Focus on Food Engineering Research and Developments

Vivian N. Pletney
Editor

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FOCUS ON FOOD ENGINEERING RESEARCH AND DEVELOPMENTS

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FOCUS ON FOOD ENGINEERING RESEARCH AND DEVELOPMENTS

PREFACE

Food engineering refers to the engineering aspects of food production and processing. Food engineering includes, but is not limited to, the application of agricultural engineering and chemical engineering principles to food materials. Genetic engineering of plants and animals is not normally the work of a food engineer.

Food engineering is a very wide field of activities. Among its domain of knowledge and action are:

- Design of machinery and processes to produce foods.
- Design and implementation of food safety and preservation measures in the production of foods.
- Biotechnological processes of food production.
- Choice and design of food packaging materials.
- Quality control of food production.

Chapter 1 - Drying has been one of the most important techniques used in food preservation for long years. The drying process has to be performed considering energy economy and the quality standards for the product. Therefore, it is of great importance to understand the physical phenomena taking place in the drying processes. Various mass transfer mechanisms such as molecular diffusion, capillary flow and hydrodynamic flow may take place during the drying process of food materials. Drying is generally composed of a series, parallel and/or series-parallel combination of these mechanisms. In addition to the complexity because of these various transport mechanisms in the drying processes, the structures of materials are also too complex. These constitute the main reasons that make the understanding and modeling the drying process difficult. There are three basic approaches used in modeling as empirical, semi-empirical, and theoretical. Empirical and semi-empirical approaches consider only external resistance to mass transfer between product and air while the theoretical approaches consider only internal resistance to mass transfer. At the theoretical modeling two kinds of approaches are used. These are discrete approach and continuum approach. In discrete approach, transport is examined in a network structure representing the material structure and generally the purpose of use of this approach is to determine transport parameters as an alternative to the experimental measurements. On the other hand, continuum approach is commonly used for describing the transport taking place at macroscopic level. In continuum approach, the food material is considered as a fictitious continuum and the effects of the physical phenomena taken into consideration are lumped into effective transport coefficients. There are many models suggested based on continuum approach. The main difficulty in using a model based on a continuum approach arises from determination of these effective transport parameters. Most of the transport parameters are strongly dependent on concentration, temperature and material structure. Various models have been suggested to clarify the effect of temperature and concentration on transport parameters. However, relatively little is known on the effect of structure on transport parameters.

In conclusion, it may be stated that drying of food materials is a complex unit operation and main problem to overcome on the way to better understand and describe drying processes is to reveal the effect of structure on transport.

Chapter 2 - This paper discusses numerous problems occurring in relation to microbiological quality of lactic acid cheese. Lactic acid cheese constitutes the source of various nutritive substances, what results in a possibility of allochthonous micro-flora to grow despite the presence of starter micro-flora. One of the issues discussed herein comprised the results of microbiological research depending on tvarog packing system. The influence of packing system on surface micro-flora population was assessed. Moreover, the problem of growth of enterococci and LAB (Lactic Acid Bacteria) populations depending on stage of tvarog production as well as packing system was also raised. The issue of interactions occurring among micro-organisms that re-infect tvarogs and the influence of these interactions on the growth of individual micro-organisms was also discussed. The author also presented the possibility to apply JMTPH computer program for assessment of the dynamics of changes of tvarog micro-organisms during product storage. Another chapter includes assessment of the influence of lactic acid bacteria on the behaviour of individual groups of micro-organisms occupying tvarog surface, depending on packaging hermetic properties. It was also very important to assess the safety of tvarogs in the context of a possibility of enterotoxin synthesis in conditions of various packing systems. Finally, the models of optimising lactic acid cheese quality were presented, what included application of plant additives of biostatic character, modification of used packaging as well as employing the probabilistic mathematical model helpful in evaluation of enterotoxin synthesis, depending on the level of staphylococci and yeast populations.

Chapter 3 - Many developing countries are rich in agricultural and food resources but are unable to maximize the export income they earn from them because they lack value-adding technology. In other words, developing countries typically must sell their products in cheap unfinished form to nations which possess the technology that adds profitability to these goods. Accordingly, if developing countries wish to earn more revenue for the improvement of their people's employment and education, they must develop food engineering technology alongside other food science technologies. These efforts at technological self-improvement should be supported by the developed countries as the reduction of the knowledge and income gaps between the industrialized and developing worlds will do much to further global peace and happiness.

The desired trend for food engineering research is to focus on developing engineering technology that will help to improve tropical fresh produce quality. This chapter discusses three facets of this trend. The first aspect concerns the physical properties of tropical fruit and vegetables, which consist of post-harvest loss, physical characteristics, mechanical properties, firmness, friction, and non-destructive quality grading techniques relating to mangoes, mangosteen, durian, sweet tamarind, guava, tangerines, snake egg plants, white long radish and lime. The second aspect concerns innovations in machinery and devices used with mangosteen, durian, young coconut, dry over-mature coconut and baby corn. State of the art design, operating principles and key performance tests of tropical fruit machinery and inventions will be reviewed. The third aspect concerns packaging technology, particularly that which is directed towards the extension of the shelf life of the aforementioned tropical fresh produce.

There are three current realities which inform this book. They are as follows: that there is a high incidence of post-harvest loss and a corresponding magnitude of shortage in research and development work on tropical fresh produce; that the global flow of information is increasing while agricultural labor is becoming scarcer and more expensive; and that tropical produce engineering technology must be thoroughly understood. Accordingly, we make two recommendations: for producer countries to instigate a dramatic increase in the research and development that they conduct into tropical fresh produce, and in the support that they provide for this research; and that the research trend should cover all economic tropical fruit and vegetable goods grown in the producer countries and all aspects of engineering technology that they use, with a particular emphasis on developing computerized non-destructive techniques for quality assurance.

Chapter 4 - Fruits are products of a very important nutritional interest. Nevertheless, and mainly due to their relatively short shelf-life and modern-day eating habits, the level of consumption is below that recommended by the World Health Organization. In this sense, the development of foods with a high fresh or processed fruit content, that maintain the nutritional and sensorial properties of the fresh fruit, may contribute to stimulating the interest of the consumer, thus increasing the product consumption. Osmotic dehydration (OD) techniques have been widely applied in fruit processing, since they require little energy and allow us to obtain high quality products. However, its industrial use may be limited by the management of the osmotic solution (OS). To solve this problem, the re-use of the OS in more than one OD cycle, with or without a previous re-concentration stage, may be considered. When there is no re-concentration, the re-use will be limited by the possible microbiological contamination and by the progressive dilution that takes place after each OD cycle, which may affect the kinetics of the osmotic process. On the other hand, as some native hydrosoluble compounds, such as volatiles, acids, minerals, vitamins and phytochemicals, will be released together with water into the OS during OD, its management as an ingredient in some product formulation seems to be an interesting alternative. To this end, this work analyses the viability of formulating a fruit-gel product with the osmodehydrated fruit (strawberry, kiwi or grapefruit) and the re-used OS obtained from the dehydration step, in order to diminish the loss of flavour, aroma and functional components of the fruit and avoid the generation of by-products in the process. In this study, the number of OS re-use cycles has been optimized, on the basis of its microbial recounts, the dilution level, the solution enrichment in fruit bioactive compounds, the fruit-solution ratio used during the dehydration step and the fruit-gel ratio in the final product. The kind and concentration of gelling agents, which best favour the properties of aspect (transparency) and texture of the gels, taking the peculiar composition of the re-used OS used as gelling medium into account, have been identified. The conditions in which the fruit pieces are mixed with the gelling solution have also been studied and defined. Finally, the fruit-gel product formulation conditions have been optimized, on the basis of its sensory acceptance and its compositional stability during storage, ensuring the thermodynamic equilibrium between the fruit and the gel when mixed.

The microbiological stability of the product was of at least 15 days in refrigerated storage. During this time, the evolution of some properties such as phytochemicals, vitamins, acids, volatile compounds, colour and texture was studied.

Chapter 5 - The development of new attractive dehydrated fruit-based products, to be consumed as dried or rehydrated, with high quality and reasonable shelf-life, will increase and diversify its availability in the market. In this sense, it is necessary to optimize the dehydration operation conditions to achieve not only the maximum process efficiency and control, but also various characteristics in the final product in relation to colour, texture, water activity, nutritive value, etc. Air drying has been the most frequently selected process for industrial food dehydration, due to its efficiency, versatility and easy management. However, it is known that it provokes considerable changes in sensory and nutritional quality. Some research works refer to the advantages of applying microwaves to convective drying associated with the fast volumetric heating of the product due to its high penetration power. On the other hand, the application of certain pre-treatments before drying operation, such as vacuum impregnation or vacuum pulsed osmotic dehydration, could help to enhance the stability and quality attributes, as high temperatures are not employed and specific solutes can be incorporated into the porous structure. In this chapter the advantages of microwave application to convective drying of apple and strawberry are pointed out. These are related to the great reduction in process time and to the fact that they allow obtaining a dehydrated product with a greater resistance to deformation and fracture and a greater stability during commercialization. Nevertheless, its use is not recommendable when the product has to be used or eaten after its rehydration, as the structural damage caused by microwaves decreases the mechanical resistance and the retention capacity of the incorporated liquid phase. The colour of dehydrated or rehydrated product is more affected by microwave treatments when the fruit pigment content is relevant, as occurs with strawberry anthocyanins. Application of a previous vacuum impregnation/osmotic dehydration step with sugared solutions is always recommended.

Chapter 6 - Food products are always under the risk of infestation by pests. In view of the competitive markets, there has been increasing demand for quality in foods in terms of freedom from pest and pesticide contaminants. Also, it is very important for trade purpose suffer economic and quality losses. Zero tolerance of insect pest in foods has been adopted in some of countries and there is a tendency to achieve this goal in overall the world.

The governments, the food industries and exporters are dependent on fumigation as a quick and effective tool for insect pest control in food commodities. Fumigants are widely used for pest elimination in these commodities. Toxic substances have therefore been used to destroy for example pests, as well as their eggs, larvae, cocoons and adults. Currently used substances, such as methyl bromide, hydrogen phosphide, ethylene dioxide, malathion etc., are characterized by more or less serious problems. In recent years, that fumigation technology based on the chemical control of products has been facing threats/constraints because of regulatory concerns, the development of resistance, handling hazards, residues, food safety, cost, carcinogenicity, involvement in ozone depletion, resurgence, environmental pollution and other factors. Reliance upon fumigation as an overall solution to infestation problems in food products has become questionable. The chemical action of fumigants upon commodities and the environment has necessitated the withdrawal of many fumigants from the market. Also, some of them are being phase out their uses at the international level.

Due to becoming the target of increasing criticism of toxic substances, such concerns have led to the development of non-chemical methods for the control of insect pests that infest food commodities. One such method is the high pressure carbon dioxide application, which mainly involves the use of CO_2 at high pressure (10-40 bar) for food fumigation. It is a new effective, non-chemical, non-residual, safe, fast and environmentally friendly method for the food industry. It has been generated and developed within last 20 years. Carbon dioxide is a fumigant and being used to control pests in the food industry. After extensive testing, high pressure carbon dioxide fumigation can be accepted as the advanced pest control technology for the future. Nowadays, it is particularly indispensable for the gentle, safe, natural and organic food products. If operation time for the fumigation is constraint and non-chemical treatments are required, this technique is suitable for conventional products.

Chapter 7 - Membrane based clarification and concentration of fruit juice has become a popular unit operation in modern fruit juice processing industries. The well known membrane modules used for this purpose are tubular and spiral wound modules. Therefore, design of these modules is of utmost industrial importance. The key parameter for design of membrane modules is mass transfer coefficient. Most of the fruit juices have non-Newtonian rheology, e.g., power law, ellis fluid, etc. Till today, the mass transfer coefficient for such systems used is approximated from the corresponding relations developed for Newtonian fluids. Hence, a detailed fluid flow modeling with non-Newtonian rheology is urgently warranted. In the present work, this aspect is attempted. The expressions of the mass transfer coefficients are derived from the first principles for laminar, non-Newtonian fluid flow in a porous conduit. The effects of the permeation are incorporated quantitatively in the mass transfer coefficient from a theoretical basis. The analysis is carried out for various non-Newtonian rheologies. Effects of the operating conditions, i.e., Reynolds number, permeate flux, etc. on mass transfer coefficient are also investigated. Two flow geometries are considered. Flow through a tube and that through a rectangular thin channel, which are useful for the design of the tubular and spiral wound cross flow membrane modules. The developed relations of mass transfer coefficients would be of tremendous help to the design engineers.

Chapter 8 - A laboratory roll stand Variostuhl, equipped with smooth rolls (250 mm diameter, 100 mm length), was used to examine, under simulated commercial conditions, the effect of roll speed and roll differential on the reduction of sizings and coarse middlings from the primary break passages of the wheat flour milling process. The samples were obtained from the industrial mill, intercepting the sizings and coarse middlings from the 1st, 2nd and 3rd break stage that normally would have gone to the purification system, as well as intercepting the purified sizings (cleaned middlings) that normally would have gone to the reduction system of the wheat flour milling process. As roll velocity increases flour release was increased, milling energy consumption rose while flour quality (as determined by ash content) was not affected. By increasing roll velocity it is possible to increase feed rate to the rolls and, therefore, the disposable roll surface is used more efficiently. Flour release rose when differential was increased from 1.1 up to 1.25 but decreased when differential increased from 1.25 up to 5.0. Increasing roll differential led to an increase in milling energy consumption. These effects can be explained by the relative contribution of compressive and shearing forces acting on the particles passing through the grinding zone of the smooth rolls. Considering the results obtained in this study (flour release, flour quality and milling energy consumption) a differential of 1.25, relative to a fast roll speed of 5 m/s could be designated as optimal.

Chapter 9 - The Ivory Coast cocoa beans were convectively roasted at 135°C, at the air flow rate of 1.0 m/s and relative air humidity (RH) of 0.4%, 2.0% and 5.0%. Volatile components of raw and roasted beans were analyzed by SPME/GC/GCMS and identified by comparing their retention indices with that of standards included in a database and their mass spectra with standard spectra included in NIST computer library. Almost 100 different volatile compounds were identified in examined samples of roasted cocoa. They ranked among aldehydes, ketones, alcohols, esters, monoterpenes, pyrazines, acids, lactones, furan derivatives, and sulfur-containing compounds. It was found that a rise in the relative air humidity from 0.4% to 2.0 and 5.0% increased the contents of pyrazines, volatile acids, esters, furan derivatives, and sulfur-containing compounds in a headspace of roasted cocoa. In contrast, the contents of alcohols and aldehydes in the headspace were considerably lower when the cocoa beans were roasted at the relative air humidity of 5.0% as compared to that when less humid air was used for convective heating.

Chapter 10 - Cooking and drying are two main unit operations used widely in food processing. Consecutive cooking and drying operations supplies perfect properties to gain to food products and called as bulguration. Individually, the former method is used nearly for all food products before consumption. Cooking is a well-known way to destruct microorganisms, insect, insect eggs and larvaes for food safety. Also, it increases the digestive property of food with starch gelatinization, protein gelation and textural softening. However, it is very difficult to store this product without drying due to its high moisture content after cooking. Therefore, food products should be dried. Drying is required to prolong storage time of food products. Bulguration is the gaining of the some functional characteristics on the finished product such as the resistance to mold contamination, insect attacks and radiation, inactivation of enzymes and microorganisms, encapsulation of numerous nutritional components in food products, easy preparation after bulguration due to semi and ready-to-eat form, obtaining long shelf-life having economical products with safety, decreasing undesired components e.g. phytic acid in contrast to increasing desired one e.g. folate/folic acid. As raw materials, cereals, pulses, seeds, vegetables, fruits etc. can be used.

Recently, the use of bulguration in the food industry dramatically increases as an optimal method due to above situations. Bulguration is an ancient technique; however, the modern technology re-discovered it. In this chapter, the techniques of bulguration are explained with examples. Also, the results of the recent researches are given.

Chapter 11 - It is well known that sorption isotherms of foodstuffs are very important for design, modeling and optimization of important processes for example drying, aeration, predicting of stability and quality during packaging and storage of food. Many literature reviews conclude that the BET (and its modifications) and the GAB sorption isotherm equations are the most popular and applicable for description of isotherms of foodstuffs. The authors showed recently the applicability of the GDW model for description of water sorption on different foodstuffs. Moreover, it was also shown that the GAB model (also widely applied in food science) is the special case of the GDW equation. In this review the authors present the current state of art and also an attempt of application of different models of water sorption, namely CMMS, DD and modified CDS for description of water sorption data on different starch samples and other foodstuffs.

Chapter 12 - This paper aimed to make a longer-term forecast analysis on global food nutrition supply and demand. The forecasts of supplies of food calories and proteins for the world and various regions over the period 2010-2030 were given, and food nutrition supply and demand balance in the forecast period was discussed.

If the past pattern continues, the global total food calorie supply would grow at the annual rate of 13.43±0.71 kcal/cap/day and reach 3210.4±67.3 kcal/cap/day in 2030. Total food calorie supplies for all of the regions would grow during the forecast period and, in most regions they are forecast to be greater than 3000 kcal/cap/day from 2015-2020. Total food protein supply for all regions but not Oceania, is forecast to grow during the forecast period. The proportion of animal sourced protein in total food protein supply is in 2030 forecast to increase and reach 35.5%, 61.6%, 56.8%, and 21.7% for Asia, Europe, South America, and Africa.

Food calorie supply in the world is expected to exceed the adequate energy intake after around 2015. Strong focus should be worldwide put on the over-intake of food calorie in the near future. Global food protein supply is not expected to be greater than the adequate range during the period 2010-2030. Food protein supply in Africa and Caribbean would be just a little greater than the basic demand in the forecast period. Food protein intake in these regions should be improved in the coming years.

CONTENTS

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Expert Commentary

COMPUTER-VISION BASED ANALYSIS OF COLOR AS A TOOL FOR FOOD PROCESS CONTROL

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ABSTRACT

The color is the first sensation that the consumer perceives and uses as a tool to accept or reject, because the color observation allows the detection of certain anomalies or defects of a product. Commercial color-measuring devices are designed to contact the materials to perform the color measurements. The main drawback of using these devices is the limitations in size and geometry of the area that subjected to color measurement, because they measure a small area with a fixed geometry making the measurement quite unrepresentative for heterogeneous materials like many processed foods. With a digital imaging system, it is possible to register the color of foods using three-color sensors. In this case, surface color of the food is detected online in a non-contact manner and monitored throughout the process. By using appropriately developed computer algorithms, highly accurate and reliable information can be obtained about the color changes in a food during processing. This kind of algorithm can be used as a process control tool for automatic visual inspection in an industrial production process and can improve the overall quality of the product. The advantage of computerized visual inspection over inspection by humans is that machines can evaluate color continuously and objectively. This chapter describes novel approaches for a non-contact computer vision based color measurement system and its potential applications in food processing.

1. INTRODUCTION

The overall appearance of any object is a combination of its chromatic and geometric attributes. Both of these attributes should be accounted for when making visual or instrumental assessments of appearance. The color is the first sensation that the consumer perceives and uses as a tool to accept or reject, because the color observation allows detecting certain anomalies or defects of a product.

The human eye has receptors for short (S), middle (M), and long (L) wavelengths, also known as blue, green, and red receptors. This means, in principle, three parameters are required to describe a color sensation. A specific method for associating three parameters (or tristimulus values) is called a color space which specifies how color information is represented. A color component is also referred to as a color channel. The XYZ is the first color space that mathematically defined by the Commission Internationale d'Eclairage (CIE) in 1931. The L*a*b* color space is perceptually uniform and the most complete model defined by the CIE in 1976 to serve as a device-independent, absolute model to be used as a reference. It is based on the XYZ color space as an attempt to linearize the perceptibility of color differences, using the color difference metric described by the Macadam ellipse. The non-linear relations for L*, a* and b* are intended to mimic the logarithmic response of the human eye. Here, L* is the luminance or lightness component, which ranges from 0 to 100, and parameters a* (from green to red) and b* (from blue to yellow) are the two chromatic components, which range from –120 to 120 [1-3].

2. Instrumental Measurement of Color

A lot of color-measuring instruments are available in the market for several applications. Most of them are designed to contact the materials to perform the color measurements. These instruments are successfully used for color measurement of homogenous materials. However, the main drawback of using a color-measuring instrument is the limitations in size and geometry of the area that subjected to measurement. A commercial instrument usually measures a small area with a fixed geometry. This makes the measurement quite unrepresentative for heterogeneous materials like many food items [4]. Repetitive measurements are therefore required to increase the accuracy. In most cases, increasing the repetitions is not a viable approach for irregularly shaped objects. Instead, an approach taking the overall surface into account is required to obtain meaningful information about the color. This is especially important for industrial applications in which the color homogeneity is an important feature of the material. In such a case, commercial color measuring instruments are not fit for purpose as a process control and/or product quality control tool.

3. Computer Vision Based Measurement of Color

A typical image captured by a digital camera consists of an array of vectors called pixels. Each pixel has red, green and blue color values:

$$x[n,m] = \begin{bmatrix} x_r(n,m) \\ x_g(n,m) \\ x_b(n,m) \end{bmatrix}$$

where, X_r, X_g and X_b are values of the red, green and blue components of the (m,n)th pixel, respectively. In digital images, X_r, X_g and X_b color components are represented in 8 bits, i.e., they are allowed to take integer values between 0 and 255 ($=2^8-1$) [5].

RGB values of an image captured by a digital camera can be converted into device-independent L*a*b* units. Computational approaches that convert RGB values into L*a*b* units have been previously reported using the standard equations [2,6,7]. However, usefulness of a computer vision system as a tool for color measurement depends on the accuracy of color transformation. Digital cameras have built-in white-balancing systems modifying actual color values, therefore pixel values in an image captured by a camera of a machine vision system or a consumer camera may not correspond to true colors of imaged objects.

Therefore, it is better to build calibrated models by using the charts which reflect the variations in color space. The necessity of a calibration process to obtain device-independent L*a*b* color units have been previously underlined [8]. However, the information is lacking on how the accuracy of color measurement could be improved by calibration process in these reports.

3.1. Description of the Technique

Following section describes a computer-vision based technique calibrated with ANN modeling to measure color in foods. The model allows a user to determine a polygonal region of interest. This feature increases the accuracy in color measurement when compared to commercial color-measuring devices. To perform the color measurement, digital images of food samples are taken using a color digital camera under well controlled conditions (illumination, lamp angle and distance).

The calibration of computer vision based color measurement system was performed by using an Agfa 5x7 inch reflective color chart (figure 1) which is an internationally accepted IT8 standard (IT8.7/2-1993) with device-independent color definitions. The chart consists of 288 colored squares, and has been designed to represent the color space from full saturation to near neutrals at highlight, mid-tone and shadows.

Figure 2 shows the algorithm used to convert camera RGB values to spectrophotometric CIE L*a*b* values. Based on this algorithm, the first step is the conversion of color values from RGB to L*a*b* using the standard conversion equations, and the second step is the correction of L*a*b* values through an ANN model.

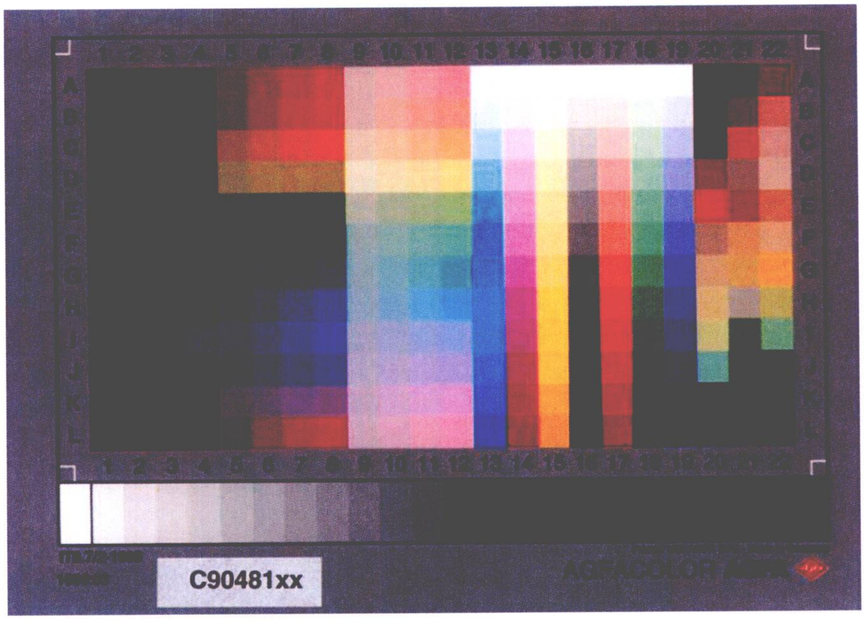
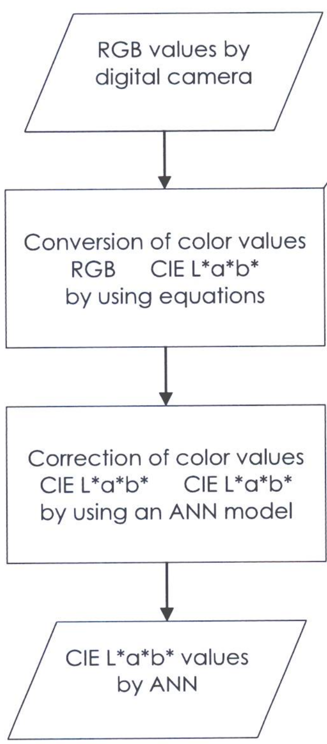


Figure 1. Agfa 5x7 inch color chart (IT8.7/2-1993) used to build a calibrated ANN model for the correction of monitor L*a*b* values.




```
= 2.4

RGB to XYZ

//Observer:2° ; Illuminant: D50

var_R = ( R / 255 )      //Where R = 0 ÷ 255
var_G = ( G / 255 )      //Where G = 0 ÷ 255
var_B = ( B / 255 )      //Where B = 0 ÷ 255

if ( var_R > 0.04045 ) var_R = ( ( var_R + 0.055 ) / 1.055 ) ^ 2.4
else                   var_R = var_R / 12.92
if ( var_G > 0.04045 ) var_G = ( ( var_G + 0.055 ) / 1.055 ) ^ 2.4
else                   var_G = var_G / 12.92
if ( var_B > 0.04045 ) var_B = ( ( var_B + 0.055 ) / 1.055 ) ^ 2.4
else                   var_B = var_B / 12.92

var_R = var_R * 100
var_G = var_G * 100
var_B = var_B * 100

X = var_R * 0.4360 + var_G * 0.3851 + var_B * 0.1431
Y = var_R * 0.2225 + var_G * 0.7169 + var_B * 0.0606
Z = var_R * 0.0139 + var_G * 0.0971 + var_B * 0.7142

XYZ to L*a*b*

var_X = X / ref_X  // ref_X = 96.422
var_Y = Y / ref_Y  // ref_Y = 100.000
var_Z = Z / ref_Z  // ref_Z = 82.521

if ( var_X > 0.008856 ) var_X = var_X ^ ( 1/3 )
else                    var_X = ( 7.787 * var_X ) + ( 16 / 116 )
if ( var_Y > 0.008856 ) var_Y = var_Y ^ ( 1/3 )
else                    var_Y = ( 7.787 * var_Y ) + ( 16 / 116 )
if ( var_Z > 0.008856 ) var_Z = var_Z ^ ( 1/3 )
else                    var_Z = ( 7.787 * var_Z ) + ( 16 / 116 )

CIE-L* = ( 116 * var_Y ) - 16
CIE-a* = 500 * ( var_X - var_Y )
CIE-b* = 200 * ( var_Y - var_Z )
```

Figure 2. Algorithm used to convert camera RGB values to spectrophotometric CIE L*a*b* values.