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Applied Spectrometry Associates, Inc.
W226 N555G Eastmound Drive
Waukesha, WI 53186

Phone: (414) 650-2280
FAX: (414) 650-2285

CHEMSCAN - AN ON-LINE ULTRAVIOLET SPECTRAL PROCESS ANALYZER

Bernard J. Beemster and Kenneth J. Schlager
Biotronics Technologies, Inc.
W226 N555B Eastmound Dr.
Waukesha, WI 53186
(414) 896-2650

Abstract

ChemScan is a product line of ultraviolet, on-line process analyzers that grew out of a NASA SBIR program targeted at on-line monitoring of plant nutrient solutions as part of the NASA CELSS program. The original goal for NASA was to provide on-line measurement of all the hydroponic plant nutrients necessary to develop and maintain a plant growth facility in space. Two different spectrometric techniques were applied to provide on-line measurements of all plant nutrients. One technology, ultraviolet absorption spectrometry, provided on-line measurements of nitrate, iron and some of the transition metal nutrients. This technology not only demonstrated a capability to meet these CELSS needs but has now been incorporated into a family of commercial analytical instruments used for environmental process monitoring and control applications.

A second technology, Liquid Atomic Emission Spectrometry (LAES), also originated in this same NASA SBIR, is still at an earlier stage of development and is expected to reach the market in the next 18-24 months.

INTRODUCTION

Long term space missions require interactive life support systems, where the crew can participate in the exchange of consumables and waste products within an artificial environment on board the spacecraft. This Controlled Ecological Life Support System (CELSS) includes the production of hydroponically grown plants, which provide a source of food, contribute oxygen and consume carbon dioxide within the space capsule. The plants, which include grains, lettuce, potatoes, peanuts and other crops, are characterized by rapid growth cycles, minimal consumption of resources and high concentrations of protein. The hydroponic nutrient solutions are a complex chemical matrix that contain all of the nutrients and trace elements necessary for plant growth. Light and atmosphere are also provided.

Plants uptake specific nutrients and trace elements at different rates depending on their nature and upon the their stage of growth. A depletion of any of the nutrients or trace elements in the recirculating nutrient solution can retard plant growth or result in the loss of the crop. It is therefore necessary to frequently monitor the chemistry of the nutrient solution to assure that the correct concentration of each component is maintained. If a specific component is deficient, the solution must be adjusted to resolve the deficiency. Table 1 shows the components of a typical nutrient solution for hydroponics.

On January 3, 1990, Biotronics Technologies was awarded a Phase I SBIR, Fiber Spectrometry for On-Line Analysis of Nutrient Solutions. NASA's objective for the SBIR project at Biotronics was to promote the development of a system to automate the task of nutrient solution chemical analysis and nutrient component adjustment. The Phase I project was to evaluate the feasibility for a single compact system that would be capable of performing automatic on-line analysis of all of the hydroponic nutrient solution components and could provide information to a feed control system to adjust the hydroponic solution chemistry as required.

DESCRIPTION OF THE TECHNOLOGIES

A very important secondary objective for the Phase I project was the evaluation of methods that could eliminate sample preparation and wet chemistry steps for the analysis. If the analysis is to be performed on an unfiltered "raw" sample which is nevertheless a complex chemical matrix, the selected technology must be able to be selective for each component or eliminate the effects of background chemistry while analyzing for a specific component. The hypothesis advanced by Biotronics was that pattern recognition techniques could be used in conjunction with spectrometry to characterize the contribution from each component to the overall spectral signature of the solution, and thus yield information concerning

TABLE 1. Nutrient Solution: Desired Concentration Levels

Component		Typical ppm	ppm Range
Potassium	(K)+	117	39-156
Nitrogen	(NO3)-	105	70-140
Phosphorous	(H2PO4)-	15	9-22
Calcium	(Ca)++	100	60-140
Magnesium	(Mg)++	24	12-36
Sulphur	(SO4)--	32	16-48
Sodium	(Na)+	11	2-18
Chlorine	(Cl)-	17	3-28
Iron	(Fe)+++	5	3-11
Boron	(BO3)---	0.249	0.162-0.432
Manganese	(Mn)++	0.253	0.165-0.549
Copper	(Cu)++	0.024	0.012-0.127
Zinc	(Zn)++	0.01	0.006-0.131
Molybedenum	(MoO4)--	0.005	0.004-0.096

the concentration of the component in the solution. The approach selected employed a combination of Ultraviolet-Visible Absorbance Spectrometry (UVAS), Liquid Atomic Emission Spectrometry (LAES) and chemometric analysis algorithms. The techniques have been the subject of numerous technical papers and reports (Schlager and Ruchti 95). A graphic presentation of the technical concept can be found on Figure 1.

Although spectrometry is a well established laboratory technology, its use for on-line analysis applications is highly innovative, particularly so when multiple wavelength data is obtained and the system must be calibrated to recognize matrix changes resulting from the change in concentration of a single component. This is particularly challenging in a dynamic situation, where several components can be changing simultaneously. Pattern recognition techniques were demonstrated to be capable of extending the utility of a well known laboratory technique such as UVAS and of being the foundation for a new technique such as LAES.

During the Phase II project, a prototype spectrometer that incorporated both UVAS and LAES technology was designed, tested and applied to the analysis of hydroponic nutrient solutions. This prototype instrument was delivered to the Kennedy Space Center for evaluation in on-line operation. The UVAS portion of the instrument performed reasonably well in on-line testing, but the LAES instrumentation required a significant degree of expert attention to produce accurate values. While UVAS technology was ready for commercialization, LAES technology required additional development (Schlager 92)(Beemster, Schlager, Kahle and Wilson 92).

Since that time the LAES technology has received strong support from a number of federal agencies including NASA, the U.S. Navy and the U.S. Air Force. The Naval Research Laboratory sponsored an oceanographic development of LAES called OHAES system (for Oceanographic Hybrid Absorption Emission Spectrometer). This system was tested on an oceanographic training ship at the United States Naval Academy in Annapolis, Maryland during the year 1993 with significant success. More recently, the U.S. Air Force on an SBIR program has supported the development of a groundwater

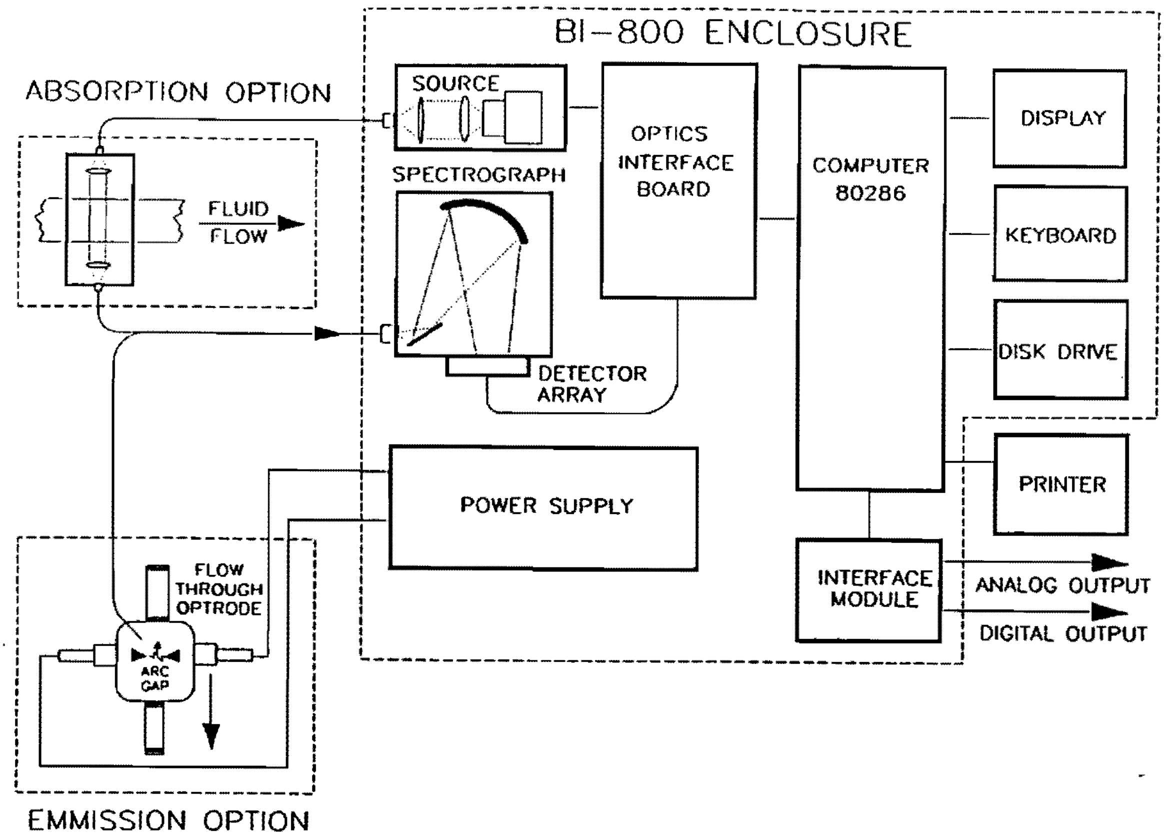

Figure 1. Hybrid Absorption/Emission Spectrometer

toxic metals version of LAES for environmental remediation application. And finally, NASA has continued its support of the program through the Johnson Space Center CELSS group under Dr. Keith Henderson where a Phase I SBIR was completed on a new version of LAES. The primary remaining problems of LAES development relate to improved accuracy and reducing the need of operator intervention. Great progress has been made in both of these areas, particularly on the recent NASA SBIR program. Prospects now indicate that LAES will be ready for commercialization in about 18 months. The primary markets targeted will be the electronics manufacturing and the metal plating industries (Beemster and Kahle 93)(Kahle and Beemster 95)(Beemster and Kahle 95).

COMMERCIALIZATION STRATEGY

A technology, even if reduced to a prototype and demonstrated as feasible for a specific NASA application, may not be close to the form required for commercialization. A technology, to be commercialized, must be incorporated into a specific product. And specific products, to be successful, must be targeted to specific customer applications. NASA applications do not often duplicate mass market commercial applications since each have their own unique performance specifications and operating conditions. Therefore, the first commercialization task for a NASA technology is the selection of target commercial customers and applications. This is exactly the reverse of the typical commercial development process, where the starting point is the customer application, followed by the development of a product that incorporates whatever technologies are appropriate to meet the needs of the customer. When the starting point is a given technology, care must be taken to select an application that makes economic use of the technology. There must also be a willingness to adapt the technology to the application requirements of a specific target customer.

At Biotronics, there was a temptation to select the greenhouse industry as a commercial target, as this was the commercial application most similar to the NASA application, especially the hydroponic greenhouse segment. Upon examination, however, it was apparent that the industry, while very large in economic terms, was characterized by a great many small facilities and a few very large facilities. Only the few very large facilities could afford the probable cost of an on-line analyzer system, and it was unlikely that very many of these facilities could justify the cost of a system for periodic automatic chemical analysis to replace their manual sampling and testing routines. The potential benefits that drive use of the technology for space applications (unmanned automatic monitoring of multiple nutrient parameters with a single compact system) simply did not translate into the equivalent commercial application. In the space application, if a crop is lost, so too may be the mission or the crew. In the commercial application, only some money is lost. In the space application, the cost of manual testing and adjustment is very high in terms of the alternative uses of the time. In the commercial applications, the cost is very low.

It was apparent that applications needed to be found where the economics could justify the projected $10,000 to $30,000 selling price for an on-line ultraviolet spectrometer product. The likely attributes of such applications were:

1. nutrients or heavy metals as the measured parameter

2. aqueous media

3. a critical need for "real time" analysis due to

    a. the production of a high value product, or
    b. control of a critical processes, or
    c. controlled feed of expensive chemicals.

It was also clear that significant funding beyond the SBIR program would be needed to design, test, introduce and market commercial products for any mass market application. Thus an additional requirement was defined for a partner that would fund the development of an initial product.

An initial application that was identified was the monitoring and control of recirculating cooling water. In these applications, specially formulated chemicals are added into the cooling water for control of scale and corrosion within the cooling system. If underfed, heat exchange efficiency is reduced and if not corrected, a mechanical failure within the system could result. If overfed, the cost of the chemical treatment program will be excessive. The treatment formulations typically contain heavy metals (zinc, chromate, molybdate) and other components with strong ultraviolet absorbance. The ability of the technology to detect the specific chemicals used in these formulations was confirmed in a series of laboratory tests at Biotronics. The application thus appeared to meet the technical criteria.

The cooling water treatment market is not a fragmented market. In fact, the market is very close to a classic monopsony (shared monopoly) where a few firms control all or most of the market. In this case, over 80% of the market is controlled by the top 5 firms. A competitive advantage for any of these firms can have a significant long term impact on market share. Biotronics was fortunate to form a relationship with one of the top three firms in the water treatment industry, who provided funding for the design of an on-line analyzer that could be used in an industrial environment and would be used to detect certain components in the specific products manufactured by the firm. This program ran in parallel with the completion of the Phase I SBIR and the initial activity under the Phase II SBIR and involved both the design and manufacture of on-line analyzer products. The design of the analyzer, while exclusive for the cooling water application, was available for Biotronics to use in any other application.

The second commercial application selected by Biotronics was the monitoring and control of municipal wastewater treatment processes. The processes are characterized by a variable chemistry, which changes with the time of day and the mix of industrial wastes that enter the treatment plant. This creates a variable demand for the treatment process, including the chemicals that are introduced as a part of the treatment process. These treatment plants have enormous volumes and their output is expected to meet strict requirements. The parameters of most importance are nutrients such as nitrate, ammonia and phosphate. Here again, preliminary tests conducted at a wastewater treatment plant in Wisconsin indicated that a parameter such as nitrate, which had been successfully detected on-line in NASA nutrient solutions, could also be detected on-line in wastewater.

The work at Biotronics to develop applications in municipal wastewater treatment were conducted following completion of the NASA Phase II project and in parallel with the later stages of the cooling water analyzer development project. The marketing channel is a network of independent manufacturer's representatives.

As acceptance of both OEM cooling water products and municipal water and wastewater products accelerated, it became clear that a sustainable business had emerged. It was also clear that this business required an infusion of management, technical and capital resources in order to maximize its long term potential. A strategy was developed to spin-off the products and technology into a separate company that could raise its own equity and debt financing.

Commercialization of the ChemScan product line at Biotronics raised some serious questions concerning the proper organizational approach to commercialization of any technology using an SBIR. Biotronics' experience would indicate that there are three basic overall approaches to commercializing the results of a successful SBIR program:

1. Product-Market Dedication
   The SBIR company can shift its primary focus to the developed technology deemphasizing all other research and development.

2. Spin-Off Company
   The SBIR company can initiate the formation of a new spin-off company that sharply focuses on the newly-developed technology and marshals the managerial and financial resources to commercially launch the product and sustain a profitable on-going business.

3. External Licensing
   Licensing the technology to a corporate partner represents a third alternative. This alternative was explored, but the terms offered by potential partners did not seem very attractive. There was also some question whether the technology would receive the attention and support it seemed to require.

The first of these alternatives would seem to have been the intention of Congress in establishing the SBIR program. The emphasis on Phase III commercialization is usually formulated in this context.

Since Biotronics is currently the developer of a number of potentially commercially attractive technologies, however, the single product-market dedication alternative is not a particularly attractive one. For this reason, Biotronics has selected the second alternative - the spin-off company. Such an alternative allows for the continued pursuit of multiple technology developments by Biotronics while at the same time providing the focus and resources necessary for successful commercialization.

One concept appears quite clear. A third alternative of trying to service multiple technology developments while launching a new commercial venture internally is really not a viable one. For over two years, attempts to blend a multiple project R and D program with the start of the ChemScan business severe strained the resources of a small technology company. The product did get launched, orders were received and products were successfully installed in customer installations, but the experience only emphasized the need for both the focus and resources necessary for real commercial market success.

Although there are undoubtedly many variations within the above two commercialization approaches, it must also be clear that Congress did not envision an SBIR program where small companies would accumulate SBIR awards like trophies with little or no attempt at follow-on commercialization. There seems little rhyme or reason to support SBIR as a small business corporate welfare program.

CONCLUSIONS

The NASA SBIR program for the development of an on-line ultraviolet process analyzer fulfilled both a NASA need in CELSS and laid the foundation for a product development program that launched a new instrumentation business. The two key ingredients for successful commercialization at Biotronics were:

1. Finding a corporate partner that would support product development in return for a restricted market application leaving Biotronics free to pursue other markets for the product.

2. Forming a spin-off group (initially a division and later a separate company) to develop, manufacture and market the product.

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References

Beemster, B.J., K.J. Schlager, S.J. Kahle and M.A. Wilson (1992) "A Hybrid Absorption/Emission Spectrometer for In-Situ Detection of Toxic Chemicals in Water and Wastewater, Hazardous Materials and Environmental Management Conference & Exhibition", Detroit, Michigan.

Beemster, B.J. and S.J. Kahle (1993) "On-Line Analysis of Nitrate and Iron in Drinking Water, American Water Works Association", San Antonio, Texas.

Beemster, B.J. and S.J. Kahle (1995) "On-Line Analysis of Nitrate and Nitrite in Wastewater Without the Use of Reagents Through Multiple Wavelength Absorbance Spectrometry, Water Environment Federation Specialty Conference", Minneapolis, MN.

Kahle S.J. and B.J. Beemster (1995) "The Use of Multiple Wavelength Ultraviolet-Visible Spectrometry for On-Line Analysis of Wastewater Process Samples, Water Environment Federation Specialty Conference", Minneapolis, MN.

Schlager, K.J. and T. L. Ruchti (1995) "An Overview of Chemometrics, SPIE Biomedical Optics '95 Conference", San Jose, California.

Schlager, K.J. (1992) "Instrumentation for Plant Health and Growth, COSPAR", Washington, D.C.