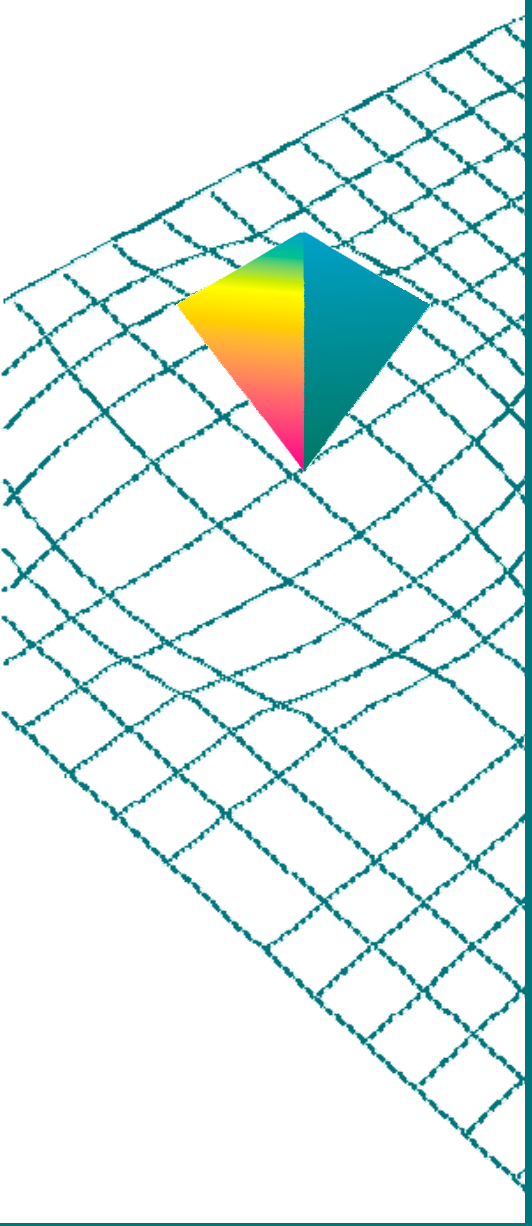
TECHNISCHE UNIVERSITÄT
ILMENAU

50. Internationales Wissenschaftliches Kolloquium

September, 19-23, 2005



Maschinenbau von Makro bis Nano / Mechanical Engineering from Macro to Nano

Proceedings

Fakultät für Maschinenbau /
Faculty of Mechanical Engineering

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=15745

Impressum

Herausgeber:	Der Rektor der Technischen Universität Ilmenau Univ.-Prof. Dr. rer. nat. habil. Peter Scharff
Redaktion:	Referat Marketing und Studentische Angelegenheiten Andrea Schneider Fakultät für Maschinenbau Univ.-Prof. Dr.-Ing. habil. Peter Kurtz, Univ.-Prof. Dipl.-Ing. Dr. med. (habil.) Hartmut Witte, Univ.-Prof. Dr.-Ing. habil. Gerhard Linß, Dr.-Ing. Beate Schlütter, Dipl.-Biol. Danja Voges, Dipl.-Ing. Jörg Mämpel, Dipl.-Ing. Susanne Töpfer, Dipl.-Ing. Silke Stauche
Redaktionsschluss: (CD-Rom-Ausgabe)	31. August 2005
Technische Realisierung: (CD-Rom-Ausgabe)	Institut für Medientechnik an der TU Ilmenau Dipl.-Ing. Christian Weigel Dipl.-Ing. Helge Drumm Dipl.-Ing. Marco Albrecht
Technische Realisierung: (Online-Ausgabe)	Universitätsbibliothek Ilmenau ilmedia Postfach 10 05 65 98684 Ilmenau
Verlag:	isle Verlag ISLE, Betriebsstätte des ISLE e.V. Werner-von-Siemens-Str. 16 98693 Ilmenau

ISBN (Druckausgabe):	3-932633-98-9	(978-3-932633-98-0)
ISBN (CD-Rom-Ausgabe):	3-932633-99-7	(978-3-932633-99-7)

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=15745

50. Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
19.-23. September 2005

J. H. AGARWAL and VIJAYA AGARWAL

Potential Applications of Chip-based Systems for Management of Quality and Food Safety in Dairy Processing Industry

ABSTRACT

QUALITY AND SAFETY OF PRODUCTS, CONFORMING TO LEGISLATIVE regulations, is an important consideration for dairy processing industry. Time-consuming and laborious techniques involving wet-chemistry are currently used for monitoring the product quality on off-line basis. Regulatory agencies and dairy processing industry need fast, cost-effective, on-line and automated methods that are accurate and reliable for rapid and frequent monitoring and quality control of raw materials and products at various stages of a production process.

The chip-based technology, using the miniaturized electronic mechanics (MEM), has a great potential for quality monitoring of a product in dairy processing. Unlike conventional quality and process control systems, the technology facilitates low-cost device-level integration of on-line measurements, quality monitoring and process control functions as the microprocessor and microcontroller components are embedded in to the chips.

The widespread use of antibiotics and chemotherapeutics to control diseases and improve animal performance in dairy parlors has led to the occurrence of veterinary drugs and chemical residues in dairy products. Many countries have introduced more restrictive control measures but traditional microbial and test methods are not sensitive enough to meet new regulations and classical analytical techniques are often precluded owing to the

level of experience, skills and cost required. Biosensors, biochips and biochip-arrays technologies, based on a concept to use the chip as a reaction platform with single or multiple specific antibodies attached on the surface, offer alternative methods to detect and measure concentrations of residues and contaminants (such as pesticides, antibiotics, growth promoters, veterinary drugs, pathogenic bacteria and their toxins). These methods are highly sensitive, do not require elaborate sample preparation, and can be rapidly carried out on-line at a low cost. Besides, the biosensors can also be used in the detection of metabolic levels in veterinary testing and animal husbandry, for example estrus detection by monitoring progesterone levels in milk, on-set of spoilage in meats.

Some state-of-the-art devices are described and their scope in quality and food safety in dairy processing industry is discussed illustrating a few applications.

Keywords: *Biosensors, chip-based systems, instrumentation, on-line testing, quality and safety, dairy products, contaminants and residues.*

1. 0 BIOSENSORS, BIO-CHIPS AND BIOCHIP-ARRAYS

1.1 Biosensor

A BIOSENSOR IS A COMPACT ANALYTICAL DEVICE INCORPORATING A biological or biologically derived sensing element either integrated within or intimately associated with a physicochemical transducer. The usual aim of a biosensor is to produce either discrete or continuous digital electrical signals which are proportional to single analyte or a related group of analytes [1]. The main components of a biosensor are: a biological sensing element, a transducer, a signal conditioner, a data processor and a data display. The biocatalyst converts the substrate to product. The transducer that converts it to an electrical signal determines this reaction. The key part of a biosensor is the transducer, which makes use of a physical change accompanying the reaction. The reaction, typically, may be heat absorption or generation as in calorimetric biosensors, changes in distribution of charges causing a electrical potential to be produced

(potentiometric biosensors), movement of electrons produced in a redox reaction (amperometric biosensensors), effects due to mass of the reactants or products (piezo-electric and microcantilever biosensors), generation or absorption of optical radiation during the reaction (optical biosensors).

1.2 Biochip

A biochip is a solid subtract with multiple specific ligands - such as antibodies, antigens – attached at pre-defined sites on the surface. The chip utilizes the basic principle of immunology. In a typical biochip [2], up to about 25 tests are pre-fabricated onto the biochip surface. With advancement in technology, the capacity of tests per chip is on increase.

1.3 Biochip-Array

The technology is based on the concept to use a biochip as a reaction platform, with multiple specific ligands. After addition of a sample to the biochip, analytes present in the sample bind to specific ligands and generate corresponding chemi-luminescent signals for the measurements.

Dedicated user-friendly software(s) control all operations from onboard maintenance, to calibration validation, to automatic system initialization, to sample profiling for a variety of tests with a facility to pre-defined cut-off values for semi-quantitative measurements – a feature desirable for on-line quality and process control in production processes.

1.4 Microprocessors and Microcontrollers Embedded Chip-based Systems

Unlike conventional systems for quality and process controls in production units, the chip-based systems facilitate cost-effective device-level integration of on-line measurements, quality monitoring and process control functions. For this purpose, the microprocessor and microcontroller components are embedded into the chips.

Conventional modular systems used for quality control functions in production processes are with a sensing module, a processing module (usually a microcomputer or a computer)

and a control module that are separately housed and functionally wired to each other. In chip-based systems, these modules can be easily integrated. Analog signals from the transducer after signal amplification and noise filtration are converted to digital signals and passed to a microprocessor where the data is processed. The signal amplifier, noise filtering unit and the microprocessor are embedded in the chip itself. A microcontroller can be added into the chip for control functions. The integrated package – the sensor, associated electronic circuit, the microprocessor and the microcontroller – acts as an on-line quality control device by which certain parameters related to quality of the product can be monitored and controlled within the pre-specified limits. In further developments, a wireless circuit is added to the chip for non-contact interface between the chip and the external equipment.

2.0 QUALITY MONITORING OF MILK

2.1 Measurement of Progesterone

Estrus detection is a financial concern in reproductive management of dairies, as missed estrus is a main cause of lost income. A biosensor reported by Claycomb and Delwiche [3] was employed for measurement of progesterone in bovine milk and detection of estrus. The sensor was designed to operate on-line using microinjection pumps and valves for fluid transport, fiber optics and photodiodes for light measurement, and a control computer to control the sequencing of operation.

2.2 IGF-1 Detection in Milk

Recombinant bovine somatotropin (rBST) treatment is adopted in dairy parlors to augment cows' milk yield. Insulin-like growth factor-1 (IGF-1), a suspected carcinogen, is present in milk from cows treated with rBST. Its presence in milk for human consumption is potentially a health hazard. A surface plasmon resonance-based biosensor system was developed [4] for evaluation of IGF-1 in cows' milk. The features of the technology – fully automated, measures in real time, and sharpened yes/no response offer several advantages compared to conventional enzyme-linked immunoassay (ELISA).

2.3 Fat, Protein, Lactose, Urea, SNF, Bacteria and Somatic Cells in Milk

and Milk Products

Semi-automatic, off-line detection and measurements on components and constituent values of fat, protein, lactose, SNF, urea, individual bacteria (such as bacillus, lactobacillus, pseudomonas, bacterium) and somatic cells are performed by near-infrared techniques and flow cytometry [5]. Flow cytometry is a method to measure various biological parameters of cells by first treating them with light absorbing or fluorescing compounds and then passing them through a narrow fluid stream that is interrogated with a laser beam. These instruments are computer controlled and software driven. With some modifications and employing auto-sampling attachments, the systems can be adopted for on-line working, however at higher costs compared to that of chip based systems.

2.4 Urea in Milk

A potentiometric biosensor, in which the bio-component part was an urease coupled to an ammonium ion selective electrode of a transduder, was developed for measurement of urea concentrations in milk samples. Response time was low, typically 2 min. Emerging concern of the presence of urea in milk, in particular in "synthetic milk", necessitated the development of the technique [6].

2.5 Pesticide residue in milk

In immunoassay-based pesticide detection systems, the enzyme linked immunosorbent assay (ELISA) combines selective antibodies with sensitive enzyme reactions to produce analytical systems capable of detecting very low levels of pesticides. The immunochemical reaction contributes high selectivity due to the extraordinary discriminatory capability of antibodies. The powerful catalytic ability of the enzyme provides highly sensitive detection [7].

A rapid immunoassay kit for pesticide detection [8] utilizes micro-sized magnetic particles as solid support. Detection and quantification of a pesticide in a sample involves three steps. Step 1: The sample to be analyzed, an enzyme conjugate (a pesticide labeled with an enzyme), and the magnetic particles with attached antibodies are added to a disposable test tube. Incubation for 15-20 minutes is carried out. Any pesticide present in

the sample and the pesticide in the enzyme conjugate compete for the limited number of antibody binding sites on the magnetic particles. Step 2: A magnetic field is applied to the test tube. All particles are pulled and held to the tube wall while unbound reagents are decanted. Particles are washed twice. Step 3: A colour reagent is added to develop a coloured immunocomplex in which the colour intensity is inversely proportional to the concentration of the pesticide in the sample. The colour intensity is measured spectrophotometrically. A microprocessor-based analyzer automatically converts immunoassay optical readings to sample concentrations. Programs for various assay methods are stored along with the calibration data for convenient and instantaneous operation.

The kit provides highly sensitive detection. Typical detection ranges for some of the pesticides in liquid samples are: 0.05 to 5.0 ppb (parts per billion) for alachlor, 0.25 to 100 ppb for aldicarb, 0.046 to 5.0 ppb for atrazine, 0.1 to 5.0 ppb for carbendazim, 0.25 to 3.0 ppb for carbaryl, 0.06 to 5.0 ppb for carbofuran, 0.04 to 3.0 ppb for cyanazine, 0.7 to 50 ppb for 2,4-D, 0.05 to 5.0 ppb for metolachlor, and 0.02 to 5.0 ppb for paraquat.

Specific immunoassays, using an amperometric biosensor, for detection of 2.4-D and 2,4,5-T herbicides were developed [9]. The total time for assay was less than 20 min. The ranges of detection of 2,4-D and 2,4,5-T were $1x10^{-11}$ to $5x10^{-7}$ M and $5x10^{-11}$ to $5x10^{-7}$ M, respectively. For determination of 2,4-D in milk, the method was applied without a sample pre-treatment.

A biosensor-based pesticide detection technique, employing surface plasmon resonance and using real-time biospecific interaction analysis, is reported for detection of pesticides [10]. The biospecific interface was a sensor chip to which a derivative of atrazine had been covalently bound. Monoclonal antibodies against atrazine were mixed with the sample containing herbicide, and then the solution reacted with the biospecific interface. As the interaction between free antibodies and the immobilized derivative bound to the surface proceeded, the surface plasmon resonance response changes inversely to the concentration of atrazine. A detection limit of 0.05 ppb of atrazine in

sample was reached. The analysis time was about 15 minutes, and after each measurement regeneration of the sensor chip was carried out. In some recent developments, plastic disposable biosensors and piezoelectric crystal biosensors with surface modification are being experimented and perfected for detection of pesticides in liquid samples.

2.6 Detection of Toxins

Under an USDA-ARS National Program on Food Safety, a biosensor-based immunoassay using suface plasmon resonance has been developed [11] to detect *Staphylococcus auresus* enterotoxin A and B in food samples such as milk, meats. These toxins cause gastroenteritis. The toxin molecules in the sample bind to the sensor surface, and the refractive index at the surface changes. The time it takes for a response from the interaction provides a measure of how much toxin is actually present in the sample. The method can detect multiple bacterial toxins in a sample. Detection level is of the order of 10 ppb of toxin per gram of sample.

2.7 Detection and Assays for Bacteria

Test kits, based on adenosine triphosphate (ATP) bioluminescence, for on-site, same day detection and assays of food-borne pathogens *E. coli O157, Listeria* and *Salmonella* are now available [12, 13]. The fastest testing laboratory procedures currently in use require at least 24 hours delivering the results, at which point the products are to be stored awaiting clearance

3.0 QUALITY MONITORING OF MEATS

3.1 Meat Freshness Assessment

For rapid assessment of meat freshness, a biosensor-array was employed to measure glucose concentration at depths of 2 and 4 mm below the meat surface [14]. The results indicated that *in situ* assessment of complex food conditions such as microbial or oxidative spoilage, progressive fermentation is feasible by using a knife-probe biosensor-array that provides glucose depth profiling close to the surface.

3.2 Detection of Meat Spoilage and Aging

A sensor composed of Ag/AgCl electrode and a platinum electrode on which putrescine or xanthine oxidase were immobilized was used to monitor meat quality to estimate bacterial spoilage and progress of aging [15]. The method was based on potential-step chrono-amperometric technique in which the potential applied was stepped from 300 mV to 600 mV. The results indicated that with some modifications and further refinements the method can be used for the estimation of meat quality during aging.

In another approach [16], a two-line flow injection analysis (FIA) biosensor was used for simultaneous detection of bacterial spoilage and the progress of aging. The sensor was applied to a vacuum packed meat stored at 0.5 and 10 deg C. The results indicated that the progress of aging could be monitored in the entire (0.5 - 10 deg) temperature range, and the bacterial spoilage could be detected before the appearance of putrid odour at 5 and 10 deg C. Thus the FIA biosensor is useful for quality control of meat aging at 5 and 10 deg C, but not at 0 deg C.

3.3 Electronic Olfaction for Spoilage Detection

For dairy processing and food industry, electronic olfaction devices (e-noses), are being experimented to sense bacterial contamination and resulting spoilage in products. A typical e-nose has two major components: a sensor that detects odours and a set of electronic circuit elements that interprets the resulting signals. The sensor incorporates materials like metal oxides or advanced polymers. When exposed to certain volatile compounds or combinations of them, the sensor material changes its size, colour, or electrical resistance. By using several different materials in an array of sensors mounted on a single chip, an e-nose is made to sense multi-odours [17, 18].

3.4 Molecularly Imprinted Polymers for Meat Freshness

One of the markers of meat spoilage is the decarboxylation of free amino acids in meat by enzymes released by spoilage micro-organisms. Presence of two of these products, putrescence (1,4-diaminopentane) and cadaverine (1,5-diaminopentane), correlate well with surface bacteria counts. Molecularly imprinted polymers (MIPs), a class of

synthetic polymers that are tailored to selectively detect a particular substance, undergo a detectable colour change when brought in contact with biogenic amines (such as putrescence, cadaverine). This property is used in evaluation of meat freshness. MIPs can be incorporated into meat containers or employed in fiber optic detection devices to detect probable spoilage of meat within the container.

4.0 DRUG RESIDUE IN MEATS, MILK AND MILK PRODUCTS

Drug-use plays an integral part of modern dairying. Some veterinary drugs were originally introduced to improve animal health and enhance their performance; for example, anabolic steroids (testosterone, trenbolone) and B-agonists (clenbuterol, brombuterol) – to increase the quality and efficiency of meat production; corticosteroids – for cattle fattening; oestrogenic hormones (stillbenes, zerol) – for growth promotion in cattle; antibiotics (chloramphenicol, sulphadiazine) – for treatment of diseases (pneumonia, rhinitis, mastitis). Many such drugs accumulate in animal tissue and enter the food chain for human consumption once the animal is slaughtered for meat or through other products of dairies. These drugs can have detrimental effects on human. As the use of drugs can not be totally prevented, it has become necessary to take measures to protect the consumers from the effect of drug residues in food.

Sensitive and cost effective methods of monitoring drug residue in dairy products are essential to ensure that residue levels remain within the permitted regulatory limits. Chromatographic methods like gas chromatography – mass spectrometry (GC-MS), LC-MS have been used to monitor drug residue levels. Some diagnostic kits employ ELISA technology for the measurements. An ELISA based commercially available kit [19] can be fully automated. The kit has certain advantages over the conventional GC-MS; such as: 5 to 10 times greater sensitivity, ready to use support for sample pre-treatment, faster operation (a throughput of up to 120 samples in 2-3 hours), lower equipment cost and easy-to-use.

5.0 CONCLUDING REMARKS

Pressure on the dairy processing industry to bring quality and safe products to market has never been so intense. With standards in food safety continually on the rise and increasingly attentive consumers to satisfy, the technology to monitor product quality plays a vital role. Biosensors and chip-based systems show a great potential for applications in the dairy processing industry, particularly where rapid, low cost, high sensitivity and specificity measurements in on-line working are required. The technology, however, must overcome several obstacles before becoming a commercial success. Some of these are: faster transfer of technology from lab to industry, production and availability of reliable and inexpensive sensors specific to dairy product quality monitoring, and integration of the technology in the existing dairy processing systems.

REFERENCES:

[1] Collings, A.F. and F. Caruso (1997). Biosensors: recent advances. *Rep. Prog. Phys.*, Vol. 60, 1997, pp. 1397-1445.

[2] Randox Laboratories (2004). Evidence investigator and biochip array technology. Randox Laboratories Ltd., Antrim, UK, June 2004.

[3] Claycomb, R.W. and M.J. Delwiche (1998). Biosensor for on-line measurement of bovine progesterone during milking. *Biosensors and Bioelectronics*, Vol. 13, No. 11, Nov. 1998, pp. 1173-1180.

[4] Guidi, A., L.L. Robbio, D. Gianfaldoni, R. Revoltella and G.D. Bono (2001). Comparison of a conventional immunoassay (ELISA) with a surface plasmon resonance-based biosensor for IGF-1 detection in cows' milk. *Biosensors and Bioelectronics*, Vol. 16, No. 9, Dec. 2001, pp. 971-977.

[5] Bentley Instruments (2003). Analytical instruments for milk and milk products. Bentley Instruments, Inc., Chaska, Minnesota, USA, Apr. 2003.

[6] Verma, N. and M. Singh (2003). A disposable microbial based biosensor for quality control in milk. *Biosensors and Bioelectronics*, Vol. 18, No. 10, Sept. 2003, pp. 1219-1224.

[7] Agarwal, V. and J.H. Agarwal (2000). Remedial measures for environmental sustainability: Electronics and information technology based tools. *Third International R & D Conference on Sustainable Development of Water and Energy Resources*, 29 Feb. – 03 Mar. 2000, Jabalpur, India (Conference Proceedings, Vol. 2: Water Resources, pp. CS-30 – CS-42).

[8] Ohmicron (1999). Rapid Assays - meeting the challenge for a safe environment. Ohmicron, Newtown, Pennsylvania, USA, Aug. 1999.

[9] Medyantseva, E.P., M.G. Vertlib, M.P. Kutyreva, E.I. Khaldeeva, G.K. Budnikov and S.A. Eremin (1997). The specific immunochemical detection of 2,4-dichlorophenoxyacetic acid and 2,4,5-trichlorophenoxyacetic acid pesticides by amperometric cholinesterase biosensors. *Analytica Chimica Acta*, Vol. 347, No. 1-2, 30 July 1997, pp. 71-78.

[10] Minunni, M. and M. Mascini (1993). Detection of pesticide in drinking water using real-time biospecific interaction analysis. *Analytical Letters*, Vol. 26, No. 7, 1993, pp. 1441-1460.

[11] Core, J. (2005). New detection methods improve food safety. *Agricultural Research*, Vol. 53, No. 1, Jan. 2005, pp. 15-17.

[12] Alaska Food Diagnostics (2004). Fastrak - Ultra rapid testing instrument for food safety. Alaska Food Diagnostics PLC, Salisbury, UK, Oct. 2004.

[13] Neogen Corporation (2004). Foodborne test kits. Neogen Corporation, Lansing, USA, 2004.

[14] Rogers, E.K., E.J. D'Costa, J.E. Sollars, P.A. Gibbs and A.P.F. Turner (1993). Measurement of meat freshness in situ with a biosensor array. *Food Control*, Vol. 4, No. 3, 1993, pp. 149-154.

[15] Yano, Y., K. Yokoyama, E. Tamiya and I. Karube (1996). Direct evaluation of meat spoilage and the progress of aging using biosensors. *Analytica Chimica Acta*, Vol. 320, No. 2-3, 29 Feb 1996, pp. 269-276.

[16] Yano, Y., N. Miyaguchi, M. Watanabe, T. Nakamura, T. Youdou, J. Miyai, M. Numata and Y. Asano (1995). Monitoring of beef aging using a two-line flow injection analysis biosensor consisting of putrescine and xanthine electrodes. *Food Research International*, Vol. 28, No. 6, 1995, pp. 611-617.

[17] Schaller, E., J.O. Bosset and F. Escher (1999). Practical experience with electronic nose system for monitoring the quality of dairy products. *Chimia* (Swiss Chemical Society's *International Journal of Chemistry*), Vol. 53, No. 3, 1999, pp. 98-102.

[18] Agarwal, J.H. (2004). Anti-agriculture designs: suggested action plan. *IETE Technical Review*, Vol. 21, No. 2, March-April 2004, pp. 149-151.

[19] Randox Laboratories (2004). Drug residue. Randox Laboratories Ltd., Antrim, UK, March 2004.

Appendix 'A' lists some more references on topics related to quality and food safety.

ABOUT THE AUTHORS

J. H. AGARWAL. Former University Professor and Director (Instrumentation), Jawaharlal Nehru Agricultural University, Jabalpur, India. Dr. Agarwal is associated with several Ministries / Departments of Government of India as Expert Member on technical committees and is active in professional societies like Institution of Electronics and Telecommunication Engineers, Indian Science Congress, Computer Society of India.

He is a pioneer in the field of applications of Electronics, Microprocessors, Computers and Information Technology in Agriculture. In 1970s, associated as an Expert with the Electronics Commission of India and the Scientific Advisory Committee to the Cabinet, Govt. of India, he introduced the Applications of Electronics and allied technologies in Agriculture in India. Thereafter, he has been guiding a large number of programmes under the ICAR, CSIR, DST, DOE, and several Universities. During 1985 to 1995, Dr. Agarwal headed a prestigious project of UNDP and Govt. of India on "Applications of Microprocessors and Computers in Agriculture". Under the Project and deputed by the UNDP and GOI, he visited several countries (USA, UK, Australia, Germany, Japan, China, etc.) on technical missions.

He has been a Member of National Executive Committee of CSI and served as the Chairman of CSI Division III on Scientific Applications of Computers and Information Technology. He served on the National Council of Institution of Electronics and Telecommunication Engineers as its Vice President, and the DOEACC Society of Ministry of Communications and Information Technology, Govt. of India as a Member on its Governing Body.

VIJAYA AGARWAL. Presently with the Department of Agricultural Structures & Environmental Engineering, Electrical Engineering Division, at Jawaharlal Nehru Agricultural University, Jabalpur; India,

she holds a Postgraduate Degree in Electronics and Telecommunication Engineering. Her areas of interest are: Applications of Electrical, Electronics and Computer Engineering in Agriculture, Rural Electrification and Energy Efficient Systems. She has about 40 publications to her credit. She has chaired sessions and delivered key-note / invited lectures in several National and International Conferences.

Prof. Agarwal has been the President of the Engineering Sciences Section, Indian Science Congress during 1993-94. She served as a Member of the National Executive Committee and the National Council of the Indian Science Congress for several terms. She is also actively associated with the Indian Women Scientists' Association and contributing in their scientific activities. Countries visited : Austria, Canada & USA.

■

APPENDIX 'A'

Additional References :

Food and Drug Administration (1985). Animal Drug Analytical Manual, Association of Official Analytical Chemists, Arlington, VA, USA, 1985.

Food and Drug Administration (1987). Pesticide Analytical Manual Volume II: Methods for Individual Pesticide Residues, U.S. Department of Health and Human Services, Washington, DC, USA, 1987.

Food Safety Inspection Service (1991). Analytical Chemistry Laboratory Guidebook, U.S. Department of Agriculture, Washington, DC, USA, 1991.

Wieneke, A.A. (1991). Comparison of four kits for the detection of staphylococcal enterotoxin in foods from outbreaks of food poisoning. *International Journal of Food Microbiology*, Vol. 14, 1991, pp. 305-312.

Hartman, P.A., B. Swaminathan, M.S. Curiale, R. Firstenberg-Eden, A.N. Sharpe, N.A.Cox, D.Y.C. Fung and M.C. Goldschmidt (1992). Rapid methods and automation in food microbiology. In: Compendium of Methods for the Microbiological Examination of Foods, Vanderzant, C and D.F. Splittstoesser (Eds.), American Public Health Association, Washington, DC, USA, 3rd Edition, 1992, pp. 665-746.

Lehotay, S.J. and R.J. Argauer (1993). Detection of aldicarb sulfone and carbofuran in fortified meat and liver with commercial ELISA kits after rapid extraction. *Journal of Agricultural and Food Chemistry*, Vol. 41, No. 11, 1993, pp. 2006-2010.

Lehotay, S.J. and R.W. Miller (1994). Evaluation of commercial immunoassays for the detection of alachlor in milk, eggs and liver. *Journal of Environmental Science and Health*, Vol. 29 (Part B), No. 3, 1994, pp. 395-414.

Swaminathan, B. and P. Feng (1994). Rapid detection of food-borne pathogenic bacteria. *Annual Review of Microbiology*, Vol. 48, 1994, pp. 401-426.

Food and Drug Administration (1994). Pesticide Analytical Manual Volume I: Multiresidue Methods, 3rd Edition, U.S. Department of Health and Human Services, Washington, DC, USA, 1994.

Minunni, M., M. Mascini, G.G. Guilbault and B. Hock (1995). The quarz crystal microbalance as biosensor, a status report on its future. *Analytical Letters*, Vol. 28, 1995, pp. 749-764.

Venkitanarayanan, K.S., M.I. Khan and B.W. Berry (1996) .Detection of meat spoilage bacteria by using the polymerase chain reaction. *Journal of Food Protection*, Vol. 59, No. 8, 1996, pp. 845-848.

Medina, M.B. (1997). SPR Biosensors: food science applications. *Food Testing and Analysis*, Vol. 3, No, 5, 1997, pp. 14-15 & 36.

Artmann, R. (1997). Sensor systems for milking robots. *Computer and Electronics in Agriculture, Special Issue: Robatic Milking*, Vol. 17 (1), 1997, pp. 19-40.

Argauer, R.J., S.J. Lehotay and R.T. Brown (1997). Determining lipophilic pyrethroids and chlorinated hydrocarbons in fortified ground beef using ion-trap mass spectrometry, *Journal of Agricultural and Food Chemistry*, Vol. 45, No. 10, 1997, pp. 3936-3939.

Loung, J.H., P. Bouvrette and K.B. Male (1997). Developments and applications of biosensor in food analysis. *Trends in Biotechnology*, Vol. 15, 1997, pp. 369-377.

Witte, W. (1998). Medical consequences of antibiotic use in agriculture. *Science*, Vol. 279, 1998, pp. 996-997.

Nouws, J.F.M., G. Loeffen, J. Schouten, H.V. Egmond, H. Keukens and H. Stegeman (1998). Testing of raw milk for tetracycline residues. *Journal of Dairy Science*, Vol. 81, 1998, pp. 2341-2345.

Gehring, A.G., D.L. Patterson and S-I Tu (1998). Use of a light-addressable potentiometric sensor for the detection of *Escherichia coli* O157:H7. *Analytical Biochemistry*, Vol. 258, 1998, pp. 293-298.

Demarco, D.R., E.W. Saaski, D.A. Mccrae and D.V. Lim (1999). Rapid detection of *Escherichia coli* O157:H7 in ground beef using a fiber-optic biosensor. *Journal of Food Protection*, Vol. 62, 1999, pp. 711-716.

Ivnitski, D., I. Abdel-Hamid, P. Atanasov and E. Wilkins (1999). Biosensors for detection of pathogenic bacteria. *Biosensors and Bioelectronics*, Vol. 14, 1999, pp. 599-624.

Nice, E.C. and B. Catimel (1999). Instrumental biosensors: new perspectives for analysis of biomolecular interactions. *BioEssays*, Vol. 21, 1999, pp. 339-352.

Boer, E. and R.R. Beumer (1999). Methodology for detection and typing of foodborne microorganisms. *International Journal of Food Microbiology*, Vol. 50, 1999, pp. 119-130.

Gabaldon, J.A., A. Maquieira and R. Puchades (1999). Current trends in immunoassay-based kits for pesticide analysis. *Crit. Rev. Food Sci. Nutr.*, Vol. 33, 1999, pp. 519-538.

Wright, P.F.A. and E. Apostolou (1999). Advances in immunochemical methods of analysis for food contaminants. In: Environmental Contaminants in Food, Moffat, C.F. and K.J. Whittle (Eds.), CRC Press, Sheffield, UK, 1999, pp. 81-103.

Barth, K., R. Fishcer and H. Worstorff (2000). Evaluation of variation in conductivity during milking to detect subclinical mastitis in cows milked by robotic systems. In: Robatic Milking, Hogeveen, H. and A. Meijering (Eds.), *Proceedings of International Symposium*, Lelystad / Nederlands, 17-19 Aug. 2000, pp. 89-96, Wageningen Press, Wageningen, The Nederlands.

Mottram, T.T., J. Hart and R.M. Pemberton (2000). Biosensing techniques for detecting abnormal and contaminated milk. In: Robatic Milking, Hogeveen, H. and A. Meijering (Eds.), *Proceedings of International Symposium*, Lelystad / Nederlands, 17-19 Aug. 2000, pp. 108-113, Wageningen Press, Wageningen, The Nederlands.

Irwin, P., A. Gehring, S-I Tu, J. Brewster, J. Fanelli and E. Ehrenfeld (2000). Minimum detectable level of *Salmonellae* using a binominal-based bacterial ice nucleation detection assay (BIND). *Journal of AOAC International*, Vol. 83. No. 5, 2000, pp. 1087-1095.

Lehotay, S.J. (2000). Chemical residues. *National Conference on Animal Production Food Safety*, St. Louis, Missouri, USA, 06-07 Sept. 2000.

Lehotay, S.J. (2000). Multi-class, multi-residue analysis of pesticides, strategies for. In: Encyclopedia of Analytical Chemistry - Instrumentation and Applications, Meyers, R.A. (Ed.). John Wiley & Sons Ltd., Chichester, UK, 2000, pp. 6344-6384.

Lehotay, S.J. (2001). Need for rapid screening methods to detect chemical residues in food. In: Photonic Detection and Intervention Technologies for Safe Food, Chen, Y.R. and S-I Tu (Eds.), *Proceedings of SPIE* (International Society for Optical Engineering), Vol. 4206, 2001, pp. 112-122.

Lehotay, S.J., A.R. Lightfield, J.A. Harman-Fetcho and D.J. Donoghue (2001). Analysis of pesticide residues in eggs by direct sample introduction / gas chromatography / tandem mass spectrometry. *Journal of Agricultural and Food Chemistry*, Vol. 49, 2001, pp. 4589-4596.

Tu, S-I, M. Golden, P. Andreotti, L.S.L. Yu and P. Irwin (2001). Applications of time-resolved fluoroimmunoassay to detect magnetic beads captured *Escherichia coli* O157:H7. *Journal of Rapid Methods and Automation in Microbiology*, Vol. 9, 2001, pp. 71-84.

Russell, S.M. (2001). Evaluation of the BioSys optical method for rapidly enumerating population of aerobic bacteria, Coliforms and Escherichia coli from broiler chicken carcasses. *J. Appl. Poult. Res.*, Vol. 10, 2001, pp. 141-149.

Moore, G., and C. Griffith (2001). A comparison of traditional and recently developed methods for monitoring surface hygiene within food industry: a laboratory study. *Dairy Food Environ. Sanitation*, Vol. 21, 2001, pp. 478-488.

Ditcham, W.G.F., A.H.R. Al-Obaidi, D. McStay, T.T. Mottram, J. Brownlie and I. Thompson (2001). An immunosensor with potential for detection of viral antigens in body fluids (Short communication). *Biosensors and Bioelectronics*, Vol. 16, 2001, pp. 221-224.

Foss Electric (2001). In-line dairy process control with process analytics. *P/N 5802907, Issue 2 GB, June 2001*. Foss Analytical A/S, Hilleroed, Denmark.

Foss Electric (2001). Microfoss pasteurized milk and cream application. *P/N 1025408, Issue 1 GB, July 2001*. Foss Analytical A/S, Hilleroed, Denmark.

Foss Electric (2001). Integrated milk testing Milkoscan FT 6000 – milk compositional analysis at its best. *P/N 579557, Issue 2 GB, Sept. 2001*. Foss Analytical A/S, Hilleroed, Denmark.

Velasco-Garcia, M.N. and T.T. Mottram (2001). Biosensors in the livestock industry: an automated ovulation prediction system for dairy cows. *Trends in Biotechnology*, Vol. 19, 2001, pp. 433-434.

Hall, R.H. (2002). Biosensor technologies for detecting microbiological foodborne hazards. *Microbes and Infection*, Vol. 4, 2002, pp. 425-432.

Krynitsky, A.J. and S.J. Lehotay (2002). Overview of analytical technologies available to regulatory laboratories for the determination of pesticide residues. In: Handbook of Residue Analytical Methods for Agrochemicals, P.W. Lee (Ed.), John Wiley & Sons Ltd., Chichester, UK, 2002, pp. 753-786.

Zrostlikova, J., S.J. Lehotay and J. Hajslova (2002). Simultaneous analysis of organophosphorus and organochlorine pesticides in animal fat by gas chromatography with pulsed flame photometric and micro-electron capture detectors. *Journal of Separation Science*, Vol. 25, 2002, pp. 527-537.

Tu, S-I, M. Golden, P. Andreotti and P. Irwin (2002). The use of time-resolved fluoroimmunoassay to simultaneously detect *Escherichia coli* O157:H7, *Salmonella Enterica* serovar Thyphimurium and *Salmonella Enterica* serovar Enteriditis in foods. *Journal of Rapid Methods and Automation in Microbiology*, Vol. 10, 2002, pp. 37-48.

Tu, S-I, J. Uknalis, M. Gore and P. Irwin. (2002). The capture of *Escherichia coli* O157:H7 for light addressable potentiometric sensor (LAPS) using two different types of magnetic beads. *Journal of Rapid Methods and Automation in Microbiology*, Vol. 10, 2002, pp. 185-195.

Foss Electric (2002). Microfoss raw milk application. *P/N 1025340, Issue 1 GB, Jan. 2002*. Foss Analytical A/S, Hilleroed, Denmark.

Foss Electric (2002). Microfoss yoghurt application. *P/N 1025341, Issue 1 GB, Jan. 2002*. Foss Analytical A/S, Hilleroed, Denmark.

Foss Electric (2002). Integrated milk testing – the safe choice for professional milk analysis. *P/N 1025556, Issue 2 GB, June 2002*. Foss Analytical A/S, Hillerod, Denmark.

Foss Electric (2002). Milkoscan Minor. *P/N 1025570, Issue 1 GB, Nov. 2002*. Foss Analytical A/S, Hilleroed, Denmark.

Espada, E. and H. Vijverberg (2002). Milk colour analysis as a tool for the detection of abnormal milk. *The First North American Conference on Robatic Milking, Toronto, Canada*, Proceedings pp. IV 28-38, Wageningen Press, The Nederlands, 2002.

Trilk, J. (2002). The use of electric conductivity to control milk quality and udder health. *The First North American Conference on Robatic Milking, Toronto, Canada*, Proceedings pp. V 49-54, Wageningen Press, The Nederlands, 2002.

Mottram, T.T., M.N. Velasco-Garcia, P. Berry, P. Richards, J. Ghesquiere and L. Masson (2002). Automatic on-line analysis of milk constituents (urea, ketones, enzymes and hormones) using biosensors. *Comparative Clinical Pathology*, Vol. 11, 2002, pp. 50-58.

Velasco-Garcia, M.N. and T.T. Mottram (2003). Biosensor technology addressing agricultural problems. *Biosystems Engineering*, Vol. 84 (1), 2003, pp. 1-12.

Medina, M.B. (2003). Detection of staphylococcal exterotoxin B (SEB) with surface plasmon resonance biosensor. *Journal of Rapid Methods and Automation in Microbiology*, Vol. 11, 2003, pp. 225-243.

Mastovska, K. and S.J. Lehotay (2003). Practical approaches to fast gas chromatography – mass spectrometry. *Journal of Chromatography*, Vol. A.1000, 2003, pp. 153-180.

Yu, L.S.L., S.A. Reed, T. Tarkkinen and S-I Tu (2003). Detection of *Escherichia coli* O157:H7 from food by a microplate sandwitch immunoassay using time-resolved fluorometry. *Journal of Rapid Methods and Automation in Microbiology*, Vol. 11, 2003, pp. 133-143.

Lehotay, S.J. (2004). Quick, easy, cheap, effective, rugged and safe (QuECHERS) approach for determining pesticide residues. In: Pesticide Analysis in Methods in Biotechnology, Martinez, J.L.V. and A.G. Frenich (Eds.), Humana Press, New York, NY, USA, Nov. 2004 (in press).

Schneider, M.J. and S.J. Lehotay (2004). Rapid fluorescence screening assay for tetracyclines in chicken muscle. *Journal of AOAC International*, Vol. 87, No. 3, 2004, pp. 587-591.

Schneider, M.J. and G. Chen (2004). Time resolved luminescence screening assay for tetracyclines in chicken muscle. *Analytical Letters*, Vol. 37, No. 10, 2004, pp. 2067-2078.

Schneider, M.J. (2004). Rapid fluorescence screening assay for enrofloxacin and tetracyclines in chicken muscle. *Journal of Agricultural and Food Chemistry*, Vol. 52, No. 26, 2004, pp. 7809-7813.

Gehring, A.G., P. Irwin, S.A. Reed, S-I Tu, P.E. Andreotti, H. Akhavan-Tafti and R.S. Handley (2004). Enzyme-linked immunomagnetic chemiluminescent detection of *Escherichia coli* O157:H7. *Journal of Immunological Methods*, Vol. 293, 2004, pp. 97-106.

Medina, M.B. (2004). Development of a fluorescent latex immunoassay for detection of a spectinomycin antibiotic. *Journal of Agricultural and Food Chemistry*, Vol. 52, No. 11, 2004, pp. 3231-3236.

Lehotay, S.J., K. Mastovska and S.J. Yun (2004). Evaluation of two fast and easy methods for pesticide residue analysis in fatty food matrices. *Journal of AOAC International*, Nov. 2004 (in press).

Chen, G. and L.S. Liu (2004). Hyphenation of sorbent extraction and solid-matrix time-resolved luminescence using tetracycline in milk as a model analyte. *Journal of Agricultural and Food Chemistry*, Vol. 52, No. 24, 2004, pp. 7199-7205.

Norberg, E. and I.R. Korsgaard (2004). Electrical conductivity of milk as an indicator trait for mastitis. In : Automatic Milking – a better understanding, *Proceedings of International Symposium*, Wageningen Academic Publisher, The Nederlands, 2004, pp. 254-255.

Reinemann, D.J. and J.M. Helgren (2004). Online milk sensing issues for automatic milking (Paper # 04-4191). *ASAE / CSAE Annual International Meeting*, Ottawa, Ontario, Canada, 01-04 Aug. 2004.

Ramirez-Garcia, S., V. Favry, K. Lau, G. McMahon and D. Diamond (2004). Impedance based sensor for mastitis detection in milk. In : Automatic Milking – a better understanding, *Proceedings of International Symposium*, Wageningen Academic Publisher, The Nederlands, 2004, p. 258.

Chen, G., M.J. Schneider, A.M. Darwish, S.J. Lehotay and D.W. Freeman (2004). Europium-sensitized luminescence determination of oxytetracycline in catfish muscle. *Talanta* (International Journal of Pure and Applied Analytical Chemistry), Vol. 64, 2004, pp. 252-257.

Tu, S-I, C. Wijey, G. Paoli, P. Irwin and A. Gehring (2004). Detection of viable bacteria cells by bioluminescence: a bioenergetic approach. *Journal of Rapid Methods and Automation in Microbiology*, Vol. 12, 2004, pp. 207-219.

Foss Analytical (2004). Microfoss test – application note. *P/N 1025725, Issue 1 GB, Aug. 2004*. Foss Analytical A/S, Hilleroed, Denmark.

Foss Analytical (2004). Foodscan for dairy products. *P/N 1025359, Issue 1 GB, Nov. 2004*. Foss Analytical A/S, Hilleroed, Denmark.

Foss Analytical (2004). Foodscan for meat. *P/N 1025363, Issue 1 GB, Nov. 2004*. Foss Analytical A/S, Hilleroed, Denmark.

Levin, R.E. (2004).The application of real-time PCR to food and agricultural systems – a review. *Food Biotechnology*, Vol. 18, No. 1, 2004, pp. 97-133.

National Instruments (2005). Data acquisition and signal processing (pp. 132-243). In: Measurement and Automation Catalog 2005, National Instruments, Austin, TX., USA.

Singh, A.P. (2005). Development and implementation of intelligent soft instrumentation systems. *PhD Thesis*, Punjab Technical University, Jalandhar, India, 2004/2005, pp. 1-274.

■

Authors:

UNIV. - PROF. DR. ING. J. H. AGARWAL[1]

PROF. (MRS.) VIJAYA AGARWAL[2]

[1]Ex-Vice President, Institution of Electronics and Telecommunication Engineers,
Former University Professor, JNAU Director Instrumentation &
Project Coordinator UNDP-GOI-Microprocessor Application Engineering Programme
G - 83 Krishi Nagar, Adhartal, 482 004 Jabalpur, India.
Phone: +91 (0761) 2480400
Email: jhagarwal @ sancharnet . in, jhagarwal @ yahoo . com

[2]Selection Grade Assistant Professor (Electrical Engineering),
Department of Agricultural Structures and Environmental Engineering,
College of Agricultural Engineering, Jawaharlal Nehru Agricultural University
G - 83 Krishi Nagar, Adhartal, 482 004 Jabalpur, India.
Phone: +91 (0761) 2481820
Email: agarwalvijaya @ hotmail . com, jhagarwal @ sancharnet . in

■