmental problems successfully addressed. The 'suppliers' of ion-exchange technologies is a handful of huge transnational companies with difficulties in operative decision making. Dynamic consulting companies are in an excellent position to push new technologies into the marketplace. However, they are not known as capital-rich entities. All these aspects make a wide industrial application of the new biosorption process quite a challenge

Keywords: biosorption technology; metal removal; environmental enterprise; metal recovery; biosorbent materials; electroplating effluent treatment.

Reference to this paper should be made as follows: Volesky, B. and Naja, G. (2007) 'Biosorption technology: starting up an enterprise', *Int. J. Technology Transfer and Commercialisation*, Vol. 6, Nos. 2/3/4, pp.196–211.

Biographical notes: Bohumil Volesky is the CEO and Founder of BV SORBEX, Inc., which he leads as a new technology venture focusing on advanced water treatment concepts. He is engaged in worldwide consulting activities, seminars and workshops. His areas of expertise are Biochemical Engineering and Industrial Water Pollution Control. As a Professor of Chemical Engineering at McGill University in Montreal, Canada, he has authored or co-authored close to 200 papers and presented many invited lectures at international scientific meetings around the world. His major collaborative research activities included Switzerland (ETH), Brazil, Korea, Puerto Rico, China and the Czech Republic.

Ghinwa Naja obtained her PhD in Physical Chemistry in Nancy, France. Her original research at the CNRS expanded into the fields of analytical nano-biotechnology and process engineering. With a prestigious UNESCO-L'OREAL Fellowship for Women in Science (2004–2005), she was invited as a Visiting Professor to carry out research at McGill University in Montreal, developing mathematical models and computer simulations for environmental sorption systems. The relevant results of her work earned her an ongoing engagement as the Executive Vice-President at BV Sorbex, Inc., a private company commercialising biosorption technology and involved in a worldwide consulting for industrial effluent treatment.

1 Introduction

Heavy metals (e.g., lead, copper, cadmium, zinc, chromium, etc.) are toxic even at low concentrations (Tolley et al., 1992). As they are non-biodegradable, their threat is multiplied by their accumulation in the environment through the food chain. The detoxification of metal-bearing wastewater is a pressing environmental concern. All metal processing activities lose or discharge sometimes even large quantities of heavy metals. The development and implementation of cost-effective process for removal/recovery of metals is essential to improve the competitiveness of industrial processing operations and to minimise the environmental hazard of toxic metal-containing effluents.

The capacity of certain types of microbial and seaweed biomass to remove and concentrate heavy metals from solutions provides the basis for a cost-effective technology for detoxification of industrial effluents (Atkinson et al., 1998; Brierley, 1990; Townsley et al., 1986). New biosorbent materials can be extremely competitive and cost effective, particularly in this application. Further work with biosorbents identified for their high metal uptake could best be directed to derivation of engineering process scale-up parameters for application in the clean-up of two most ubiquitous types of metal-contaminated industrial effluents: Acid Mine Drainage (AMD) and electroplating effluents (Macaskie, 1997; Tabak et al., 2003). The development and implementation of a cost-effective process for the removal and recovery of heavy metals is necessary on two fronts: first, to improve the competitiveness of mining (and electroplating) industries, which constitute a major industrial sector of manufacturing economies; and second, to eliminate toxic metals from effluents as required by environmental regulations. Biosorption technology removes heavy metals from wastewater without creating hazardous sludges at costs much lower than conventionally used ion-exchange systems. Regeneration of the biosorbent and concentration of the metal solution for eventual recovery further increase the cost effectiveness of the process.

High-sorbing biomass types have been discovered and their performance is now reasonably understood (Naja et al., 2005; Tsezos, 1984). Pilot sorption column tests should be carried out, based on earlier equilibrium metal uptake, to provide a basis for computerised process modelling of the biosorption system, which is essential for effective optimisation of the metal-removal process (Schiewer and Volesky, 1995). Computer process simulations will then significantly reduce the scope of the necessary field tests (Naja and Volesky, 2006). Development of the biosorption technology has reached the stage when it is ready for piloting with selected clients. Correspondingly, the technology is in the stage when pilot projects can be carried out to demonstrate the effectiveness of biosorbents when compared with synthetic resins for generally similar industrial applications. This line of activity should generate the necessary facts and application examples to convince and attract the technology venture equity partners, experienced consultants, biosorbent distributors and industrial clients for the process.

2 Feasibility of the biosorption venture

A brief outline of establishing an enterprise based on the biosorption technology will be discussed here (Figure 1). The feasibility of applying the biosorption process into wastewater purification would best be assessed based on a stage-wise approach. A considerable amount of research on biosorbent materials has developed a solid basis of knowledge and indicated their enormous potential. The highest priority at the early stage would be the preliminary and approximate assessment of the commercial potential and feasibility of application of the new technology (Figure 2) based on the family of new biosorbent products. Correspondingly, the preliminary stage should consist of some basic studies.

Figure 1 The enterprise based on biosorption can span a broad range or a selected specific part of it

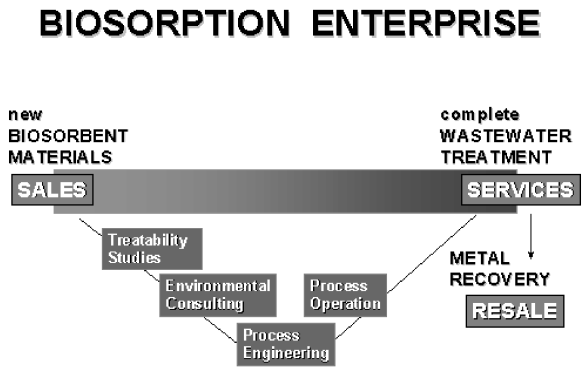
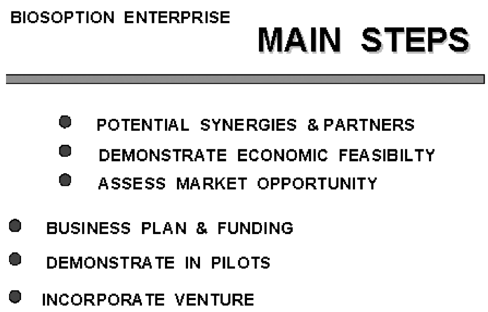


Figure 2 Technological, economic and organisational aspects need to be thoroughly developed



2.1 Assessment of the competing technologies

The current costs and market share of the established conventional processes for metal removal/recovery from dilute solutions or wastewaters have to be summarised and assessed. Similarly, for new unconventional and even new biosorbent-based processes, which are approaching the stage of application in the field.

For cases when metal removal from contaminated industrial effluents is considered, the following process alternatives can be considered for a more detailed evaluation and feasibility assessment:

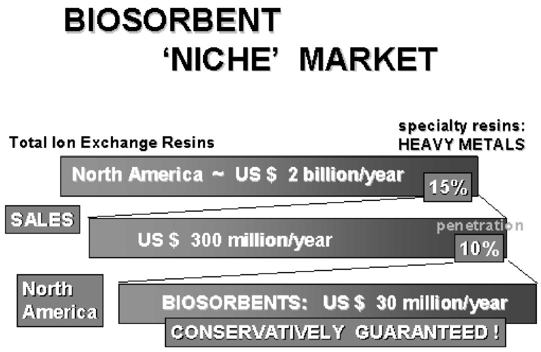
- *Precipitation* by addition of appropriate chemicals (van Hille et al., 2005), followed by conventional solid–liquid removal that could be by sedimentation, floatation, filtration, in extreme cases even by more expensive centrifugation. The metals are not that easy to recover from the resulting sludges that often eventually represent a serious disposal problem.
- *Reverse osmosis* is a membrane-based process that is very effective for removal of ionic species from solution. However, the membranes are relatively expensive both to procure and to operate. The use of elevated pressures makes this technique costly and sensitive to operating conditions. The resulting concentrated by-product solutions make eventual recovery of metals more feasible as the case also is for the ion-exchange process.
- *Ion exchange* is a process very similar to biosorption whereby the latter is known to actually function predominantly on the basis of ion exchange (Kunin, 1958). Ion exchange, however, uses mainly hydrocarbon-derived polymeric resins. The hydrocarbon basis of synthetic ion-exchange materials makes them dependent on the price of crude oil.
- *Bio-reduction* of metals and their mineralisation (turning them into natural deposits) is an attractive low-rate but cost-effective option as the knowledge and control of microbial activities involved lately significantly advanced (Rajwade and Paknikar, 2003). Large volumes of metal-contaminated water can be economically purified.

2.2 *Assessment of the market size*

While it is known that the environmentally based market for metal removal/detoxification of metal-containing (industrial) effluents is enormous, the actual figures to support this generally prevailing perception would be most convincing although not essential for launching the Company enterprise (Figure 3). The ion-exchange market is as well established as this technology itself. The manufacture and supply of ion-exchange hydrocarbon-derived polymer-based resins is concentrated in the hands of a very few transnational giant chemical companies. Rohm and Haas, Dow Chemicals, Bayer, and only a few more are the ones that have monopolised the ion-exchange market. While ion-exchange resins are commodity chemicals, it is worth mentioning that the exact figures of the sales volume and value are rather difficult to get from usual information sources. These figures appear to be a key to assessing the potential market for biosorbents. A quantitative review of the potential clientele for the biosorption metal-removal process needs to be carried out for different countries where applications of biosorption technology would be considered.

Comparison of costs between the conventional and the new technology establish the feasibility of biosorbent applications and their competitiveness in the marketplace. As the application of biosorbent technology proves cheaper and more competitive, it is anticipated that new applications, otherwise perhaps not feasible, will significantly increase the size of the current market and the scope of potential clients for biosorption technology.

Figure 3 A conservative estimate for a biosorption enterprise niche market



2.3 *Assessment of costs of new biosorbents*

At this point, it is not known what would be the real production costs of new biosorbent materials processed into suitably applicable granules. Approximate costs of different types of raw biomass need to be ascertained, as well as the costs of processing the biomass into applicable biosorbent materials maintaining their high sorption efficiency. This stage will require travel and fact-finding efforts necessary to reliably establish the exact costs and conditions under which waste industrial biomass can be obtained from the large-size industrial operators. Similarly, for the price of ocean-based biomass of selected marine algae, which has to be collected from high seas or offshore areas.

Estimation of the costs of preprocessing and drying the raw biomass to prevent its degradation will have to be carried out for selected representative types of biomass available in large quantities. Preliminary technical work needs to be carried out on the processing necessary for biomass formulation into a biosorbent product suitable for process uses. It is anticipated that different raw biomass materials (algae, fungi, bacteria) will require different and specific treatment for their optimal formulation into finished ready-to-use products. This part would entail specifically planned small-scale laboratory work and preliminary optimisation of the procedures involved resulting in an efficient biosorbent material.

Ideally, all these preliminary assessments (A, B, C) should be carried out simultaneously as part of a better quantitative estimation of the venture feasibility. They could also be carried out simultaneously with the technically oriented pilot-plant efforts.

While it is not within the framework of this text to discuss the conventional metal-removal techniques in more detail, it would suffice to say that as the emission standards tighten, the common ones are becoming progressively more inadequate or prohibitively costly for use of wastewater treatment. Better and effective metal-removal technologies are invariably more costly and often just not feasible for that purpose. The search is on for efficient and particularly cost-effective remedies. Biosorption promises to fulfil the requirements. Its overall performance and process application modes justify a comparison with the ion-exchange technology. In the comparison of ion-exchange and biosorption processes:

- the same equipment (i.e., pipes, columns, etc.) can be used with both (a given treatment installation can be interchangeably used with both types of sorbents)
- according to all estimates, biosorbents can be at least an order of magnitude cheaper (1/10)
- only a shorter life cycle can be assumed for biosorbents.

These assumptions lead to considering the low cost of the biosorbent as the primary significant difference factor between the biosorption and ion-exchange processes. For this reason, the study of the biomass sources and costs are particularly important and will allow a measurement of the economic performance of the process.

Obviously, it is no small feat to develop a business venture along these broad lines. This is perhaps why the commercialisation of biosorption technology has been so relatively slow and painful for those few who attempted it. However, the potential is undoubtedly there. While the same equipment (i.e., piping, columns, etc.) can be used with both biosorption and ion exchange, a treatment installation can be interchangeably used with both sorbents.

It is perhaps worthwhile mentioning that some sources put current established ion-exchange resin sales on the order of perhaps 2 billion US dollars per year in North America alone. While ion-exchange resins are considered a commodity on the market, the actual sales figures are not reliably available. Worldwide sales are perhaps approximately quadruple the figure for North America. However, only about 15% of the total ionex resin sales are for the specialty uses such as heavy metal removal. Considering that only 10% of that specialty-use volume could be 'penetrated' by (cheaper!) biosorbents, one is looking at the most conservatively estimated immediate and existing market for new biosorbent materials in the order of at least 30 million US dollars only in North America.

Huge markets already exist for cheap biosorbents. Electroplating and metal finishing operations, mining and ore processing operations, smelters, tanneries and printed circuit board manufacturers are a few of the industries in which metal-bearing effluents pose a problem. Altogether, more than a 1000 tons of heavy metal is released into Canadian waters by polluting industries in the area of Fabricated Metal Products Industry alone.

The potential application for biosorption appears to be enormous. While the high cost of the ion-exchange process limits its application (as demonstrated by the huge amount of untreated effluents still released), the cost advantage of biosorption technology would guarantee a strong penetration of the large market of heavy metal polluting industries. It can easily be envisaged that cheaper biosorbents would open up new, particularly environmental, markets so far non-accessible to ion-exchange resins because of their excessive costs, which make them prohibitive for clean-up operation applications.

These considerations clearly demonstrate the economic feasibility and potential of the biosorption process for heavy metal removal/recovery purposes. It should be pointed out that there is a potential added benefit of metal-recovery as an *additional source of revenue* generated by a water treatment that *must* be carried out anyway (from a regulatory and environmental point of view). This cost reduction applies to 'cheap' metal as well as 'expensive' metal, no matter what the economic indices may be.

2.3.1 Techno-economic basis

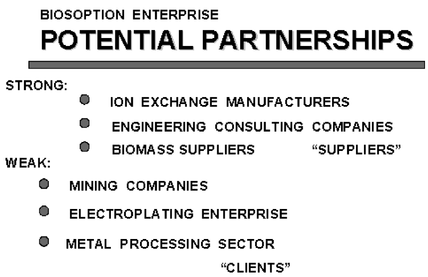
The limits of ion-exchange resins have, to a large degree, been reached and these products are considered a chemical commodity now. The growth rate of the ionex technology appears to have been a 'flat' one already for quite some time. The price of ion-exchange resins, which are hydrocarbon derivatives, is invariably linked to that of crude oil. Needless to say, crude oil is a finite resource and, in addition to that disadvantage, its price is also very much subject to the world trading stability.

The most compelling reasons for using biosorption technology, based on a renewable or waste raw material, are that it is effective and inexpensive. That certainly guarantees the possibility of easily opening new markets. There is also an extremely high development potential associated with the new concept of biosorption. The main steps required prior to the actual launching of the biosorption technology venture could be identified as seen in Figure 3.

2.3.2 Identification of potential synergies and partners

Relevant information has to be collected to develop and implement a strategy regarding potential synergies and partnership with players in suitable industrial sectors (Figure 4). Naturally, ion-exchange manufacturers should watch the developing field of biosorption particularly closely as the new products could extend their own line. However, due mainly to their enormous size reflected in corporate decision-making, the cooperation of chemical multi-nationals controlling the ion-exchange resin market is not easily forthcoming.

Figure 4 There are potential partners – and better ones …



Biosorption, as a direct competitor of ion exchange, is a tool that engineering *consulting companies* could use when designing wastewater treatment systems for their polluting clients. Biosorption would allow them to gain competitiveness by having a wider palette of remedial processes. Increased profits would stem from this kind of an enterprise not being restricted by how many times they 'sell' the process. Polluting customers would benefit from lower costs of buying the process. This goes quite contrary to the virtually 'possessive' nature of clients who are more often interested in having their problem solved – and in a proprietary manner.

The supply-side for suitable raw *biomass* represents a large new business opportunity and a good partnership chance.

The ease of operating a mobile biosorption pilot station is a very attractive feature that would facilitate testing of the process with various clients. While larger-scale pilot testing may be technically unnecessary, customers need to be reassured about the feasibility of deploying a ‘new’ system, all the more so as no previous record track for biosorption can be presented at this time.

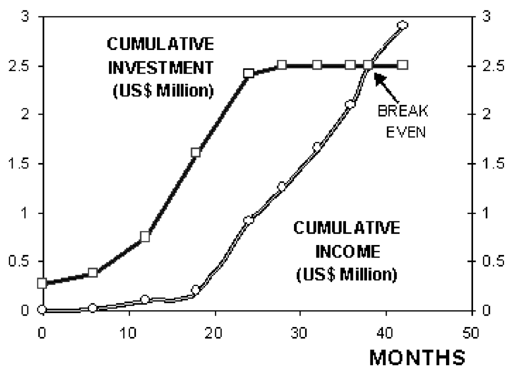
Continuing and strong R&D work in the field of biosorption cannot be overestimated. Within this framework, more effective engineering tools can also be developed for applying, scaling up and optimising sorption processes in general.

3 Financial projections

Detailed financial projections with several alternatives for Company growth could be made as summarised here. A summary of these projections with some illustrative diagrams is presented in this section.

- *Financing 1*. The Company will most likely require two infusions of capital; a first one to assist the Company development for approximately three years. Following this period of Company’s aggressive entry into the three facets of the environmental market (engineering, equipment, products), a positive cash flow could be expected (Figure 5).
- *Financing 2*. The consolidation of Company’s efforts and manufacturing facilities at this point (approximately three years after the financed start-up) will require another round of financing that will propel the enterprise into an unlimited growth phase.

Figure 5 Income of the start-up company during *Financing-1* phase follows the investment into the venture

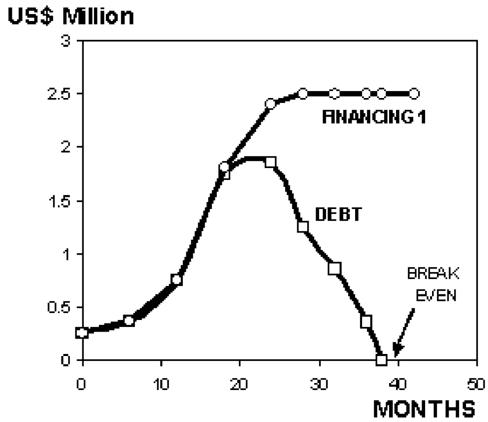


3.1 Return on investment

Revenues from early engineering services and later product and equipment sales are expected to bring the Company to the financial break even point in slightly more than three years. At that point, the equity value of the well-established enterprise is quite likely to represent a good value for the investment. Both biosorbents and sorption equipment are high-profit margin products, on average 85% and 63%, respectively. The Company’s financial projections call for net profit in approximately two years following the second round of financing. At that point, the net profit after taxes is projected to be about 25%. The projected return on stockholder’s equity (after-tax) in that period is estimated at 40%.

Figures 5 and 6 show an example of what could reasonably be expected during the venture Financing-1 phase considering the cumulative investment of US$ 2.5 million. The growth of revenues appears with some delay (Figure 5), eventually bringing slowly down the company 'indebtedness' (Figure 6).

Figure 6 As the income is generated during *Financing-1* phase, the indebtedness of the start-up company diminishes



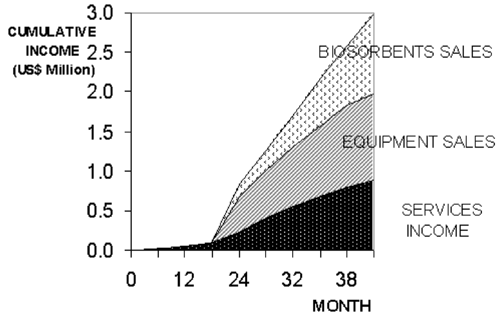
In Figure 7, it is seen what the income of the start-up biosorption venture would most likely consist of.

The income of a start-up Company based on new biosorption technology would involve three aspects:

- new family of biosorbent products
- equipment that could even be of a standard nature (sorption columns and accessories)
- engineering services centred on wastewater treatment consulting, process equipment installation and operation.

Revenue generated by these three areas would most probably start flowing in at a reverse sequence than listed above – the engineering and consulting services most likely leading up the list of earnings (Figure 7).

Figure 7 In the category of biosorption company income, water pollution control engineering services play an important and an early role



3.2 Business basis

The financial projections have been based solely on sales in North America of the Company's marketable goods and service. Strategic business alliances should be forged to reinforce the Company's process engineering and marketing capabilities. Eventually, early entry to European markets as well as those of India, Japan, South America and China is possible, probably in that order of priority.

3.3 Government support

Some unique government policies concerning particularly environmentally oriented business ventures may enable unusual grant and financing schemes for new technology-based enterprises, which offer 50–75% financing of new companies in the form of grants and additional schemes of generous loans, subsidies and tax breaks. Dynamic ventures qualifying for this unusual financial assistance can multiply any private investment by a factor of up to 2–4.

4 An example of a biosorption application (Volesky, 2003)

Biosorption appears to be particularly well suited for AMD or electroplating effluent clean-up applications. Extensive research and field work points at the biomass of seaweed *Sargassum* as the biosorbent of choice for removal of cationic heavy metals. An example of a hypothetical process is abbreviated here to illustrate the most important technical data. Owing to the technological and the underlying process principles, similarities between ion exchange and biosorption, heavy metals biosorption is most efficiently performed in fixed-bed continuous flow columns. For more details, the reader is referred to Volesky (2003).

4.1 Specifications

An industrial process operating round the clock generates 48,000 US gallons per day (gpd, ~181.5 m^3/d) of wastewater containing 40 mg/L Cu, 30 mg/L Ni, and 20 mg/L Zn at pH 4.5 (Figure 8). The following regulations concerning the metal content of industrial discharges might typically apply locally: Cu < 5 mg/L; Ni < 5 mg/L; Zn < 5 mg/L.

Biosorbent granules are tightly packed in the sorption column, however, allowing the metal-bearing stream to freely pass through the column (usually downward). Dissolved metals are gradually removed from the liquid phase, which always meets fresher and fresher sorbent as it trickles down the bed. Effluent leaving the column contains extremely low residual metals in the range of 10–50 ppb, often undetectable. When the biosorbent in the column eventually becomes fully loaded and the effluent metal concentration at the exit starts gradually increasing, the column is shut down and the flow is diverted into a second stand-by fresh column (the breakthrough point). Saturated Column 1 is then appropriately processed (regenerated, washed) to prepare it for another run (Figure 9).

Figure 8 Example of a hypothetical biosorption effluent treatment plant design specifications

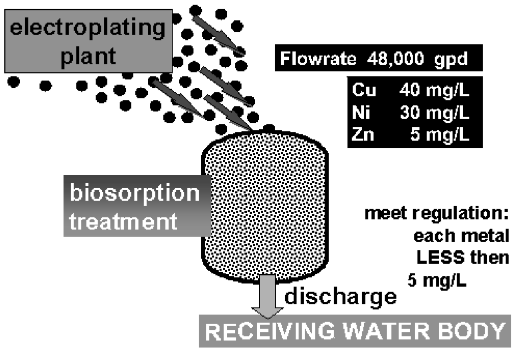
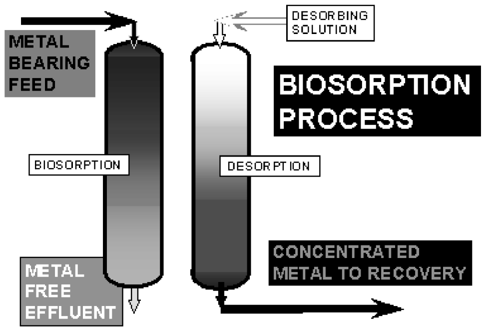


Figure 9 The fixed-bed sorption column system



The sorption column systems can be available in a variety of sizes to accommodate a wide spectrum of flow requirements and process performances. Cylindrical sorption columns do not typically exceed 1.5 m in diameter and 5 m in height. Virtually unlimited scale-up of the process is accomplished by using batteries of multiple columns that work in parallel or in series to optimise the performance of the process.

Advantages	*Disadvantages*
Most effective configuration	Cannot handle suspensions
Continuous-flow operation	Requires column alternation
Virtually unlimited scale-up	Scales up by multiplying units
No solid/liquid separation	Sensitive to pressure drop
In situ regeneration and washing	Complex valve and pipe systems

A biosorption-based effluent treatment plant is to treat the wastewater so that it would meet the specified criteria for discharge. Owing to the relative simplicity of the overall biosorption plant scheme, a flowchart of a treatment arrangement can be outlined as seen in Figure 10. The biosorption column operates on H-cycle according to the following schedule derived from preliminary, even laboratory, tests and mass balance calculations:

SORPTION: 20 hours

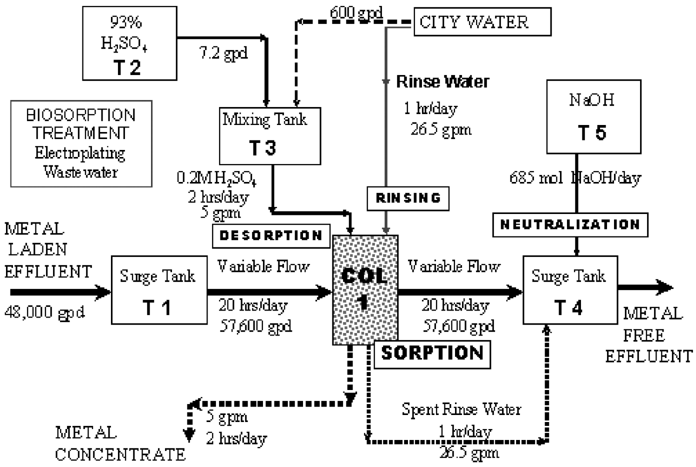
DESORPTION: 2 hours

RINSING: 1 hour

IDLE TIME: 1 hour.

The tank **T1** is designed to hold ~4 hours of flow from the upstream industrial process. The metal concentrate produced during the regeneration of the column is returned to the industrial process. Tank **T2** stores the concentrated acid that is diluted to the desired strength in Tank **T3**. The rinse water flows into the holding tank **T4** where a pH adjustment of the water takes place prior to its discharge. The pH adjustment of the biosorption column effluent also takes place in the tank **T4**. Different types of acid regeneration-recycle could also be considered. The concentrated desorption stream with high metal concentrations (up to thousands of mg/L) could be processed or sold for metal recovery.

Figure 10 Schematic flowchart of a biosorption plant for treating electroplating wastewater



The general process and equipment sizing calculations are relatively simple and are based on mass balances of the process or its sections (Volesky, 2003):

- *biomass requirements*: ~400 kg/day (packing density ~200 g/L) = 2000 L/day
- *regenerant acid requirements* (0.2 M H_2SO_4) volume for 1 column: ~2250 L/day
- *NaOH requirements* for neutralisation pH adjustments in Tank **T4**:
  - for the spent rinse water: 160 moles
  - pH adjustment of the metal free water generated by the column during sorption: 685 moles/d.

From process mass balances and individual equipment design considerations also come the equipment sizes:

Column – Diameter = 120 cm, Height = 270 cm

Tanks – **T1**: 33,250 L; **T2**: flexible; **T3**: 2,500 L; **T4**: 6,000 L; **T5**: flexible.

4.2 Biosorption plant design options

- column(s) operating intermittently + a surge tank (preferred choice for H-cycle, i.e., for effluents with low metal content)
- columns operating in pairs, one sorbing while the other is being regenerated (the preferred choice for Ca/H cycle, medium, i.e., for effluents with medium metal content).

The summary of the ionic cycles applied to *Sargassum* biomass is given in Table 1.

Table 1 Ionic cycles applied to *Sargassum* biomass

	Stage	*Feed*	*Effluent*
	Sorption	Polluted water	Metal free water
H-cycle	Regeneration	H_2SO_4	Acidic metal concentrate
	Rinsing	City water	Acidic water
	Sorption	Polluted water	Metal free water
Ca/H-cycle	Regeneration desorption	H_2SO_4	Acidic metal concentrate
	Regeneration Ca-wash	Lime	Hard water
	Rinsing	City water	Acidic water

4.3 Comments regarding the design options

The cost of an additional ion-exchange column is generally higher than the cost of a surge tank (below certain capacity). The desorption with acid is fast, and hence the regeneration of a column operating on H-cycle is completed fairly quickly. Consequently, one of the columns operating in pairs on H-cycle would be idle most of the time. However, a column operating on H-cycle has a short service time when applied to effluents containing more than 40 mg/g of metals.

The Ca-wash takes almost as much time as the saturation, thus making a column pair more efficient. Ca/H cycle allows the biosorption process to be applied to effluents containing metals in the range of 60–200 mg/L.

4.3.1 Treatment outline

The treatment of metal-bearing effluents may vary broadly, depending mainly on the type of pre-treatment required and on the content of other more common and relatively innocuous metals such as iron and then metals in anionic forms such as Cr^{6+} or anionic forms of arsenic and others.

In the simple case, four simple sequential stages may be required:

- *STAGE 1*. Biosorption of residual Cu, Zn, etc.
- *STAGE 2*. Neutralisation: Process effluent pH adjustment in a surge tank (**T4**).
- *STAGE 3*. Desorption: metals removed from biosorption column in a concentrated waste stream.
- *STAGE 4*. Rinsing: Biosorbent preparation by water wash inside the column.

4.4 Effluent quality

All metals targeted for removal/recovery (Cu, Ni, Zn) can be removed from the production plant effluent. Unlike some synthetic ion-exchange resins, *Sargassum* biomass is rather insensitive to the alkaline and alkaline earth metals (K, Na, Mg and Ca) in wastewater. Consequently, the concentration levels of these metals in the treated effluent will be only slightly lower than their respective concentrations in the original effluent. However, the toxic heavy metal levels will be well below more commonly specified limits for discharge.

4.5 Metal concentrate stream

The targeted metals, from the given effluent, can be removed and may be concentrated for the metals of interest. Owing to the different affinities of the targeted metals towards the biomass, each metal can be singled out and concentrated. The degree of metal separation and concentration depends on the respective selectivity of the metal toward the biomass, on the elution technique employed, and the concentration of the elutant. Table 2 displays the concentration factor, i.e., the factors by which the metal concentration is raised with respect to the concentration of incoming wastewater, for metals of interest.

Table 2 Concentration of metals by biosorption using *Sargassum* biosorbent (Volesky, 2003): example based on laboratory results (0.2 M H_2SO_4 as elutant, quick-wash in situ contact, no damage to biomass)

Metal	*Cu*	*Zn*	*Ni*
Concentration in (mg/L)	40	5	30
Elutant concentrate (mg/L)	6500	850	4300
Concentration factor	162.5	170	143.3
Resulting effluent (mg/L)	<0.05	<0.1	<0.03

5 Conclusion

As public awareness of the environmental impact of industrial activities increases, consequently placing greater pressure on governments and businesses to reduce pollution, more stringent environmental regulations are being enacted and enforced around the world. The increasing demand for more effective remedial technologies results in a huge window of opportunity for biosorption whose competitive advantage warrants its future success.

The initial information gathered in preliminary economic feasibility studies leads to three main conclusions regarding the application of biosorption technology:

- Viewed as a water treatment process (its currently considered primary function), biosorption allows significant cost savings in comparison with existing competing technology, i.e., ion exchange, its closest rival.
- In terms of its technical performance, operational qualities and chemical properties, the technology can be more effective in many cases than its closest rival, ion exchange. Moreover, there are indications that it also has low sensitivity to environmental and impurity factors, which make this technology widely usable.

- Additional cost reduction results from the possible recovery of heavy metals. Cost savings are obviously reinforced by a higher market value of recovered metal and lower costs of biomass. The process is even economically viable for the recovery of metals as a stand-alone activity for more 'expensive' metals (market price > \$15/kg).

Finally, there is also the added benefit that the existing wastewater treatment facilities using ion exchange can be easily converted to the biosorption process with a good payback from savings produced by operating with an equally effective process using a more inexpensive sorbent material.

The enormous potential of application for biosorption and its strong economic and technical advantages open considerable market opportunities that can actually be quantified through a responsible market analysis.

Acknowledgement

The material in this paper was abbreviated with the permission of BV-Sorbex, Inc., from the business plan of the Company. Some concepts used here also appear in Volesky (2003).

References

Atkinson, B.W., Bux, F. and Kasan, H.C. (1998) 'Considerations for application of biosorption technology to remediate metal-contaminated industrial effluents', *Water SA*, Vol. 24, pp.129–135.

Brierley, C.L. (1990) 'Bioremediation of metal contaminated surfaces and ground waters', *Geomicrobiology Journal*, Vol. 8, pp.201–223.

Kunin, R. (1958) *Ion Exchange Resins*, J. Wiley & Sons, Inc., New York.

Macaskie, L.E. (1997) 'Bioaccumulation of heavy metals, and application to the remediation of acid mine drainage water containing uranium', *Research in Microbiology*, Vol. 148, No. 6, pp.528–530.

Naja, G. and Volesky, B. (2006) 'Behavior of the mass transfer zone in a biosorption column', *Environmental Science and Technology*, Vol. 40, No. 12, pp.3996–4003.

Naja, G., Mustin, C., Volesky, B. and Berthelin, J. (2005) 'A high-resolution titrator: a new approach to studying binding sites of microbial biosorbents', *Water Research*, Vol. 39, No. 4, pp.579–588.

Rajwade, J.M. and Paknikar, K.M. (2003) 'Bioreduction of tellurite to elemental tellurium by pseudomonas mendocina MCM B-180 and its practical application', *Hydrometallurgy*, Vol. 71, Nos. 1–2, pp.243–248.

Schiewer, S. and Volesky, B. (1995) 'Modeling of the proton-metal ion exchange in biosorption', *Environmental Science and Technology*, Vol. 29, No. 12, pp.3049–3058.

Tabak, H.H., Scharp, R., Burckle, J., Kawahara, F.K. and Govind, R. (2003) 'Advances in biotreatment of acid mine drainage and biorecovery of metals: 1 metal precipitation for recovery and recycle', *Biodegradation*, Vol. 14, No. 6, pp.423–436.

Tolley, M.R., Smyth, P. and Macaskie, L.E. (1992) 'Metal toxicity effects the biological treatment of aqueous metal wastes – is a biocatalytic system feasible for the treatment of wastes containing actinides', *Journal of Environmental Science and Health Part a: Environmental Science and Engineering and Toxic and Hazardous Substance Control*, Vol. A27, No. 2, pp.515–532.

Townsley, C.C., Ross, I.S. and Atkins, A.S. (1986) 'Biorecovery of metallic residues from various industrial effluents using filamentous fungi', in Lawrence, R.W, Branion, R.M.R. and Ebner, H.G. (Eds.): *Fundamental and Applied Biohydrometallurgy*, Elsevier, Amsterdam, The Netherlands, pp.279–289.

Tsezos, M. (1984) 'Recovery of uranium from biological adsorbents – desorption equilibrium', *Biotechnology and Bioengineering*, Vol. 26, pp.973–981.

van Hille, R.P., Peterson, K.A. and Lewis, A.E. (2005) 'Copper sulphide precipitation in a fluidised bed reactor', *Chemical Engineering Science*, Vol. 60, No. 10, pp.2571–2578.

Volesky, B. (2003) *Sorption and Biosorption*, BV Sorbex, Montreal, Canada, www.biosorption.com/order