**Universitatea *Transilvania* din Braşov**

# HABILITATION THESIS

**Contributions to industrial processing optimisation of food products**

**Domain: Engineering and Management**

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**BRASOV, 2015**

# CONTENT

# REZUMAT

Teza de abilitare sintetizează activitatea de cercetare şi rezultatele autorului după obținerea titlului de doctor al Universității Transilvania din Braşov, confirmat prin diploma de doctor nr. 1062 din 12 septembrie 2001. Structurată in 4 părți, lucrarea prezintă succint, principalele rezultate obținute de către autor în urma continuării cercetărilor întreprinse în cadrul tezei de doctorat în domeniul procesarii industriale a produselor agricole şi alimentare.

Primul capitol prezintă contribuții la optimizarea funcționării uscătoarelor de cereale şi plante tehnice.

Uscarea este una dintre cele mai importante operații industriale din industria alimentară, cu un consum de energie foarte ridicat. Peste 40% din energia consumată în procesarea industrială din domeniul agroalimentar se regăseşte, într-o formă sau alta, în operațiile de eliminare apei din produse care au ca scop reducerea conținutului de umiditate până la un nivel la care activitatea microbiologică devine neglijabilă.

Oportunitatea acestui demers este dată şi de variabilitatea foarte ridicată a caracteristicilor materiilor prime (soi, regiune de proveniență, condiții climatice etc) precum şi de factori perturbatori de mediu (umiditate, temperatură). Aceste elemente au influențe considerabile asupra calității finale a produsului, iar ca studiu de caz este prezentată situația conservării capacitaților germinative a semințelor de cereale. Soluții tehnice speciale de control şi strategii diferite de abordare a proceselor de uscare sunt prezentate ulterior în capitolul 3.

Capitolul al doilea prezintă câteva contribuții la modelarea sistemelor de procesare sau de producție în domeniul agroalimentar. Sunt utilizate aplicații software specifice pentru simularea uscării produselor de tip granular cu dimensiuni între 3... 6 mm (tipic uscătoarelor de cereale sau alte plante tehnice) sau de tip pulverulent cu dimensiuni de ordinul micronilor. La baza acestor simulări stau concluzii extrase în perioada activității doctorale, în care au fost utilizate şi alte tehnici de modelare, cum ar fi analiza cu elemente finite a fenomenelor de transfer de căldură şi mecanica fluidelor.

Un alt aspect abordat în acest constituie modelarea sistemelor mediu - economie din perspectiva eco-emergetică. Modelul realizat în mediul Labview furnizează informații importante privind sustenabilitatea unui sistem de tip fermă zootehnică de mărime medie din zona Braşovului.

Capitolul al treilea abordează problema păstrării caracteristicilor fizice şi biochimice ale produselor în timpul proceselor de prelucrare. Astfel, sunt prezentate câteva metode şi tehnici moderne de control a calității produselor alimentare prin utilizarea camerelor video în spectru vizibil sau infraroşu. Sunt definiți noi indicatori de control ai calității produselor în timpul uscării, rezultați prin analiza în timp real a imaginilor cu aplicații software dedicate. O aplicație deosebită, realizată în colaborare cu HTWG Konstanz Germania, permite strategii de uscare diferite, având ca referință fie temperatura agentului de uscare, fie temperatura suprafeței produsului, masurată în spectru infraroşu. Cea de a doua strategie permite reducerea timpului de uscare cu 40-50 %, şi a fost aplicată la produse de tip măr, banană, morcov. Obiectivul final al acestor cercetări îl constituie crearea unor echipamente robuste, fiabile, cu prețuri accesibile, capabile să contribuie la controlul calității proceselor industriale specifice domeniului agroalimentar. In finalul capitolului al treilea sunt prezentate şi rezultatele unor cercetări privind conținutul de vitamina C al produselor supuse extracției subcritice la temperaturi de circa 200...300 K şi presiuni de 400... 600 Mpa.

Ultima parte prezintă sintetic rezultatele activității de cercetare şi didactice precum şi direcții de cercetare viitoare şi de dezvoltare profesională a candidatului. Toate contribuțiile originale sunt prezentate în contextul stadiului actual al cercetării ştiințifice din domeniu.

Activitatea de cercetare-dezvoltare desfăşurată de candidat pe tot parcursul profesional (1996-2015) este una bogată şi cu rezultate importante, materializate în: 11 cărți de specialitate (autor unic la trei dintre ele, prim autor la alte 2); 156 articole ştiințifice prezentate la conferințe naționale şi internaționale şi/sau publicate în reviste de specialitate, din care: 5 articole publicate în reviste cotate ISI Thomson Reuters; 5 articole publicate volume de conferință indexate ISI Thomson Reuters; 65 articole publicate în reviste şi volumele unor manifestări ştiințifice indexate în alte baze de date internaționale; 57 articole publicate în jurnale B+ sau/şi prezentate la conferințe internaționale de prestigiu; 1 grant internațional în calitate de responsabil de proiect câştigate prin competiție; 3 granturi naționale în calitate de responsabil de proiect câştigate prin competiție; 2 proiecte internaționale în calitate de membru în echipa de cercetare; 9 proiecte naționale în calitate de membru în echipa de cercetare;

De asemenea, candidatul a coordonat peste 100 de lucrări de licență/diplomă şi peste 30 de lucrări de disertație. Din anul 1996 până în prezent, în cadrul Catedrei de Maşini pentru Agricultură şi Industrie Alimentară şi apoi a Departamentului de Ingineria şi Managementul Alimentației şi Turismului, candidatul a fost responsabil al cursurilor la disciplinele: Sisteme informatice avansate în eco-biotehnologii; Proiectare asistată de calculator - modelare şi simulare; Instalații şi utilaje pentru păstrarea produselor de origine vegetală.

Un moment important al carierei universitare a candidatului îl reprezintă obținerea titlului de conferențiar universitar în anul 2007. Aceasta a confirmat atingerea gradului necesar de experiență pentru pasul următor, acela de coordonator de colectiv de cercetare şi de coordonator de teze de doctorat. În perioada următoare, până în prezent, candidatul a desfăşurat o intensă activitate de cercetare, în colaborare cu colegii mai tineri şi doctoranzi ai Departamentului de Ingineria şi Managementul Alimentației şi Turismului.

Dezvoltarea carierei universitare se concentrează de asemenea pe cele două direcții principale, de cercetare şi didactică, direcții care se completează şi se potențează reciproc.

Dezvoltarea activității educaționale se bazează o pe o permanentă preocupare pentru îmbunătățirea metodelor de predare, implicarea studenților în activitățile didactice, actualizarea informației din cursurile predate folosind resurse atât în mediu național cât şi internațional.

Dezvoltarea activității de cercetare are în vedere 3 obiective fundamentale:

a. *intensificarea cercetării în echipele internaționale* formate şi dezvoltarea unor noi conexiuni atât cu universitățile din vest cât şi cu cele din est;

b. *participarea la evenimente de specialitate* internaționale şi naționale, pentru publicarea şi diseminarea rezultatelor din cercetare;

c. *atragerea unui număr mai mare de tineri absolvenți* în activitatea de cercetare în calitate de doctoranzi şi postdoctoranzi, din țară şi străinătate.

O descriere mai detaliată a fiecărui subiect poate fi găsită în capitolul (b-ii): Planuri de dezvoltare ştiintifică, profesională şi academică.

# ABSTRACT

Habilitation thesis summarizes the research and results of the candidate after obtaining the PhD title from Transilvania University of Brasov, confirmed by the PhD diploma no. 1062 from 12 September 2001.

Habilitation thesis, divided into 4 chapters, presents briefly the main results obtained by the author after sequel research undertaken in the PhD thesis in the field of industrial processing of agricultural and food products.

The first chapter presents contributions to optimization of dryers for grains and technical plants.

Drying is one of the most important industrial operations from food industry, with important energy consumptions. Over 40% of the consumed energy in food processing, from the agri-food area is caused, in one way or another by water removal operations from products. The complexity of simultaneous mass and heat transfer phenomena is very important, and has the purpose, in the agri-food area, to reduce the moisture content to a level where microbiological activity becomes negligible.

The opportunity of this aproach is also given by the very high variability of raw materals characteristics (variety, region of origin, climatic conditions, etc.) as well as the environmental disturbance (humidity, temperature). These elements have considerable influence on the final quality of the product and, as a case study it is presented the preservation of grain seeds germination capacity.

Special tehnical control solutions and different control strategies of drying processes are presented further in chapter 3.

The second chapter presents a few contributions about modelling of processing and production system in agrifood area. Are used specific software aplications for drying simulation of granular products with dimensions between 3...6mm (typical for grain dryers or other technical plants) or powdery type having dimensions of micron order. Underlying these simulations, are conclusions established during PhD work, in which were used other modeling techniques such as finite element analysis of heat transfer and fluid mechanics phenomena.

Another issue addressed in this area is modeling of environment - economy systems in terms of eco-emergy. The model developed in LabVIEW environment provides important information’s related to the sustainability of a medium size system, livestock farm type from Brasov area.

The third chapter approaches the conservation problems of physical and biochemical characteristics of products during processing. Thus, are presented some modern control methods and techniques of food products quality by using video camera with visible and infrared spectrum.

There are defined new control quality indicators of products during drying, by real time image analyses with dedicated software applications. A special application, jointly developed

with HTWG Konstanz Germany, enable different drying approaches, having as reference either the drying agent temperature, either surface product temperature, all measured by usig infrared techniques. The second strategie reduces drying time with 40-50 %, and was applied to different agricultural products like apple, banana, carrots. The final goal of this researches is the design of reliable and cheep equipment, in order to controll the quality of industrial processes from agri-food area.

At the end of the third chapter are presented results of researches regarding the content of C vitamin after subcritical extraction at temperatures between 200...300 K and presure between 400... 600 Mpa.

The last chapter, the fourth, presents results of research activity and specific skills and future directions of professional development. All the original contributions are presented in the context of the current state of scientific research in the field.

The research-development activity of the candidate evolves throughout his professional career (1996-2015) is impresive, matherialised by: 11 speciality books (single author at 3 of them, first author at 2); - 156 scientific articles presented at national and international conferences and/or published in speciality journals, from which: - 5 articles published in ISI Thomson Reuters journals; - 5 articles published in journal and conference volumes indexed ISI Thomson Reuters; 65 – articles published in journals and volumes of scientific events indexed in other scientific international data bases; - 57 articles published in B+ journals and/or presented at prestigious international conferences; - 1 international grant as project Director; - 3 national grants as project Director; 2 – international grants as member in research team; - 9 national projects as member in research team;

Also the candidate has coordinated over 100 BSC projects and over 30 MSC thesis. From 1996 until present, in the frame of Department for Mashinery for Agriculture and Food Industry and after in the frame of Department of Engineering and Management in Food and Tourism, the candidate was responsable of the following disciplines: Advanced Informatic Systems in Eco-Biotechnology; Computer aided design – Modelling and Simulation; Instalations and Equipments for Preservation of Vegetal Origin Products.

An important moment of University career of candidate was obtaining of the Associated Professor title in 2007. This confirmed the achievment of necessary level of experience for the next step, that of to coordinate a research team and PhD thesis. In the next period, until present the candidate has conducted an intense research activity, together with younger colleagues and PhD students from Department of Engineering and Management in Food and Tourism.

University career development also focuses on two main areas of research and teaching, ways that complement and reinforce each other.

Developing an educational activity is based on a constant concern for improving teaching methods, student involvement in educational activities, update information of courses using resources from both national and international sources.

Development of research activity is following 3 fundamental objectives:

d. Research enhancement in the frame of international team and development of new conexion, both with West and East Universitys;

e. Participation to international and national scientific events, for publication and dissemination of research result;

f. Involving a higher number of graduated young students in research activities as PhD's and postdoctoral, from Romania and abroad.

A more detailed description of each topic can be found in section (b-ii): Scientific, professional and academic development plans.

# (B) SCIENTIFIC AND PROFESSIONAL ACHIEVEMENTS AND THE EVOLUTION AND DEVELOPMENT PLANS FOR CAREER DEVELOPMENT

## (B-I) SCIENTIFIC AND PROFESSIONAL ACHIEVEMENTS

### Introduction

The scientific and professional results, presented as follow are refering to the didactical and research activity of the author, upon 13 years, as a University teacher at Transilvania University of Brasov, after obtaining PhD title.

During this period, there were published and continued the researches from the PhD period, in the frame of industrial drying of cereals and other technical plants. In particularly there were followed elements regarding the quality of the obtained products during drying, on two important sections: protection of the germination capacity of the seeds for sowing and conservation of bioactive compounds of seeds for human consumption. Limits and variation equations of drying agent temperature were established and were implemented experimentally on industrial dryers, with beneficial effects both on quality and on energy consumption appliances.

These concerns have been extended in the field of vegetables and fruits drying, thanks to exceptional collaboration with HTWG Konstanz, in the frame of which were integrated students, master students and PhD students from both institutions.

Many industrial drying processes are still based on partially found data from decades ago, which were determined empirically and where it is not sure whether these are optimal. When talking about the optimization of a drying process, first there has to be clarified which outcomes must be sought: product quality improvement, or improved simultaneously in terms of drying time and energy efficiency? In the last 20 years, the approach has prevailed to view the drying as part of an overall process and product quality pre-not only by optimizing the drying process, but also all and to improve downstream steps.

The jointly undertaken research used non invasive methods for measuring in invisible in the visible spectrum (infrared) to correlate the effects of drying (deformation, cracks, discoloration) and measured temperature from products surface.

Measurement of product surface temperature with the infrared method had allowed the aplication of special controll strategies which lead to drying time reduction with 40-50% and important energy consumption. There were realised multiple simulations of complex processes of simultaneous heat and mass transfer, using finite element analysis, analytical calculation assisted by specialized programs like Math Cad or modeling using Lab View software.

The final objective of this research is the design of compact monitoring devices, rugged and inexpensive that can be implemented in industrial drying equipments.

The conservation problem of physical and biochemical characteristics of products during processing was extended to researches regarding the content of C vitamin after subcritical extraction at temperatures between 200...300 K and presure between 400... 600 Mpa.

Another issue addressed in this area is the modeling of environment - economy systems in terms of eco-emergy. The model developed in LabVIEW environment provides important information's related to the sustainability of a medium size system, livestock farm type from Brasov area.

The results of the research activity was published partially in: 156 scientific articles presented at national and international conferences and/or published in speciality journals, from which: 10 articles published in ISI Thomson Reuters journals and proceedings; 11 speciality books (single author at 3 of them, first author at 2); - 65 – articles published in journals and volumes of scientific events indexed in other scientific international data bases; - 57 articles published in B+ journals and/or presented at prestigious international conference. The area of food processing optimization was also researched during: 1 international grant as project Director; - 3 national grants as project Director; 2 – international grants as member in research team; - 9 national projects as member in research team.

The presented results offers exceptional opportunities for development of future research, in the frame of many H2020 proposals in which we were invited to take part as team member.

# CHAPTER 1

# CONTRIBUTIONS TO OPTIMIZATION OF GRAIN DRYING PROCESS

## 1.1. Consideration about the influence of ambient air temperature and humidity on fuel consumption

The quality of the drying process is a function of the drying time, energy consumption and product quality. An optimization of the drying process must address all three aspects. The optimal management of heat transfer and mass transport do not always correspond to those of optimal quality. This realization has led to a major shift in the last 20 to 30 years, through the focus of research in the direction of quality improvement [104].

The usual process flow for the production of dried agricultural products can be broadly divided into individual steps: sorting, washing, peeling, cutting, chemical and thermal pre-treatment, drying and packaging. The individual steps [19] have a strong influence on each other. Therefore, all process steps must be checked individually. A variety of information from various disciplines (food chemistry, biology, physics and engineering, mechatronics, automation technology) must be collected, combined and converted to final control strategies.

In industrial practice, systems are widely used to provide the optimal conditions for heat transfer and mass transfer. The quality of an industrial process is also characterized by its robustness [104]. In the dryers used, the process usually takes a long time, the quality of the product is usually not optimal and the energy consumption and space requirements are very high. Many industrial drying processes are still based on partially found data from decades ago, which were determined empirically and where it is not sure whether these are optimal. Another problem of the traditional drying is represented by the growing demands of consumers in the properties of a product. It is often tried to adapt to the product quality at great expense a best-rising investment of changed requirements. This is usually done, if possible, at the expense of the efficiency of the process [104].

When talking about the optimization of a drying process, first there has to be clarified which outcomes must be sought. If it is a pure product quality improvement, or should the process be improved simultaneously in terms of drying time and energy efficiency? Is the drying unit operation considered part of the whole process? In the last 20 years, the approach has prevailed to view the drying as part of an overall process and product quality pre-not only by optimizing the drying process, but also all and to improve downstream steps [92].

The design of an effective control systems which can control in real time, the phenomena of heat and mass exchange in drying processes, involves the study of the influence of disturbances and correct dimensioning of execution elements.

In this context, drying of grain seeds, require a special approach due to the complexity of biological material, the phenomena of heat and mass transfer and external disturbances.

Removing of humidity from the harvested seeds take place in the autumn, in months September-November, period of the year characterized by large variations in temperature and humidity durring the day.

For this reason, temperature and humidity of the ambient air, which need to be mixed with the exhaust gas to become dry agent, are disturbing factors which influence significantly the thermal conditions from the drying chamber. The specialized literature provides relatively les data about grains drying, existing recommendations of the producer in notes of technical installations. [ 49], [50], [54 ]

In the following it is shown, the quantitative assessment of these factors on the needed consumed fuel, so that the temperature inside the drying chamber is always constant.

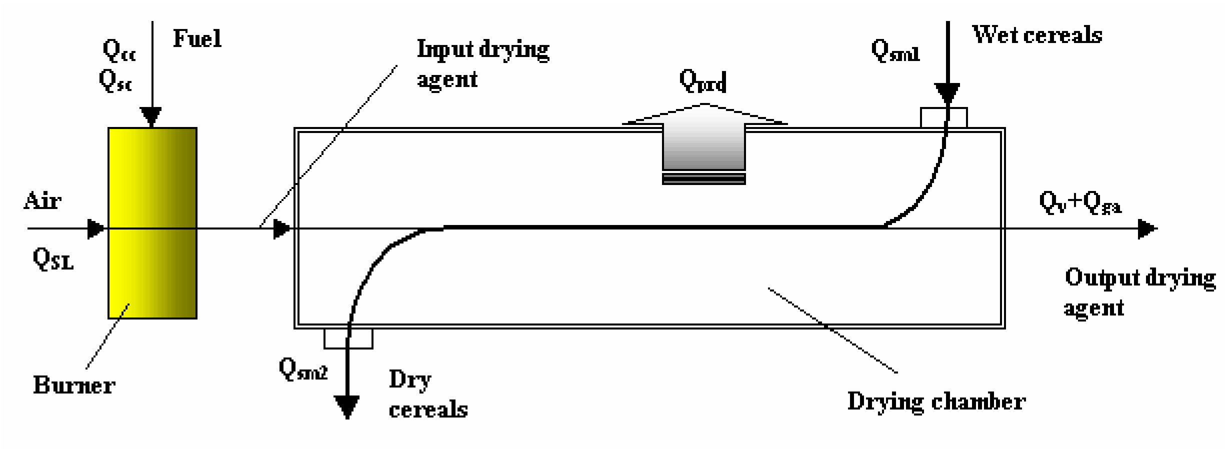



*Figure 1.1. Diagram of thermal balance of a seed dryer*

This influence can be translate into a complex function (which may be expressed in a number of areas), that can be stored on the process computer and which will calculate at each change of disturbances, the needed fuel, making the necessary corrections on the control valve of the fuel flow.

Starting from dryer heat balance equation (fig.1.1), it can be write:

$$\Sigma Q_{ii} = \Sigma Q_{ej}; \quad \Sigma Q_{ii} = Q_{cc}+Q_{sc}+Q_{SL}+Q_{sm1}; \quad \Sigma Q_{ej} = Q_{sm2}+Q_{v}+Q_{ga}+Q_{prc}; \qquad (1.1)$$

where: $Q_{ii}$, $Q_{ej}$, $Q_{cc}$, $Q_{sc}$, $Q_{SL}$, $Q_{sm1}$, $Q_{sm2}$, $Q_{v}$, $Q_{ga}$, $Q_{prc}$ represent the amount of heat: incoming, outgoing, chemical fuel, fuel sensitive, sensitive to air, sensitive to material input, sensitive to material output, necessary to water vaporization from product, sensitive of flue gas, lost by convection and radiation [52]

As a simplifying assumption it was considered that, the heat loss through the transport system bodies of product through the dryer are constant and are embedded in Qprc.

Specifying all these terms, follows:

$$Q_{cc} = C\ Hic;\ Q_{sc} = C\ ic;\ Q_{SL} = C\ \lambda\ V_{LMIN}\ i_L; \tag{1.2}$$

$$Q_{sm1} = G_1\ c_{m1}\ t_{m1};\quad Q_{sm2} = G_2\ c_{m2}\ t_{m2};\quad Q_v = G_1\ \frac{U_1 - U_2}{100}\ (i_{a2} - i_{a1}); \tag{1.3}$$

$$Q_{ga} = V_{ga}\ i_{ga} = C\ V_{ga}\ i_{ga};\ Q_{prc} = \Sigma Q_{ii} - \Sigma Q_{ej} = \eta\ \Sigma Q_{ii}, \tag{1.4}$$

where: C is the fuel flow, in $Nm^3/h$; $H_{ic}$ - calorific value of the fuel, in KJ/kgK; $i_c$, $i_L$, $i_{ga}$, $i_{a1}$, $i_{a2}$ - enthalpies of fuel, combustion air, flue gas, water at incoming or outgoing, in KJ/kg; $\lambda$ - coefficient of air excess to burn fuel; $V_{LMIN}$ - minimum amount of air necessary for combustion of fuel, in $m^3$; $V_{ga}$ - flue gas volume, in $Nm^3/Nm^3$; $V_{ga}=V_{gamin}+(\lambda-1)V_{Lmin}$; $\dot{V}_{ga}$ = flue gas flow, in $m^3/s$; $c_{m1}$, $c_{m2}$, $t_{m1}$, $t_{m2}$, $U_1$, $U_2$ - specific heats, in KJ/kg; temperatures, [°C], material humidity at incoming and outgoing, [%] [55].

Therefore, the heat balance equation becomes:

$$C\ H_{ic} + C\ i_c + C\ \lambda\ V_{LMIN}\ i_L + G_1\ c_{m1}\ t_{m1} = G_2\ c_{m2}\ t_{m2} + G_1\ \frac{U_1 - U_2}{100}\ (i_{a2} - i_{a1}) + C\ V_{ga}\ i_{ga} + \eta\ (C\ Hic + C\ ic + C\ \lambda\ V_{LMIN}\ i_L + Q_{sm1} + G_1\ c_{m1}\ t_{m1}). \tag{1.5}$$

For the specific case, regarding the drying of wheat seeds, being aware of the following parameters:

$t_{m1}$ =20°C, $t_{m2}$ =70°C , $U_1$=30%, $U_2$=14%, $c_{m1}$= $c_{m2}$=1.84 KJ/kgK,

$H_{ic}$=8500 Kcal/kgK; (marsh gas) $i_c$=8.22 Kcal/kg;

$i_L$=1,004+x(2500+1,86$t_{aer}$);

x=0.005, 0.02..0.1Kg/Kg; $t_{aer}$=0,5..45°C; $c_{pa}$=1.002Kcal/kgK; $t_{ga}$=90°C;

$i_{ga}$=1,004+x(2500+1,86$t_{ga}$); $\lambda$=6.510; $V_{LMIN}$=10,16 $m^3$; $V_{ga}$=70,48 $Nm^3/Nm^3$; $G_1$=5000 kg/h; $\eta$=25%

Thus, applying the transformation 1Kcal=0.239 KJ, equation (1.5) become:

$$(C\cdot H_{ic} + C\cdot i_c + C\cdot\lambda\cdot V_{LMIN}\cdot(1.004t_{aer} + x(2500+1.86t_{aer}))\cdot 0.239 + G_1\cdot 1.84\cdot 0.239\cdot t_{m1})\cdot 0.75 =$$
$$G_1(1-\frac{U_1}{100}+\frac{U_2}{100})\cdot 1.84\cdot 0.239\cdot t_{m2} + G_1\frac{U_1-U_2}{100}c_{pa}(t_{m2}-t_{m1}) + C\cdot V_{ga}\cdot(1.004t_{ga} + x(2500+1.86t_{ga})) \tag{1.6}$$

Solving the equation using symbolic calculation model of Math Cad 7 in relation to C, leads to the solution:

$$C(t_{aer},x) = -\frac{G_1(0.329\cdot t_{m1} - 0.439\cdot t_{m2} + 0.004\cdot t_{m2}\cdot U_1 - 0.004\cdot t_{m2}\cdot U_2 - 0.01\cdot c_{pa}\cdot U_1\cdot t_{m2})}{0.75(H_{ic}+i_c)+\lambda\cdot V_{LMIN}(0.179\cdot t_{aer} + 448.125\cdot x + 0.333\cdot t_{aer}\cdot x) - V_{ga}\cdot(1.004t_{ga} + x(2500+1.86t_{ga}))} \tag{1.7}$$
$$-\frac{0.01\cdot c_{pa}(U_1\cdot t_{m1} + U_2\cdot t_{m2} - U_2\cdot t_{m1})}{0.75(H_{ic}+i_c)+\lambda\cdot V_{LMIN}(0.179\cdot t_{aer} + 448.125\cdot x + 0.333\cdot t_{aer}\cdot x) - V_{ga}\cdot(1.004t_{ga} + x(2500+1.86t_{ga}))}$$

By changing the variables: $t_{aer}\rightarrow$ p şi x$\rightarrow$ m, it is defining the matrix $F_{i,j}$:=C($p_i$,$m_j$), where:

$$p_i = p_{min} + i\frac{p_{max} - p_{min}}{p_n}; \quad m_j = m_{mjn} + j\frac{m_{max} - m_{min}}{m_n}; \; i = 0..p_n - 1; \; p_n = 31; \; m_n = 31;$$

$$j = 0..m_n - 1; \; m_{mjn} = 0; \; m_{max} = 20; \quad p_{min} = 0; \; p_{max} = 30.$$

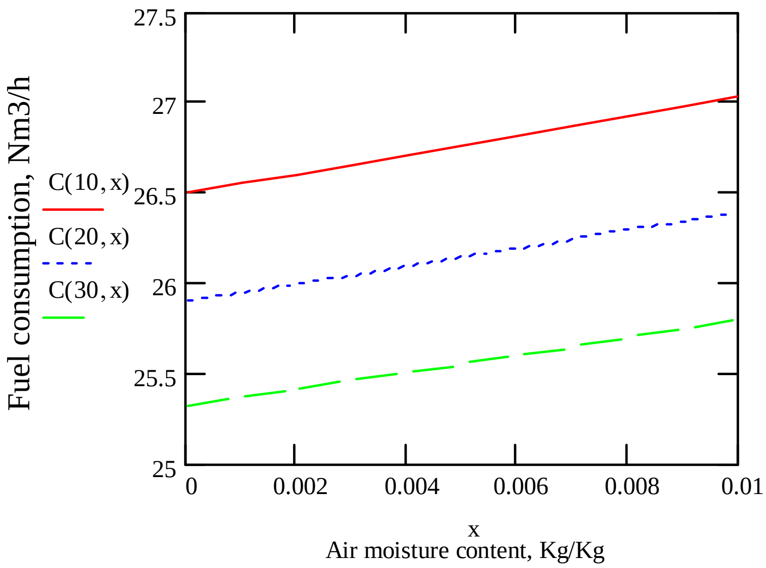



*Figure 1.2. Fuel requirement depending on the ambient humidity*

This function, entered in the memory of the process computer, allows the calculation of the needed fuel to be burned, to maintain the temperature in the drying chamber. Based on experimental results, and depending on the architecture of the drying chamber, the relationship can be corrected with certain coefficients.

In the initial conditions, where varies only a parameter of the environment (temperature or humidity), it can be seen in figures 1.2 and 1.3 the evolution of fuel consumption (methan gas).

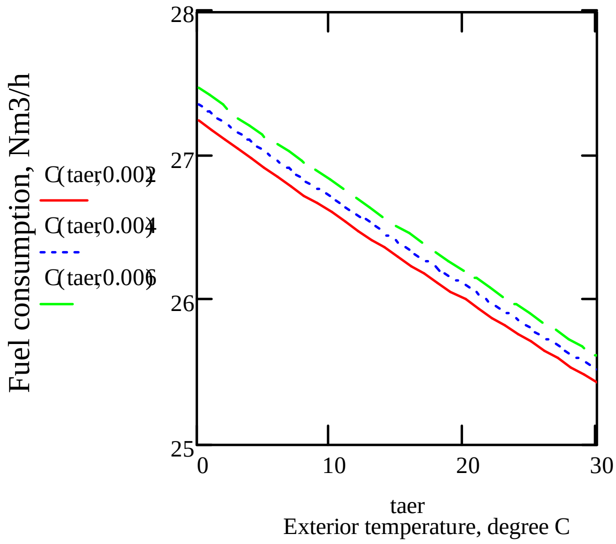
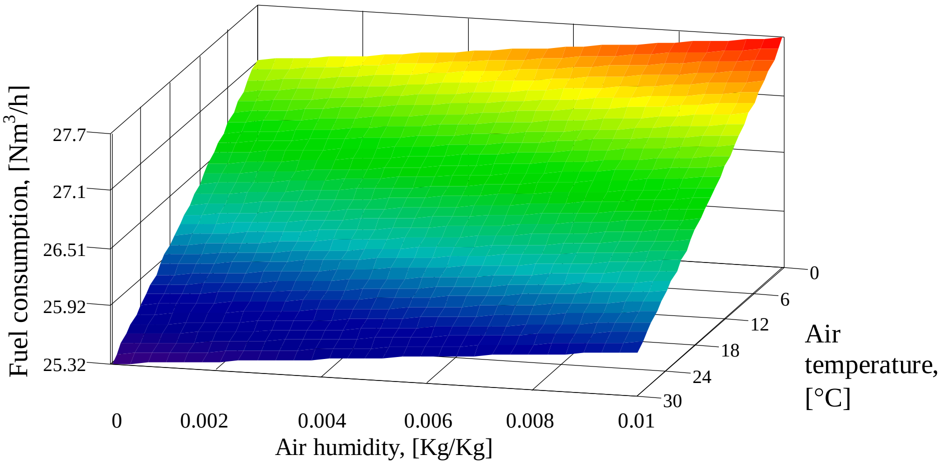



*Figure 1.3. Fuel requirement depending on the ambient temperature*




F

*Figure 1.4. Fuel requirement depending on ambient temperature and humidity needed to maintain the imposed thermal regime in drying chamber*

In practice, there are many situations when, the two effects cumulate, leading to an considerable decrease of temperature in the drying room.

To highlight the overlapping of the two effects, is necessary the graphical representation of the function $C(t_{aer},x)$ in three-dimensional coordinates.

Therefore, it highlights the need to equip the modern dryers with automatic control systems, that memorizing an area like the one in figure 1.4, in oreder to eliminate undesirable influence of the variation of parameters, as discussed, that occur in the drying process, by modifying the necessary fuel flow, in order to maintain an imposed thermal regime inside the drying room.

## 1.2. Fuel flow variation depending on humidity and temperature of the seeds during drying process

During the harvesting campaign, at reception bases of grain seeds and other technical plants are brought systematically discrete quantities of harvest, that may have different characteristics in terms of humidity.

This disturbing factor, together with temperature variation of seeds that will come into dryer over a day, produce a number of shortcomings in the correct operation of drying installations.

The following is a quantitative understanding of these influences on the necessary fuel to be consumed in order to maintain a constant thermal regime in the drying room.

For this it was considered the case of drying a quantity of corn, whose specific heat varies with the humidity and temperature according to the relation:

$$c_m = \frac{U(26.6 + 0.116 \cdot t_m)}{100 + U}, \tag{1.8}$$

where: U is seeds humidity, %; $t_m$-seeds temperature, °C.

Are also known the following parameters:

$t_{m1}$ =0...30°C, $t_{m2}$ =60°C , $U_1$=16...26%, $U_2$=14%,
$H_{ic}$=8500 Kcal/kgK; $i_c$=8.22 Kcal/kg; $i_L$=4.97 Kcal/kg;
$c_{pa}$=1.002Kcal/kgK; $i_{ga}$=47,2 Kcal/kg; $\lambda$=6.510;
$V_{LMIN}$=10,16 $m^3$; $V_{ga}$=62,77 $m^3$/h; $G_1$=5000 kg/h;
$\eta$=25%; $i_{a1}$=16.003 Kcal/kg; $i_{a2}$=656.294 Kcal/kg.

Starting from the general equation of heat balance, making the replacements, results:

$$\begin{aligned}&(C \cdot H_{ic} + C \cdot i_c + C \cdot \lambda \cdot V_{LMIN} \cdot i_{aer} + G_1 \frac{(26.6 + 0.116 t_{m1})U_1}{100 + U_1} t_{m1}) \cdot 0.75 = \\ &G_1(1 - \frac{U_1}{100} + \frac{U_2}{100}) \frac{(26.6 + 0.116 t_{m1})U_2}{100 + U_2} t_{m2} + G_1 \frac{U_1 - U_2}{100}(i_{a2} - i_{a1}) + C \cdot V_{ga} \cdot i_{ga}\end{aligned} \tag{1.9}$$

Solving the heat balance equation (1.9) using the symbolic calculation module Math Cad relative with C, leads to the solution:

$$C(t_{m1},U_1)=-G_1\frac{t_{m1}\dfrac{U_1}{U_1+100}(19{,}95+8{,}7\cdot 10^{-2}\cdot t_{m1})}{0.75(H_{ic}+i_c+\lambda\cdot V_{LMIN}\cdot i_{aer})-V_{ga}\cdot i_{ga}}-$$

$$-\frac{t_{m2}\dfrac{U_2}{U_2+100}(26{,}6+0{,}16t_{m2}+0{,}266U_1+1{,}16\cdot 10^{-3}t_{m2}U_1-0{,}266U_2-1{,}16\cdot 10^{-3}U_2t_{m2}}{0.75(H_{ic}+i_c+\lambda\cdot V_{LMIN}\cdot i_{aer})-V_{ga}\cdot i_{ga}}-$$

$$-\frac{10^{-2}(U_1i_{a2}+U_1i_{a1}+U_2i_{a2}-U_2i_{a1})}{0.75(H_{ic}+i_c+\lambda\cdot V_{LMIN}\cdot i_{aer})-V_{ga}\cdot i_{ga}} \qquad (1.10)$$

with which it can be determine the fuel flow variation, required to be burned, based of variations in the product at entering into the dryer, for a imposed thermal regime in the drying chamber.

Considering the constant values $t_{m2}$, $U_2$, λ, $V_{LMIN}$, $i_L$, $H_{ic}$, $i_c$, $G_1$, η (for a constant drying regime) result the overall transfer function of the automatic control system, that will be used by computer to correct the fuel flow sent to the burner, at any change of cereals temperature and humidity before entering in the dryer. In the figures 1.5 and 1.6 it can appreciate the fuel consumption dependence based on the values of this two parameters.

It is found that for the typical value of the seeds temperature at entrance in the dryer (curve C(20,U1)), increases of values for seeds humidity (15...27%) require increases of fuel flow with 5...7%. Instead the decrease of the values for seeds temperature (figure. 1.5) with 10...15°C (situation frequently encountered in the autumn) involves increases with 15...20% of fuel flow (curve C(tm1, 20)), figure 1.6 .

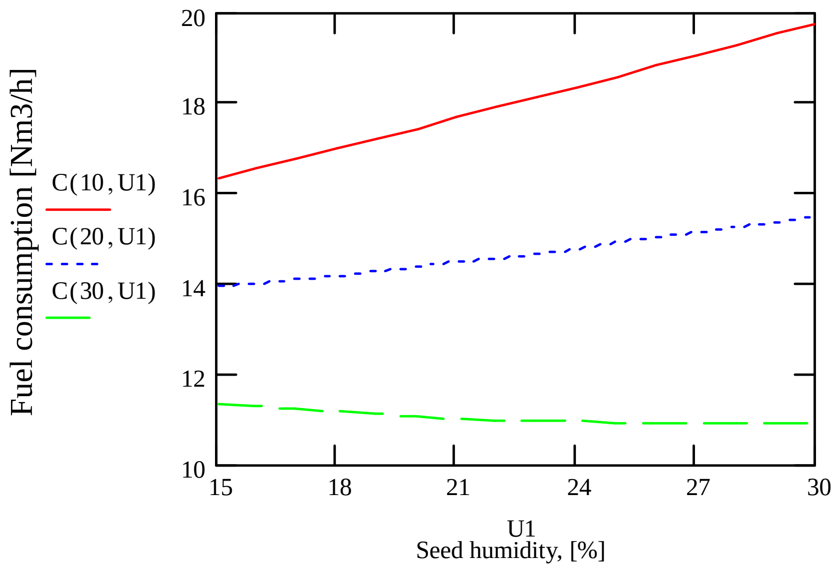



*Figure 1.5. Changing the fuel requirement based on seeds humidity changes*

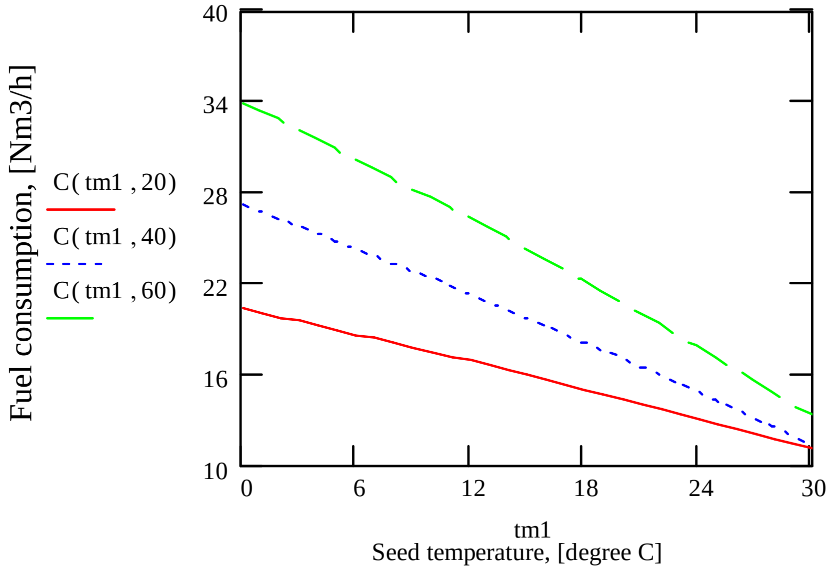



*Figure 1.6. Changing the fuel requirement depending on seeds temperature changes*

This indicates that a significant amount of energy is consumed by raising the temperature of the seeds.

Taking this into consideration and the favorable impact of low humidity of the ambient air on economy operation, it is recommend drying of the seeds during the day, usually when these two conditions are met.

Decreasing of necessary fuel with increasing of seeds humidity at entring under certain conditions (curve C(30, U1), figure 1.5), is explained by the increase of enthalpy of the product in the same time with its humidity and by the fact that necessary fuel has been calculated for a constant thermal regime and not for a required period of drying.

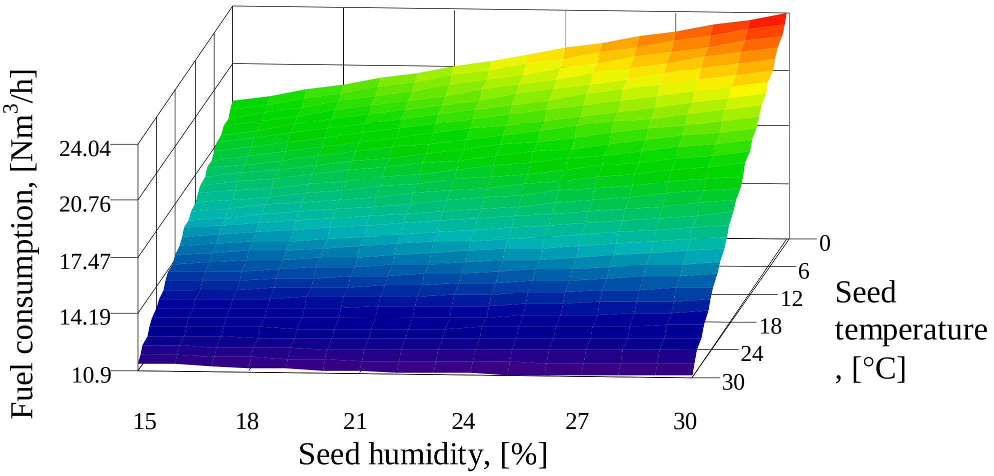
To highlight overlapping effects is necessary graphical representation of the function $C(t_{m1},U_1)$ in three-dimensional coordinates.

By changing of variables:

$t_{aer} \rightarrow p$ and $x \rightarrow m$, matrix is defined $F_{i,j}:=C(p_i,m_j)$, where:

$$p_i=p_{min}+i\,\frac{p_{\max}-p_{\min}}{p_n}; \quad m_j=m_{min}+j\,\frac{m_{\max}-m_{\min}}{m_n}; \; i=0..p_n-1; \; j=0..m_n-1;$$

$$p_n=31;\; m_n=16;\; p_{min}=0;\; p_{max}=30;\; m_{min}=15;\; m_{max}=30.$$




F

*Figure 1.7. Changes in fuel flow depending on the temperature and humidity seed at entering in the dryer*

Figure 1.7 shows that when there is an accumulation of unwanted influence of these two parameters, the rate of increase in fuel demand can often increase with 80...90%. Therefore it is found that, not knowing of evolution of the factors influence the evolution of drying process and not equipment of dryers with performante automatic control systems, that can correct the operation of one or more basic components from the drying system, in order to eliminate interference effects that can lead to serious shortcomings towards quality of cereals, but also in terms of the economy system.

The ideal solution is implementing of an adjustments and control systems driven by a computer, that has the possibility to store complex functions between parameters that characterized the dryer at a time and deal effectively with the idea of maintaining the optimum thermal regime.

**Conclusions**

Looking at figures 1.1, 1.2, 1.3, 1.4 and 1.5 the effect of temperature and humidity of the ambient air or seeds humidity at entering in the dryer, shows the following:

- the greatest influence on the heat balance is given by seeds temperature at entering in the dryer, in the sense of big decrease of the necessary fuel in the same time with increase of seeds temperature;

- increasing of the ambient air humidity, also bring an extra caloric contribution by increasing enthalpy but the mass transfer (humidity) from seeds to the drying agent is difficult, in conclusion needs to be increase stationary time for drying period with constant speed in the dryer or needs to be made more passes through the installations;

- increasing of the air temperature has a positive influence on economy system by reducing of necessary fuel. At the same time, increasing the speed of humidity transfer through the increase of diference between the content of current humidity and the humidity content at saturation in case of drying agent;

- whereas the majority of silos, seeds are stored outside before drying and have a temperature approximately equal to the ambient temperature, it is recommended drying operation during the day, when ambient temperatures are higher.

## 1.3. Contribution to the calculus of maximum temperature of drying agent depending on seeds humidity and their destination

### *1.3.1 Thermodynamic characteristics of seeds*

**The thermal conductivity of wheat and maize** it was determined experimentally by Kazarian and Hall since 1965. To determine this parameter they used linear heat source method.

An empty cylinder in interior, with a height of 25 cm and a diameter of 7 cm it was filled with grains, and an electric resistance was placed in the center. Two currents of 0.49 A and respectively 0.56 A were used in order to obtain different temperatures in the cylinder.

However, for these two different currents were not noticed significant differences in the thermal conductivity values. For maize heating lasted 16 min with a current of 0.49 A, and for wheat heating time was 10 minutes with the same intensity of electric current.

In order to calculate the **thermal diffusivity**, the granules were placed in a parallelepiped from copper where have been placed at certain distances temperature sensors.

Parallelepiped was placed in an ice-water bath. Based on information provided by temperature transducers, knowing the distance between them it could calculate the thermal diffusivity.

The values obtained for the diffusivity and the thermal conductivity in the range of 8.8 to 52,7°C temperature, are shown in tables 1.1 and 1.2.

*Table 1.1 Thermodynamic characteristics of maize grains*

| Humidity, % | Density, kg/m$^3$ | Specific heat, kJ/kgK | Thermal conductivity, W/mK | Thermal diffusivity, $\cdot 10^{-7}$, m$^2$/s |
|---|---|---|---|---|
| 0,91 | 754,54 | 1,532 | 0,117 | 1,019 |
| 5,08 | 751,33 | 1,692 | 0,122 | 0,983 |
| 9,81 | 746,53 | 1,834 | 0,127 | 0,9391 |
| 14,7 | 748,13 | 2,027 | 0,132 | 0,9056 |
| 20,1 | 724,10 | 2,223 | 0,136 | 0,8669 |
| 24,7 | 709,68 | 2,374 | 0,142 | 0,8875 |
| 30,2 | 682,45 | 2,462 | 0,144 | 0,9236 |

*Table 1.2 Thermodynamic characteristics of wheat grains*

| Humidity, % | Density, kg/m$^3$ | Specific heat, kJ/kgK | Thermal conductivity, W/mK | Thermal diffusivity, $\cdot 10^{-7}$, m$^2$/s |
|---|---|---|---|---|
| 0,68 | 772,16 | 1,453 | 0,098 | 0,9262 |
| 5,45 | 776,97 | 1,570 | 0,102 | 0,8953 |
| 10,3 | 778,56 | 1,792 | 0,108 | 0,854 |
| 14,4 | 764,15 | 2,094 | 0,113 | 0,8204 |
| 20,3 | 741,92 | 2,186 | 0,115 | 0,7998 |

The results show that there is a linear relationship between the thermal conductivity and humidity content, which may be expressed by the equation of the regression:

$$\lambda = 10^{-2}(0{,}9501 \cdot U + 9{,}821)\text{, for wheat and} \quad (1.11)$$

$$\lambda = 10^{-2}(0{,}9385 \cdot U + 11{,}826)\text{, for maize,} \quad (1.12)$$

where: U is the humidity content of the seeds, as a percentage.

As expected, the thermal conductivity increases with increasing humidity content. Instead thermal diffusivity decreases constant with increasing humidity for wheat and for maize decreased also to the value of 20%, after which there is a growing trend.

The explanation for this phenomena is the specific heat and density change with increasing of humidity content ($a=\lambda/c_v$). Calculated values of thermal diffusivity, based on experimental data $\lambda$ and $c_v$, were 6...21% higher than those measured for wheat. For maize, the same difference varied between 10...16%. The reason for this discrepancy is the experimental errors and limitations of tools.

**Experimental criteria equations.** Processing of experimental data obtained by various experimental techniques in thermal regime stationary quasi-stationary (or regular) and non-stationary, is presented under the form of equation criteria such as:

$$Nu= C Re^{m} Pr^{n}; \quad (1.13)$$

$$Sh=C_1 Re^{p} Sc^{q}, \quad (1.14)$$

where:

$$Nu=\frac{\alpha d_p}{\lambda} \text{ is Nusselt criterion at convective heat transfer;} \quad (1.15)$$

$$Re=\frac{w d_p}{\nu} \text{ - Reynolds criterion;} \quad (1.16)$$

$$Pr=\frac{\nu}{a}=\frac{\nu \rho c_p}{\lambda} \text{ - Prandtl criterion;} \quad (1.17)$$

$$Sc=\frac{\nu}{D} \text{ - Schmidt criterion at convective mass transfer;} \quad (1.18)$$

$$Sh=\frac{\beta d_p}{D} \text{ - Sherwood criterion at convective mass transfer;} \quad (1.19)$$

where: D is the diffusion coefficient, in $m^2/s$; $\lambda$ - thermal conductivity, W/mK, $d_p$ - particle diameter, m; $\alpha$ - convective heat transfer coefficient, $W/m^2K$; w - speed drying agent, m/s; a -

thermal diffusivity, $m^2/s$; $\nu$ - kinematic viscosity of drying agent, $m^2/s$; $\beta$ - convective mass transfer coefficient in m/s.

Analysis of existing criterial equations from speciality literature shows a partial analogy between the processes of energy transfer (heat) and the transfer of matter (mass), where: $C=C_1$; m=p; n=q=1/3, so:

$$Nu=CRe^{m}Pr^{1/3}; \tag{1.20}$$

$$Sh=CRe^{m}Sc^{1/3}. \tag{1.21}$$

Analysis of the experimental results, of the numerous criterial equations and corresponding nomograms allows to specify recommendable relations for the current design of devices with fixed granular layers. Thus, for the stationary regime of fixed granular layer, average coefficients $\alpha$, $\beta$ can be determined by the following relations:

1. In the area of $Re_{ec}=30\ldots8\cdot10^4$; Pr(Sc)=0,6…3600:

$$Nu_{ec}=0{,}395Re_{ec}^{0{,}64}Pr^{1/3}; \tag{1.22}$$

$$Sh_{ec}=0{,}395Re^{0{,}64}Sc^{1/3}. \tag{1.23}$$

For regular shaped particles, the medium dispersion in precision of criterion Nu (Sh) is ±15%.

For irregularly shaped particles, with strong rough surfaces, the medium dispersion is +30 ...- 50%;

2. In the area of $Re_{ec}=30\ldots2$; Pr(Sc)=0,6…3600: (1.24)

$$Nu_{ec}=0{,}725Re_{ec}^{0{,}47}Pr^{1/3}; \tag{1.25}$$

$$Sh_{ec}=0{,}725Re^{0{,}47}Sc^{1/3}. \tag{1.26}$$

The standard deviation is the calcul accuracy is ±15%.

3. In the area of $Re_{ec}$=2...0,01, where is present the influence of free convection is introduced also Grashof equivalent criterion equivalent:

$$Gr'_{ec}=\frac{gd^3{}_p}{\nu^2}\frac{\varepsilon}{1-\varepsilon}\frac{\rho_s-\rho}{\rho}, \tag{1.27}$$

in which: $g = 9,81\ m/s^2$; $\nu$ - kinematic viscosity of the gas phase that fills the fixed layer, $m^2/s$; $\rho$ - medium density, kg/m3; $\rho_s$ - gas density at saturation for equilibrium of evaporation from the surface of the granule, kg/m3.

If is replaced the simplex $(\rho_s - \rho)/\rho$ from previous relationship with the difference in concentration (saturation, $C_s$ and in fluid phase, $C_\infty$) results:

$$Gr'_{ec} = \frac{gd^3{}_p}{\nu^2}\frac{\varepsilon}{1-\varepsilon}\frac{C_s - C_\infty}{C_\infty}. \tag{1.28}$$

In these conditions, if $Gr_{ec} \le 10^4 Re_{ec}$, the influence of free convection can be neglected and are recommended the relations:

$$Nu_{ec}=0,515Re_{ec}^{0,85}Pr^{1/3}, \tag{1.29}$$

$$Sh_{ec}=0,515Re_{ec}^{0,85}Sc^{1/3}, \tag{1.30}$$

with medium dispersion accuracy of ±25%.

If the case $Gr'_{ec} > (Gr'_{ec})_{cr}=10^4Re_{ec,}$ the influence of free convection of a fluid phase that is stationary (or moving) in layer is important, increasing the thermal and mass flows $\dot{q}, \dot{m}$. The phenomenon is complex and poorly mastered by measurements, so from this reason it is recommended by a first approximation, using the relations:

$$Nu_{ec}=0,115\varepsilon(Gr'_{ec}Pr)^{1/3}, \tag{1.31}$$

$$Sh_{ec}=0,115\varepsilon(Gr'_{ec}Sc)^{1/3}, \tag{1.32}$$

which leading to the medium dispersion accuracy of ±50% accuracy.

4. For heating or cooling of the granular fixed layer in the non-steady regime, in the range $Re_{ec}$=50...5000, it is recommended the following relations:

$$Nu=0,166Re_{ec}^{0,725}Pr^{1/3}, \tag{1.33}$$

$$Sh=0,166Re_{ec}^{0,725}Sc^{1/3}, \tag{1.34}$$

wich leading to maximum dispersion of ±20% precision.

At research with high precision it must assure in the experiment the complete similarity and analogy conditions, which is extremely difficult. In these criterial equations the equivalence signification is:

$$Nu_{ec} = \frac{\alpha d_{ec}}{\lambda}, \; Sc_{ec} = \frac{\beta d_{ec}}{D}, \; \mathrm{Re}_{ec} = \frac{w d_{ec}}{\nu}, \tag{1.35}$$

where the equivalent diameter of the granular layer is:

$$d_{ec} = \frac{4\varepsilon}{a_0}, \tag{1.36}$$

where: ε is the porosity of the granular layer; $a_o$ -grain specific surface, $m^2/m^3$.

### *1.3.2. The influence of drying regime on seed quality*

The drying operation of the seeds, depending on how it is driven, can affect both positively and negatively their quality.

A sudden drying at temperatures too high at seed with very high humidity, causing instant drying of grain coating, welding of exterior ends of the capillaries, closing of pores from grain surface and prevent outside diffusion of water from the grain.

In such cases, by vapor accumulation in capillaries and formation of overpressure, inside the seeds occurs cracking and breakage, and to some products (peas, beans, etc.) the seeds are peeled and unfold in cotyledons (halves).

At the agricultural products destinated for beer manufacturing or for sowing, if drying is done irrationally, it is a diminishes or completely lost of germination characteristics. By applying a suitable drying process (at an optimal temperature regime and with a humidity extraction which do not force the drying) can significantly improve the viability of the seeds (germination), and in some cases, when it is lower, by application of certain heat treatments can influence the growth of germination.

For products assign for human consumption, animal feed and industrialization through the drying process, as well as reducing humidity, it aims to maintain, and where possible, improvement of chemical components and technological features [1], [3], [10], [14].

In this respect it was found that the drying temperatures may greatly influence the extent and nature of the substances contained in the seed.

When the grain mass is heated to temperatures bigger than 60...70 °C (depending on product nature), the chemical components have changes which determine the reduction of qualitative characteristics of the grains. The starch from cereals, heated in aqueous solution at more than 70 °C swell and crack, at 100...110°C it dehydrates and at 120...140 ° C it is transform in dextrin.

Protein substances changes its properties, positively or negatively, as the drying process is conducted in a rational or irrational mode.

In general, protein denaturation begins at temperatures which variates between 50...65°C, depending on the characteristics of the substances. Choosing an appropriate thermal regime can positively influence the characteristics of proteins. It was found that in case of wheat with hard gluten, heated about 55°C, improves its baking qualities. Contrary, for batches of wheat with soft gluten temperature of 45°C is sometimes too high. In case of these seeds, at heating over 45°C, gliadin and glutenin from wheat does not bind in suitable proportions, the percent and qualitative characteristics of the gluten decreases, it becomes soft and philanthe and baking characteristics decreases.

Fats from agricultural products and in particular those of oilseeds, heated to extremely high temperatures can decompose partially, and in this case the acid increases.

Vitamins A and B from the straw cereal grains (wheat, rye, barley, oats) can be heated at high temperatures up to 100...120°C, without negative effects. Vitamin C from fresh harvested peas begin to distinguish when the beans are heated to approximately 50°C.

With regard to qualitative changes at the products which dry during after maturation period it was found that low temperatures at the beginning of the drying process and which gradually increase while humidity reduction, accelerates their maturation, improve the physical, biochemical and technological properties of seeds. Treating of these products with too high temperatures, which suddenly act, has harmful effects on seeds and determine compromise of germination and their food characteristics.

The drying time of grain mass depends largely on the initial humidity content (before drying) and the shape of the water in grain: free humidity (water mechanically linked) or hygroscopic humidity or related (the water is physically bound or chemical and physical bound). Part of hygroscopic humidity, the one chemically bound can not be removed in the drying process. Chemically bound water molecules are closely combined in colloidal molecules from grain (proteins, carbohydrates).

The heat acts differently on colloidal organic substances from grain. The substances most stable to the heat action are fat and hydrocarbonates. At temperatures up to 60°C changes are not yet visible, but above this level accompanied by a high grains humidity leads to the phenomenon of gelatinization and partial decomposition of starch with dextrins formation. In addition, in the above conditions, it is possible also the caramelization of sugars, with formation of dark caramel, which lead to grains staining or complete baking of them. At temperatures above 60°C appears partial decomposition of fats, which increase the acidity of the grains.

Influence of heat can have a favorable character only if applied a judiciously drying regime, respectively if takes into account the correlation of the following three factors: the temperature of the drying agent, the speed of the drying agent and the temperature of grains mass. Choosing of drying regime depends, in turn, by humidity, degree of maturation and further destination of the product. [2], [5], [6], [13].

The specific characteristics of each grain drying influences the choice and management of drying regime. The following will present some recommendations made by the specialty literature towards drying regime for some seeds.

In determining of wheat drying regime needs to consider the following:

• grains humidity at entry in the dryer;

• maximum heating temperature of the grains;

• gluten characteristics;

• temperature of the drying agent.

In tables 1.3 and 1.4 are shown the parameters used to dry the wheat for consumption or sowing.

At **wheat** drying must be taken into account that as at high humidity content of grains, the drying temperature should be lower.

*Table 1.3 The characteristic parameters for the drying process in case of wheat for consumption*

| Gluten qualities | Wheat humidity, % | Maxim temperature of drying agent, °C | | | Grains temperature during drying, °C |
|---|---|---|---|---|---|
| | | Drying with a single stage | Drying in two stages | | |
| | | | Stage I | Stage II | |
| Hard | until 20% | 100 | 80 | 100 | 50 |
| | over 20% | 80 | 70 | 80 | 45 |
| Normal | until 20% | 110 | 100 | 120 | 60 |
| | over 20% | 90 | 80 | 100 | 50 |
| Soft | until 20% | 120 | 110 | 130 | 70 |
| | over 20% | 100 | 90 | 110 | 60 |

If the wheat grains are heated above the permissible limit, it deteriorates gluten, flour hydration capacity decreases, dough attributes to retain gas decreases, bread crust is cracked, bread volume is reduced and core porosity is uneven.

At **rye** drying should be considered that its skin is less porous than wheat and therefore water removing from the grains is more difficult, requiring higher temperatures for drying (table 1.4 and table 1.5).

*Table 1.4 The characteristic parameters for the drying of seeds for germination*

| Cereal | Humidity, % | Maxim temperature, °C | |
|---|---|---|---|
| | | Drying agent | Product |
| Wheat | under 20% | 75 | 45 |
| | 20...23% | 70 | 45 |
| | over 23% | 60...65 | 40 |
| Rye | under 20% | 80 | 45 |
| | 20...23% | 70 | 40 |
| | over 23% | 65 | 40 |
| Barley | under 20% | 80 | 40 |
| | 20...23% | 70 | 40 |

Temperatures shown have no adverse effect on the bakery characteristics of rye, because protein substances - gliadin and glutenin – are not associated so therefore do not form gluten that could be damaged by temperature increase.

**Maize** is the cereal to whom the grains humidity content immediately after harvesting is the best conditions of 18 ... 22%. It is known that the maize grains are larger than the others and therefore the evaporation surface of the mass of grains is reduced.

*Table 1.5 The characteristic parameters for the drying process of rye seeds for consumption*

| Rye humidity, % | Maxim temperature of drying agent, °C | | | Grains maxim temperature, °C |
|---|---|---|---|---|
| | Drying with a single stage | Stage I | Stage II | |
| until 18 | 120 | 130 | 130 | 60 |
| 18…21 | 115 | 100 | 130 | 60 |
| over 21 | 105 | 80 | 120 | 60 |

Because of the corneum stratum, elimination of water by drying is slower. If the maize grains are dryed at a too high temperatures, it cracks in one or more places, and becomes very brittle, and endosperm changes its cohesion and grinding process turns into fewer pearl cereals and more cereal flour, which is not wanted in manufacturing technology of pearl cereals. Maize drying regime is normally performed in two stages (Table 1.6).

*Table 1.6 The characteristic parameters for the drying process of maize grains*

| Destination | Humidity, % | Maxim temperature of drying agent, °C | | Grains maxim temperature, °C |
|---|---|---|---|---|
| | | Stage I | Stage II | |
| Maize for curent consumption | >25 | 80 | 90 | 50…60 |
| | 18...25 | 90 | 100 | 50…60 |
| | <18 | 100 | 110 | 50..60 |
| Maize for germination | >25 | 70 | 80 | 30...40 |
| | 20..25 | 60 | 70 | 30...40 |
| | <20 | 50 | 60 | 30...40 |

The embryo of grain maize is located in the part where the transfer of humidity takes place. Because of this tensions occurs in grain, causing cracks when water elimination in the environment is accelerated by a high temperature gradient, because in this case the humidity in neighboring layers can not replace at the same speed the eliminated water.

The drying process must be driven in time so that the embryo humidity loss can be compensate with the one arrived from its exterior layers and the grain to be able to preserve its power of germination. Therefore, the setting of drying parameters of a maize mass is based on the analysis of the water content of the embryos.

Grain humidity determines the stability of its qualitative characteristics during application of high temperatures. Thus, for example, at a 3% grain humidity, they can resist without depreciate for 20 minutes at temperatures up to 110...120°C, while the newly harvested grains and high humidities lose the qualitative characteristics even at a temperature of 60°C.

It should be keep in mind that freshly harvested maize and high humidity is more sensitive to high temperatures because grain coating in this phase is less permeable to water vapor.

Applying these conditions of drying agent with high temperature leads to a sudden drying of the coating, which makes it more waterproof. This phenomenon leads in turn to a kind of hardening of the grain, which is manifested by the accumulation of water vapor in the peripheral layers of the endosperm, which bob release is hampered by excessive contraction of the pores in the coating, due to its drying of the high temperature regime. At these grains occurs the starch hydrolysis with forms of dextrinization and denaturation of proteins.

For these reasons maize loses its original attributes of quality, reason because maize lots artificial dried, especially those lots subjected to any wrong drying treatments are not recommended for use in the production of maize flour or other specific foods.

Because the system of vegetation almost permanently in water and because of the harvesting in rainy season, humidity content of the **rice** grains in most cases exceeds 18 %, humidity that must be removed immediately after harvesting. Rice drying is done at a lower temperature regime than other grains, so it acquires cracks, breaks during the skinning, changes color and decreases its food value.

The single stage dryers, the maximum temperature of the drying agent is 65 °C and the maximum grains temperature 38 °C.

In the case of multi-stage dryers, the maximum temperature of the drying agent in stage I is 65 °C and in the second stage 70 °C, and the maximum temperature of the grains does not exceed 40 °C. Humidity which must be reach the rice grains after drying is 15...16 %, and in the decortication process to waste through the so-called mechanical losses, since about 1%.

It is recommended that at rice pass through dryer, to make the removal of water in a proportion of about 3%.

**Barley** grains differ by other cereals in that they are coated with a thick and dense bents, in which case the water elimination speed is low. Barley drying temperatures are similar to those of rye.

**Oat** grains compared to other cereals gives easier water (Table 1.7). If case of this product needs to take into consideration that at higher temperatures of drying agent, chaff falls from the grain falls and lights.

**Drying of vegetable grains** is make at a moderate temperature regime and of a products passage through the dryer, humidity extraction must be small. If there is a forced drying at high temperature and high extraction, grain coating crack and seed splits into two halves. This is explained by the fact that at high temperatures, skin dry very fast, reduces its volume and is waterproof. On the other hand, the core of the grain will dry more slowly under the influence of the elasticity and the water vapor pressure in capillaries they swell, while the coaing contracts.

*Table 1.7 The characteristic parameters for the drying process of oat seeds for animal feed*

| Oat humidity, % | Maxim temperature of drying agent, °C | | | Grains maxim temperature, °C |
|---|---|---|---|---|
| | At installation with a single stage | At installation with two stages | | |
| | | Stage I | Stage II | |
| until 18 | 120 | 120 | 120 | 50 |
| 18 …21 | 110 | 100 | 120 | 50 |
| over 21 | 115 | 90 | 120 | 50 |

This mismatch between dry skin and core, and the difference in volume that occurs between these parts during forced drying cause cracks og grains coating. This phenomena is very pronounced in beans and has a lower intensity at pease and soybean.

Among the seeds of legumes, beans and pease are dried artificially in low amounts. The harvesting of these products is done in the summer months, when rainfall is low and grains are harvested in dry condition. For some quantities which are harvested with high humidity is recommended natural drying (because of the difficulties that are encountered by skin cracking at artificial drying).

Artificial drying of **bean seeds** is done in the drying installation with stages, with indirect agent and preheat sector. Maximum extraction of bean passage through the dryer is 3%.

The sudden transition from temperature of the drying sector to the temperature of the cooling sector produces grains shrivel and degradation. For this reason it is recommended that between the drying and cooling sector to have a neutral or standing sector, which attenuates the shock of sudden change in temperature.

The thermal drying regime recommended to maintain the germination is shown in table 1.8.

*Table 1.8 The characteristic parameters for the drying of beans seeds for germination*

| Humidity, % | Maxim temperature, °C | | |
|---|---|---|---|
| | Drying agent | | Product |
| | Stage I | Stage II | |
| over 18 | 40 | 45 | 30 |
| under 18 | 45 | 55 | 40 |

**Grains pease** drying is made generally in the dryers indicated for the bean. It can be done drying also in indirect agent installations fitted with a single stage, but the thermal regime should be moderate.

Maximum extraction at a passage of the pease through the dryer is 5% at installations with two stages and 4% at installations with one stage (table 1.9).

*Table 1. 9 The characteristic parameters for the drying of pease seeds for germination*

| Humidity, % | Maxim temperature, °C | | |
|---|---|---|---|
| | Drying agent | | Product |
| | Stage I | Stage II | |
| over 18 | 50 | 60 | 30 |
| under 18 | 60 | 70 | 40 |

At soybean harvest done in autumn months when rainfall are abundant, so the seeds generally have a high percentage of humidity and artificial drying is mandatory, the natural drying is possible only rarely during this period.

Drying of **soybeans seeds** can be done with most types of dryers. The thermal regime is presented in table 1.10. The maximum extraction of humidity at one passing of product through the dryer is 4%. Among **oilseeds**, sunflower is dried in the largest amount, flax seeds in small quantities, and the pumpkin seeds are dried rarely.

*Table 1.10 The characteristic parameters for the drying process of soy seeds for germination*

| Humidity, % | Maxim temperature, °C | | |
|---|---|---|---|
| | Drying agent | | Product |
| | Stage I | Stage II | |
| over 20 | 50 | 65 | 28 |
| 16...20 | 55 | 70 | 32 |
| under 16 | 60 | 75 | 35 |

At the artificially drying of sunflower seeds, under certain conditions may occurs pyrophoric substances which in connection with the outbreak sparks enter in the dryer, can ignite, causing accidents and extensive damage. Also sunflower seeds are exposed to ignition and because of coating which easily burn, and because to high oil content of the core.

For this reason, the drying of sunflower seeds are preferred installations where the combustion gases do not act directly on the product.

Optimal drying regime is presented in table 1.11. The maximum extraction of humidity at product passing through the dryer is 5%.

*Table 1.11 The characteristic parameters for the drying process of sunflower seeds for consumption*

| Humidity, % | Maxim temperature, °C | |
|---|---|---|
| | Drying agent | Product |
| over 20 | 75 | 45 |
| 15...20 | 83 | 50 |
| under 15 | 90 | 55 |

Drying of flax seeds is made with good results at installations with indirect agent and in particular at vacuum dryers. Drying can be done also in installations with directly agent, but in these dryers is absolutely necessary to ensure complete combustion of the fuel. At incomplete combustion smoke and soot that is emitted from the furnace is fixed to the surface of the seeds, decreasing their quality. The recommended drying regime for flax seeds is presented in table 1.12.

*Table 1.12 The characteristic parameters for the drying process of flax seeds*

| Humidity, % | Maxim temperature, °C | | |
|---|---|---|---|
| | Drying agent | | Product |
| | Stage I | Stage II | |
| over 20 | 60 | 70 | 40 |
| 15...20 | 50 | 60 | 35 |
| under 15 | 45 | 55 | 30 |

For seeds where it was indicated the thermal regime for drying in two stages, but the product requires only one pass through the dryer, and the used installation has only a single stage, the thermal regime is that resulting from the average of the two stages.

For products where it was indicated a single stage and drying is done in installations with two stages, in the first step the temperature should be about 10% lower and in the second stage about 10% higher than indicated.

*Table 1.13 Recommendations towards thermal regime of seeds drying*

| Biological material | Drying agent temperature, °C | | Seeds temperature, °C | | |
|---|---|---|---|---|---|
| | Seed for germination | Seeds for human consumption or animal feed | Seed for germination | Seeds for human consumption | Seed for animal feed |
| Maize | 60...82 | 93...110 | 43 | 54 | 60 |
| Wheat | 37...65 | 65...82 | 40 | 48 | 60 |
| Sorghum | 60...82 | 110...121 | 43 | 60 | 60 |
| Barley | 48...76 | 82...93 | 40 | 48 | 60 |
| Oat | 60...82 | 93...110 | 40 | 60 | 60 |
| Soy | 48...76 | 82...93 | 40 | 60 | 60 |
| Rice | 32...48 | 60...71 | 40 | 48 | 60 |
| Flax | 32...48 | 60...71 | 43 | 43 | 43 |
| Rape | 32...48 | 60..71 | 43 | 48 | 60 |
| Beans | T ambient air + 10°C | 43...65 | 43 | 48 | 60 |
| Sunflower | 40...60 | 43...65 | 40 | 50 | 60 |

Temperatures mentioned above are maximum temperatures which should not be exceeded. In the specialty literature the optimal values towards drying thermal regime of the seeds are not unitary are presented. Sometimes, from one work to the other, these values differ considerably, since the product temperature depends, in addition, by the temperature of the drying and other factors, such as: the architecture of the drying chamber, the overall thermal transfer coefficient, the average humidity of the ambient air and so on. [8], [11], [15], In table 1.13 are presented recommendations on the thermal regime of seeds drying, depending on their destination. During the drying process, the seds humidity content vary continuously in a decreasing mode after complex legislation.

As shown, to maintain in a high proportion the original qualities of the seeds it is necessary a correlation between the temperature of drying agent and current humidity of the seeds. This requirement can be met by implementing in the existing and functional dryers of an automatic control systems.

In the specialty literature, the correlation temperature of drying agent and seeds humidity is in a discontinuous form, for different levels of humidity.

For a normal operation of the automatic control system is necessary that the transfer function of temperature of drying agent = f (seeds humidity) to be precisely known on the definition field.

The conditions for seeds drying varies from one species of grains to another, and according to their future destination. These terms refer to the temperature of the drying agent of the seeds mass and humidity content and stationary time of the material in the dryer.

Between these sizes is a correlation of a complex form, which depends on a number of constructive and functional parameters of the dryer: drying chamber architecture, speed and humidity of the drying agent, movement mode of material towards the drying agent etc.

The temperature of the seeds mass and also drying time (for an extraction of imposed humidity) can be adjusted by changing the value of the temperature of the drying agent.

Experimental research in the field, recommended a series of thermal regimes, depending on the initial seeds humidity, drying time and destination.

These recommendations concern staple correlations for different stages of seeds humidity at entering in the dryer (table 1.13).

In order to obtain a maximum quality of seeds is necessary to know and apply every time (through a system of automatic control) the dependence: *temperature drying agent = f (seeds humidity).*

The analysis of the literature, shows that the function *f* has the form:

$$T(\tau, U)=a + b \log(U) + c \log(\tau), \tag{1.37}$$

where T is temperature of drying agent, °C; τ-process time, minutes; U-product humidity, %; a, b, c-constants which depend by product and its destination.

Finding the values of the constants a, b, c involves solving a system of equations of the form:

$$T_1(\tau_1, U_1)=a + b \log(U_1) + c \log(\tau_1); \tag{1.38}$$
$$T_2(\tau_2, U_2)=a + b \log(U_2) + c \log(\tau_2); \tag{1.39}$$
$$T_3(\tau_3, U_3)=a + b \log(U_3) + c \log(\tau_3). \tag{1.40}$$

Makeing a synthesis between recommendations of the literature presented in chapter 3, recommendations from documentation of dryers construction companies like GSI, Massey Fergusson and Farm Fans and recommendations from other observations made during experimental research, it was applied this calculation method for three cereals (wheat, maize, rye) and two technical plants (soybean, sunflower). In case of wheat for germination, using the matrix: $T = \begin{bmatrix} 40 \\ 50 \\ 65 \end{bmatrix}$, $U = \begin{bmatrix} 29 \\ 23 \\ 16 \end{bmatrix}$, $\tau = \begin{bmatrix} 30 \\ 40 \\ 50 \end{bmatrix}$

and Mathcad working environment it was obtained the following results expressed by curves and surfaces from figures 1.8 and 1.9.

Therefore, it is necessary to adjust the drying temperature of the wheat seeds for germination according to equation:

*$T(\tau, U) = 192 - 75\log(U) - 24\log(\tau)$.*

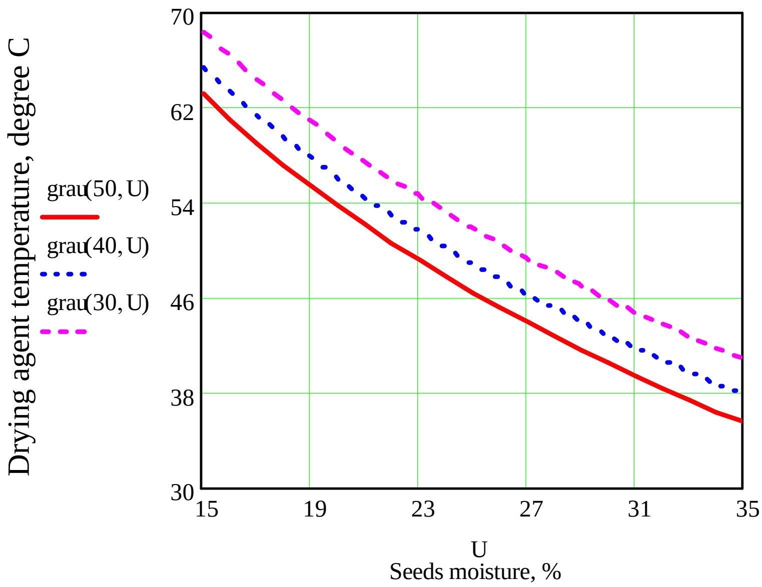



*Figure 1.8. The maximum temperature of the drying agent, depending on the humidity of wheat seeds for germination*

It should be noted that this equation does not take into account the influence of seeds temperature entering in the dryer or by humidity of drying agent. Also the limits of validity falls within a variation range of the filtration speed of (0.4 ... 1.0 m/s).

From figure 1.8 emerges that the temperature of the drying agent should be set in this case, within the range 38...68°C to a change in seeds humidity between 15...35%. Also, it can be seen that in order to maintain the characteristics of germination, increasing of stationary time of the seeds in the dryer (which may be dictated, for example, by a high humidity of drying agent or by seeds entry in the dryer at low temperature), involves reducing the maximum allowable temperature for drying agent. In figure 1.9 it is illustrates the area obtained by combining of all possible operating modes, for seeds humidity variations at entrance, between 15...35% and drying time between 30...100 minutes.

Following the same argument, it is possible, deduction of similar equations also to other biological materials for germination.

Similarly it has been done for finding functions T(τ, U) for the case of seeds used in consumption, but using, in all cases, higher indicated temperatures.

Also, for comparison analysis between different kinds of seeds (of maize, rye, soybean, sunflower), in figures 1.10 and 1.11 are shown developments of maximum temperature of the drying agent, for each of the two destinations (germination and consumption).

Table 1.14 presents the functions T(τ, U) for each type of seeds and destination.

*Table 1.14 Comparison between equations T(τ, U), based on seeds destination*

| ***Biological material*** | ***Equations T(τ, U) based on seeds destination*** | |
|---|---|---|
| | ***Germination*** | ***Consumption*** |
| Wheat | T(τ, U)=192-75 log U-24 log τ | T(τ, U)=239-50 log U-56 log τ |
| Maize | T(τ, U)=216-73 log U-25 log τ | T(τ, U)=216-64 log U-22 log τ |
| Rye | T(τ, U)=189-28 log U-45 log τ | T(τ, U)=263-54 log U-50 log τ |
| Soybeans | T(τ, U)=186-82 log U-11 log τ | T(τ, U)=191-61 log U-17 log τ |
| Sunflowers | T(τ, U)=164-39 log U-39 log τ | T(τ, U)=183-40 log U-42 log τ |

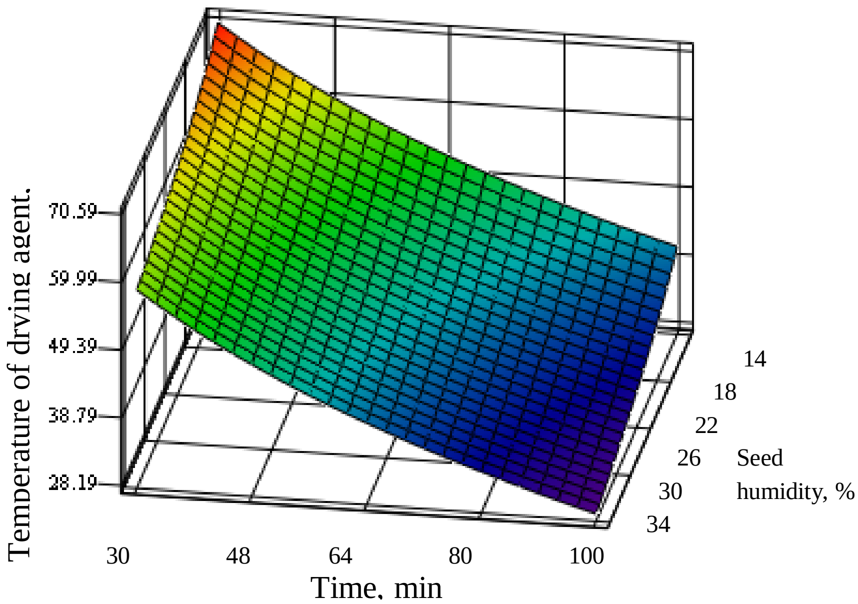



*Figure 1.9. The maximum temperature of the drying agent, depending on the process and humidity of wheat seeds for*

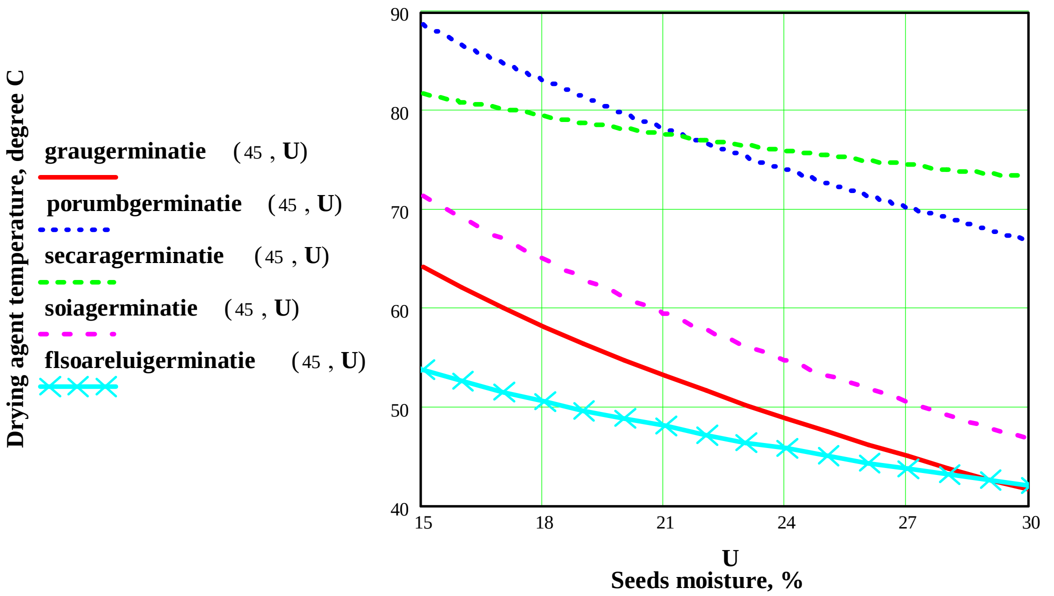



*Figure 1.10. A comparative study between the maximum temperature of drying agent according to the type of seeds for consumption*

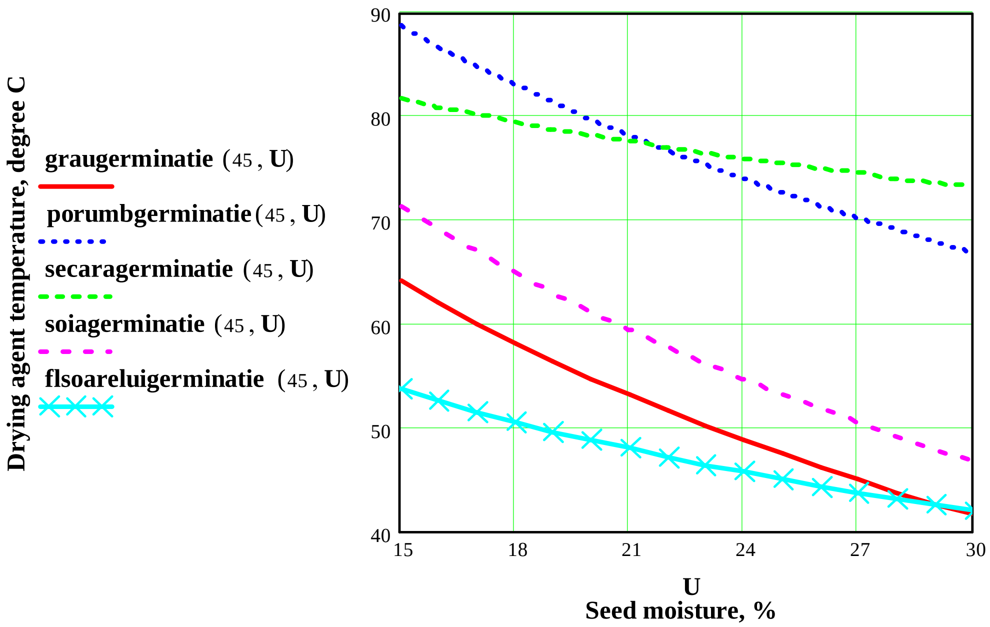



*Figure 1.11. A comparative study between the maximum temperature of drying agent according to the type of seeds for germination*

## 1.4. Study of the drying process influence upon the germination capacity of cereals and technical plant - Case- study- Soybean

### Introduction

The problem of seeds grains and technical plants drying, as basis for further germination is empirically studied in the literature, often not existing a separate approach towards products for consumption. In this chapter are briefly presented some results of the project CEEX 3059/11/10/2005 „Research towards increasing the capacity of germination of grain and technical plants seeds, by controlling and monitoring the parameters of drying process. Applications to maize and soybeans".

After research were applied temperature curves presented in previous chapters and were extracted a series of important conclusions, on how the germination capacity is influenced by the temperature of the drying agent, with reference to the fuel required to complete the technological process.

**The literature recommends** that soybean seeds drying is done at a moderate thermal regime and at passage of products through the dryer, the extraction of humidity must be small. If there is a forced drying, at high temperature and high extraction, the coating crack and seed loosen in the two halves. This is explained by the fact that at high temperatures, the skin dries fast, reduces its volume and became waterproof. On the other hand, the core dries slowly and under the influence of the elasticity and the water vapor pressure from capillaries, they swell, while the coating contracts.

This mismatch between dry skin and core, and the difference in volume that occurs between these parts during forced drying, cause cracks of grains coating.

*Table 1.15 Parameters characteristic to drying process of soybeans for germination*

| | Maximum temperature, °C | | |
|---|---|---|---|
| Humidity, % | Drying agent | | Product |
| | Stage I | Stage II-a | |
| Over 20 | 50 | 65 | 28 |
| 16...20 | 55 | 70 | 32 |
| Under 16 | 60 | 75 | 35 |

The literature recommends artificially drying of **soybean seeds**, in drying installations in stages, with indirect agent with preheat sector. The thermal drying regime recommended to maintain germination is shown in Table 1.15

The sudden transition from temperature of the drying sector to the cooling sector produces grains shrivel and degradation. For this reason it is recommended that between the drying and cooling sector, to have a neutral or standing sector, which attenuates the shock of sudden change in temperature.

During the drying process, the humidity content of seeds varies continuously, decreasing after complex legislation. As shown, to maintain a high proportion qualities of the original seeds, is necessary a correlation between the temperature of the drying agent and current seeds humidity. This requirement can be met by implementing in the existing dryers operation, an automatic control systems.

The drying regime of soybean seeds is normally carried out in two stages, but in order to achieve maximum quality of seeds it is necessary to know and be applied in each moment (in an automatic control system) the dependence: seeds temperature = f (seeds humidity content, the drying time).

In the previous chapter it was established the form of continuously variation of temperature given by the equation from table 1.16.

*Table 1.16*

| ***Biological material*** | ***Equations T(τ, U) based on seeds destination*** | |
|---|---|---|
| | ***Germination*** | ***Consumption*** |
| Soybean | T(τ, U)=186-82 log U-11 log τ | T(τ, U)=191-61 log U-17 log τ |

The graphical representation of these classes of functions is shown in the figures below (in figure 1 for three drying times of 30, 40 and 50 minutes, and in figure 1.12 for the entire duration of the humidity and drying time considered).

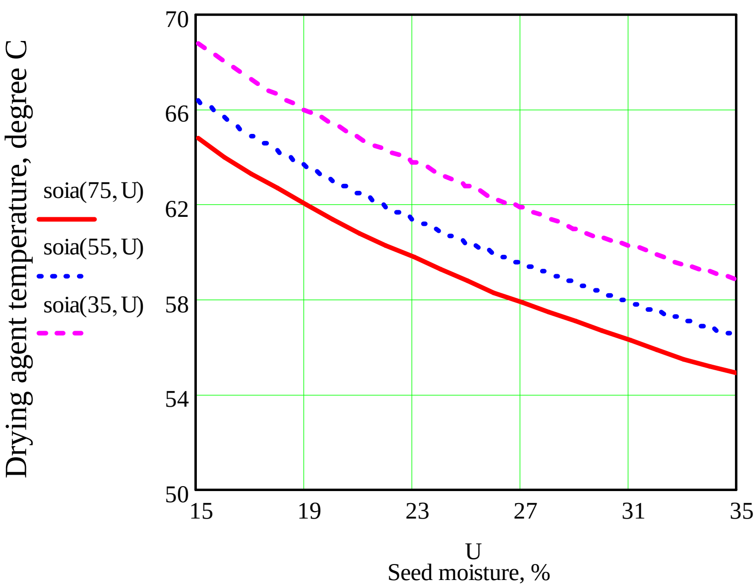



*Figure 1.12. Maximum temperature of the drying agent, depending on moisture of soybean seeds detinated for germination*

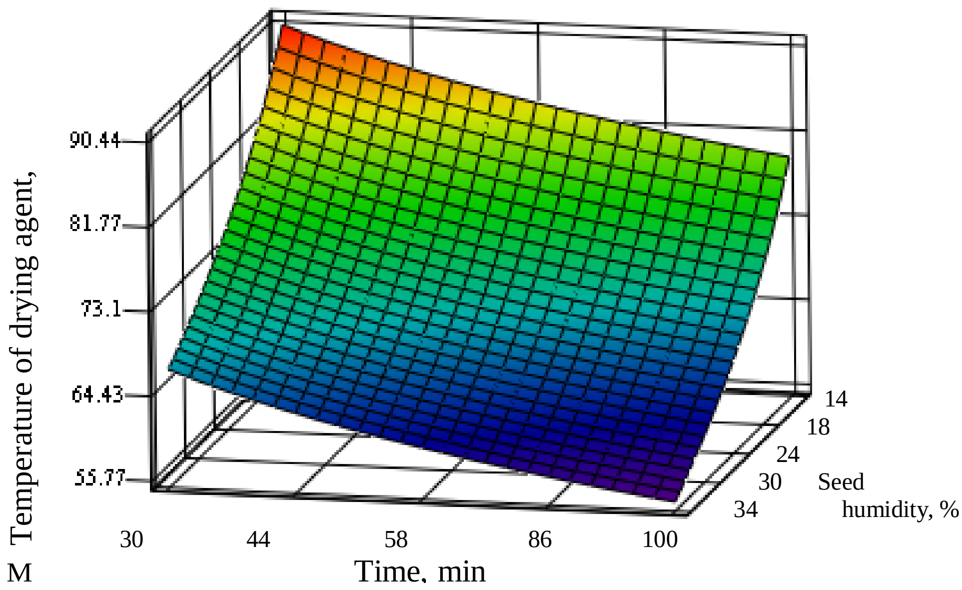



*Figure 1.13. Maximum temperature of the drying agent, depending on the process lenght and moisture of soybean seeds detinated for germination*

From figures 1.12 and 1.13 it can be extract the fact that the temperature of the seeds should be adjusted in this case, within the range 37...75°C to a change of seeds humidity between 15...35%. Also, it can be seen that, in order to maintain the characteristics of germination, the increasing of stationary time of the seeds in the dryer (which may be dictated, for example, by high humidity of drying agent or seeds entering in the dryer at low temperature), involves reducing of the maximum allowable temperature for drying agent.

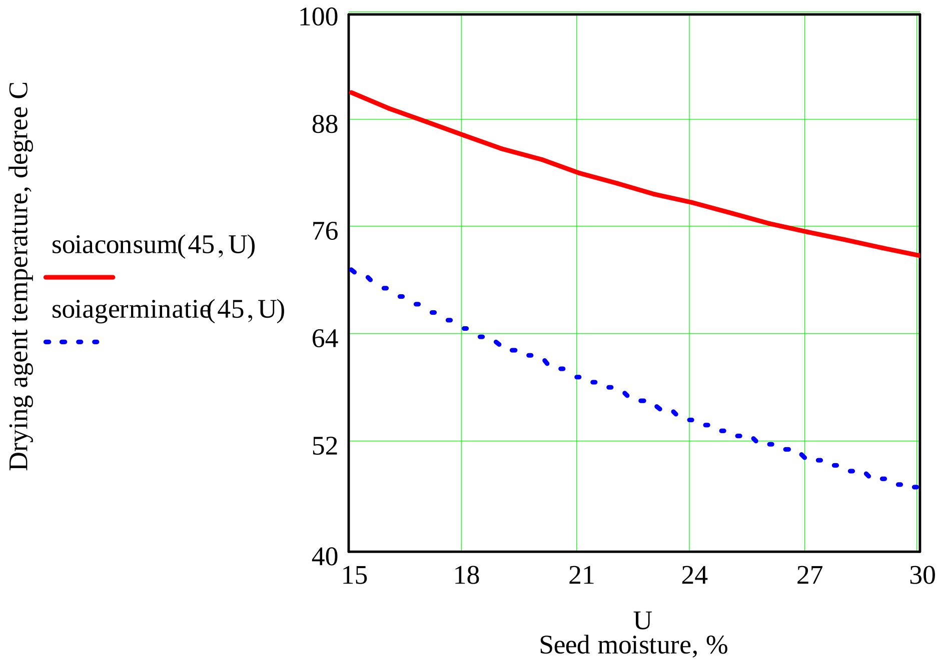



*Figure 1.14 shows a comparison between the maximum levels of temperature of drying agent for soybeans seeds for consumption or germination.*

**Experimental research on the influence of drying regime on germination capacity of soybean seeds**

To check the accuracy of the model, nine samples were performed, in different working conditions, on an industrial dryer GSI. Table 1.17. presents a summary of the specific conditions of conducting experimental research. The first three samples were aimed at highlighting how the germination of seeds after drying, decreases with increasing value of thermical agent temperature.

In these tests, the temperature of the drying was kept constant throughout the process at values of 75, 65 and 60°C recommended in the literature (figure 1.15, 1.16, 1.17). The duration of the drying process it was set to 40 minutes, followed by seeds cooling for 10 minutes, as recommended in the technical memo of the dryer.

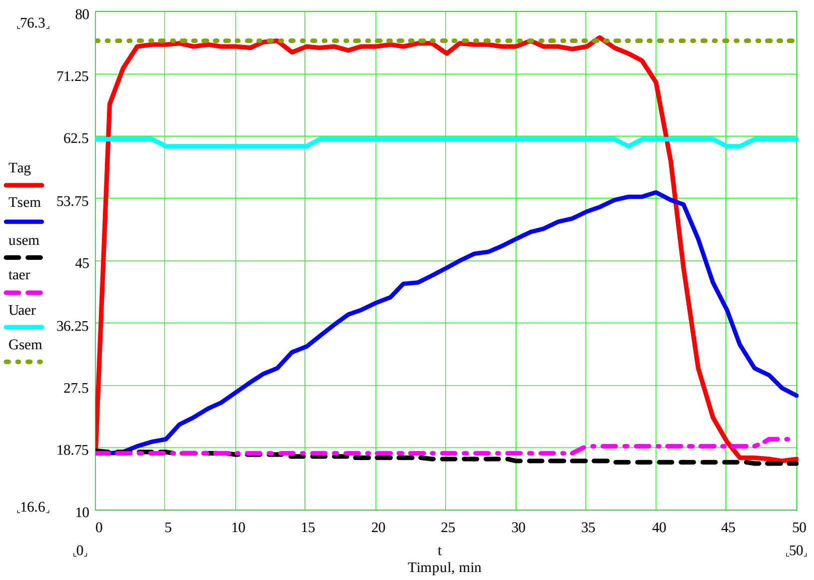



*Figure 1.15. Variation of parameters specific drying process in case of sample 1*

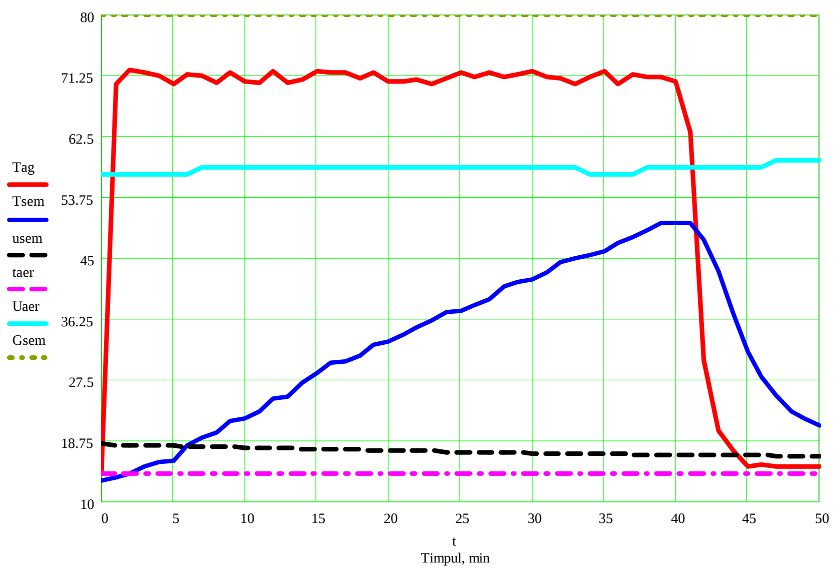



*Figure 1.16. Variation of parameters specific drying process in case of sample 2*

Tabel. 1.17. Results of experimental researches

| No. | Biological material (seeds) | Destination | Drying process time, minutes | Cooling proces s time, minutes | Seeds temperature, ºC | Drying agent temperature, ºC | Initial germination % | Final germination, % | Initial seeds humidity % | Final seeds humidity % | Specific fuel consumption $10^{-3}$ $Nm^3$/Kg water |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Soybeans | Germination | 40 | 10 | 18,2…54,2 | 75 | 91 | 76 | 18,3 | 16,6 | 91 |
| 2. | Soybeans | Germination | 40 | 10 | 14,1…51,1 | 70 | 91 | 80 | 18,3 | 14,5 | 86 |
| 3. | Soybeans | Germination | 40 | 10 | 12,2…42,8 | 65 | 91 | 80 | 17,9 | 15,2 | 82 |
| 4. | Soybeans | Germination | 50 | 10 | 18,1…44,7 | 50…65 | 91 | 84 | 20 | 15,3 | 89 |
| 5. | Soybeans | Germination | 40 | 10 | 12,2…48,1 | 55…70 | 91 | 83 | 20,1 | 14,2 | 85 |
| 6. | Soybeans | Germination | 40 | 10 | 12,0…53,1 | 61…75 | 91 | 81 | 19,8 | 14,8 | 84 |
| 7. | Soybeans | Consumption | 35 | 15 | 18,0…56,2 | 70…85 | 91 | - | 20,0 | 14,0 | 79 |
| 8. | Soybeans | Consumption | 35 | 15 | 10,0…61,5 | 80 | 91 | - | 20,2 | 16,0 | 93 |
| 9. | Soybeans | Consumption | 35 | 15 | 7,9…58,7 | 80 | 79 | - | 20,1 | 18,0 | 95 |

.

Drying was carried out at a constant thermal regime, respectively variable, with change of drying agent temperature in the same time with humidity of soybeans seeds, according to established functions.

Analysis of the experimental results obtained in the samples 1, 2 and 3 (figure 1.15, 1.16, 1.17). highlights the following:

- in the range of 40 minutes (corresponding to the actual drying time) the maximum temperature reached by the soybean seeds is 54,2; 51,1 or 42,8°C;
- the drying agent reaches its regime temperature (75, 70, respectively 65°C) in a period of about 2 minutes, which is then maintained with an accuracy of ± 2°C;
- cooling period (10 minutes) leads to the seeds cooling until the value of 24,5, 20,2 respectively 19°C;

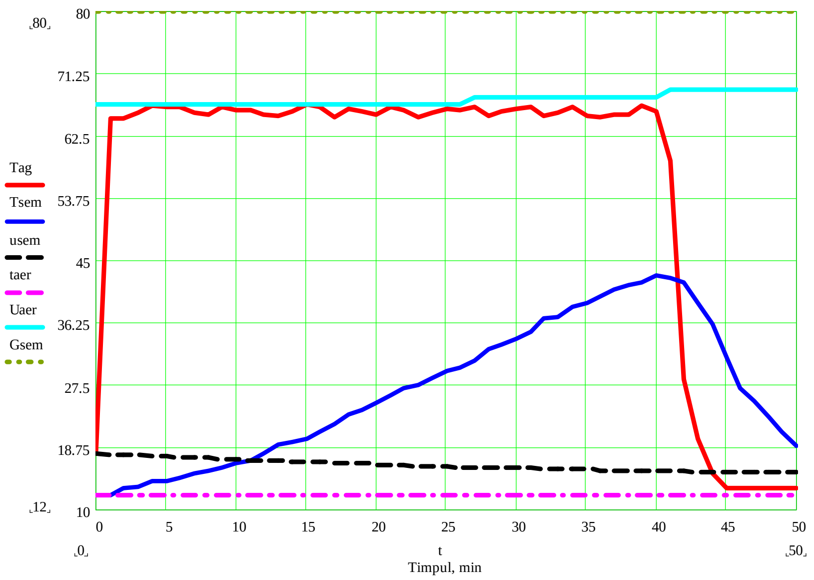



*Figure 1.17.Variation of parameters specific drying process in case of sample 3*

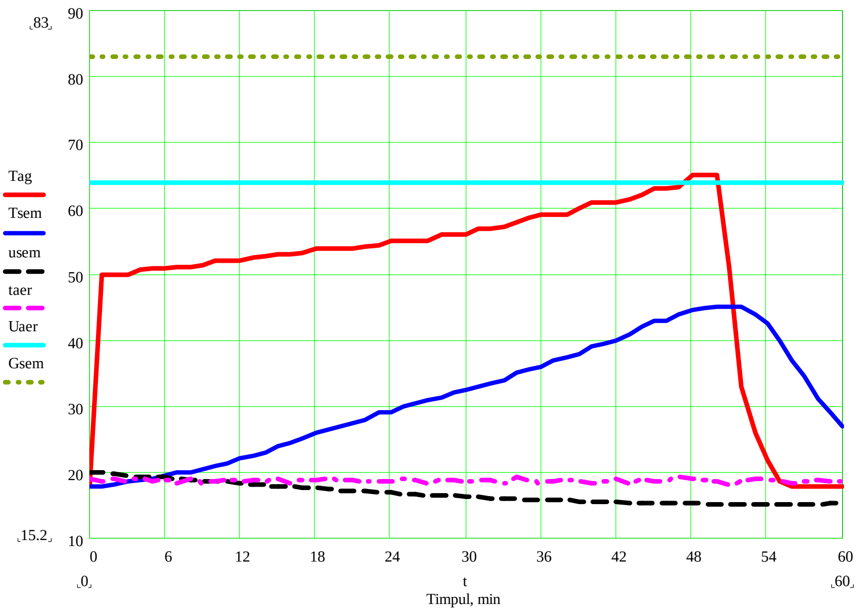



*Figure 1.18. Variation of parameters specific drying process in case of sample 4*

- constant thermal regime of 75°C for drying agent (in sample 1) causes a pronounced decline from the germination value of 91% (grains germination before drying) to the value of 76%. The final high humidity and high fuel consumption necessary to remove a kg of water (0,091 $Nm^3$/kg) indicates partial seeds "hardening" by sealing the pericarp, by using a high-temperature of drying agent, early in the process;

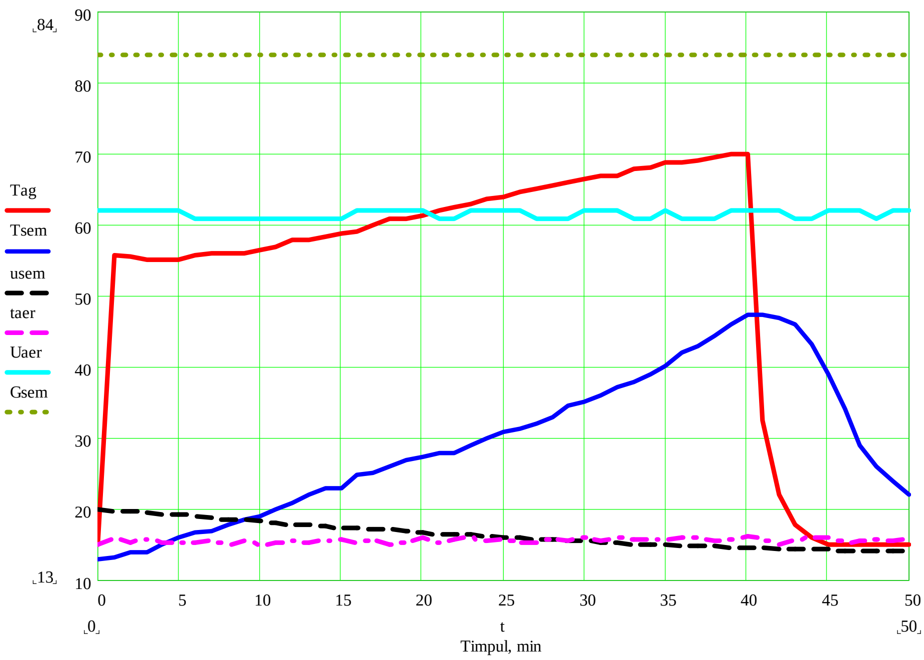



*Figure 1.19 . Variation of parameters specific drying process in case of sample 5*

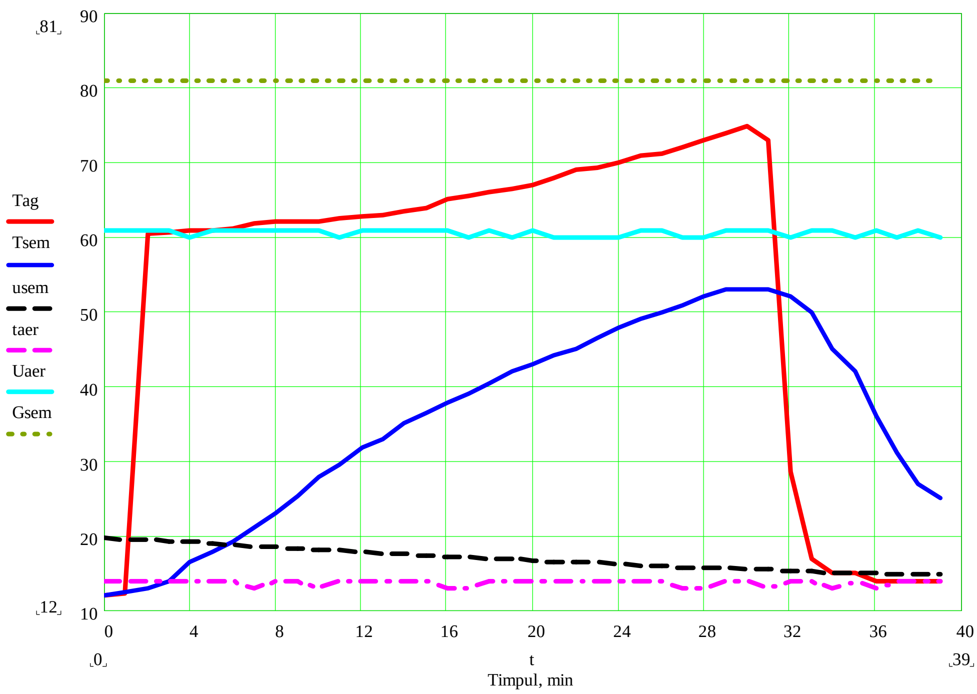



*Figure 1.20. Variation of parameters specific drying process in case of sample 6*

- samples 2 and 3 (table 1.18, figure 1.16 and 1.17) indicate the same germination of 80% of the grains after drying, final humidity were 14,5 respectively 15,1. The milder thermal regime has favorable effects on germination, but also on fuel consumption. Since the flow of removed humidity is higher in sample 2, it is found that this regime is the most recommended in these conditions, even the specific fuel consumption is higher.

Samples 4, 5 and 6 (figures 1.18, 1.19, 1.20) monitored the implementation of thermal variable regime depending on the humidity evolution of soybean seeds according determined functions and highlight the effects on germination. The analysis shows the following results:

- there is an overall increase of final germination, towards the dryer situation at a constant drying agent;
- the highest value of germination it was obtained in sample 4 (84%), but fuel consumption it was high, due to long duration of the drying process;
- decrease the duration of the drying period leads, to an increase in the maximum temperature of the drying agent; therefore germination for sample 6 it is lower, at 81%;
- optimal process is the one recorded for sample 5, with a specific consumption of 0,085 $Nm^3/kg$ and 83% germination.

Samples 7, 8 and 9 (figures 1.21, 1.22, 1.23) have pointed out that the adjustment of humidity flow removed from the mass of soybean seeds, under conditions of variable thermal regime (sample 7) or stable at low ambient humidity (sample 8) and the high (sample 9). Analyzing the experimental results it can be can draw the following elements:

- sample 7 drive through variable thermal regime to a low final humidity content of 14.0%, correlated with a decrease in specific fuel consumption. In this case the temperature of the drying agent varies according to the corresponding equation from table 4 between 70 and 85°C. It is noted that the seeds reach a maximum temperature of 56,2°C, but no adverse effects occur because at that time their humidity is already low (15.2%).

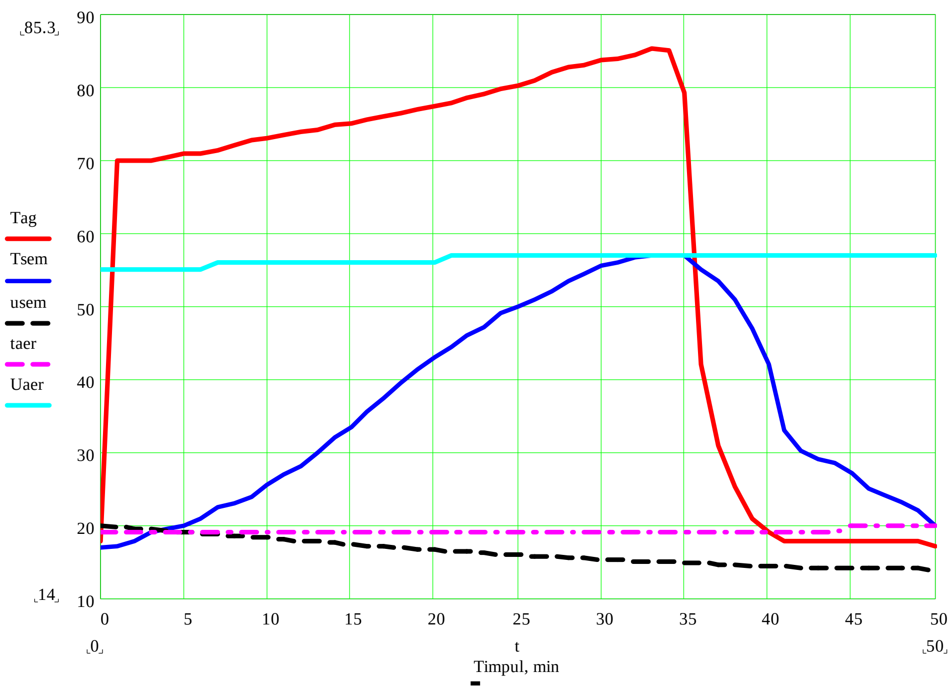



*Figure 1.21. Variation of parameters specific drying process in case of sample 7*

- in the case of the sample 8, due to the high temperature of the drying agent, on the one hand, and on the other the low humidity environment (42%), the drying speed is high from the beginning, that produce the pericarp "hardening ". The effect is the final higher humidity of the seeds, 16.0%.

- high humidity of the ambient air leads, in the case of the sample 9, to the increase of specific fuel consumption towards sample 8, from 0,093 $Nm^3/kg$ to 0,095 $Nm^3/kg$.

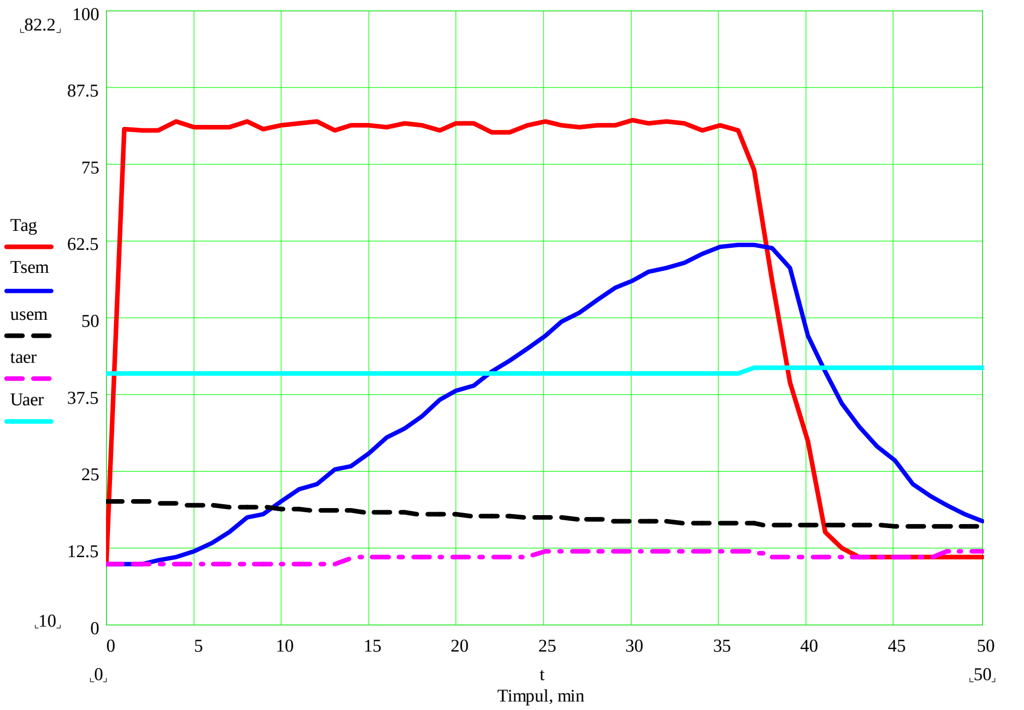



*Figure 1.22. Variation of parameters specific drying process in case of sample 8*

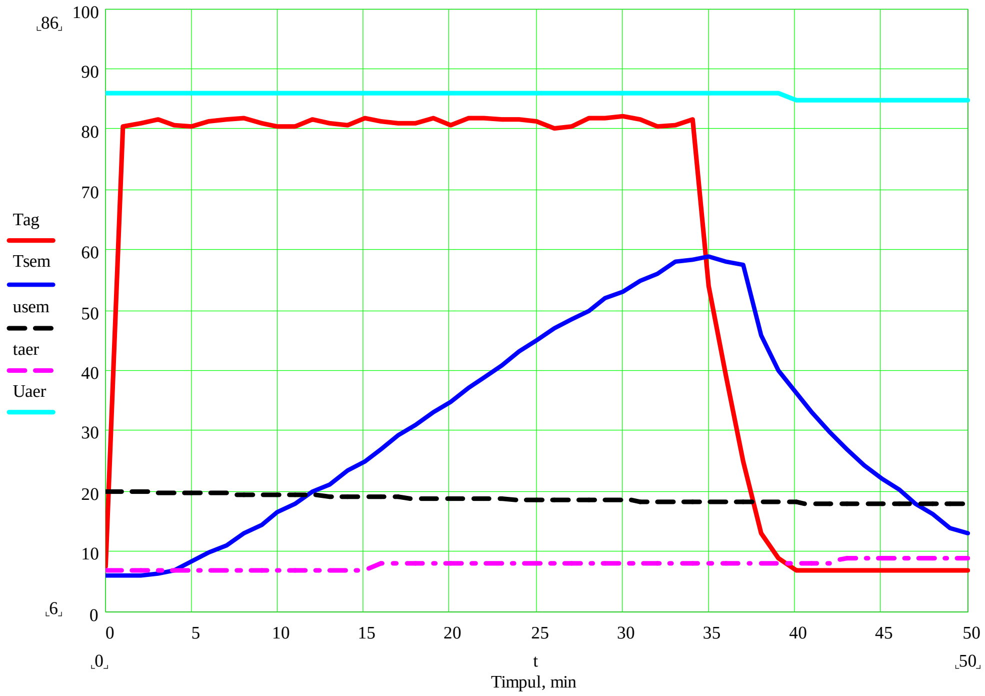



*Figure 1.23. Variation of parameters specific drying process in case of sample 9*

It appears that the use of variable temperature for drying agent, using the model presented, lead to higher final germination up to 22% and also lower specific fuel consumption by 3...14%.

It is noted that, in the case of soybeans seeds, for obtaining a high germination is recommended as a suitable thermal regime of the sample 4, with a 7% reduction in germination (from 91% to 84%). As noted, this requires increase of drying time and thus increase of fuel consumption. An easy extraction of humidity involves a low specific fuel consumption and therefore these samples are most effective from this point of view.

**Conclusions**

1. The main objective of the experimental research in real working conditions consisted of continuously adjusting the temperature of the drying agent based on seeds humidity from the dryer, and highlighting effects that occur on seeds germination, their final humidity and specific fuel consumption compared to the situation when temperature of the drying agent is kept constant throughout the process.

2. Within experimental investigations have been considered the following: determining the maximum temperature level to preserve seeds quality at a constant drying regime; constructive factor analysis, functional and working of the energy parameters of the process; determine the influence of environmental temperature and humidity on required fuel consumption to evaporate one kilogram of water.

3. To determine germination, seed samples taken before and after drying process were sent to inspectorate for quality of seeds and planting material from Brasov, where were used professional methods and techniques, according to national standards. To determine the germination, seeds samples taken before and after drying process were sent to inspectorate for quality seed and planting material in Brasov, where they use professional methods and techniques, according to national standards.

4. The analysis of experimental data shows that for conservation of fullest germination qualities of soybean seeds dried to a constant thermal regime, in conditions of medium energy consumption it is recommended a temperature of drying agent of 50-65°C and a time drying for 40 minutes, followed by cooling for at least 10 minutes.

5. The automatic adjustment of the temperature of the drying agent, based on seeds humidity subjected to drying there were obtained the following effects:

- in the case of soybeans seeds:
    - improve final germination up to 12% (from 76% sample 1, to 84% sample 4);
    - reduction of specific fuel consumption with maximum 12% (from 0,091 $Nm^3$/kg, sample 1 to 0,079 $Nm^3$/kg sample 7).

6. Increased ambient humidity leads to lower overall drying speed. Experimentally it has been found that the increase in ambient relative humidity from 40% (sample 8) to 85% (sample

9) involve an increase by about 2% in specific fuel consumption (from 0,093 $Nm^3/kg$ to 0,095 $Nm^3/kg$) and increase the final humidity content by about 2% (from 16.0% to 18.0% humidity).

7. The relatively slow increase of medium temperature of the seeds mass indicates a global coefficient of heat exchange with a low value, because of low filtration rate. This, however, leads to a progressive heating of the seeds, even in the case of using a constant temperature of drying agent, with favorable effects on the final germination of the seeds. Therefore, it is assumed that the use of thermal control of the drying agent according to the seeds humidity may lead, in the case of other types of dryers, at more substantial improvement of the seeds germination after drying.

8. The changing of global heat transfer coefficient (eg, by increasing the airflow of the fan) is another way to adjust the drying regime, which deserves to be a future research direction.

9. In most of the samples carried out, respecting the cooling time established by the dryer installation manufacturer, leads that in the final of this operation, the temperature of the seeds is with 5...10 degrees higher than the ambient temperature. Under certain conditions, this can lead to a degradation of certain quality indicators, and from this reason it is recommended to extend the period of cooling inside dryer with about 5 min.

# CHAPTER 2

## CONTRIBUTIONS TO THE MODELLING OF FOOD PROCESSING AND PRODUCTION SYSTEMS

## 2.1. Simulations of an automatic adjustment system of seeds drying

### *2.1.1 Drying kinetics of agricultural products*

In the drying process of a wet material while under constant conditions in time, there are several successive periods, in which the humidity content of the product ranges in some way determined, in particular, by water-binding mode, the conditions of transfer for heat and substance. In figure 4.7 is presented the time evolution of several parameters in the drying process, through curves: 1-air temperature; 2-product the temperature; 3-product humidity; 4-drying speed; 5-hygrometric degree of balance of the product.

The first stage of the process is characterized by the tendency of the material surface to reach a temperature equal to the wet thermometer temperature, characteristic to environment. If the initial temperature is lower, the material will heat until the surface temperature reaches the wet thermometer temperature. During this period will occur also humidity vaporization phenomena, but in small amounts (low evaporation speed) and material humidity will have a slight decrease (section AB). If the initial temperature of the wet material is higher than the wet thermometer temperature of the environment in which the drying takes place, in a first stage will apear a phenomenon of autoevaporation with temperature decrease at wet thermometer temperature and a decrease in the humidity of the material. Throughout this phase, the material surface remains wet, and the vapor pressure of the liquid from the surface of the product is equal to the saturation pressure of the liquid at that temperature.

After the material surface reached the wet thermometer temperature, while the material surface remains wet (material acts as a wet thermometer) drying occurs at a vapor pressure equal to the saturation pressure of pure liquid at that temperature (wet thermometer temperature) (curve 2, figure 2.1). At this time, based on heat transfer from the air at material surface and substance transfer from material surface to air it takes place an evaporation process at constant speed, with linear decrease of product humidity reported at dry substance (curve 3, figure 2.1). At the same time there is a substance transfer phenomena (humidity) inside the material to the surface under the influence of the concentration gradient.

The vapor pressure of the liquid from material ($p_m$) during this period is constant and equal to the saturation pressure at wet thermometer temperature, which makes the hygrometric degree of balance of the product is maintained constant and equal to the unit (curve 5, figure 2.1).

Removal of humidity during this period is limited by heat transfer phenomena. The only factor that can increase the drying speed during drying period with constant speed this period is the temperature of the drying agent because material surface temperature remains constant and on the heat transfer partially coefficient air-surface can influence less.

This phenomenon, as described, is perfectly at dry boiling. In case of drying by driving in hot air, when the heat is provided by hot air, there is an adiabatic process which attract decrease of air temperature. In order to respect the constant temperature it is necessary that the air speed at material surface to be sufficiently large to move the air charged with humidity and the material surface is always in contact with air with the same temperature and the same humidity content . Increasing the air speed helps to increase the heat transfer coefficient.

When the product in drying is in dynamic balance with air, the evaporation at constant speed process can be described by:

- a relationship of substance transfer:

$$\frac{dW_e}{d\tau} = AK_s\left(p_s - p_v\right); \tag{2.1}$$

- a relationship of heat transfer:

$$\frac{dQ}{d\tau} = A\alpha\left(t - t_u^{'}\right) \tag{2.2}$$

In this relationship, taking into account that at the heat transfer surface respectively substance, it take place a process of evaporation and passing the vapor in the gas stratum, if is replaced $dQ=dW_e r$, the overall heat transfer relationship can be made in the form of:

$$\frac{dW_e}{d\tau} = A\frac{\alpha}{r}\left(t - t_u'\right). \tag{2.3}$$

In the relations (1.1), (1.2) and (1.3) notations has the semnifications:

$\frac{dW_e}{d\tau}$ is the water flow removed from the product, in kg/s; A-product free surface (the surface of the substance transfer from the product to gas, respectively the surface of heat transfer from the gas to the product), in $m^2$; $K_s$ – the coefficient of substance transfer at the contact surface product-gas, expressed in s/m, where pressures are taken in $N/m^2$; $p_s$, $p_v$ - the pressure of the pure liquid at wet thermometer temperature $t_u'$, respectively partial pressure of vapors in gas, in $N/m^2$; $\alpha$ - partial coefficient of heat transfer from the air to the wet surface of the product, in $W/m^2$grd; r - heat of vaporization of humidit from the product to the temperature of the liquid $t_u'$, in J/kg; $t, t_u'$ - gas temperature respectively surface temperature of the product equal to the wet thermometer temperature of the gas.

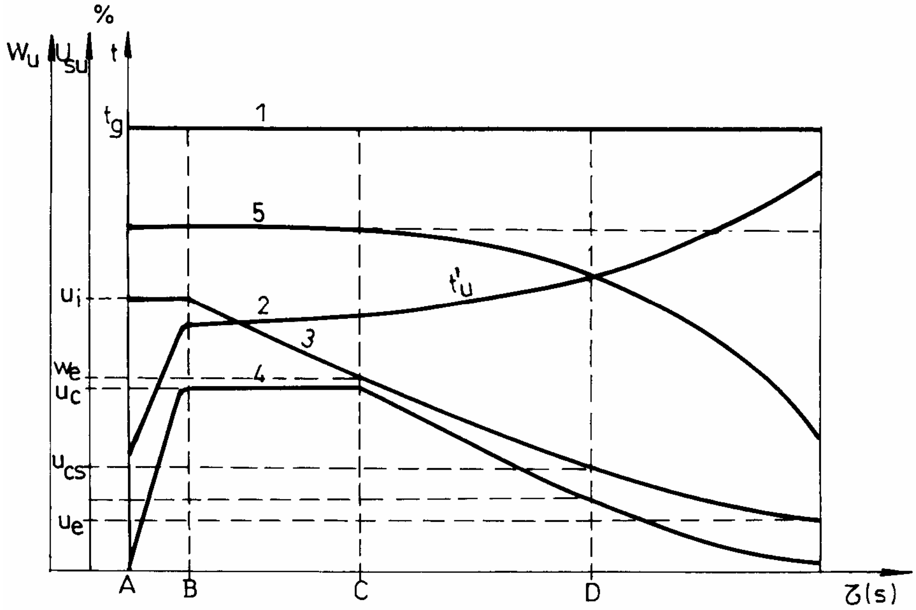



*Figure 2.1. Drying diagram*

As the substance transfer coefficient is less accessible, the evaporated water flow during drying period at constant speed in air curent is calculated from the temperature difference between the air temperature and air wet thermometer temperature (the temperature of the product surface) and the partial coefficient of heat transfer α from the air to the surface of the product.

When water migration from the interior to the surface no longer compensates the amount of water evaporated from the surface, deployment of drying process suddenly changes. On the product surface start to appear dry spots, product surface temperature, and even in mass product begins to increase, the product humidity slowly decrease, the drying speed decreases more and more, the hygrometric degree of the balance of the product decrease, below one unit. Drying is no longer dominated by superficial, it is dominated by the migration of humidity through capillaries of the product, which takes place under the influence of the transfer coefficient of the substance and the humidity concentration difference between inside and product surface.

The time of water migration from inside to the surface is no longer compensate the water evaporated from the surface coincides with the removal of wetting water and water mechanically connected and starting removal of water osmotic connected and then adsorption of water. Product humidity at this point is a humidity characteristic and is called **main critic humidity** ($u_c$). It characterizes the end of drying at constant speed and the beginning of the drying at speed decreasing.

It characterizes the end of drying at constant speed and the beginning of the drying at decreasing speed. The value of the critical humidity, for a given product can be considered a constant, because it decreases slightly with increasing temperature of drying agent.

**Drying period at decreasing speed** is characterized by varying all the parameters that characterize the product, even if the characteristics of the drying agent are maintain constant (temperature, humidity content, movement speed at the surface of the product). Product humidity will decrease slowly, drying speed tending to zero. The temperature of the material increases at first quickly, then more and more slowly, tending to reach the temperature of the drying agent. Hygrometric degree of balance of the product will begin to decrease, at first slowly and then faster. The heat transfer from the gas to the surface of the product will decrease, because decrease the temperature difference between the drying agent and the product.

When the vapor pressure of the liquid from material ($p_m$) is equal to the partial pressure of water vapor from the air ($p_v$), the removal of humidity from the product stop and the drying speed becomes zero. Product humidity from this moment is called the **equilibrium humidity ($u_e$).**

Drying period at decreasing speed can be divided into two or more phases. In the first phase drying speed decrease uniform, then uniform decrease may occur but with other slope of the curve or linear decrease. Any change in the slope of the curve by varying the drying speed, on curve appears an inflection point. These inflection points are characterized by a certain amount of humidity of the product. The humidity of the product at the inflection points on the curve of dring speed is called **secondary critical humidity**. In the figure 2.1 the coordinate point $u_{cs}$, D, represent a second critical humidity.

In the process of drying by driving the air current is necessary that water which need to be removed from the material to go through the following steps:

• the water move from the inside to the surface of the material. Humidity transport inside the material can be achieved in different ways, determined by the way in which the water is related and the cause which determine the movement: capillary, diffusion in the liquid phase, vapor diffusion etc. The process is complicated and it is considered as a whole an **inner diffusion process**;

• water which reached the maerial surface to vaporize and to be coached by ambient air to particle subjected to drying. Vaporization of water and passage in ambient air is a combined heat transfer process and diffusion at liquid-gas interface. The process is considered on the whole **external diffusion**.

Together, these two processes considered elementary form the drying, and the speed of humidity removal from the product or the drying speed is the speed of elementary process but slower.

Attempts to establish the theoretical equations on which to calculate the drying speed depending on the initial and final properties of the product subject to drying and conditions of process realization on theoretical considerations have led to complicated and difficult equations to apply. Therefore, to determine the speed drying, are used experimental data obtained in laboratory conditions and transposed to the industrial conditions, on the basis of derived equations using the idealized physical models of elementary processes.

The drying speed is defined as the amount of humidity removed per unit area of the material subjected to drying in the unit of time. In the differential form drying speed can be expressed by the equation:

$$w = \frac{dW_e}{Ad\tau}, \tag{2.4}$$

in which: w is the drying speed, in $kg/m^2s$; $W_e$ – the humidity to remove, in kg; A - total surface of the material subjected to drying in $m^2$; τ - drying time, in s.

For a known drying speed, drying time is determined by integrating the equation (2.4):

$$\tau = \int \frac{dW_e}{Aw}. \tag{2.5}$$

If humidity to remove is expressed in terms of the amount of substance completely dry $G_{us}$ from material subjected to dry and initial humidity ($u_{sui}$) and final humidity ($u_{suf}$) is relate to dry substance of the material subjected to drying (in kg/kg), it can be write:

$$W_e=G_{us}(u_{sui} - u_{suf}), \tag{2.6}$$

and by integrating equation (2.5) becomes:

$$\tau = \frac{G_{us}\left(u_{sui} - u_{suf}\right)}{Aw}. \tag{2.7}$$

Integrating in this way is valid only at w = const.

The drying speed depends on a big number of factors, so it is difficult to find functions that take into account the influence of these factors. Despite the complexity of the phenomenon based on drying kinetics can be determined drying time from theoretical point of view.

Despite the complexity of the phenomenon, based on drying kinetics can be determined drying time on theoretical way.

To determine the drying time must be considered two phases below:

• the drying at constant speed, when the process is limited by the conditions from contact surface air-material;

• the drying at decreasing speed, when the process is limited by material diffusion from inside to contact surface air-material.

From a theoretical perspective, the drying operation is studied in two variants related to the characteristics of the drying agent:

• **drying under constant conditions** for drying agent. On this premise, the drying air has constantly and everywhere the same humidity and the same temperature. Drying in this case resulting in unsteady regime;

• **drying under variable conditions**, when the air changes the humidity and temperature. Under these conditions drying is studied in stationary regime. The process is realized with air and material parameters variation in the length of the dryer, but these parameters remain constant over time at each point of the dryer.

Drying under variable conditions is realized in dryers with continuous operation, in which the product flows in co-current or counter-current with drying agent.

In these two variants drying is analyzed in the drying period at constant speed and also in drying period at decreasing speed.

For drying period at decreasing speed it is analyzed separately the period with uniform decreasing speed and period with non-uniform decreasing speed. In the area of cereal and other technical plants seed drying, are used most often systems in which the drying agent cross the material in a perpendicular direction, keeping constant humidity and temperature. Further analysis will be under constant drying conditions for drying agent.

**Drying period at constant speed.** During this period, as shown, is remove the liquid water from the material surface exposed to air. The drying speed during this period does not depend on the material properties, but depend on heat transfer from the air to the material surface and diffusion of water vapor in the air.

According to the equation (2.2) and (2.3), heat transfer is determined by relation:

$$\frac{dW_e}{d\tau} = A\frac{\alpha}{r}\left(t - t'_u\right) \ , \tag{2.8}$$

and transfer of substances by relation:

$$\frac{dW_e}{d\tau} = AK_s\left(p_s - p_v\right). \tag{2.9}$$

Equation (4.27) can be put in the form:

$$\frac{dW_e}{d\tau} = AK'_s\left(x_s - x\right), \tag{2.10}$$

in which $x_s$ and x are the saturation humidity respectively air humidity at temperature t of used air as drying agent.

If it is considered the defining equation of $x_s$ and x according to the vapor pressure:

$$x_s=0,622\frac{p_s}{p-p_s} \text{ and } x_s=0,622\frac{p_v}{p-p_v}, \tag{2.11}$$

and taking into account that $p_s$ respectively $p_v$ are small compared with p (working pressure), so that $p-p_s \cong p$ and $p-p_v \cong p$, it can be deduct the relationship between $K_s$ and $K'_s$:

$$K_s\left(p_s - p_v\right) = K_s'\left(0{,}622\frac{p_s}{p} - 0{,}622\frac{p_v}{p}\right) \qquad (2.12)$$

or:

$$K_s' = K_s\,\frac{p}{0{,}622}. \qquad (2.13)$$

From the relations (2.8) and (2.10) follows:

$$\frac{\alpha}{r}\left(t - t_u'\right) = K_s'\left(x_s - x\right). \qquad (2.14)$$

If from the relation (2.13) is deduct the expression of transfer coefficient of substance at the contact surface product-gas is obtained:

$$K_s' = \frac{\alpha}{r}\,\frac{t - t_u'}{x_s - x}. \qquad (2.15)$$

In order to maintain constant conditions, the air must travel from the surface of the product at a speed as high as possible, so that the forced flow is achieved. In the case of gas, taken in acount that the value of Prandtl criterion is a constant, the value of $\alpha$ can be deduct from criterial equation:

$$Nu = cRe^m, \qquad (2.16)$$

in which neglecting the constant measure or with a small influence in the usual area of temperatures where the drying is realized, for $\alpha$ is obtained:

$$\alpha = C(w\rho)^m, \qquad (2.17)$$

or by entering this value in relation (2.15) and forming from constant measures a unique constant, it is obtain:

$$K_s' = \frac{C\left(w\rho\right)^m}{r}\,\frac{t - t_u'}{x_s - x} = C_1\left(w\rho\right)^m. \qquad (2.18)$$

The product $w\rho$ from equation (2.17) represent the speed of mass movement of the air in kg/m$^2$s.

Taken into consideration the experimental measurements, equation (2.18) becomes:

$$K_s' = 91(w\rho)^{0,8}, \tag{2.19}$$

in which $K_s'$ is expressed in kg/m$^2$s.

Drying duration in drying period at constant speed is deduct from equation (2.10) after the replacement is done:

$$dW_e = -G_{su} d(u - u_c), \tag{2.20}$$

where: $u_c$ is the main critical humidity reported to dry substance.

Replacement is done under condition $u_i > u_c$, where $u_i$ is the initial humidity of the product. Relation (2.6) by substitution and integration becomes:

$$\frac{-G_{su} d(u - u_c)}{d\tau} = AK_s'(x_s - x); \tag{2.21}$$

$$d(u - u_c) = K_s' \frac{A}{G_{su}}(x_s - x)d\tau; \tag{2.22}$$

$$\int_{u_i - u_c}^{u - u_c} d(u - u_c) = K_s' \frac{A}{G_{su}}(x_s - x)\int_0^{\tau} d\tau; \tag{2.23}$$

$$u_i - u = K_s' \frac{A}{G_{su}}(x_s - x)\tau. \tag{2.24}$$

For $u = u_c$ result $\tau_1$ which is the drying time for the first constant period.

$$\tau_1 = \frac{G_{su}(u_i - u_c)}{K_s' A(x_s - x)}. \tag{2.25}$$

**Drying period at decreasing speed.** This time, when the drying speed decreases and the humidity drops below the critical humidity is divided for convenience into two stages:

• stage where drying speed decreases uniform as the wet surface of the material decreases due to drying of the product;

• drying stage with decreasing speed uneven, the drying speed is determined by internal diffusion of water.

The duration of the first drying stage at decreasing speed is determined by the same conditions as the drying time at a constant speed (the relation 2.25), but in which the total area A is replaced with the surface still wet $A'$ at the considered time. Humidity variation during this period evolves from critical humidity $u_c$ to the equilibrium humidity $u_e$. Taking into consideration the variation of the humidity, the report between initial wet surface and wet surface $A'$ at a specific moment is determined by the report of humidity diferences of substance in case of the two surface. It follows:

$$\frac{A'}{A} = \frac{u - u_c}{u_c - u_e}. \tag{2.26}$$

so: $dW_e = -G_{su} d(u - u_c)$, (2.27)

and $A' = A \dfrac{u - u_c}{u_c - u_e}$, (2.28)

substituting in (2.6), separating the variables and integrating, it is obtain:

$$\frac{-G_{su} d(u - u_c)}{d\tau} = A \frac{u - u_c}{u_c - u_e} K'_s (x_x - x); \tag{2.29}$$

$$-\frac{d(u - u_c)}{u - u_e} = K'_s \frac{A}{G_{su}} \frac{x_s - x}{u_c - u_e} d\tau ; \tag{2.30}$$

$$\int_{u_c - u_e}^{u - u_e} -\frac{d(u - u_e)}{u - u_e} = K'_s \frac{A}{G_{su}} \frac{x_s - x}{u_c - u_e} \int_0^{\tau} d\tau ; \tag{2.31}$$

$$\ln \frac{u_c - u_e}{u - u_e} = K'_s \frac{A}{G_{su}} \frac{x_s - x}{u_c - u_e} \tau . \tag{2.32}$$

For $u = u_c'$ ($u_c'$ the first secondary critical humidity) are obtained drying period for the second period ($\tau_2$) and drying time for the third period ($\tau_3$).

$$\tau_2 = \frac{G_{su}}{K'_s A} \frac{u_c - u_e}{x_s - x} \ln \frac{u_c - u_e}{u'_c - u_e}. \tag{2.33}$$

In stage III the drying can not be considered dependent on the air properties used as drying agent, but only the phenomena of internal diffusion. The duration of this stage is given by the equation:

$$\tau_3 = \frac{4 l^2}{D \pi^2} \ln \frac{u'_c - u_e}{u_f - u_e}, \tag{2.34}$$

in that l is the thickness of the material subjected to drying, in m; D-diffusion coefficient of the liquid, in $m^2/s$.

To calculate the drying time, in previous relationships intervenes the drying surface, critical humidities and equilibrium humidity, and in the last relationship also the diffusion coefficient. These elements can not be determined by theoretical calculations, for their use are necessary corresponding experimental data.

### *2.1.2 Approaches about drying process control of agricultural products*

From theoretical research already done, results the fact that for realize seeds drying in the conditions under strict control of drying regime (to maintain germination characteristics), it is necessary to act on a grain time-varying temperatures. This can be achieved through a continuous dryers with special design of the drying chamber.

The same effect can be obtained in the discontinuous dryers with automatic batch operation, in which the seed layer is stable and varies over time the amount of heat supplied by the burner system. This principle present the great advantage that the temperature variation of the drying agent during a batch can take complex shapes (which can not be reproduced by the drying chamber architecture) and variable based on other parameters external to the process (seed type, environmental conditions, etc.).

Designing of a system for automatic adjustment and implementation to a seed dryer, raises specific problems, so it is useful computer simulation of the operation of such systems.

Such a system is required to meet two main conditions:

1. to change fuel flow, when modifying one of the following parameters:
    - ambient temperature;
    - seeds temperature at entering in the dryer;
    - the humidity content of the ambient air;
    - seeds humidity at entering in the dryer.
2. to correct in every moment of a batch, the temperature of the drying agent, depending on the evolution of seeds humidity from the drying chamber.

For clearer view of how the two above requirements met, the problem of automatic dryer system simulation it was divided into two cases:

- simulations of the dryer over a period of several days, when external parameters varies by random laws;
- simulation during a batch operation, when considered constant external conditions.

By using Simulink module of MATLAB it was performed block diagram needed for simulation of automatic control system (figure 2.2). As input have been considered variables as: the

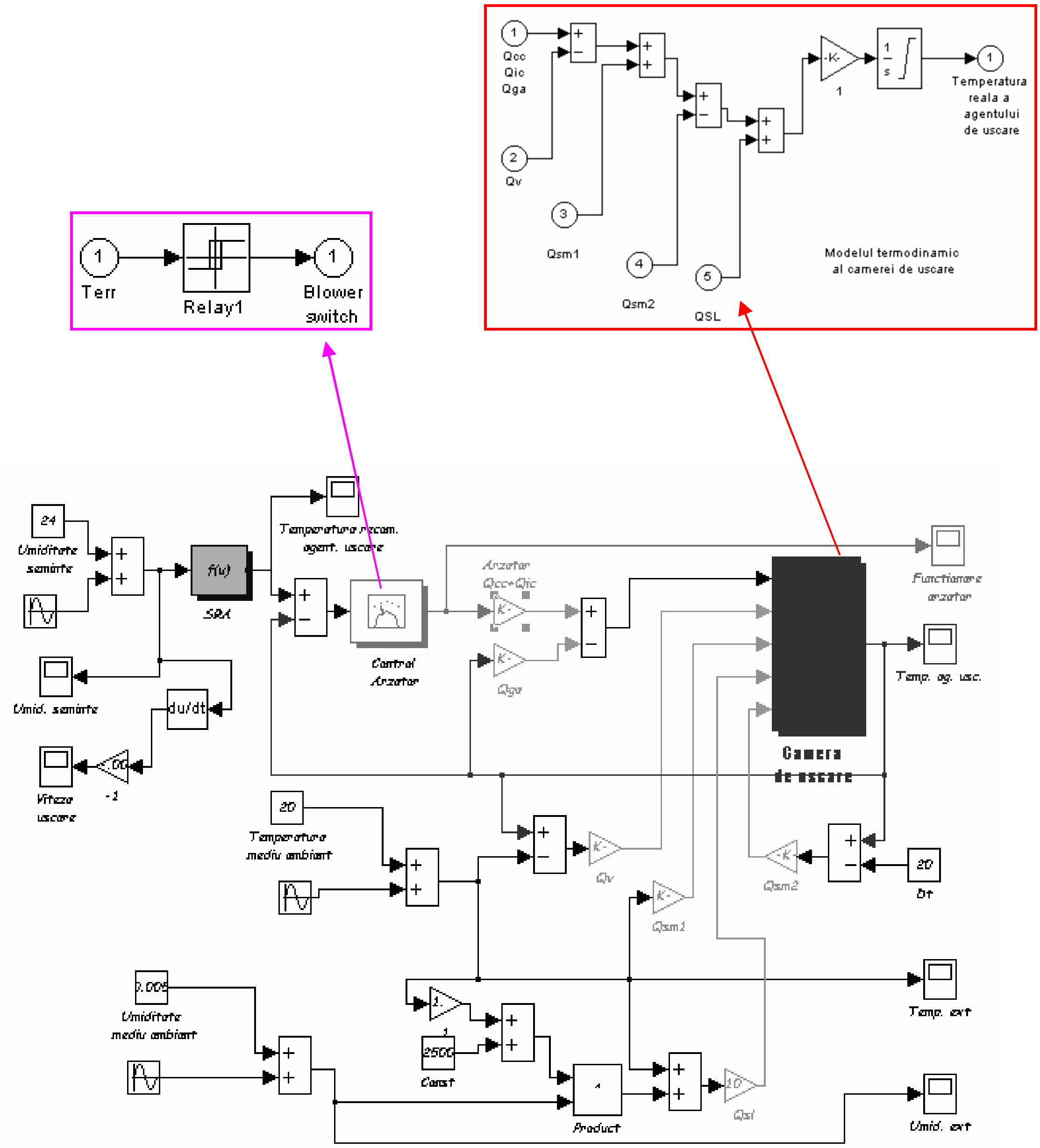



*Figure 2.2. Block diagram of the operation of a simulation of automatic adjustment system of the thermal regime for a seeds dryer*

seeds humidity, the humidity content of the ambient, temperature of the ambient. The seeds temperature at entering in the dryer it was considered equal to the ambient temperature.

The operation model is as follows: based on the seeds humidity (figure 2.2) by the transfer function T(τ, U), theoretically determined in the previous chapter, it is calculated on a range of recommended values for temperature of drying agent. This range of values represent the reference value inserted into compared element of the automatic control system.

The "Control burner" from figure 2.2 provides value 1 (burner operates) if the difference between the recommended temperature for drying agent and the real temperature of the drying agent is greater than 1°C, and value 0 if the difference between the two temperatures is less than 1°C.

Simulation of temperature and humidity content variations of the environment it was achieved by sinusoidal functions.

Based on the introduced input, are calculated the heat flows from drying chamber, according to heat-balance equation:

$$Q_{cc} + Q_{sc} + Q_{sl} + Q_{sm1} = Q_{sm2} + Q_v + Q_{ga} \,. \tag{2. 35}$$

Heat loss through radiation and convection were neglected [60]. Using the same notations of chapter 2.1. can be calculate the heat balance components, depending on the variable input quantities:

$$Q_{cc} = C \cdot H_{ic} = 8500 \cdot 40 = 340000 \text{ kcal/h}, \tag{2.36}$$

where: $H_{ic}=8500$ kcal/Nm$^3$; $C=40$ Nm$^3$/h.

$$Q_{sc} = C \cdot i_c = 40 \cdot 8{,}22 = 320 \text{ kcal/h}, \tag{2.37}$$

where: $i_c=8{,}22$ kcal/Nm$^3$.

$$Q_{sl} = C \cdot \lambda \cdot V_{lmin} \cdot (1{,}005 \cdot t_{amb} + x_{amb} \cdot (2500 + 1{,}88 \cdot t_{amb}) \cdot 0{,}239) = 40 \cdot 6{,}51 \cdot 10{,}16 \cdot (t_{amb} \cdot 1{,}005 + x_{amb}(2500 + 1{,}88 \cdot t_{amb}) \cdot 0{,}239) = 632{,}31 \cdot (t_{amb} \cdot 1{,}005 + x_{amb}(2500 + 1{,}88 \cdot t_{amb})) \tag{2.38}$$

where: $\lambda=6{,}51$; $V_{lmin} = \dfrac{V(O_2)\min}{0{,}22} = 10{,}16 \dfrac{Nm^3 aer}{Nm^3 comb}$;

$$i_L = (1{,}004t + x(2500 + 1{,}86t))0{,}239 \text{ [kcal/kg]}. \tag{2.39}$$

$$Q_{sm1} = G_1 \cdot c_{m1} \cdot t_{amb} = 1000 \cdot 1{,}84 \cdot 0{,}239 \cdot t_{amb} = 439{,}75\, t_{amb} \text{ kcal/h}, \tag{2.40}$$

where: $G_1=1000$ kg/h; $c_{m1}=1{,}84 \cdot 0{,}239=0{,}439$ kcal/kgK.

$$Q_{sm2} = G_2 \cdot c_{m2} \cdot t_{amb} = G_1 \cdot \left(1 - \frac{U_1}{100} + \frac{U_2}{100}\right) c_{m2} t_{m2} = 1000\left(1 - \frac{24}{100} + \frac{14}{100}\right) 1{,}84 \cdot 0{,}239 \cdot t_{m2} = = 395{,}7 \cdot t_{m2} \text{ kcal/h}, \tag{2.41}$$

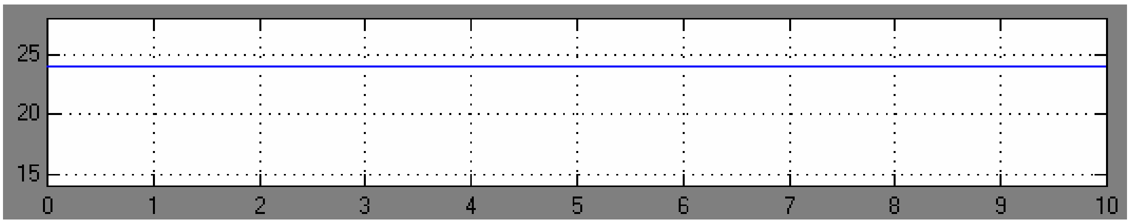
where: $G_2 = G_1 \cdot \left(1 - \dfrac{U_1}{100} + \dfrac{U_2}{100}\right)$ kg/h; $U_1=24\%$; $U_2=14\%$; $c_{m1}=0{,}439$ kcal/kgK.

$$Q_v = G_1 \frac{U_1 - U_2}{100}(i_{a2} - i_{a1}) = 1000 \frac{24 - 14}{100} 1{,}004 \cdot (t_{ga} - t_{amb}) = 100{,}4 \cdot (t_{ga} - t_{amb}), \tag{2.42}$$

where: $i_{a2}=c_{pa} \cdot t_{ga}$; $i_{a1}=c_{pa} \cdot t_{m1}$; $c_{pa}=1{,}004$ kcal/kgK.

$$Q_{ga} = C \cdot V_{ga} \cdot c_{pga} \cdot t_{ga} = 40 \cdot 70{,}48 \cdot 0{,}314 \cdot t_{ga} = 885{,}22 \cdot t_{ga} \,, \tag{2.43}$$

where: $V_{ga} = V_{gamin} + (\lambda - 1) \cdot V_{lmin} = 1{,}45 + 5{,}51 \cdot 10{,}16 = 70{,}48$ Nm$^3$/Nm$^3$; $c_{pga}=0{,}314$ kcal/kgK.

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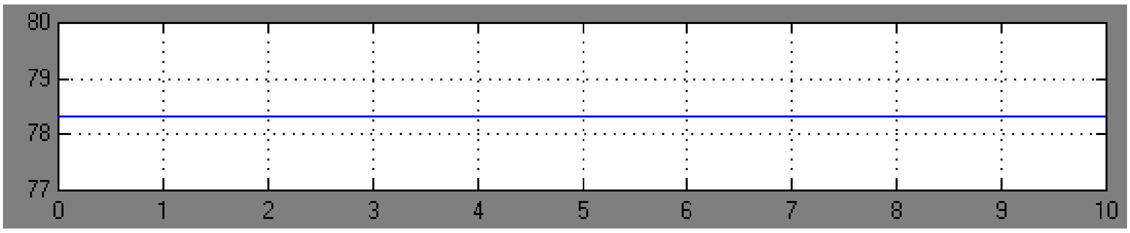


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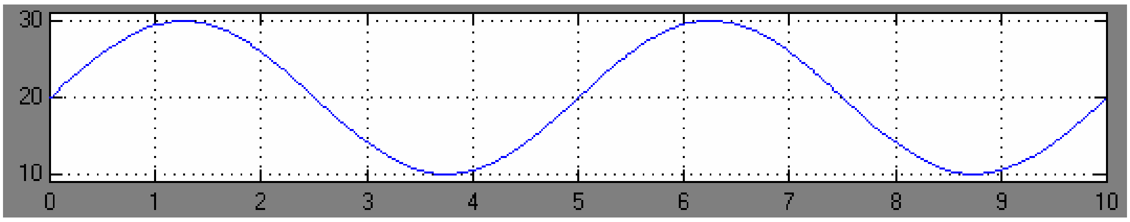


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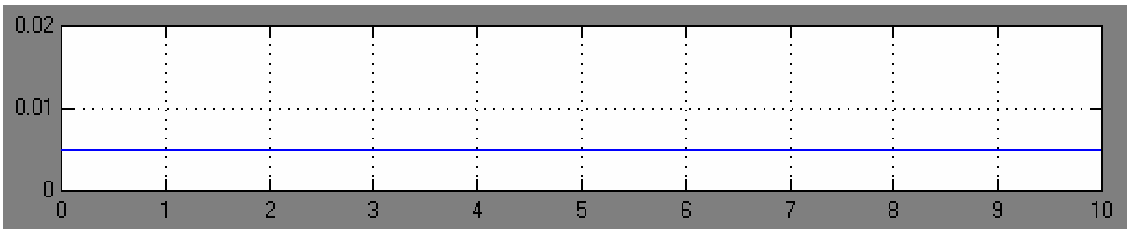


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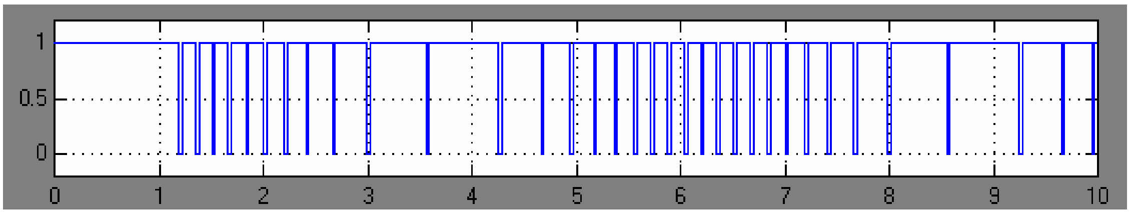


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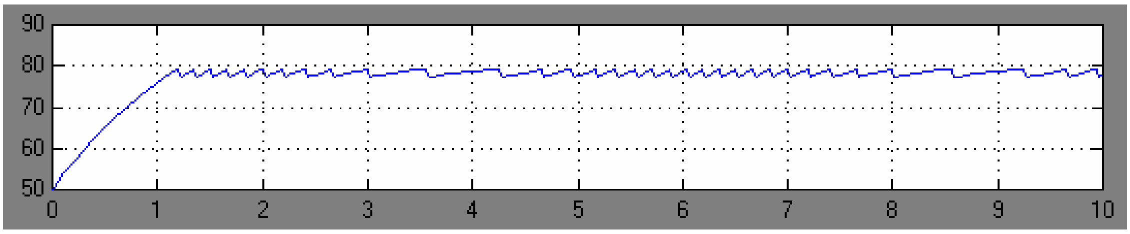



*f.*

*Figure 2.3. The evolution of specific parameters (temperature [°C] time [min]) obtained from simulation operation of a system for automatic adjustment of the thermal regime in a seeds drier at ambient temperature variation*

The achieved model allows, with support of continuous integration block, viewing the variation of the following quantities:

- the humidity content of the ambient air;
- outside temperature;
- the temperature of the drying agent (obtained from the heat balance of the drying chamber);
- the recommended temperature for drying agent;
- seeds humidity;
- drying speed;
- frequency and duration on / off for burner.

A first simulation aimed to highlight the operation of the automatic control system at changing environmental parameters (temperature, humidity content).

For this it was considered a constant value of seeds of 24% (figure 2.3, a) in the range of operation of the dryer for 10 minutes.

According to the relationships from table 2, the recommended temperature for the drying agent is also constant T = 78,2°C (figure 2.3, b).

The ambient temperature varied by a sinusoidal form with ± 10°C around 20°C with a period $2\pi/5$, according to the graph from figure 2.3, c.

The humidity content of the ambient air, in this situation it was considered constant, equal to 0.005 kg/kg (figure 2.3 d). Behind simulation, in figures 2.3, e and f it can be draw the following conclusions:

- at start the burner of installation remain in powering about 1 ... 2 minutes (figure 2.3, f), time required to raise the temperature of the drying agent at recommended value of 78°C. In this period, no conclusions can be drawn about the influence of outdoor temperature (which is in a growth phase (figure 2.3, c)) on the operation of the burner;
- after reaching the operating temperature is carried out a correlation between the consumption of fuel and the ambient temperature. This inverse relation between the two quantities is evidenced by the frequency and duration of interruptions in the operation of the burner, as follows:
    - ♦ in the range 3,5...4,5 minutes the burner works almost continuously, corresponding to an outside temperature of approximately 10°C;
    - ♦ in the range 5,5...6,5 minutes, the frequency of decoupling is about 0,1Hz, lasting about 3...4 s, corresponding to an outside temperature of about 30°C.

To simulate the operation of the burner in a single batch are done the following assumptions:

- ambient air temperature and humidity, with values of 20°C respectively 0.005 kg;

- the entering temperature of the seeds is equal to the ambient temperature.

The developed model is based on heat transfer equations and can not give information towards variation in time of humidity of granular layer subjected to drying.

Because of this reason it can not define any reference size $T_{agusc}$ (which in this case must be variable over time, according to seeds humidity).

To solve this problem it is necessary to apply the drying kinetics elements [16 ], [24 ], [33], [44].

Starting from the speed drying equation, valid for the period of drying at constant speed:

$$u_2 - u = k_s' \frac{A}{G_{su}} (x_s - x)\tau \, , \tag{2.44}$$

results the duration of this period and humidity variation:

$$\tau = \frac{G(u_i - u)}{k_s' A (x_s - x)} ;$$
$$u = u_i - k_s' \frac{A}{G_{su}} (x_s - x)\tau \quad . \tag{2.45}$$

For the first sub-phase of drying at a decreasing speed:

$$\ln \frac{u_c - u_e}{u - u_e} = k_s' \frac{A}{G} \frac{x_s - x}{u_c - u_e} \tau \text{, results:} \tag{2.46}$$

$$\tau = \frac{G}{k_s' A} \frac{u_c - u_e}{x_s - x} \ln\left( \frac{u_c - u_e}{u - u_e} \right); \quad u = u_e + \frac{u_c - u_e}{e^{\frac{k_s' A \tau}{G_{su}} \frac{x_s - x}{u_e - u_c}}} \tag{2.47}$$

For the third period, the relationship:

$$\tau = \frac{4l^2}{D\pi^2} \ln \frac{u_c' - u_e}{u - u_e} ,$$
$$\text{results:} \quad u = u_e + \frac{u_c' - u_e}{e^{\frac{\pi^2 D \tau}{4l^2}}} . \tag{2.48}$$

Taking into account also the seeds preheating period $\tau_0 = G(i_1 - i_0)$, can express the overall variation in seeds humidity in the form:

$$u(\tau)=\begin{cases} \left(1+\frac{\tau_0}{10000}\right)u_i-\frac{k_s' A\tau^2}{2G\tau_0}(x_s-x), \text{ dacă } 1\le\tau\le\tau_0; \\ u_i-k_s'\frac{A}{G}(x_s-x)(\tau-\tau_0), \text{ dacă } \tau_0\le\tau\le\tau_0+\tau_1; \\ u_e+\frac{u_c-u_e}{e^{\frac{(\tau-\tau_1-\tau_0)k_s' A(x_s-x)}{G(u_c-u_e)}}}, \text{ dacă } \tau_1+\tau_0\le\tau\le\tau_0+\tau_1+\tau_2; \\ u_e+\frac{u_c'-u_e}{e^{\frac{\pi^2 D(\tau-\tau_1-\tau_2-\tau_0)}{4l^2}}}, \text{ dacă } \tau_1+\tau_2+\tau_0\le\tau. \end{cases} \quad (2.49)$$

In figure 2.4 is represented the graph function u(τ), in case of maize seeds under the following conditions:

A=200 $m^2/m^3$; G=1000 kg; v=0,6 m/s; $x_s$=0,008 kg/kg; x=0,006 kg/kg; $U_i$=22%; $u_i$=0,282 kg/kg; $U_{c1}$=20,5%; $u_{c1}$=0,258 kg/kg; $U_{c2}$=15,5%; $u_{c2}$=0,183 kg/kg; $U_f$=14%; $u_f$=0,163 kg/kg; $U_e$=10%; $u_e$=0,111 kg/kg; D=$1,611\cdot10^{-7}$.

In the real operation of the automatic control system, the humidity values depending on time are provided by the transducers mounted in the seeds layer [61], [62], [63].

According relations from table 1.15, the recommended temperature for drying agent varies between 72°C and 88°C according the curve from figure 2.5.b.

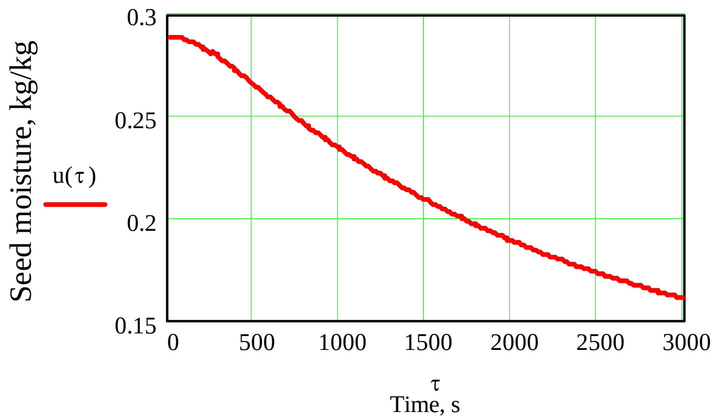
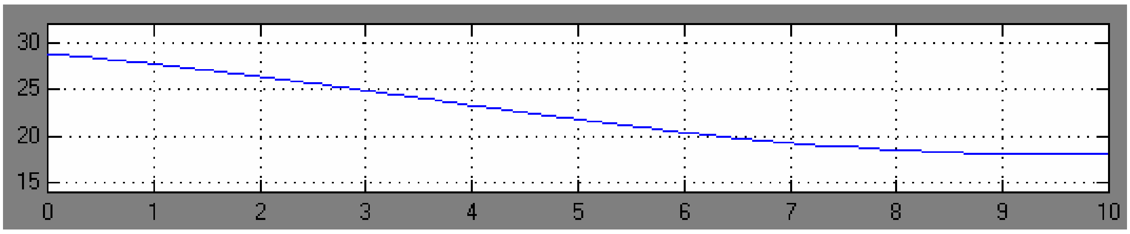
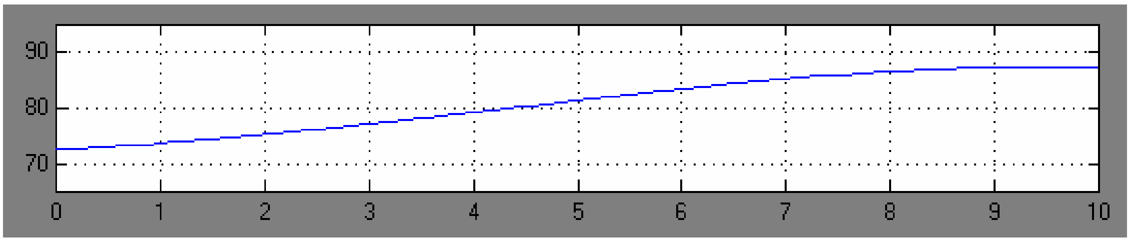



*Figure 2.4. The theoretical variation of seeds humidity according to the time*

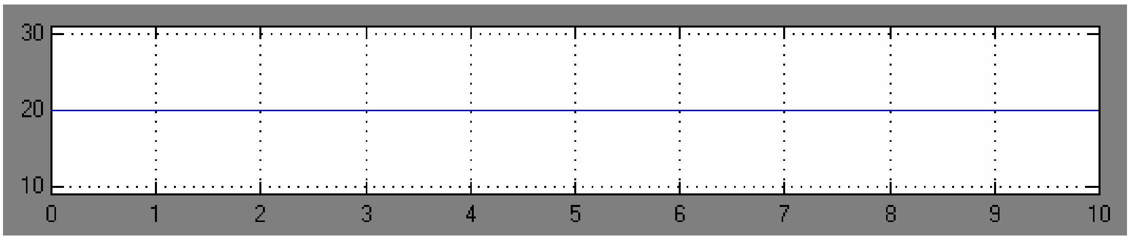
Both, temperature and humidity environment were considered constant, with the values of 20°C and 0.005 kg/kg (figure 2.5 c and d).



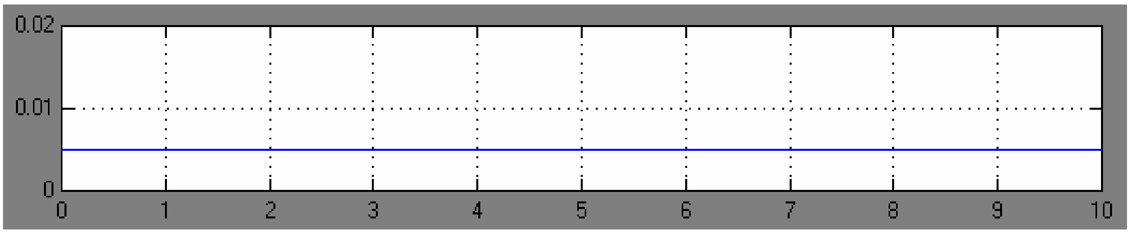

*a.*



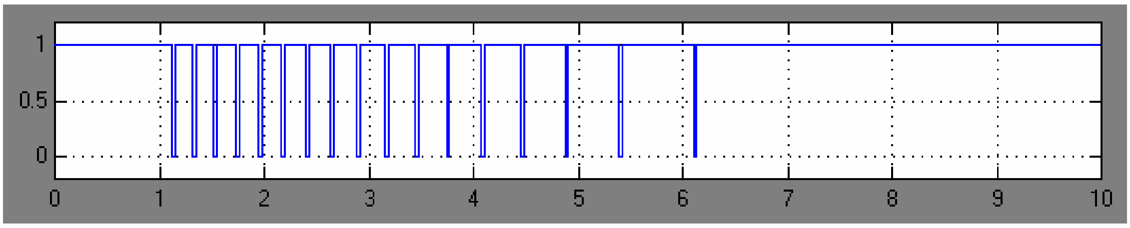

*b.*



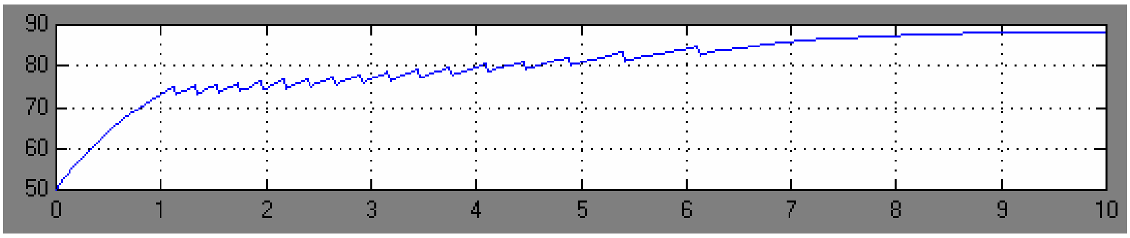

*c.*




*d.*




*e.*




*f.*

*Figure 2.5. The evolution of specific parameters, (temperature[°], time [min]) obtained from the simulation of the operation of an automatic adjustment system of the thermal regime in a seeds dryer, at seeds humidity variation*

**Conclusions**

In the simulation, from the figures 2.5.e and 2.5.f it can be draw the following conclusions:

- as in the previous case, at start, it is necessary a period of about one minute of continuous operation of the burner in order to bring the temperature of the drying agent to the lower limit of recommended temperature for drying agent (figure 2.5, a);

- after this period, the life of the burner increases progressively with the need for heating up of recommended temperature of drying agent (figure 2.5, b);

- after about seven minutes, according to 85°C temperature and seeds humidity of 21%, the automatic control system command the uninterrupted operation of the burner. Since this moment, as noted in the previous simulation, any decrease in ambient temperature put the system unable to keep the temperature of the drying agent to the recommended value. Therefore, it can be conclude here that for a safe operation, must be taken one of the following measures:

  - ♦ increasing the flow of the burner;
  - ♦ increase the calorific value of the used fuel.

Both measures lead to increased chemical heat $Q_{cc}$=$CH_{ic}$ of fuel, which has a major contribution to the heat balance.

Using the model shown in figure 2.2, based on the same argument it can be highlight the specific operation mode, with problems that may occur, when changes in whole or in various combinations, after different laws of variation, the parameters of ambient air or material.

## 2.2. Simulation of Drying Process of Powdery Materials

### *2.2.1. Introduction*

In the frame of drying process leading, the most common control algorithm is known as a PID (proportional-integral-derivative) controller. The PID algorithm is implemented in the feedback control system in which the output of the process is compared to a set point (desired value) of the output. If the output is different from the set point, the controller adjusts the input to reach the set point. The problems that a PID controller have, in relation to the drying process, is that the controller does not take into consideration physical constraints of the process and that implementation does not provide an opportunity to optimize a process in addition to reaching the desired set point. [110], [111], [112]

This supposes an aggressive controller behavior that will make the process to pass the set point and then would try to reach again the set point by changing the input. For avoiding these situations, in petrochemical plants are using for five decades the Model Predictive Controller (MPC).

Such concept consists of three key elements: predictive model, optimization in a temporal window and feedback correction. The controller predicts process behavior and proactively optimizes control as it is shows in figure 2.6. Model predictive control (MPC) is a fairly general class of algorithms for feedback and feed forward control. Various MPC techniques have in common that a model of the process, subject for control, is used to predict the effects in process variables due to actual and future changes in manipulated outputs and feed-forward variables.

The main objectives of an MPC are:

1) Prevent violations of input and output constraints;

2) Drive some output variables to their optimal set points while maintaining other outputs within specified ranges;

3) Prevent excessive movement of the input variables;

4) Control as many process variables as possible when a sensor or actuator is not available.

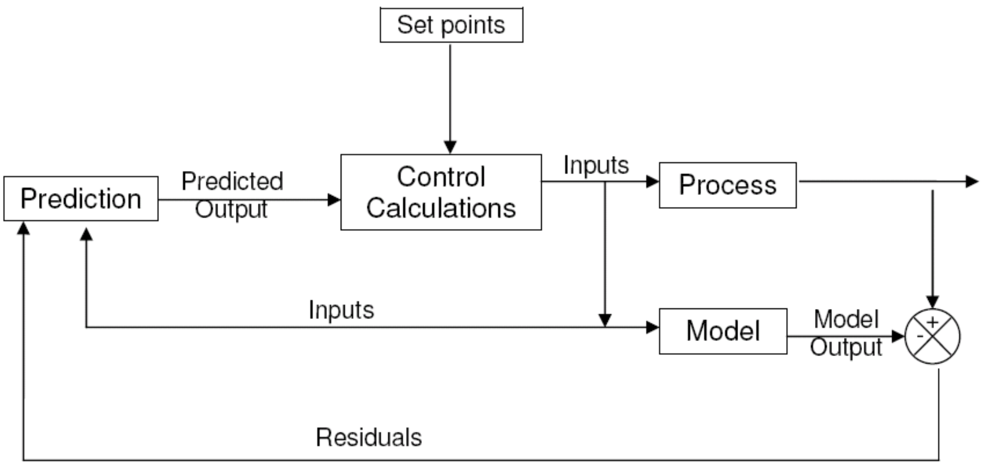



*Figure 2.6. General block diagram of a Model Predictive Control algorithm (Edgar, Mellichamp & Seaborg, 2004)*

### *2.2.2. Materials and Methods*

For building of the predictive grain dryer model was used the LABVIEW programming environment. For the beginning, it is necessary to describe mathematically the drying phenomena.

Many studies have been made to understand the behavior of the drying process. In the table 2.1 it shows the main theoretical models used by researchers in the last decade. The assumptions made to develop these kinetic models were:

a. The falling rate period is linear and is represented by a single line from the critical moisture content to the equilibrium moisture content.

b. The feed conditions of the heating medium remain unaltered during the drying process.

According with this assumption the drying curve consists of four stages: pre-heating, constant drying rate, falling drying rate, and dry surface diffusion.

In each step, heat and mass transfer takes place, dominating the constant and falling drying rate regions. These phenomena contribute to the change in moisture content of the cereals grains.

The main disadvantage of the presented models is that the control parameters are not expressed, so can it not be used directly for designing of controller.

*Table 2.1 Mathematical models for granular material drying*

| Authors | Mathematical model describing |
|---|---|
| Alden (1998) | Temperature Difference Technique<br>$w_p=f(\Delta T)$; $w_p$-moisture content of material, ΔT-temperature drop in the direction of flow |
| Robinson (1992) | Temperature Difference Technique<br>$w_p=A(\Delta T)^b-C(\Delta t)^d$; $w_p$-current humidity of material, % ΔT-temperature drop in the direction of flow<br>A, b, C, d-adjustable parameters Δt-drying time |
| Montenegro (2000) | Hybrid models for the drying curve. The constant rate region is controlled by external condition as long as the drying flux is linearly dependent on the mass transfer coefficient. This region is also dependent on initial humidity and drying rate. For a porous material the initial drying rate may remain constant over a wide range of moisture content, often ending this region at very low average moisture content |
| Chandran, Subba, Varma (1990) | For the constant rate period, moisture content of material is: $w_p=w_{po}-kt$<br>For the falling rate:<br>$w_p = w_p^+ + (w_{pc} - w_p^+)\exp\left[\frac{-k(t-t_c)}{(w_{pc}-w_p^+)}\right]$, where $w_{po}$, $w_{pc}$, and $w_p^+$ are the initial, critical and equilibrium moisture content respectively, $R$ is the drying rate, expressed as weight of water evaporated per unit weight of dry material and unit time, $t$ is the drying time, and $t_c$ is the time where the moisture content is equal to the critical moisture content. |
| Arocho (2004) | $w_p = \frac{w_c \cdot \rho \cdot Q_a \cdot C_p}{k_{Ya}} \ln\frac{(T_i - T_w)}{(T_0 - T_w)}$; $k_{Ya} = A \cdot Sc^b \cdot \mathrm{Re}^c (\frac{D_{H_2O-air}}{d})$ ,where: $k_{Ya}$- mass transfer coefficient, $A$, $b$, $c$ are adjustable parameters, $Sc$ is the Schmidt number, $Re$ is the Reynolds number, $D_{water-air}$ is the diffusivity and d is the diameter of the particle |
| Wildfong (2002) | For the constant rate period, moisture content of material is: $w_p=w_{po}-kt$. For the falling rate:<br>$w_p = \frac{6}{\pi^2}\left[\sum_{n=1}^{\infty}\frac{1}{n^2}\exp(-n\pi^2\frac{D_m \cdot t}{R^2})\right](w_{po} - w_p^+) + w_p^+$, where $D_m$ is the average solvent diffusivity trough the particles and $R$ is the average radius of the particles |

In this direction, in 2006, J Pacheco has developed a proper mathematical model, starting from water balance around the material inside the dryer.

This mass balance (equation 2.50), which can be used for any type of dryer, expresses the negative accumulation of water in the powders as equal to the water removed from it.

$$m_{pow}\frac{dw_p(t)}{dt} = -k_{ya}(t)[Y_{\mathrm{int}}(t) - Y_{air,o}(t)], \tag{2.50}$$

where: $k_ya$ (t): Mass transfer coefficient [kg of dry air/s]; $Y_{int}$ (t): Inter phase humidity [kg water/kg of dry air]; $Y_{air}$ (t): Air humidity [kg water/kg of dry air. A first assumption in this theory is that the drying process is a continuous process, assumption that creates a problem since there are no steady state constants in a batch process. In other words what are determined are steady state constants that depend on operating conditions, or pseudo-steady state constants.

The second assumption taken into consideration is that the inlet air humidity is presumed constant. The last assumption used and the most important is that the mass transfer area is not constant and depends on the humidity of the material.

After linearization, transforming using Laplace and Taylor, and expressing the parameter $k_{ya}$, the equation 2.50 becomes [ ]:

$$w_p(s) = \frac{-k_q e^{-\theta_1 s}}{\tau s + 1} Q_{air,i}(s) - \frac{-k_t e^{-\theta_{21} s}}{\tau s + 1} T_i(s) \tag{2.51}$$

or, more generally,

$$\frac{dw(t)}{dt} = [K_q \cdot Q_i(t) + K_t \cdot T_i(t)] \cdot (1 - e^{-\frac{k_\tau}{t}}) \tag{2.52}$$

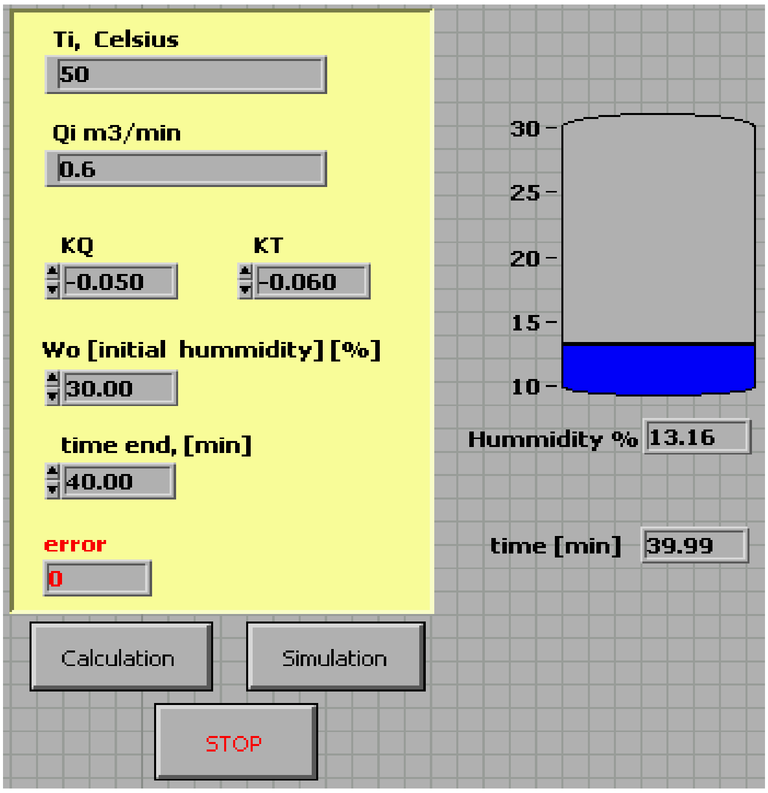



*Figure 2.7. The front panel of the simulation model*

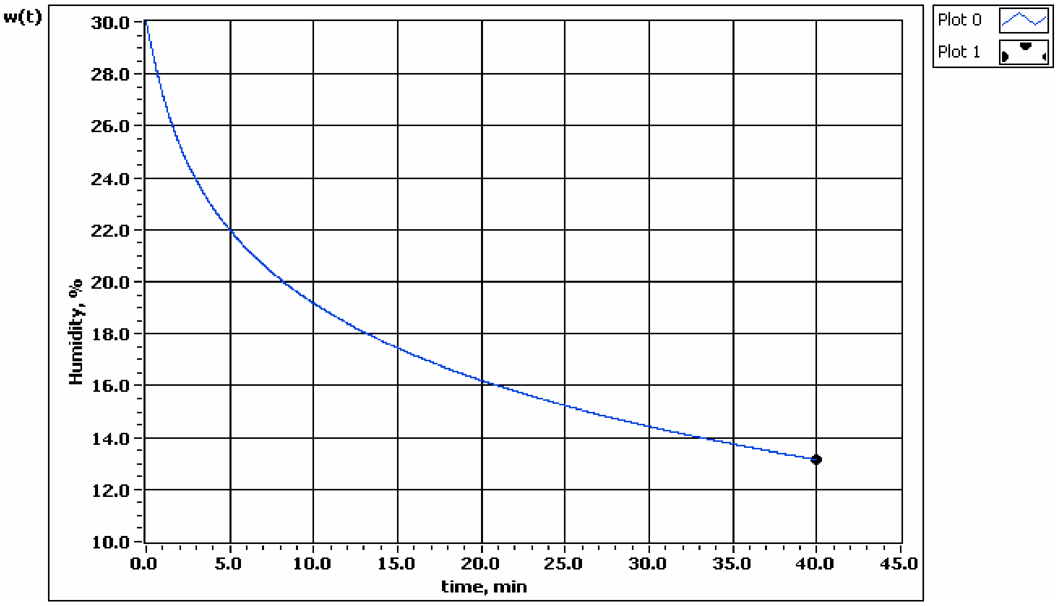



*Figure 2.8. Humidity vs. time evolution diagram for drying –LabView specific case simulation (Ti, Qi=cst)*

### *2.2.3. Results*

Based on the last theoretical model it was built a virtual instrument in the frame of LABVIEW programming environment. he application solves ordinary differential equations (2.52) with initial conditions, using the Runge Kutta method. The Runge Kutta method works with a fixed step rate but with a higher degree of accuracy than the common Euler method. Starting from initial condition $w_0$ with temperature of drying of $T_i$ = 50 Celsius degrees and air flow $Q_i$= 0.6m$^3$/min, it was determined the values of $K_q$ and $K_t$ , as it shows in figure 2.7.

The front panel contains an indicator type tank level that shows realistic the value of material humidity. Below, other two numeric indicators show the values of humidity and the current drying time. In the left side there are two string controllers (for $T_i$ and $Q_i$). The application accepts here constant values (as in figure 2.7) or time dependent function. (see results in figure 2.10). Below there are controllers for setting the values for *Kq*, respectively *Kt*.

These values are determined experimental, being the similitude factors [34], [35], [36], [37]. Also, exist indicators that show error of Runge Kutta calculus and another controller for setting the drying duration.

The whole application is controlled by three push-buttons in the next order: run-calculation-simulation-stop.

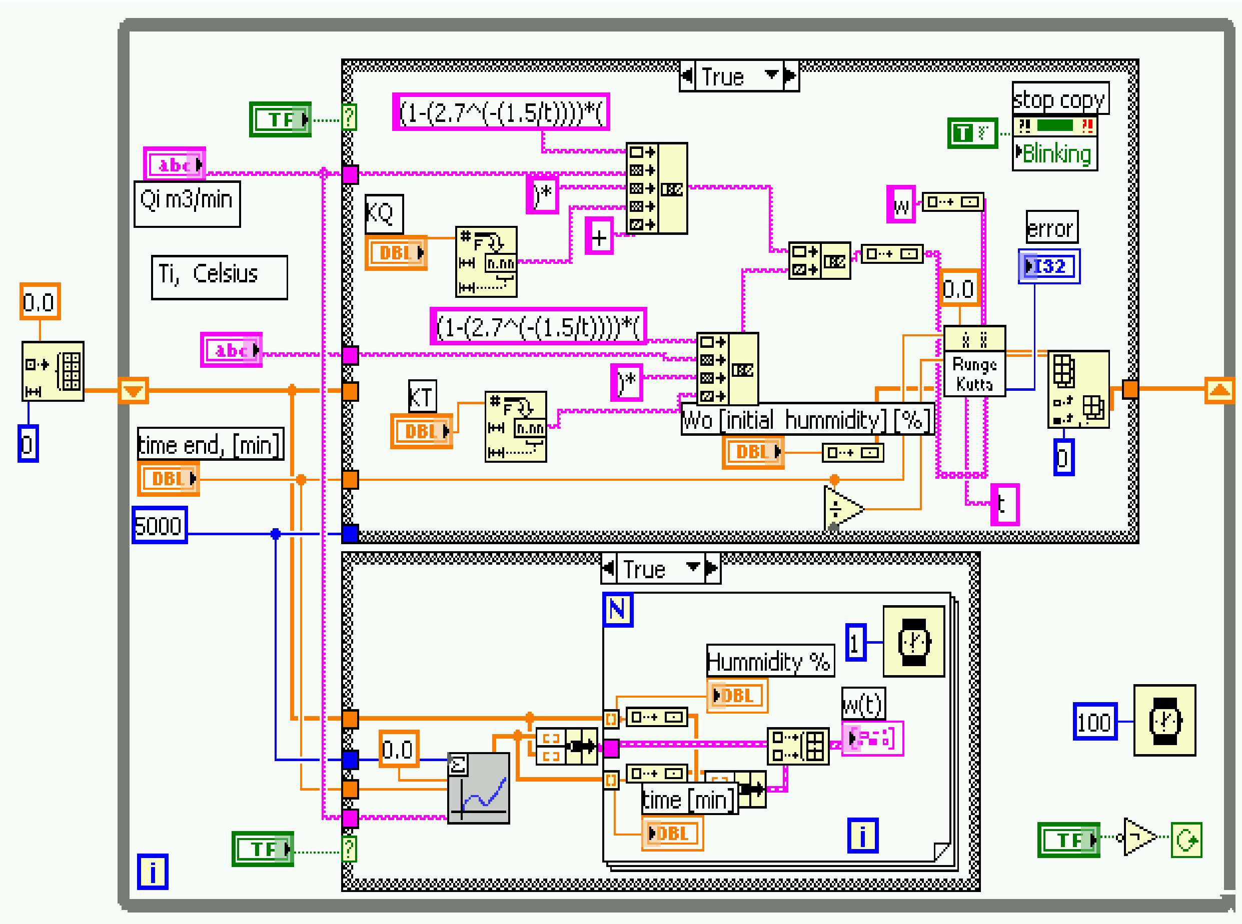



*Figure 2.9. Block diagram of the LabView drying simulation using Runge Kutta method*

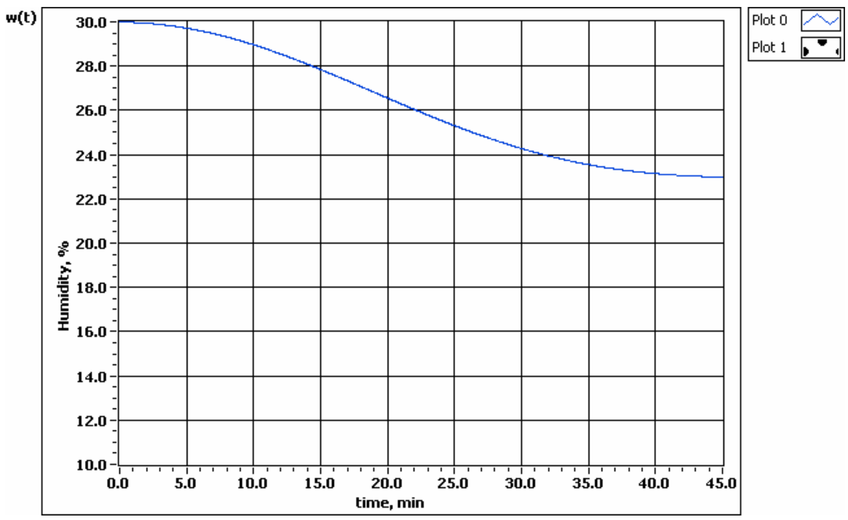



Figure 2.10. *Humidity vs. time evolution diagram for cereals drying-variable drying temperature*

The block diagram it is represented in figure 2.9 and consists of the main blocks: first block (on the upper side) for input of differential equation that describes the phenomena and solves it, and the second block (on the bottom side) for visualization of the results, as shown in figure 2.8. The prediction possibilities of this application are shows in figure 2.10, where the drying temperature was not constant, but it was a sinusoidal function in time:

*Ti=40 x (1-cos(t/8)).*

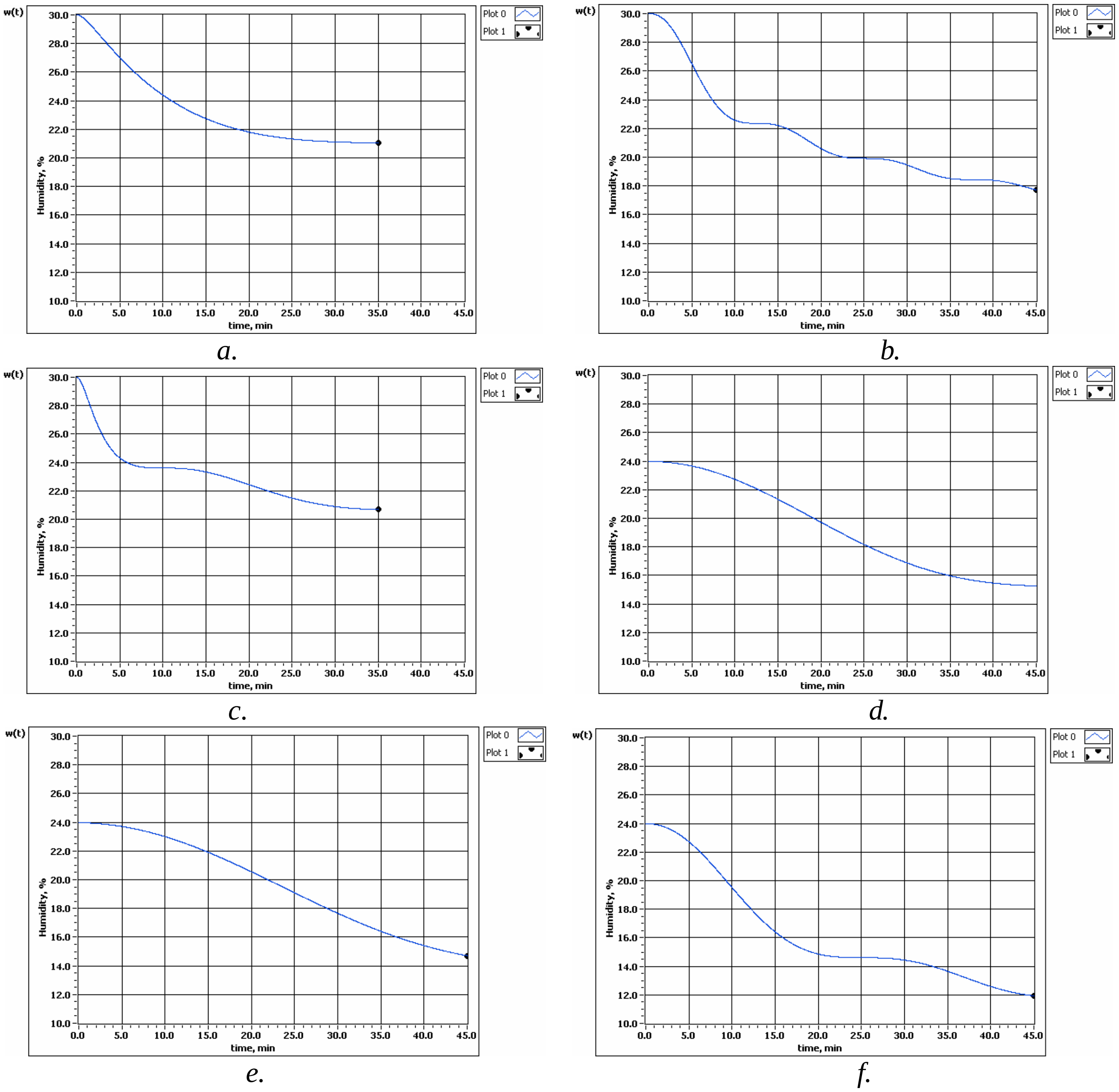



*Figure 2.11. Different types of simulation accomplished with the model developed*

In figure 2.11 are presented other simulation accomplished with the model:

a) *Ti=50 x (1-cos(t/2);*

b) *Ti=cos(2*sqrt(t));*

c) *Ti=30 x (1-cos(sqrt (t));*

d) *Ti=40 x (1-cos(t/8);*

e) *Ti=50 x (1-cos(t/8);*

f) *Ti=40 x (1-cos(t/4).*

The application does not describe explicitly the dependence of the model to the physical properties of the material being dried, though the adjustable parameters do depend directly to the physical properties as to the operational conditions.

## 2.3. Emergetic Simulation Model of Agroecosystem – Case Study of Animal Breeding Farm

### *2.3.1. Introduction*

The process of simulation in the environment-economy systems, such as the agro-ecosystems, mainly uses the logical models as a bases of trying to copy the dynamic of the real situation of the system, for example an animal breeding farm. Simulation gives the possibility to assess the most likely effects of the various decisions under the frame of the environment – economy system (EES). Thereby all negative consequences can be avoided and can be introduced more efficient methods, with reference to feed-back and feed-before mechanisms, as adjusted cybernetic elements in the process of integrated management [7], [4], [70].

The systems with environment-economy interface, being in fact anthropized ecosystems, may be transformed in view to the sustainable development. We mean to adjust the economic development to the ecologic bearability. In this context, the goods and the services of the environment, the output of the processing of the resources, together with the influence of the market demands are the elements of the economy remodelling. All this may be synthetically expressed by certain parameters which may have as a result the help in taking decisions in piloting (the management) the EES.

The main objective of the simulation is to offer the possibility to calculate the amount of the resources necessary to obtain a certain behaviour of the EES, with a specific level of the inputs.

### *2.3.2. Method*

As a basis of study in the elaboration of the parameters was used the emergetic analysis method (the eco-energetic method) which was offering the advantage of a unitary, synthetically and systemic expression [109], [110]. [70]. We must note that the first stage of the method is extremely laborious, including energetic diagrams and calculations emergetically expressed of the system flows and of its components. The second stage of the method is based on the three major flows of input and output from the system expressed as emergetic sums (noted in the accepted model of interface as $I^+$ and $F^+$ – the inputs and respectively $Y^-$ – the outputs). Based on this, the table 2.2 shows the main emergetic parameters of sustainable development of the environment-economy systems (EES).

The simulation process consists in the use of the theoretical model (flow chart, shown in figure 1), in order to highlight the real behaviour of the system. By modifying one or more input sizes respecting laws described by linear mathematical functions (right variation or with a certain downhill) or non-linear ones (sinusoidal, tangential), can be underlined the dynamic function of the real system [12].

The obtained information from the flow chart was utilised through the determinist simulation technique, using MATLAB/SIMULINK application.

*Table 2.2. The emergetic parameters of sustainable development of the environment-economy systems (EES)*

| Nr. | Parameter | U.M. | Calculation equation | Observations |
|---|---|---|---|---|
| 1 | The degree of concentration of the energy | J/J effective | Solar energy (type A) / Energy from syst. (Type B) | It shows the degree of concentration of the energy in every point of the system by the number of joules energy type A incorporated in a unity of B type. |
| 2 | System emergy, or emergy of C type ($C^{emJ}$) | emJ | EpJ . $Tr^{emJ/J}$ | The eco-energetic unity of measure, it is capable to measure the action of the available energy in a period of time (ex. 1 year). EpJ = effective energy measured in the System. Tr = solar transformity, or “tran- sformation – conversion” of the solar energy: the quantity of solar energy necessary to introduce a unity (1 joule) from a certain good. |
| 3 | The real work $(\rho)$ | EmJ | $F^+ + I^+$ | The eMergetic sum of human labour ($F^+$ flood) and the environmental work ($I^+$ flood). |
| 4 | The energy externality (xE) | EmJ/year | $\frac{I^+}{I^+ + F^+}$ | The external gain of order of the EEs by the free environment used, evaluation taking into account the environment externality ($I^+$) repre-sented by the non-price goods and services of the environment (low quality energy), as well as the eco-nomic externalities ($F^+$) represen-ted by the goods and services bought on the market (high quality energy). |
| 5 | The efficacy of EEs (e) | Nr. (e<1) | $\frac{Y^-}{F^+ + I^+}$ or $\frac{Y^-}{\rho}$ | The efficiency of the system expressed by the relation between the useful eMergy of the incomes got by the outputs from the system ($Y^-$) and the eMergy spent by the inputs as an environment system and from the market. |
| 6 | The intensity of the purchase of the goods from the market or the eMergy $(i_\rho)$ | EmJ or emJ/ha | $\frac{Y^-}{F^+}$ | It shows the level of the inputs in the system as a contribution through the environmental work with the realized production. |
| 7 | The intensity of the environmental work $(i_m)$ | EmJ or emJ/ha | $\frac{Y^-}{I^+}$ | It shows the level of the inputs in the system as a contribution through the environmental work with the realized production. |
| 8 | The intensity of the production support through the environmental work $(i_\omega)$ | EmJ or emJ/ha | $\frac{I^+}{Y^-}$ | It shows in principle the support by the environment of the economic sphere (of the outputs), representing a calculation element for the objective evaluation of the sustainability. |
| 9 | The draining coefficient (D) | % | 100 $e^2$ | It shows the relation from the environment externalities “digested” in order to equilibrate the environment-economy discords; it is the combustion element to start and sustain the draining from the environment towards the economic subsystem. |

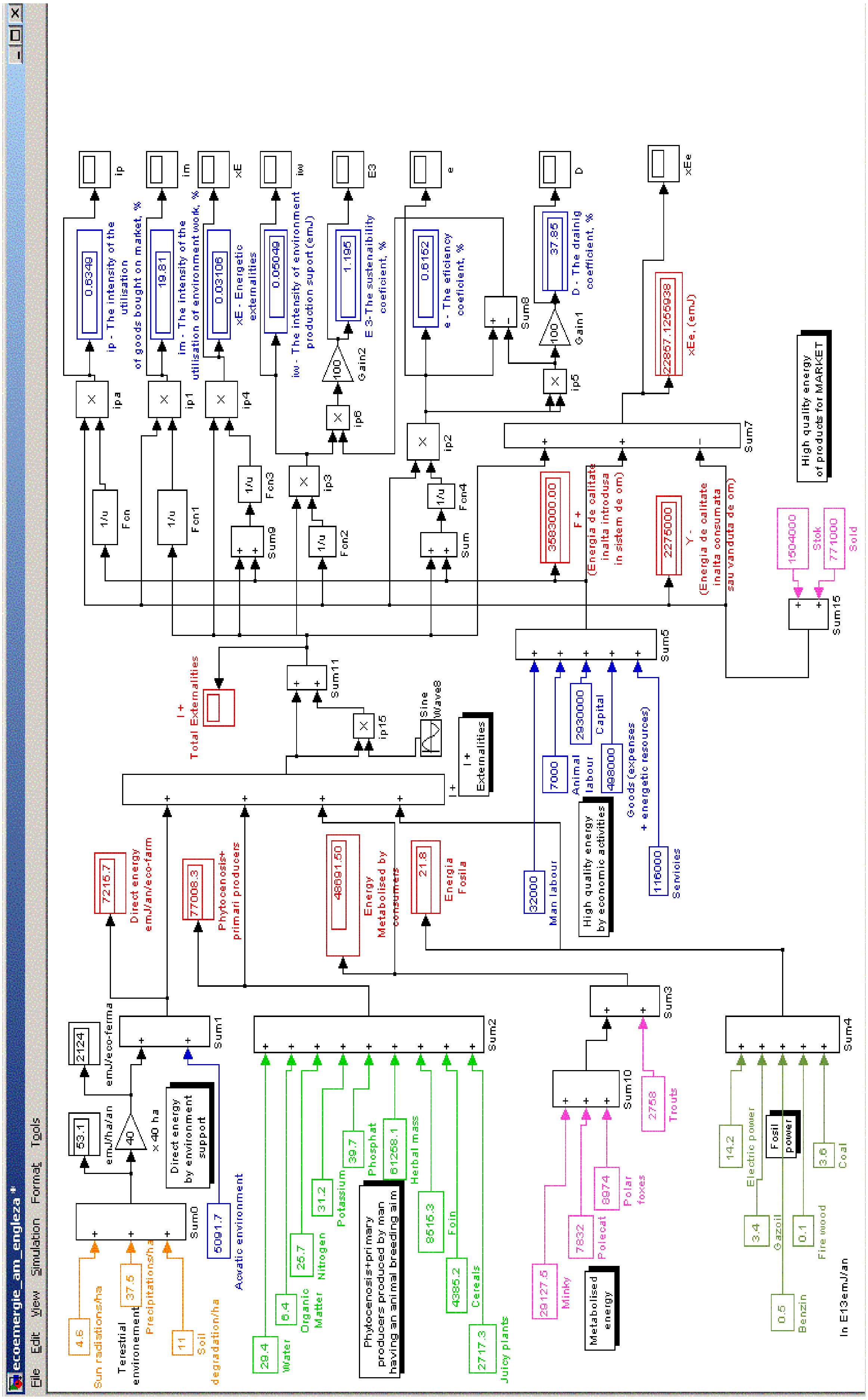



*Figure 2.12. The simulation model of an agroecosistem variable parameter: Environment externalities $I^+$.*

This simulation, used under the frame of the given system, has the possibility to point out needed decisions for the exact calculation of the resources necessary to obtain a certain result pre-established with a certain level of the inputs. [109], [110], [111]

The purpose is to rule out the present uncertainties in the farm during every day life for the sake of convenience and routine.

### *2.3.3. Results and Discussions*

The present paper is based on a flow chart [43], [70] made after a case study, quantified through the eco-energetic (emergetic) analyses method, done in a carnivorous animal breeding farm (rainbow trout and fur animals: minks, polecat and polar foxes) with an average effective of 12000 fur animals and 200000 trout, with an average biomass of approximately 46 t, with a habitat surface of approximately 10 ha, at an altitude of 560 m, agro-ecological conditions specific to the temperate zone.

The respective case study has structured the energetic diagram of the farm, with the help of which, through the solar transformity and the existing energy in each point of the system it has calculated the emergetic contribution of the environment externalities, of the financial flow introduced by man through the economic activity and the market influence trough buying and selling, aiming to satisfy the population demands [70], [134].

From the flow chart can observe the fact that the inputs are structured on groups, in which are highlighted the composing elements. Are also mentioned the outputs and losses, as well as the main piloting parameters of the system.

Under the presented conditions, the simulation is suggested as a work manner to study the variable interdependence and the possible results.

The first simulation analyses the situation in which is considered to be most often met in the productive activity, namely the one linked to the variation of the environment externalities, under the conditions when the economy contribution (the human activity) and the market influence are assumed to be constant.

For a suitable analyses of the environment variation effects on other specific followed parameters, it was used a sinusoid in time function (to express the environment externalities), with an amplitude of ± 25% face to the average value of the environment contribution (132937, 3 E13 emJ/year).

Consequently to the application of the simulating program were obtained results synthesised in figure 2 *a*, *b*, *c*, *d*, *e* and table 2.2.

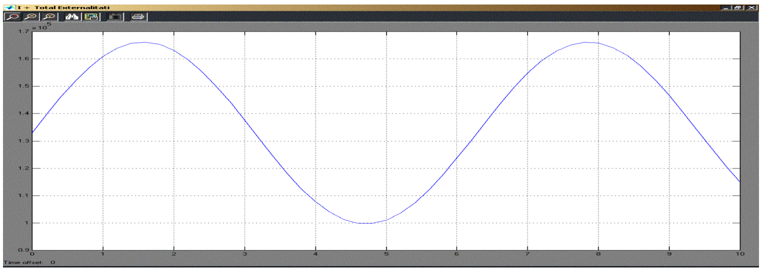


*Figure 2.3 The evolution in time of the environment contribution*

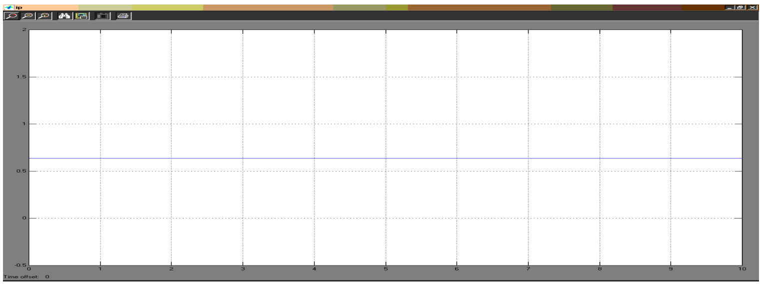


*Figure 2.4 The evolution in time of the intensity of the goods purchased on market*

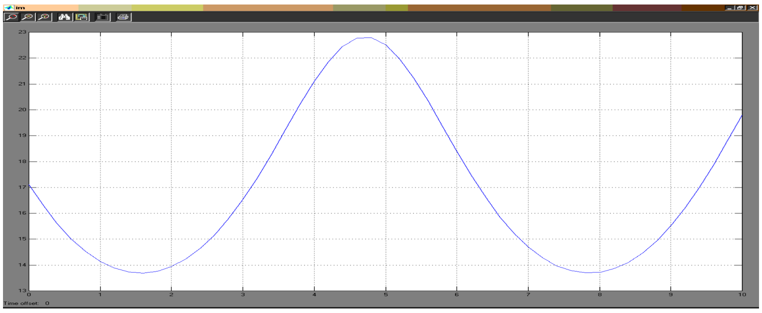


*Figure 2.5 The evolution in time of the intensity of the utilisation of the environment work*

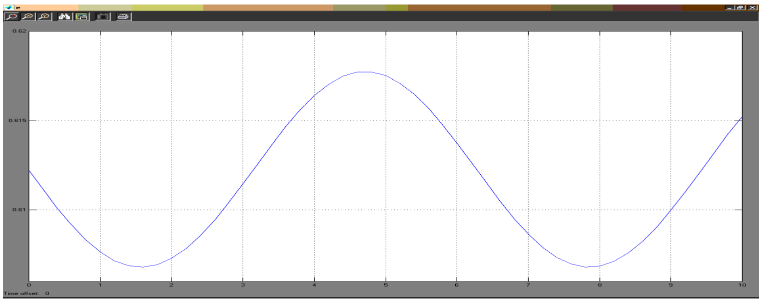


*Figure 2.6 The evolution in time of the system efficiency coefficient*

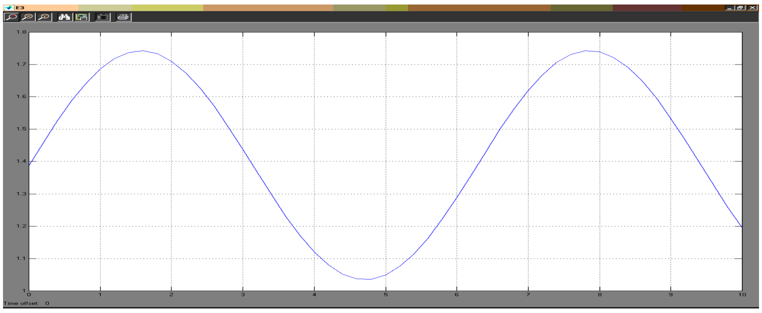
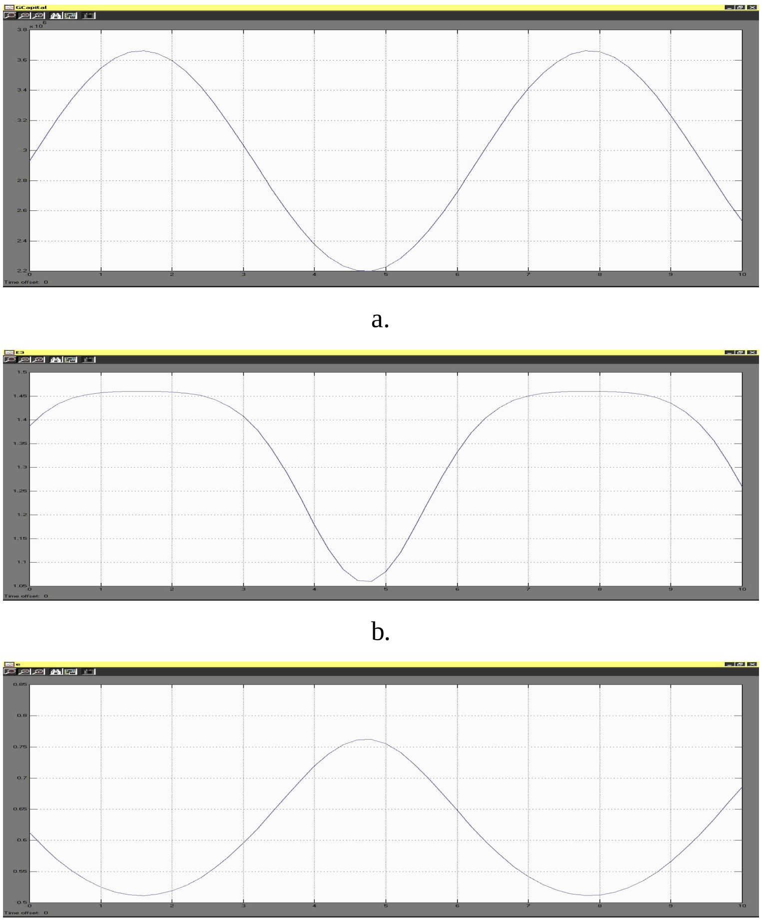


*Figure 2.7 The evolution in time of the sustainability coefficient*

*Table 2.3. Estimation of the effects of the non-price contribution variation of the environment introduced in EES through utilised simulating variants*

| Specification | Intensity of the goods purchased on market ($i_p$) | Intensity of the environment work utilisation ($i_m$) | System efficiency coefficient (e) | System sustainability coefficient ($E^3$) |
|---|---|---|---|---|
| Environment externality variation with + 0…25 % | Uniform | - 0…3.5 % | - 0…0,5 % | + 0…26,09 % |
| Environment externality variation with - 0…25 % | Uniform | + 0…5,7 % | + 0…0,6 % | - 0…24,64 % |
| Simulation results | The growth as well as the decrease of the environmental externalities DO NOT affect the output of the market purchased goods used to achieve result (production) in the given system. | The growth of the environment externalities with up to 25 % may lead to reduce the output of the utilisation of the environment work with up to 3,5 %. In exchange the diminishing of the environment externalities with up to 25 % may lead to a growth of the output of the utilisation of the environment work with up to 5,7 %. | The growth of the environment externalities with up to la 25 % may lead to diminish the system efficiency with up to 0,5 %, while the diminishing of the environment contribution with up to 25% would lead to the growth of the system efficiency with up to 0,6 %. | The growth of the environment externalities with up to 25 % significantly influences the sustainability growth (with 26,1 %), while the diminishing, at the same level, has a similar effect, i.e. the sustainability diminishing (with 24,6 %), underlying the fact that the level of the utilised environment externalities expresses a sustainability about the optimum in report with the economic activity developed under the frame of the system. |
| Partial conclusions | The variation of the environment contribution (+/-) does not influence the expenses on market purchased goods for the production achievement. | It can be observed that a certain amount of natural capital has been uselessly spent, but which hasn't economically influenced (the environment work being non-price), but which may lead in time to the appearance of certain prejudices as for the environment protection. | The variation of the environment contribution (+/-) shows the growth or diminishing of the EES efficiency approximately at the same ratio, which shows the registered level of the environment externalities, is optimum for a farm with carnivorous species integrated in the corresponding ecosystem. | The level of the environment contribution introduced in the system has been optimum as for the sustainability, indicating an equilibrium concerning the sustaining capacity by the environment of the economic activity from the given system. |

Another simulation proposed the situation in which the capital varies as sinusoidal function like in fig. 2.8a. (2.2 x 10E6 3.7 x 10E6). In fig. 2.8. b the sustainability coefficient can be observed with a different shape, and fig. 2.8c. shows d. the system efficiency coefficient.



a.

b.

c.

*Figure 2.8. The evolution in time of the specific parameters Capital, $E^3$, e,*

### *2.3.4. Conclusions*

The general conclusion to be drawn from what we have mentioned above is that, consequently to simulations done in the analysed EES (ecosystem with carnivorous farm) through environment externalities variation of +/- 25 % the contribution of the environment used in the given system is optimum in report with the dynamic equilibrium of the system. A certain reduction of the environment externalities would have grown under a certain amount the output of utilising the environment work (up to 5 %), but the aspect is non-significant taking into account the optimum sustainability level of the system, the one indicating an equilibrium concerning the sustaining capacity by the environment of the economic activity of the given system. [59], [60], [70], [71].

If the capital varies the system shows an inertial effect from the sustainable point of view, as well as the system efficiency coefficient.

# CHAPTER 3

# CONTRIBUTION TO THE PRESERVATION OF PHYSICOCHEMICAL AND QUALITY ATTRIBUTES OF BIOLOGICAL PRODUCTS

## 3.1 Contribution to the design of visible spectrum optical checking system

### *3.1.1. Introduction to the concept low cost non-invasive measurement systems*

In this chapter we should underline the extraordinary collaboration with HTWG Konstanz, Germany, in the field of agri-food products drying. [134]. As a novelty element it is underlined the concepts of adaptive, image analysis based, control systems for drying and other processes [135], [136]. It has been developed a database containing relevant chemical, sensorial, textural and optical properties in order to control the system according to target properties.

**Development of low cost non-invasive measurement systems:** The big potential of hyper - and multi-spectral imaging (HSI and MSI) to improve food safety and food quality inspection is only now beginning to be exploited.

The application of HSI and MSI to the control of food processing, however, is yet undeveloped. There are disadvantages to incorporate hyper spectral cameras in the processing unit: they are expensive and require precision motors for mirror or translation stage movement, which are sensitive to mechanical disruption. Image acquisition time is high (on the order of seconds to minutes, depending on the image size and spectral resolution); the hyper spectral image size is extremely large and image processing requires high speed and huge memory resources. The aim is to develop a less expensive, more robust, faster imaging method which may be incorporated into a food processing unit to yield real-time control of processes based on continually updated spectral information from the dynamically changing foodstuffs. This imaging method will couple narrow-band LED illumination sources to CCD cameras in a similar manner to existing MSI devices on the market, but with application –specific targeting of spectral regions previously identified from HSI analysis. The proposed work includes: (1) identification of spectral regions of interest, for fruits and vegetables, through further empirical measurements, image analysis and development of tensor decomposition analysis; (2) selection of LED channels and design of illumination device; (3) design and development of illumination-imaging-coupled device for incorporation into industrial dryers.

### *3.1.2. Research method*

In order to accomplish the objectives mentioned above, there where performed a series of important experiments in collaboration with HTWG Konstantz, Germany, with a team of master and PHd students from both Universities. [139], [140] The convective dryer used for research is equipped with an PLC type automatic control system (Siemens 57/300), infrared thermometer, electronic scale, CCD camera and a data storage system. (fig. 3.1) [136], [137], [138].

The dryer contains an air condioning unit and a drying chamber. The humidifier is composed of a water bath (W), a heater (H, 31 KW), a refrigeration unit (K, 8 KW), and nozzles (S). The water temperature can be adjusted between 4...75ºC, and can be measured by two thermocouples (d, e). The air is heated in four heating units. (H2-H5, 40KW), and its temperature can be adjusted between 10...160 ºC. The air goes into the humidifier, in countercurrent with the water flow, and is driven thru the radiator into the drying chamber through the (x) or (U) paths. CCD chamber/camera (j, DFK31BU03H) is in the drying chamber, on a special support, and for lightness it is used a LED system. A pyrometer (h, Heitronics KT15) is installed to determine the surface temperature of products. The products are located on the T sieve; the air flow could operate horizontally or vertically.

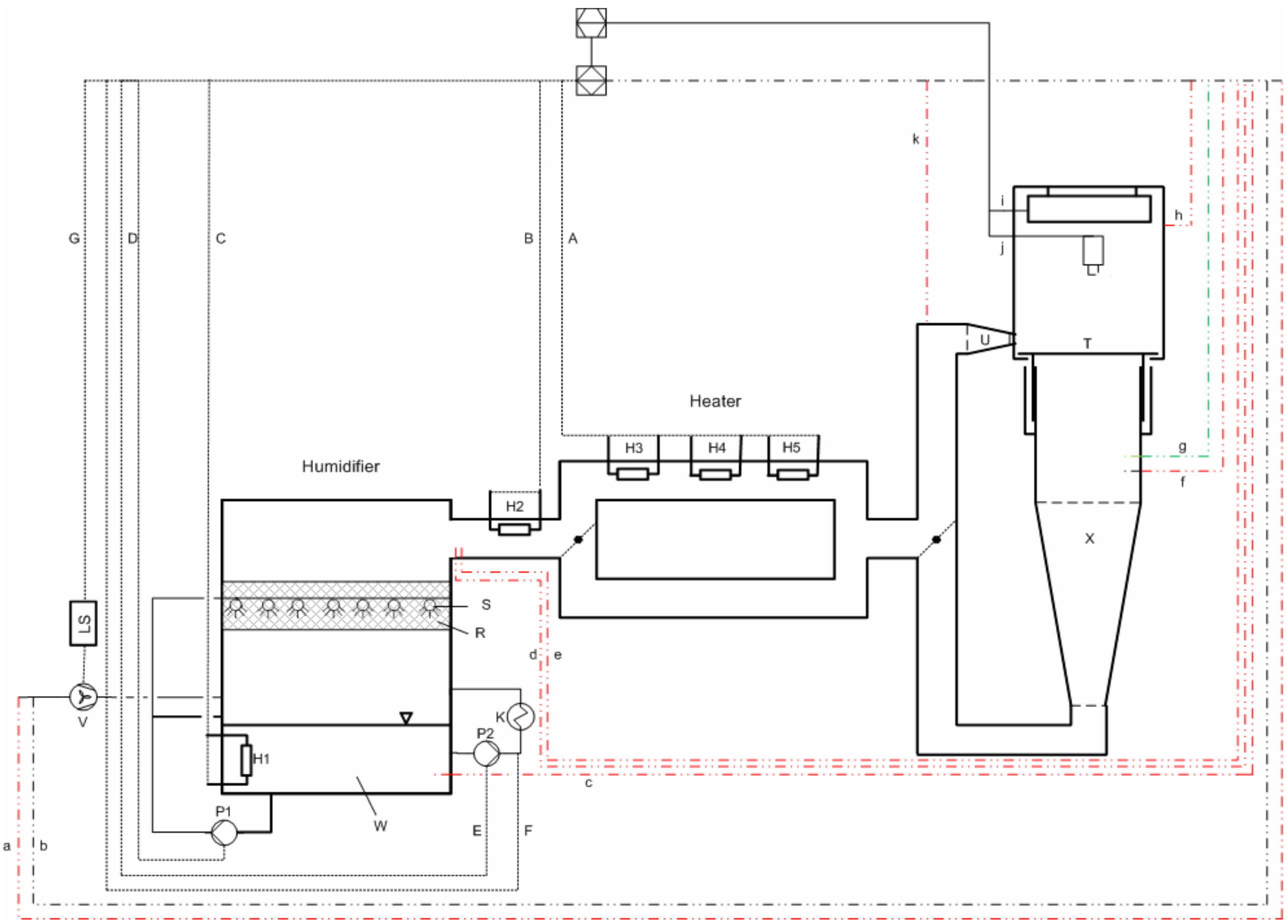



*Figure 3.1 Scheme of the laboratory dryer*

During the drying process, the color and size where noninvasively measured from 5 to 5 minutes with the CCD (j) camera.

The temperature was constantly measured with the help of the pyrometer (h) that was placed in the drying chamber. The air temperature (a), of the water bath (c), the temperature of the dried bulb (d) and of the humid one (e), as well as the drying room temperature (f, k), where measured with the help of some thermocouples. The air flow was measured with an anemometer (b). All values were transferred in PLC and from there in HMI WinCC. Weight was measured continuously using a precision scale (I Sartorius CP 12001s) and transferred to a LabView application for processing. The samples were dried; up to a content of approximately 0,13g water/g dried substance.The process is considered finished when the drying curve becomes horizontal. There were applied different strategies of drying: when the air temperature is constant or when the temperature of the product surface is constant.

### *3.1.3. Effect of drying air temperature on surface product temperature*

Knowledge of the product temperature during drying is important to evaluatethe influence of the drying process on physicochemical and quality attributes. This is because the reactions between food components are often accelerated during drying leading to significant reduction in quality and nutritional value.

The reaction rates are strongly affected by the temperature and moisture content of food during drying . In the next graphic are presented the theoretic curves: drying agent temperature, product weight decreases linearly, becoming horizontal after a certain period of time, surface temperature of product which increases until a certain moment, then becomes constant, reaching the drying air temperature.

Figure 3.2. shows the effect of air temperature on surface product temperature at air velocity of 4.5 m/s dew point temperature of 15˚C and thickness of 3mm.[77], [138], [139]

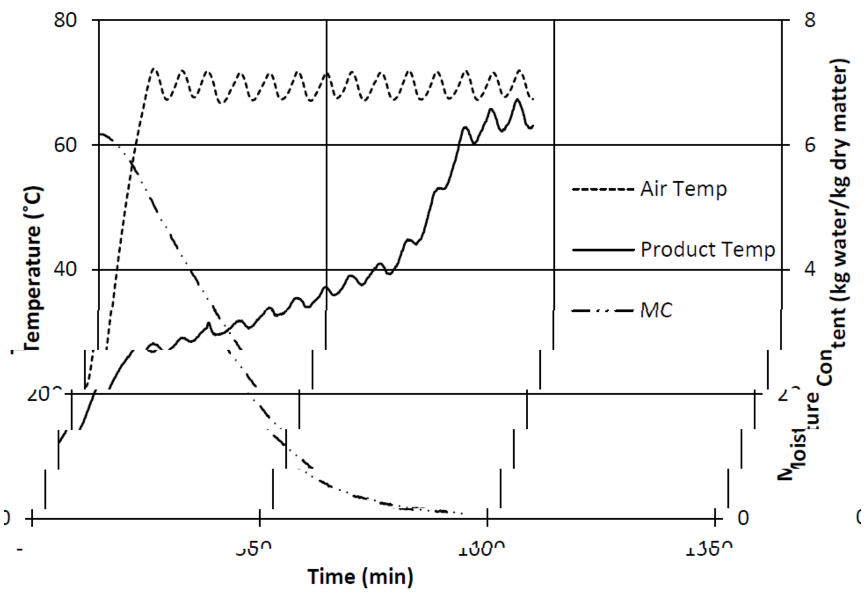



*Figure 3.2. Tipical development of the surface product temperature with drying time ( air temperature - 70˚C at air velocity of 4.5 m/s)*

It was observed, that there was a direct relationship between surface product temperature and air temperature at any given drying time, in that the surface product temperature increased with increase in drying air temperature. At the onset of the drying process, the surface product temperature of product was much lower than the set air temperature due to the effect of evaporative cooling. As drying continued, the moisture at the surface decreased and the internal resistance to moisture transport increased, thus the evaporation zone moved from the surface into the material. This implied that the heat necessary for evaporation had to be further transferred from the surface into the material to evaporate the moisture, in order to accomplish the phenomena of drying as being a simultaneously heat and mass transfer process. This temperature gradient was required for heat and mass transfer to take place. As the moisture content of product continued to decrease, the product temperature also increased until the set air temperature was reached. This implied that when the product temperature became relatively constant, the samples were relatively dry suggesting that it could have attained the equilibrium moisture content at the set air temperature. It was noted that, the gelatinization temperature of matooke is 72˚C, glass transition temperature is approximately less than 67˚C, however, from the results it was observed that the surface product temperature at the end of drying, on average was approximately less than 67˚C, implying that the glass transition temperature was not exceeded. .[77], [138], [139]

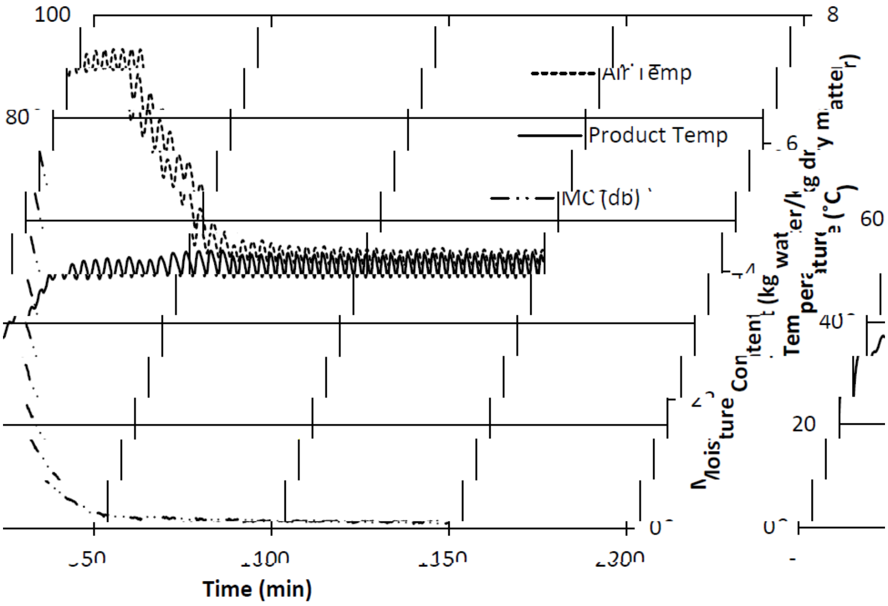



*Figure 3.3. Development of air temperature with drying time for a given set infrared surface (product temperature of 50˚C, air velocity of 4.5 m/s)*

It was observed from figure 3.3. .[77], [138], [139] that the air temperature shot up during the first region of drying, when the product temperature reached the set temperature, the air temperature started decreasing tending to the set product temperature. The drying air temperature becomes relatively constant but slightly above the set product temperature, because the temperature gradient required for continuation of the drying process. .[140], [141], [142]

The first region when the air temperature shot could be attributed to the high moisture content of the product that it required high energy to evaporate the moisture from the product and also to overcome the effect of evaporative cooling effect. The effect of setting the product temperature, reduced the drying time by half. Comparing the results of drying when air temperature was set at 50˚C, and when the product temperature was set at 50˚C, with other processing parameters kept constant at air velocity 4.5 m/s, dew point temperature 15˚C and thickness 3mm.

The drying time for set air temperature was approximately 200 min, while that for the set product temperature was approximately 100 min. This indicated that by setting the product temperature, it reduced the drying time by 50%; in other words, setting the product emperature the drying process automatically turned itself to stepwise (stepdown) drying process. This was similar to step-wise drying reported by Chua et al., 2001, which significantly reduced the drying time to reach the desired moisture content with improved product color.

### *3.1.4. Drying process in constant air temperature*

When the drying speed is constant, the liquid water from the material surface that is exposed to air, is removed; drying is the same as the air moisturizing process in a contact with a liquid water surface. The drying rate is independent of the material properties, but depends on factors that influence the diffusion of water vapor in air: air velocity, crossing direction of air in relation with the wet surface, liquid temperature and air humidity.

Drying rate, namely the moisture mass that is removed per time unit is equal with the mass of water vaporized per time unit.

Next are presented results obtained by drying slices of Golden Delicious apples.

The apples were sliced to a 4mm thickness and their seeds wear was removed. In the next figure are presented images of an apple slice that was photographed once in 40 minutes.

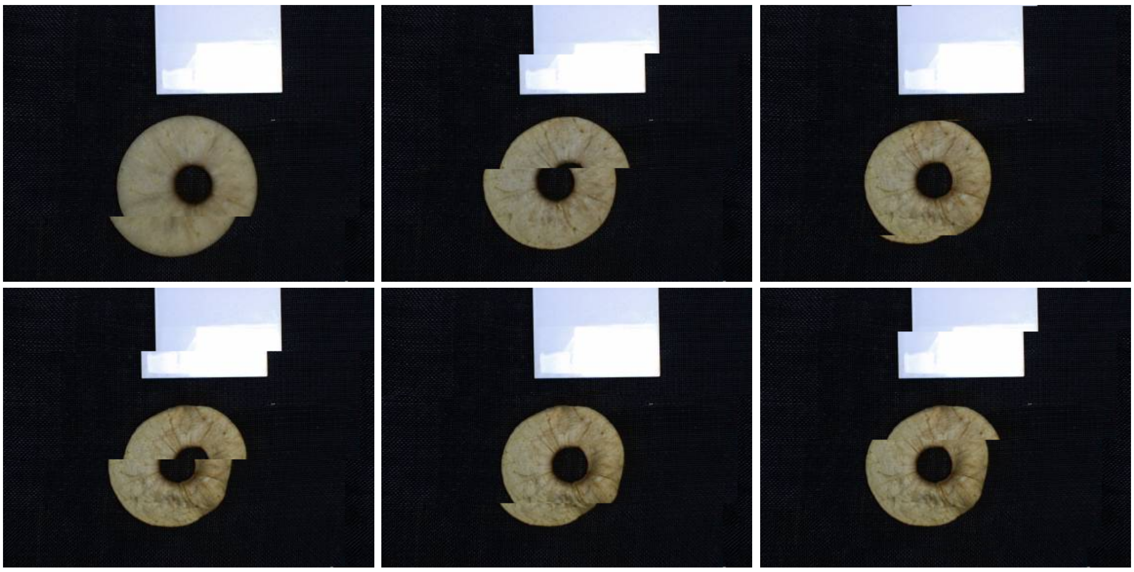


*Figure 3.4. Images of apple slices during drying process (intervals 40 min, drying agent temperature= 60 °C) (apple, Golden Delicios variety)*

There can be observed the changes of color and size. It was used a constant air temperature of 60 °C, dew point temperature 17,5 °C and a speed of 2 m/s.

In the next chart it is presented the products weight in function of time. On the blue curve can be observed the initial weight of products subjected for drying, 80g.

With the passage of time, the weight decreses and after about 130min, the curve becomes constant which suggest that the drying process is coming to an end.

The pink curve indicates the ratio between the water quantity expresed in grams and the quantity of dry substances, also expressed in grams.

This ratio was 9 at the begining, and after that decreases due to water removal from product and becomes constant next to the 130 minutes value. It is recommended to stop the drying process when the x is approximately 0,13.

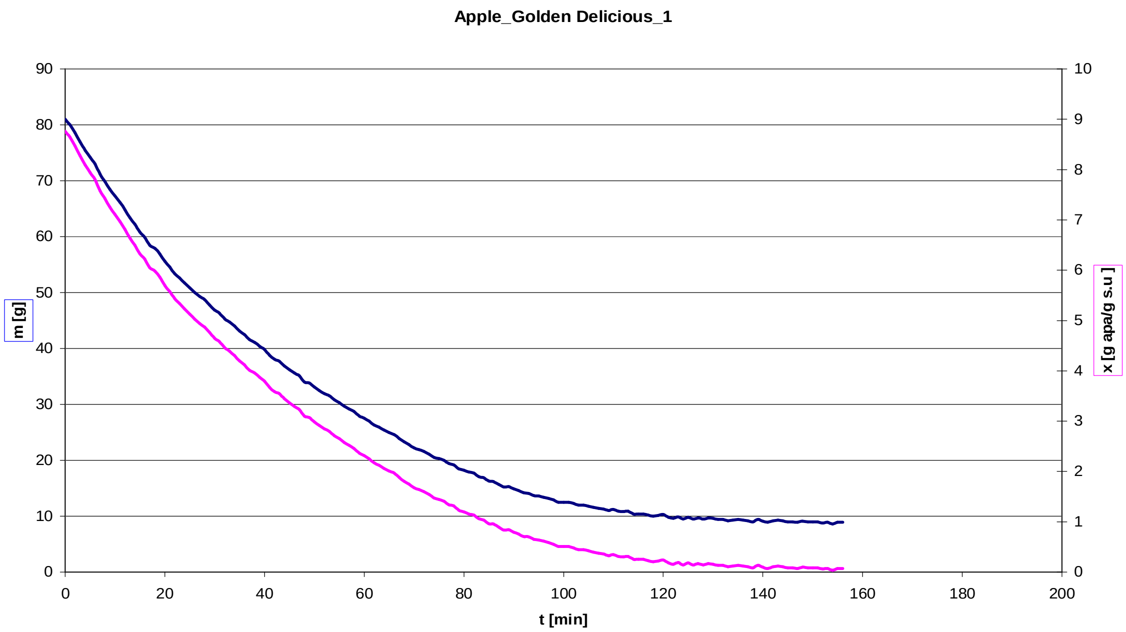



*Figure 3.5. Mass and moisture content vs time of apple slices during drying process*

In the next chart the blue curve represents the drying temperature which, from the beginng until the end of the process is constant at 60 ºC.

The red curve indicates the temperature from the products surface, temperature that is measured with the infrared pyrometer.

This temperature was initially 29 ºC, reaching a constant value, close to the temperature of the drying air, after approximately 80min.

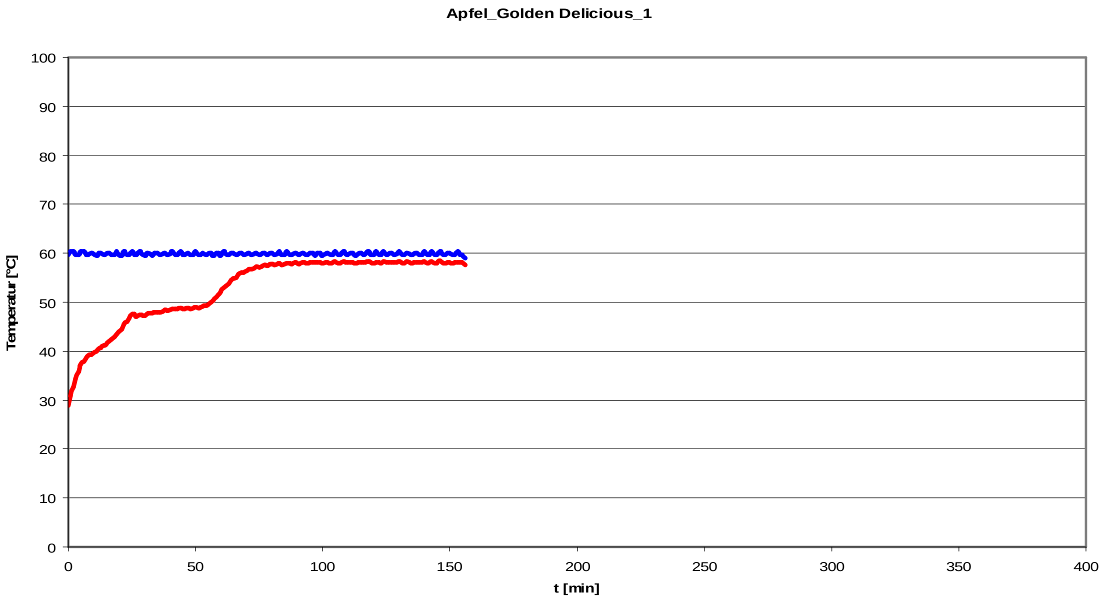



*Figure 3.6. Drying agent temperature and product surface temperature of apple slices during drying process*

There have been many experiments on thermo-sensitive products such as carrots, onions, pineapple and papaya. In Annex no 2 are presented obtained results, using the same research methodology.

Temperature, dew point and air speed were the same in each case, namely 60 °C, 17.5 °C and 2 m/s.

### *3.1.5. Drying when the product surface temperature is constant*

Another drying strategy in the literature, but without any evidence of optical effects is the one in which the reference for the automatic control system is the products surface temperature, and not the drying agent temperature.

There have been made a series of experiments using two temperatures along the drying process. There were used apples from the Jona Gold variety, the preparation for the drying process was identical with the case presented before. The air speed was 2m/s, and the dew point temperature 17,5 ºC.

For the next experiment, at the beginnig it was used a temperature of 90 ºC, and after when the samples arrived at a weight of approximetely 30g (15% dry substance), the temperature was changed to 80 ºC.

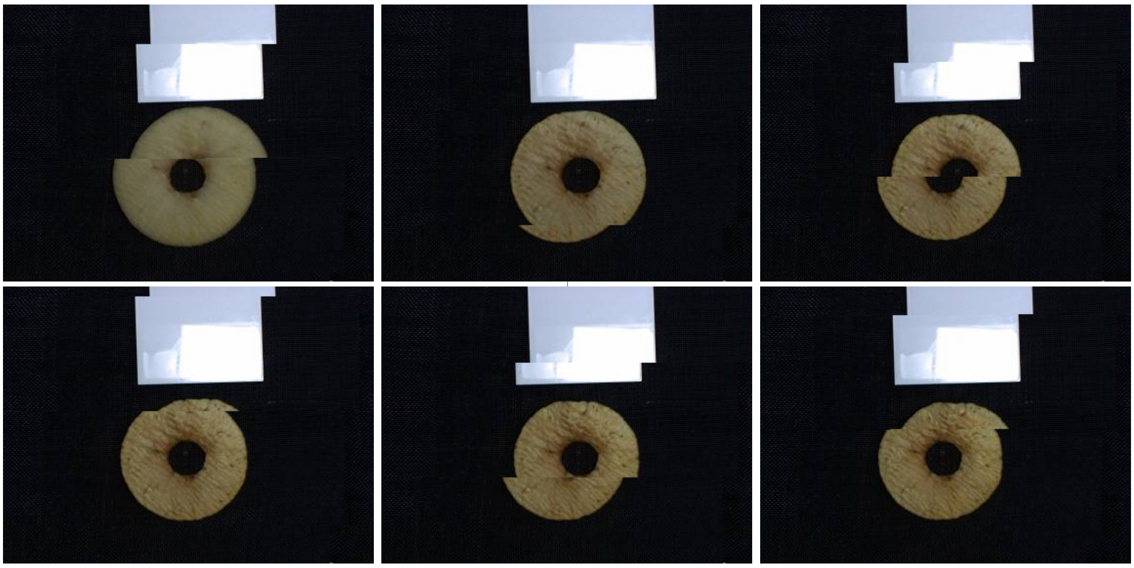


*Figure 3.7. Images of apple slices during drying process (interval 40 min, drying agent temperature= 60℃) (apple, Golden Delicios variety)*

In the next chart it is represented the weight of product in function of time. On the blue curves can be observed the initial weight of the product that is proposed to be dried, approximately 100g.

During time, the weight decreases and after about 200 minutes the curve becomes constant, which means that the drying process is close to the end.

The pink curve indicates the ration between the quantity of water in grams on the quantity of dried substance, also expressed in grams. This ratio was 5 at the begining, and after decreasing because of water elimination from product it becomes constant at the 200min value. It is recommended to stop the drying process when the x is approximately 0,13.

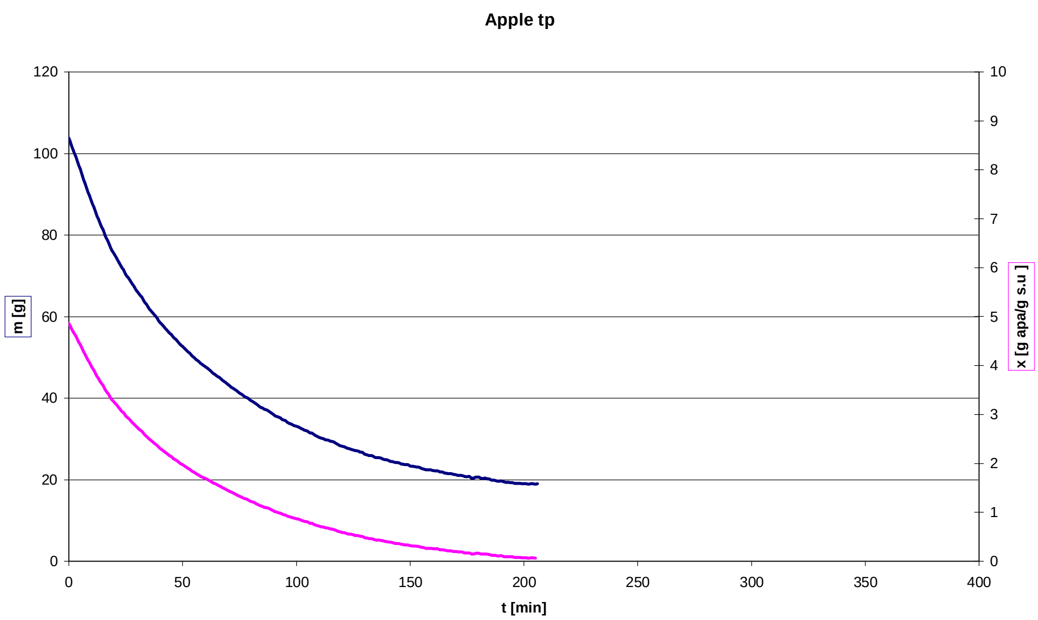



*Figure 3.8. Mass and moisture content vs time of apple slices during drying process*

In the next chart the blue curve represents the drying temperature which at this point isn't constant anymore.

At the beginning it was 90°C and decreases slowly until is becomes as value approximately equal with the products surface temperature, which is represented by the red line. When we have around 30g of dry product, the temperature is changed to 80ºC.

The temperature from the products surface is continuously measured with the infrared pyrometer. It was set from the beginning at 50 ºC, but when the air temperature changes, it also changes.

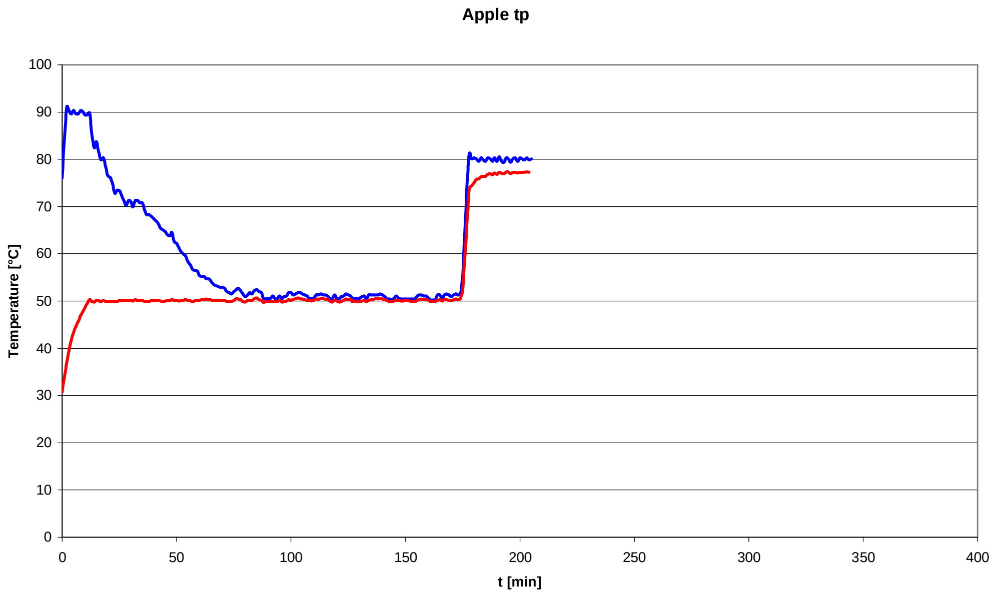



*Figure 3.9. Drying agent temperature and product surface temperature of apple slices during drying process*

After the pictures were taken, they were post processed. First, they were cropped, including maximum surface from the fruit slice. Then, the pictures were analyzed in order to determine medium values for RGB contains and also 3D diagram's, for a qualitative results of isolated area color changing.

For synthetic presentation, there were selected 3 important moments (0h0min, 2h0min, 4h0min). Figure 3.10. shows the pictures of apple, surface 3 D plot, and the values of R, G, B, mean RGB value, and luminance=0.299R+0.587G+0.114B. All this data are shown for the main moments of the drying process (0h0min, 2h0min, 4h0min)

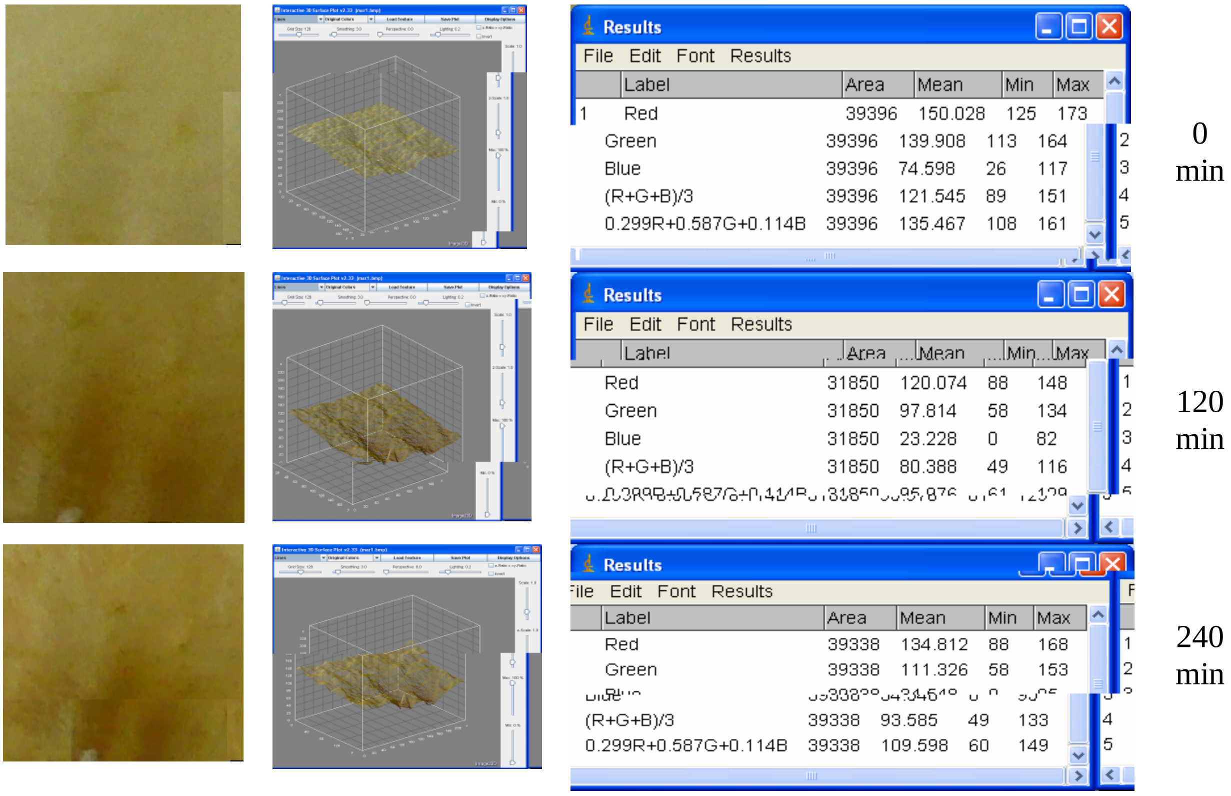



*Figure 3.10. Analyses of apple color changes during drying process*

The RGB-values are used to calculate the X,Y,Z-Values and then the L,a,b values of the pixels by the procedures given by [80], [86], [137].

The first step is to transform the RGB-values in XYZ-(tristimulus)-values:

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \end{vmatrix} * \begin{vmatrix} R \\ G \\ B \\ 1 \end{vmatrix} \tag{3.1}$$

The second step is to transform the X,Y,Z values in CIE-L*a*b* values (CIE, 1932):

$$\begin{aligned} L^* &= \begin{cases} 116 * \left(\frac{Y}{Y_n}\right)^{1/3} - 16 & \text{if } \left(\frac{Y}{Y_n}\right) > 0.008856 \\ 116 * \left(\frac{Y}{Y_n}\right) & \text{if } \left(\frac{Y}{Y_n}\right) < 0.008856 \end{cases} \\ a^* &= 500 * \left[\left(\frac{X}{X_n}\right)^{1/3} - \left(\frac{Y}{Y_n}\right)^{1/3}\right] \\ b^* &= 200 * \left[\left(\frac{Y}{Y_n}\right)^{1/3} - \left(\frac{Z}{Z_n}\right)^{1/3}\right] \end{aligned} \tag{3.2}$$

The values given by [30], [113] for the matrix coefficients and the constants in the transformation equation for a 2° observer, D65 illumination and reference RAL white standard are used.

The Total Colour Change TCD Values is calculated from the L*,a*,b* values with the function [86].

**Discussion**

The colour changes proceed very fast at high temperatures, due to a decomposition reaction. The research methodology and the presented results allow the construction of robust and inexpensive tools for process monitoring and controlling. Using optical monitoring of products during drying processes can have other uses besides color changes. [141]

Another parameter that can be taken into consideration is visible cross section of the product. This parameter indicates the shrinkage of the product, as the surface of the particle visible to the camera can be determined by counting the pixels which belong to it. The change of the number of these pixels corresponds to the change in visible cross section.

The correlation between this value and shrinkage of the particle volume depends on the particle's shape and can be expressed for simple geometries as spheres, cubes etc. [142]

The product shrinks more and faster if dried at high temperatures. However, the shrinkage process is rather complicated due to the inhomogeneous moister distribution during the drying process. Fast surface drying and – if present the transition of the materials from rubbery in glassy state – may provoke case hardening and thus surprising effects. [143]

This effect may be due to the rapidly drying and hardening of the surface of the particles. During the remaining drying process, these parts of the particle can not change their size and shape anymore, even if moisture is removed from the particle.

## 3.2. Contribution to the infrared spectrum optical cheking system design

### *3.2.1. Introduction*

Infrared cameras convert infrared radiation into colors of the visible spectrum. They are used in many fields where temperatures are observed and knowledge about temperatures of an area is more significant than of only one spot. Their advantage to common temperature sensors is that no contact between object and sensor is needed and interruption of drying process can be prevented. Temperature plays the most crucial role in a drying process and influences the quality of the product. Vegetables and fruits consist of numerous nutrients and the objective of drying is to preserve foods without big loss of nutrients. But not only nutrients, also color, texture and flavor change when the temperature is too high. Only very few temperature changes cause a much greater loss of food quality and product temperature is a relevant parameter which should be considered during drying. Empirically adjusted drying air temperature of 50…60°C is known to prevent great loss of nutrients, but it does not prevent the product from overheating at the end of the drying process. Investigating the product temperature by infrared cameras helps to stop the deteriorative impact of heat, which happens in the end of the drying process when the product heats up [50], [64].

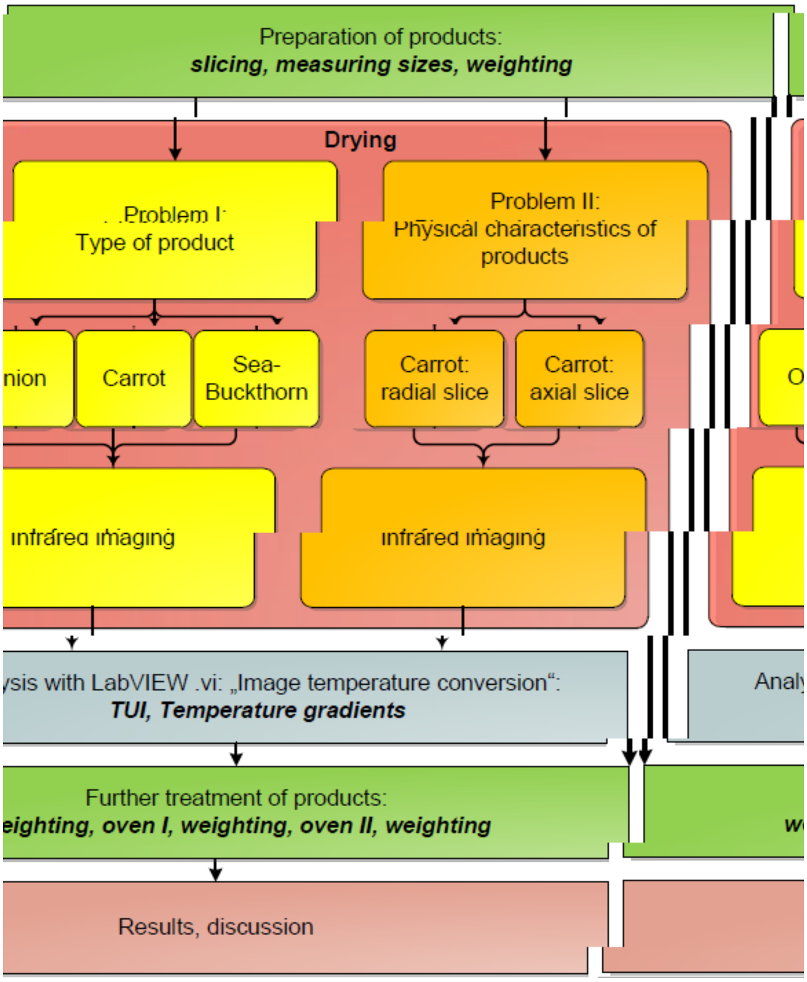



*Figure 3.11. Research proposed methodology by using infrared imaging*

### *3.2.2. Method*

Infrared imaging has already been done for monitoring the drying process for paper industry rough surfaces, wood industry, protein-sugar mixtures and citrus surface. However, infrared imaging has not yet been done for agricultural products, such as sliced vegetables and fruits [62], [64].

Through a successful research the following objectives should be achieved:

- visualizing the temperature distribution during drying by obtaining infra-red images.

- development of a tool to evaluate the acquired infrared images. Therefore, a .vi written in LabVIEW is supposed to convert pixel values of colors into temperature values, and maximum, minimum and average temperature of each image is imported into Microsoft Excel®.

- identification of advantages and limitations for thermograph measurements in industrial drying processes.

- preparation of an automatic control with product temperature as command variable by using a LabVIEW .vi.

For achieving these objectives, the methodology shown in Fig. 3.4 was used. [64], [67], [74], [76], [77].

For the experiment apples, onions, potatoes, carrots and the remnants of pressed sea-buckthorn were dried. Prior to the experiment, they were bought at a local merchant and the sea-buckthorn remnants were prepared by the laboratory staff. When apple, onion and potato temperature reached room temperature, the products were cut into slices and in the case of carrot, sliced and cut into adequate size for the project. Important for the success of the experiment were similar thicknesses for comparative studies. The products are presented in fig. 3.12 and had thicknesses from Table 3.1.

*Table 3.1. Thickness and weight of product slices*

| Product | Thickness in mm |
|---|---|
| Apple | 2,35 ± 0,05 |
| Potato | 2,45 ± 0,15 |
| Onion | 2,4 ± 0,1 |
| Carrot | 2,4 ± 0,1 |
| Sea-Buckthorn | 10 |

For experimental researches, a cabinet dryer of the size 2.20m x 1.12m x 2.30m [l x b x h] was used. The dryer consists of the parts shown as schematic chart in Figure 3.13. The drying oven allows the control of temperature in the range of 30…60 degrees. The drying process was focused for obtaining o high quality products, so the drying temperature was fixed to the 55°C value.

*Figure 3.12. Apple slice (a), potato slice (b) and onion slice (c) prepared for drying*

The process takes 350 minutes in order to decrease the material humidity for long term storage. The weight of the onion slice varies between: 46.7 g at the beginning process to 5,7g at the end of the drying process.

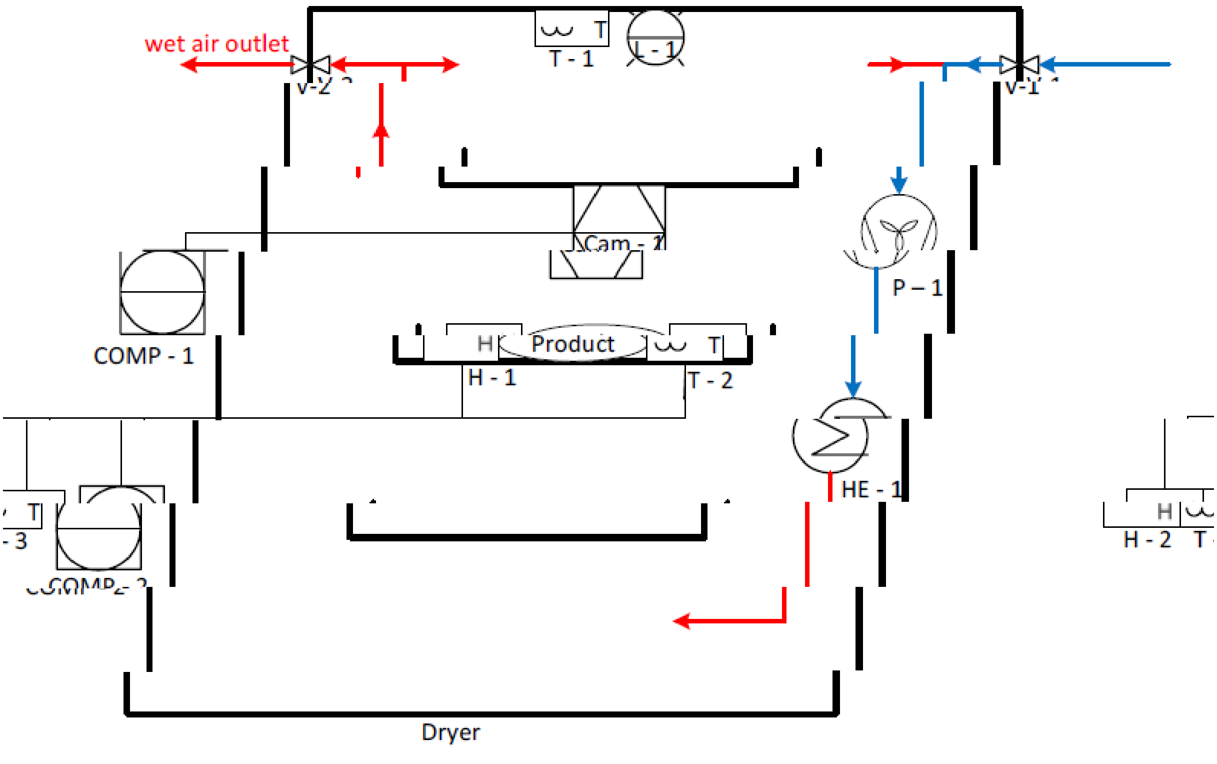



*Figure 3.13. Schematic chart of the dryer*

For the experiment a special tray was made of mesh fibers to provide good heat transfer. The dryer has an air inlet (V – 1) and outlet (V – 2). Fresh, cold, dry air from the outside is mixed with hot drying air inside the dryer. P – 1 is a ventilator and sucks the air into the heat exchanger (HE – 1), where the air is heated up. After that, the hot, dry air is dispersed in the whole dryer. The pre-set drying temperature of 50°C was regulated with a PID regulation by comparing temperature T-1 with the reference temperature. Next to T – 1 is a light arranged (L – 1) that can be turned on upon need. There are 2 additional temperature and humidity sensors used for the experiment. The temperature sensor T – 2 and humidity sensor H – 1 are placed next to the product inside the dryer. The humidity sensor H – 2 and temperature sensor T – 3 are placed outside for measuring the room temperature and humidity. These four sensors are linked to a computer (COMP – 2). The infrared camera (Cam – 1) is arranged on the upper tray of the wagon and focused towards the product. The infrared camera is linked to a computer placed outside (COMP – 1). On this computer the infrared images are processed.

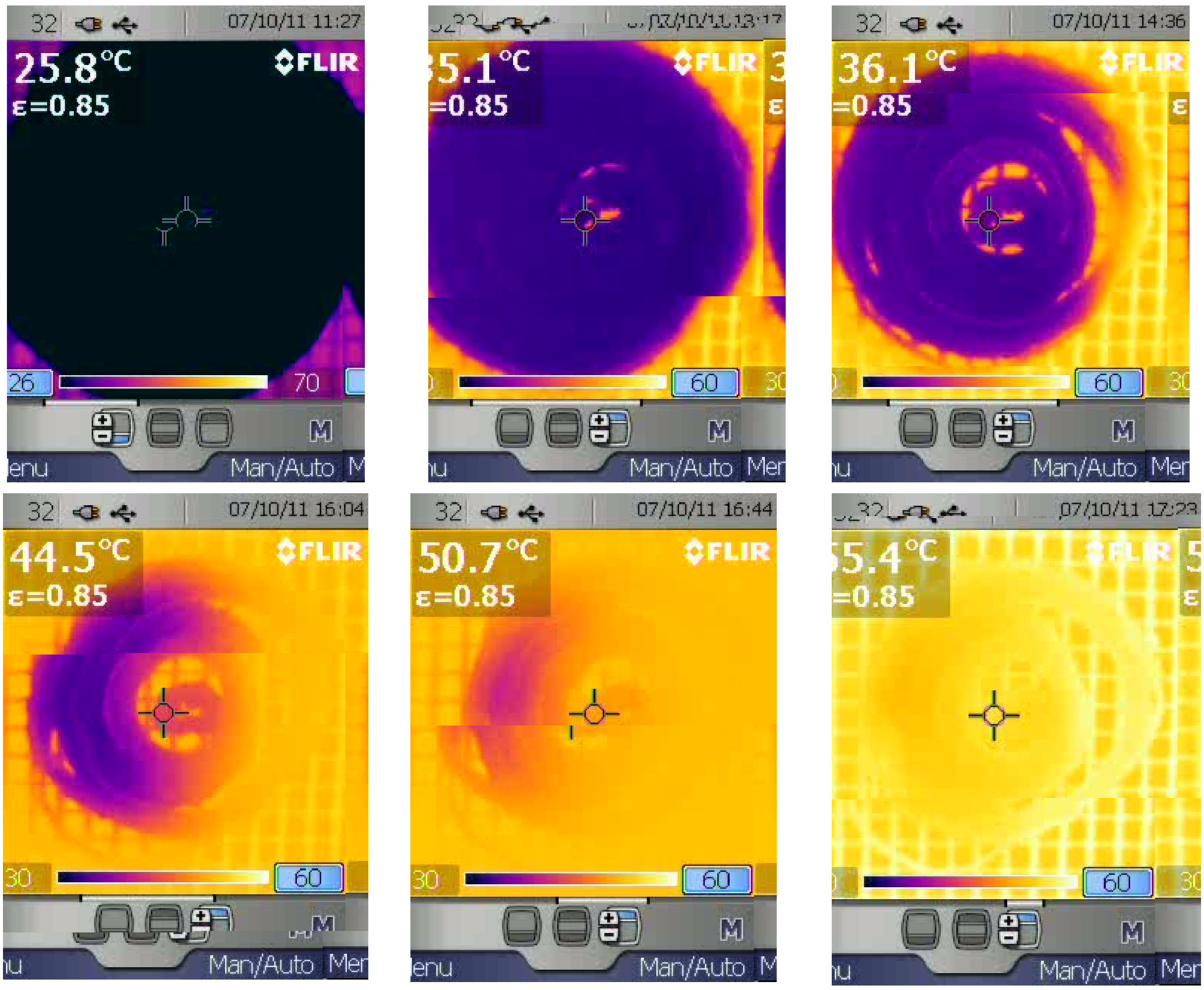



*Figure 3.14. Different thermal images from different stages of drying process of onion*

The acquisition of the surface products temperature (figure 3.14) was done using an infrared thermal scan camera type FLIR i50, with the following technical characteristics:

- Thermal sensitivity/NETD <0.10 ºC (<0.18 ºF) @ +25 ºC (+77 ºF) / 100 mK;
- Image frequency 9 Hz;
- Focus Manual;
- IR resolution 240 × 240 pixels;
- Display Built-in 3.5 in. LCD, 256k colors, 240 × 320 pixels;
- Object temperature range –20 to +120 °C (–4 to +248 °F);

0 to +350 ºC (+32 to +662 °F);

- Accuracy ±2 °C (±3.6 °F) or ±2% of reading.

Infrared camera was connected to a laptop and the images were converted into numerical matrix using LabView software (fig. 3.14). The images have 240 x 240 pixels, each of them showing the temperature of one point of the surface. In table 4.2, a list with all front panel elements is presented [63], [134].

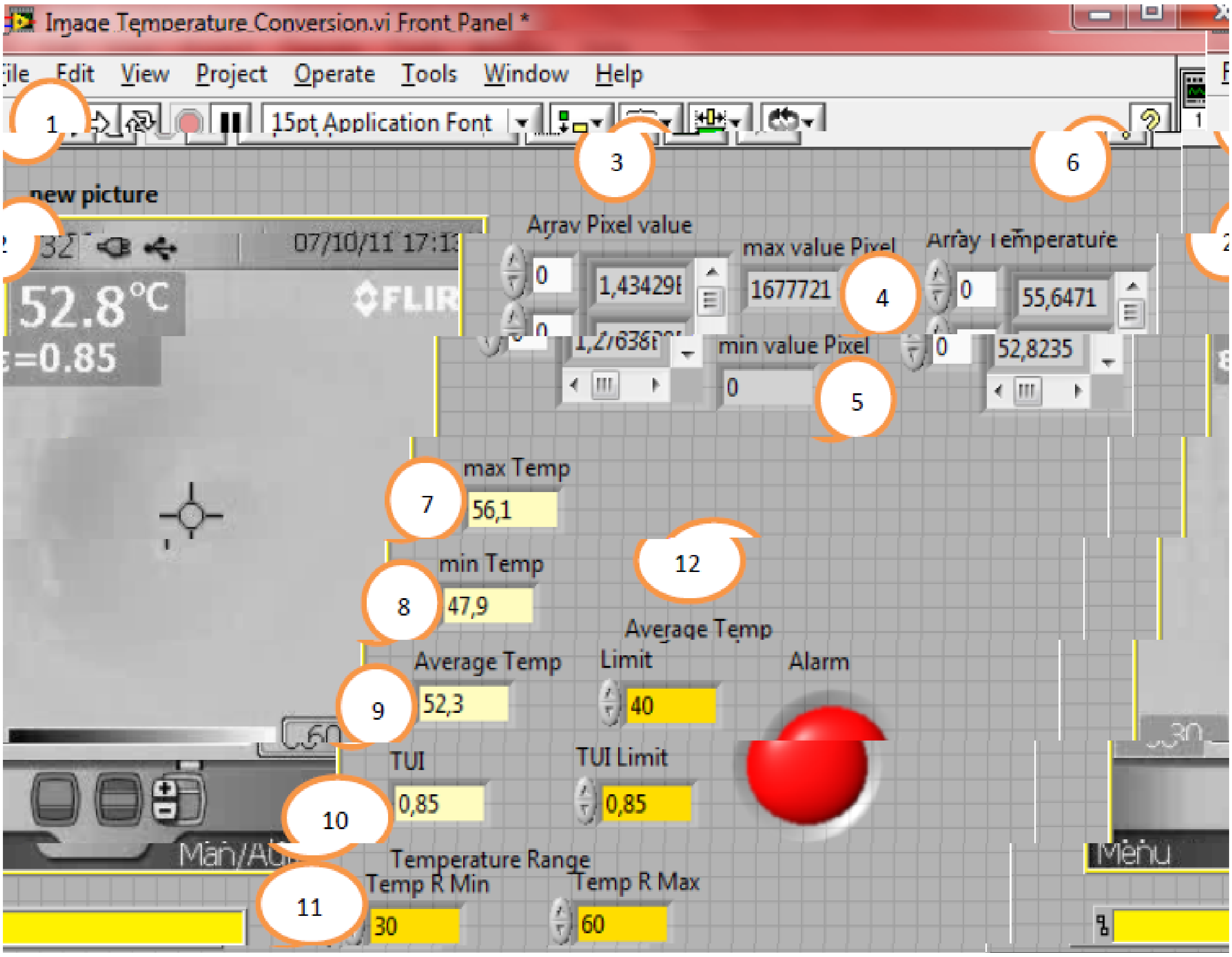



*Figure 3.15. Front Panel of LabVIEW VI "Image Temperature conversion"*

*Table 3.2 List of elements of the front panel*

| No. | Name | Description |
|---|---|---|
| 1 | Run program | When clicking this button the program starts and asks for the .jpg image to load. |
| 2 | new picture | Display of the actual, loaded .jpg image with the compatible path to file. |
| 3 | Array Pixel value | The values of each pixel for the whole image shown in a 2D-array. |
| 4 | max value Pixel | The maximum value from the 2D-array “Array Pixel value”. |
| 5 | min value Pixel | The minimum value from the 2D-array “Array Pixel value”. |
| 6 | Array Temperature | A 2D-array with temperature values. |
| 7 | max Temp | The maximum temperature from the 2D-array “Array Temperature |
| 8 | min Temp | The minimum temperature from the 2D-array “Array Temperature”. |
| 9 | Average Temp | The average of all temperatures from the 2D-array “Array temperature”. |
| 10 | TUI | The temperature uniformity index is min Temp / maxTemp |
| 11 | Temperature Range | At the start of the drying process, the temperature range is manually adjusted at the camera settings. These set-tings need to be transferred to the front panel. The temperature range indicates the minimum and maximum temperatures from the measurement during drying. |
| 12 | Average Temp Limit; TUI Limit | Two controls that indicate the drying characteristics. The input defines when an alarm is triggered. |

### *3.2.3. Results and discussion*

The infrared pictures was converted into a matrix of values by applying different tools available in LabView [134], [37], [38], [39]. The component values are stored as integer numbers in the range 0 to 255, the range that a single 8-bit byte can offer (by encoding 256 distinct values). These may be represented as either decimal or hexadecimal numbers. Furthermore, the numerical matrix can be analised and it is possible to show in real time some important values, like:

- the mean temperature of the product surface;
- the coefficient of non uniformity temperature;
- the minimum/maximum temperature value on the surface of material;
- an overheating blinker that will be use for controlling the dryer heater.

It can be observed that the onion slice suffer a phenomenon of splitting in circular layers (fig. 3.16). This makes difficult the measuring of the product temperature, especially if it can use an infrared pyrometer. Since this device measures the temperature just in one point, and sometimes this point can become out of the product surface, the temperature information is useless. This emphasized an advantage of infra-images which measure temperature in 240 x 240=57600 points.

For monitoring the drying process and visualizing in real time the temperature pattern, it was use the VLC player. This allows the viewing of the current infrared images, and captured automatically one picture/10 min. The pictures were saved into a dedicated local folder. In this way, VLC player consist also into an interface between FLIR camera and Labview software, used as the following. For having an overview of the entire drying process and for making some correlations regarding the drying process were measured 4 other thermal parameters such: the air temperature inside and outside the drying oven; the air humidity inside and outside the drying oven.

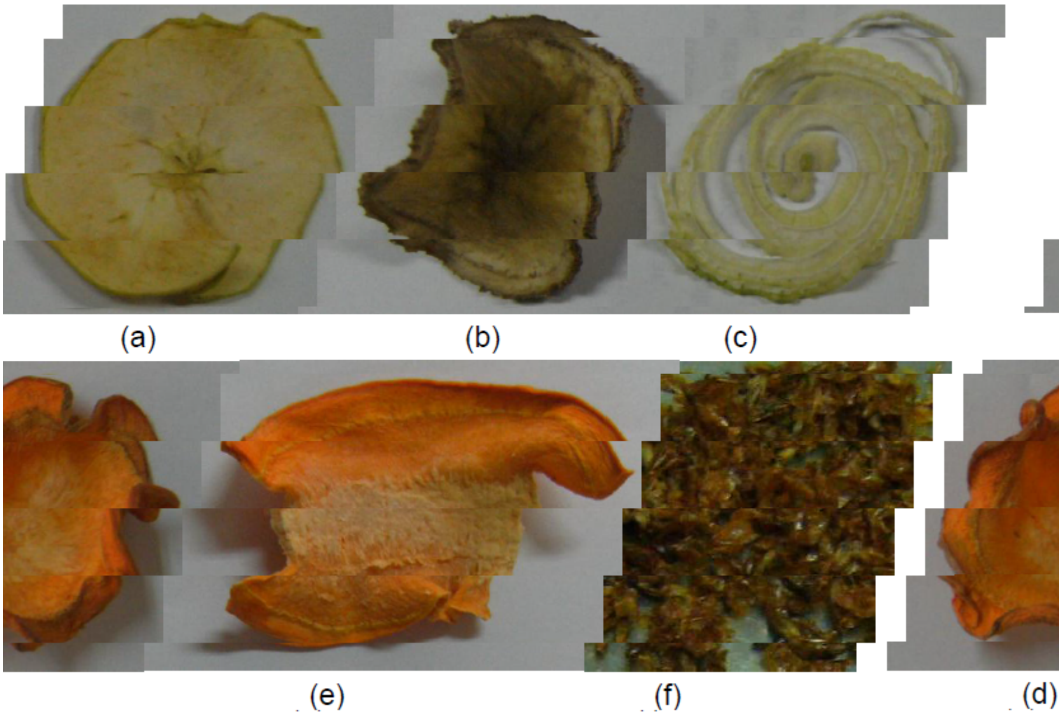



*Figure 3.16. Products after drying: (a) apple, (b) potato, (c) onion, (d) radial carrot, (e) axial carrot, (f) sea-buckthorn*

This was done by using a Nova Fourier system, which allows connecting a series of dedicated sensors. After the experiment, the products were weighted again. The removal of the remaining moisture in the dried products was done following these steps:

- 105°C for 3 hours in the first oven. The remaining materials were substances without water, dry matter.

- 600°C for 8 hours in the second oven. Remaining materials were mineral substances.

After the first and second ovens the materials were weighted again for water subtraction. The results are shown in Table 3.3.

*Table 3.3 Product weights*

| Product | Before drying [g] | After drying [g] | After 1st oven [g] | After 2nd oven [g] |
|---|---|---|---|---|
| Apple | 7,71 | 1,21 | 1,09 | 0,1 |
| Potato | 13,22 | 3,05 | 2,79 | 0,12 |
| Onion | 10,68 | 1,47 | 1,26 | 0,04 |
| Carrot – radial | 11,45 | 1,75 | 1,53 | 0,44 |
| Carrot - axial | 14,06 | 2,75 | 1,71 | 1,03 |

### *3.2.4. Conclusions*

Temperature is the most important criteria for controlling the drying process. Temperature influences drying rate, drying efficiency, process costs and product quality. However, during conventional drying processes drying air temperature is the only controlled parameter, where as product temperature is the intrinsic parameter influencing product quality. A better possibility to control the drying process by product temperature is infrared thermography. *Advantages and limitations* of using infrared cameras for drying processes are:

- the using of infrared capture images consist a proper noninvasive technique for monitoring the surface temperature of the dried agricultural products;
- a critical temperature can be assessed, it can be demonstrated when the product is overheated;
- the infrared measuring technique shows the non-uniformity of the surface temperature, an important parameter for avoiding supplemental thermal stress of the products slices; gradients following the TUI can be established for certain kinds of products and make drying process comparable;
- direct observation allows to see defects of the process equipment immediately;
- Infrared imaging allows to display product characteristics impacting the drying process by variations occurring due to pre-treatment processing of the products;
- the mean temperature using infrared technique can be used for the management of the drying process;
- a limitation was the use of the technology for a macroscopic-granular sea-buckthorn layer which did not provide moisture transfer so well. The TUI did not show a typical gradient.

For the future, the research will be focused on [25], [28], [30], [40]:

- modifying the LabView application using an output card in order to control the heater of the dryer;
- investigation related to the similarities between the pattern of temperature distribution and the shape changes in the process of different product slices.

## 3.3. The Influence of High Pressure on Bio-System Reaction Kinetics and the Preservation of Vitamin C

### *3.3.1. Introduction*

High pressure processing as a novel non-thermal method has shown great potential in producing microbiologically safer products while maintaining the natural characteristics of the food items [147], [72]. [40], [23], [125].

The inactivation of microorganisms under pressure, as well as denaturation of proteins is described by kinetic equations of the first order, with the result that the logarithm of the concentration of surviving microorganisms after processing with pressure decreases linearly with increasing processing time $t$ as - $kt$, where $k$ - rate constant for inactivation [119], [108], [146].

But in some researchers, it was indicated the data with significant deviations from linearity which are usually described by a combination of two first-order reactions as a two-phase kinetics with different rates of inactivation [101].

A two-phase kinetics is common for both vegetative and spore forms of bacteria. In such cases we can observe a slow decline of the logarithm of the concentration with time, the rate of fall in the small and large $t$ is equal to $k_1$ and $k_2$, respectively, with $k_1 > k_2$. This form of the inactivation curve indicates the existence of a small part of the population with increased resistance to the effects of high pressure. [19], [26]

To describe this behavior in the first-order kinetics in the work [74] three-phase model of inactivation through an midline metastable state was suggested, some other models of the interpolation of the kinetic curves [113], [127] are known as well. They all are based on poorly proved assumptions about the dispersion in the resistance to the pressure inside the bacterial population.

To overcome this deficiency the model of the decomposition of the n-order is used, [6]:

$$\frac{\mathrm{d}C}{\mathrm{d}t} = -kC^n \tag{3.1}$$

where the order $n$ and rate constant of the reaction $k$ are determined by the minimization of deviations from the experiment.

The area of variations $n$ was limited to an interval $1< n <1,25$ in which the course of the model curves corresponded with the observed one in the experiment.

The solution of the equation (3.1) for the case of C (0) = 1 takes the form:

$$C(t) = (1 + kt(n-1))^{\frac{1}{1-n}} \tag{3.2}$$

The corresponding kinetic curves for the different n are shown in fig. 3.16. As we can see from the figure, for the limited values *t* this result can always be represented as a combination of the first-order reactions with different *k* that is represented as a multi-phase process. In the model with a variable order of the reaction it is no need to make assumptions about the dispersion of values *k* within a bacterial population, but the variation of the order of physical reactions can be hardly physically justified for one series of experiments, when the only pressure which was effecting the system was changed [6]. For the curve with *n = 1,1* the apparent asymptote is shown (dashed line), which in combination with the dotted line describes the two-phase reaction of first order.

The deviation from the linearity is almost always take place with decreasing initial concentration of more than 7-8 orders which is observed at the long-lasting processing. In other cases, the deviations from the linearity occur at higher pressures and are observed at quite short lasting processing.

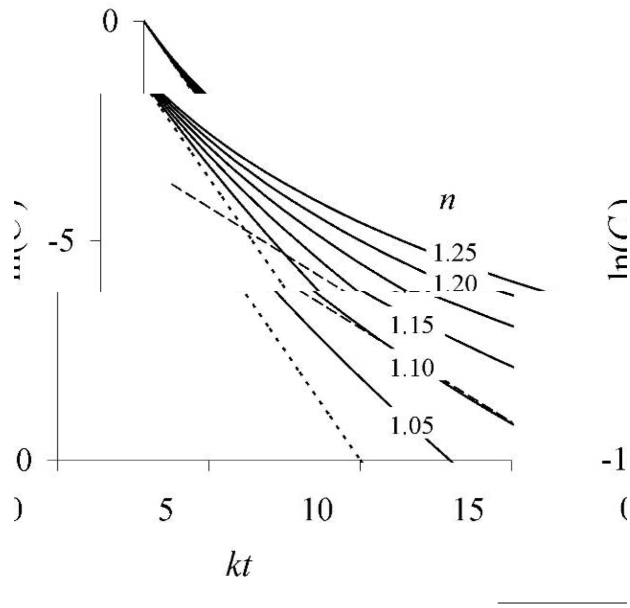



*Figure 3.17. The dependence of the logarithm of the concentration on the time for the reaction of the first order (dotted line) and higher orders (heavy line with indication of the order n).*

The reason of the first type of deviations is easily explained since the concentration falls with increasing of time or pressure.

For small values of the concentration any final experimental errors give large fluctuations in the logarithmic scale which can be interpreted as the appearance of the "tail" or other deviation from the linearity.

Therefore, the main objective of this study is to establish modeling of the microorganisms kinetics inactivation by the high pressure and carry out model certification by an experimental research.

### *3.3.2. Physics of the degradation of biological systems under high pressure*

It is known that some dysfunctions or changes which are regulated by the general thermodynamic relations occur in interactions at the molecular and intermolecular level at high pressures or temperatures in any system [130], [108] , [94]. With regard to the test pressure range (0-800MPa) and temperatures (20-80ºC) we should say, first of all about dysfunctions in hydrophobic interactions, polarization forces, hydrogen bonds which are responsible for the stability of proteins [48], [125]. In the following macromolecular or supermolecular level the processes occur at rates much lower than the rate of intermolecular processes,which can be explained primarily by the significantly large masses of these structural elements. This level includes a variety of possible dysfunctions of metabolic processes, the destruction of cell structure, polymerization, crystallization and so on - all the things that determine the complexity and the resulting reaction of living systems to the external interaction [148] and does not lend itself to the detailed modeling.

We assume that the denaturation of proteins connected with the dysfunction or distortion of the intermolecular interactions at high pressures is the "bottleneck", which determines the resulting reaction of the biosystem at the high pressure

Based on the foregoing, it is necessary to describe the kinetics of the reaction of the biosystem by the influence of the high pressure and temperature by using a purely phenomenological parameters such as the activation barrier of reactions, changes in molar volume, etc.

In this case the specific details of the structure of microorganisms or biomolecules can not be taken in consideration as the task is not to describe the details of the process of inactivation of a microorganism, degradation of an enzyme or a vitamin, but it is to determine thermodynamic parameters and environmental conditions under which a dysfunction of chemical balance in the intermolecular level leads to dysfunctions of the integrity or operation of biological systems in general.

It is assumed that the compression inactivates microbes by the change of the proteins responsible for the reproduction, integrity and metabolism [107], [119]. The high pressure can’t destroy the covalent bonds, but it is able to modify the hydrogen and ionic bonds that are responsible for maintaining proteins in their biologically active form.

Namely these features of the denaturation of proteins is usually attributed to a large variation in the resistance to high pressures of various biological structures [76].

It has long been noted a steady parallel between the heat and pressure on the activation and inactivation of proteins due to the same nature of these factors - the pressure as the sustained rate of momentum transfer vibrating molecules and temperature as the average kinetic energy of these oscillations.

### *3.3.3. The kinetics of denaturation*

Let’s consider the chemical reaction of the protein denaturation, i.e. the transfer from the native molecules into the denatured state N → D. The balance state is considered to be such state of the chemical reaction in which the ratio of the molecule number in the native *N* and denatured *D* state doesn’t change. This reaction can run in the direct and reverse direction. Until the balance is reached one of the directions prevails over the other, and in the balance state such reaction rates are set that the numbers of *N* and *D* don’t change. The state of the chemical balance doesn’t depend on the conditions under which the reaction took place, but only on the conditions under which the balance is maintained [130].

External changes of the temperature *T* and / or pressure *P* take the system from the thermodynamic balance, and stimulate a reaction in the direct N → D or reverse direction N ← D. As the test shows that the rate of these reactions are sufficiently small. Therefore, it can speak about the partial thermodynamic balance of the system - the balance in relation to the movement of molecules is established much faster than the balance in relation to their mutual transformations, that is, with respect to the composition of the N + D. Thus, we can consider the partial balance of the system as a balance for a given chemical composition [79], [16].

The analysis of the experimental data shows that the denaturation of the protein N → D is a process of activation type, i.e. passes through the formation of unstable intermediate compound called as the activated complex $\mathbf{A^*}$

$$\mathbf{N \rightarrow A^* \rightarrow D}$$

The formation of the activated complex always requires a certain amount of the energy that is due, firstly, the repulsion of electron shells and nuclei in the approach of the particles and, secondly, the need to build a particular spatial configuration of atoms in the activated complex and the redistribution of the electron density. Thus, the system must overcome the energy barrier of some kind passing from the initial state to the final one.

The activation energy of reaction is approximately equal to the excess of the average energy of the activated complex over the average level of the energy reagents. Obviously, if the direct reaction is exothermic, the activation energy for the reverse reaction of *U* 'is higher than the activation energy for the direct reaction *U*. The activation energy of direct and reverse reactions are related to each other through the change in internal energy during the reaction. The foregoing can be illustrated by the chemical reaction energy diagram (fig. 3.18).

As the temperature is a measure of the average kinetic energy of the particles increase in temperature leads to the increase in the proportion of particles whose energy is equal to or greater than the energy of activation, which leads to the increase in reaction rate constant *k*.

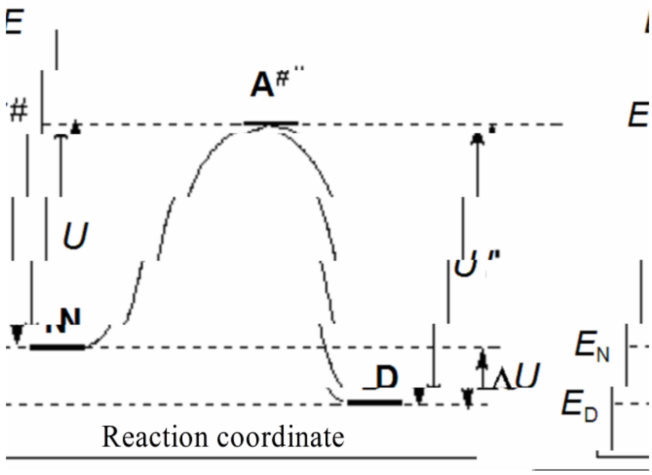



*Figure 3.18. Energy diagram of the process of protein denaturation. EN - the average energy in the native and the ED - in the denatured state, ΔU – activation denaturation barrier, and U'-denaturation, ΔU - change in the internal energy of denaturation*

Effect of the temperature on reaction rate is given by the empirical formula of Arrhenius [83]:

$$k = A\exp\left(-\frac{U}{RT}\right) \tag{3.3}$$

where U - the activation barrier between the reagents and the product (per mole of the substance). The validity of this formula is confirmed by theoretical calculations for the various simplified models.

It is worth to mention the theory of active collisions, the theory of the activated complex, calculations of potential energy surfaces, Brownian dynamics in the energy space based on the Fokker-Planck equation [79], [83].

All these theories lead to the formula (3) for the rate constant of the chemical reaction; the expressions differ only for the pre-exponential factor A. Thus, according to [68], A value can be approximately determined as

$$A = \frac{k_B T}{h} s \tag{3.4}$$

where $k_B$ - Boltzmann's constant; $h$ is Planck's constant, and the factor $s$ (can be determined from the statistical mechanics) takes values from 1 (atom-atom reactions) to $10^{-5}$ (two non-linear molecule) [68]. At physiological temperature $T = 310K$, the ratio value is $(k_B T)/h \approx 6.5 \cdot 10^{12} Hrz$. The comparison of the reaction rates at different temperatures provides an estimate of the activation barrier at normal pressure.

### *3.3.4. Material and methods*

Any product - natural, derived from processing of any organism or artificial, synthesized from non-living components represents a combination of the complex subsystems at different levels of organization. To optimize the processing process and to select the most suitable influence parameters (*p, t* and *t*), a mathematical model of the process is required, it means, the way to predict the system reaction to a particular set of parameters of influence. To construct a detailed physical model of such complex system and to calculate its reaction is not possible, but you can take the way of parameterization and the phenomenological description of the average characteristics of the behavior of the system under conditions close to thermodynamic equilibrium.

**The effect of pressure on the rate of denaturation**

In the case where the transfer N → $\mathbf{A}^{\#}$ is connected with a change in specific volume of the reagent *N* on the value of *ΔV*, to the value of the barrier *U* the work against external forces *PΔV* should be added. The formula for the rate constant k of the chemical reaction taking into account the pressure takes the form [135]:

$$k = A\exp\left(-\frac{U + P\Delta V}{RT}\right) \tag{3.5}$$

The value of *ΔV* characterizes the change in specific volume for the reaction N → D (if the transition $\mathbf{A}^{\#}$→ D is not connected with changes in the specific volume) and determines the shift of chemical balance under pressure through a change in Gibbs free energy [106]:

$$\Delta G = \Delta U - T\Delta S + P\Delta V \tag{3.6}$$

when ΔV<0 with increasing pressure the change in the free energy of the reaction *ΔG* becomes negative, which corresponds with the a shift of the chemical balance in the direction of increasing the final product D in full accordance with the principle of Le Chatelier. The rate of this transfer is determined by the rate constant [135] which also depends on the pressure through the barrier height *U + PΔV*.

Thus, the external pressure *P* affects the balance concentration ratio in the native *N* and denatured *D* states through *PΔV* term in the thermodynamic potential in [135], and also affects the rate of denaturation by changing the activation barrier *U + PΔV*.

It is likely that *U* is also changing under the pressure, *U = U (P*), since the pressure changes the dielectric properties of the medium. However, taking into account the fact that the fluid density varies slightly, we can expect that the activation barrier change induced by the pressure is small and linear with respect to *P*. Consequently, it is effectively taken into account by the addend $P\Delta V$.

**The effect of the temperature on the rate of denaturation**

In the case where the formation of the activated complex $\mathbf{A}^{\#}$ is connected with structural changes, changes in the number of degrees of freedom and etc., the entropy term - $T\Delta S$ should be added to the activation barrier of the reaction U. The value of ΔS - characterizes the change in the entropy for the reaction **N → D** (unless the transfer $\mathbf{A}^{\#}$ → D is not connected with a change in the entropy) and determines the shift of the chemical balance at the shift of the temperature through the change in Gibbs free energy [106] and also affects the rate of denaturation by changing the activation barrier $U - T\Delta S$. The condition of $\Delta G > 0$ defines the area of the stability of protein denaturation (temperature optimum).

Thus, the temperature *T* affects the balance concentration ratio in the native *N* and denatured *D* states through the addend - $T\Delta S$ in the thermodynamic potential in [107], as well as the rate of denaturation by changing the activation barrier $U - T\Delta S$. Some functional asymmetry with respect to the effect of pressure is connected with the division of the total activation barrier $U - T\Delta S + P\Delta V$ at *RT* in the Arrhenius equation. However, the temperature change $\Delta T$ in the current area of the temperature optimum of protein is small compared with the temperature *T*. Consequently, we can expect that the yield curves of the reaction depending on the pressure will be similar to the temperature dependencies with the only difference that the change in pressure $\Delta P$ can not be done negative for barodenaturation.

***3.3.5. Results and discussion***

**Modeling of the microorganisms kinetics of inactivation by the high pressure**

Inactivation of microorganisms under the influence of high temperature and pressure is considered as the description of the kinetics of protein denaturation as a one-stage chemical reaction when the system is supported by the certain temperature and pressure, and the external flows of the substances are absent. Under the concentration of the reagent we understand the number of organisms surviving after processing by the high pressure and high temperature.

The change of the concentration depending on the time *C (t)* is described by the collapse equation, as opposed to the protein denaturation the inactivation of microorganisms is usually irreversible. This approach is inherently approximate because it describes improperly the process under the normal conditions. With these remarks, we have

$$\frac{\mathrm{d}C}{\mathrm{d}t} = -kC \qquad (3.7)$$

where k rate constant of inactivation, determined from the conditions of the thermodynamic balance, since the inactivation process runs infinitely slow compared with characteristic times of collisions between molecules.

In the general case, when the temperature or pressure, in the definition of *k* (15), depends on time, a partial solution of the equation (3.7) has the form

$$C(t) = C(0)\exp\left[-\int_0^t k(t')\,\mathrm{d}t'\right] \tag{3.8}$$

In the case where the external parameters of the product processing don't depend on time, the solution is simplified:

$$\int\ C(t) = C(0)\exp(-k\,t) \tag{3.9}$$

In the practice, the temperature and pressure supported by the system are given time functions which are slowly varying that provides the applicability of the kinetic equation [108].

**Preliminary estimates**

The parameters *U* and *ΔV* were obtained by the least-square method. The first parameter is the value of the activation barrier at zero pressure, and the second is the change of the specific volume. For vitamin C, *U* = 22 kcal / mol and *ΔV* = -3,8 ml / mol for QMAFAnM, *U* = 22 kcal / mol and *ΔV* = -38,4 ml / mol.

Attention is drawn to the proximity of the parameters *U* for the different objects such as vitamin C and QMAFAnM microorganisms and mold. This can only mean one thing - the nature of the damage occurring under pressure in these objects is the same - namely, the conformational changes of the same chemical bonds in vitamin C and QMAFAnM. The difference between the changes in specific volume *ΔV* can be explained by differences in the close environment of these bonds.

To calculate the theoretical curves of the concentration of pressure at different temperatures and times we need to define another parameter *A* in the formula [107]. This option is for vitamin C and QMAFAnM assessed through separate experimental points. In the figures 3, 4 the theoretical curves are shown in comparison with experimental data.

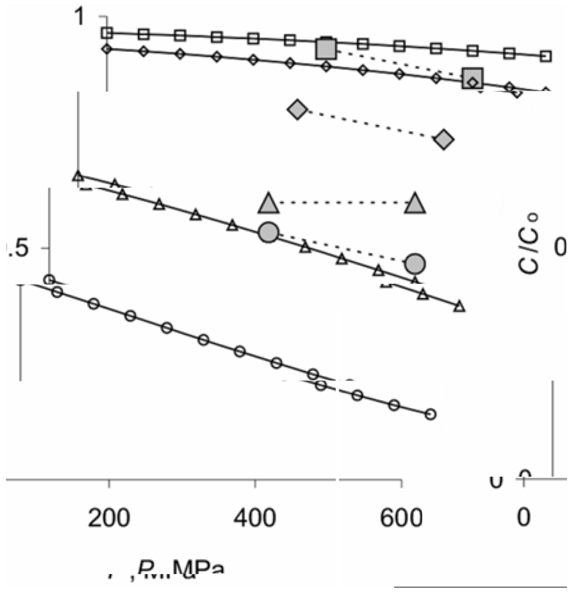



*Figure 3.19. The concentration of vitamin C in the sour cherry juice as a function of pressure for different temperatures and exposures. ° - 20 min, 45 degrees C, theoretical.; o-vitamin C, 20 min, 45 degrees C; ◊- 20 min, 25 degrees C, theoretical; ◊ - Vitamin C, 20 min, 25 degrees C; Δ- 10 min, 45 degrees C, theoretical; Δ-vitamin C, 10 min, 45 degrees C.*

The theory describes quite satisfactorily the experiment and the curves show the correct course of concentration as a function of pressure for both vitamin C and for QMAFAnM and properly reflect the trends of these dependences at the change of the temperature and processing time. [107], [108]

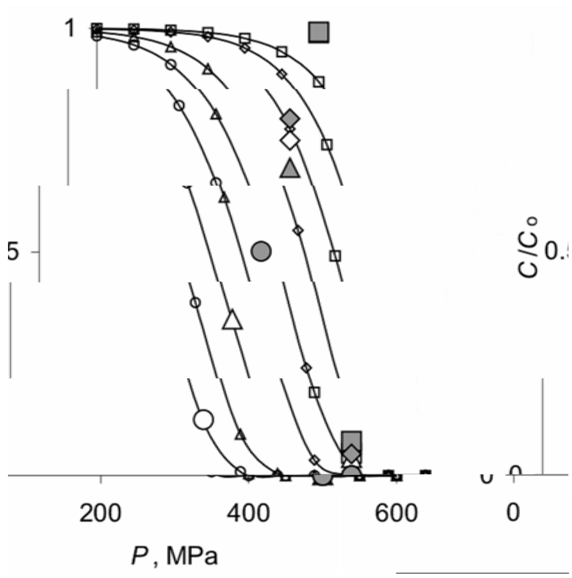



*Figure 3.20. The concentration of microorganisms in the sour cherry juice depending on the pressure for different temperatures and exposures. ° - 20 min, 45 degrees C, theoretical.; **o**-QMAFAnM, 20 min, 45 degrees C; ◊- 20 min, 25 degrees C, theoretical; ◊ - QMAFAnM, 20 min, 25 degrees C; Δ- 10 min, 45 degrees C, theoretical; Δ-QMAFAnM, 10 min, 45 degrees C; □- theory, 10 min, 25 degrees C; □- QMAFAnM, 10 min, 25 degrees C;*

Thus, in the frame of the same formulas we can obtain both slowly decomposition almost linear dependencies for vitamin C, shown in figure 3.9 and step curves for QMAFAnM and mold in Fig. 3.20, that agrees qualitative with experimental data.

**Analysis of possibilities of the model.**

Let's assume that the value of the concentration depends on the time t as well as on the temperature $T$ and pressure. Let's build selectively these plots, using the values $\Delta V$ = *-0.0002eV/MPa* - for QMAFAnM and $\Delta V$ = *-0.00002eV/MPa* - for vitamin C (Fig. 3.20) estimated [107]. Therefore in both cases we have $A = 3.88 \cdot 10^{14}$ $min^{-1}$, $U$ = *1eV*. The increase in processing time shifts the threshold for complete sterilization of microorganisms in the direction of lower pressures. The concentration of vitamin C is uniformly decreases with increasing exposure at all pressures. The increase of the processing temperature also shifts the threshold for complete sterilization of QMAFAnM towards lower pressures, while the concentration of vitamin C with increasing temperature drops rapidly at all pressures.

The increase of the processing pressure significantly reduces the time when the full sterilization is reached, where a slight acceleration of the exponential decomposition of concentration is observed for the vitamin C. Analysis shows the effect of processing temperature at the constant pressure on the dynamics of the degradation of biomolecules. The increase in temperature affects in the same way the concentration of microorganisms and vitamin C, significantly reducing the time of achievement of full sterilization, but also accelerating the degradation of vitamin C.

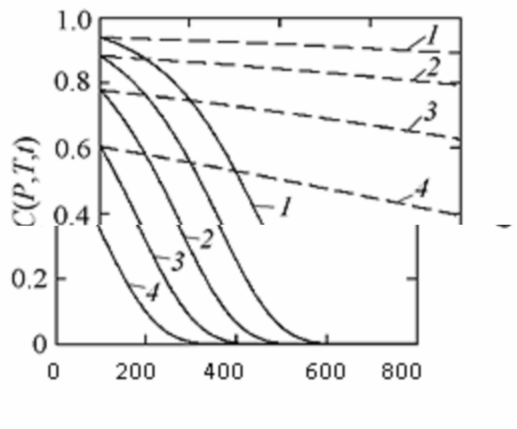



*Figure 3.21. Dependencies on the concentration of QMAFAnM (solid lines) and vitamin C (dashed lines) from the pressure P at constant temperature T = 300 K and different t delay: 1 – 10, 2 – 20, 3 – 40, 4 – 80 min;*

In case of microorganisms the effect of the temperature increase is the same as the effect of the pressure increase. For vitamin C, on the contrary, the effect of temperature increase is much greater than the effect of pressure rise - increasing processing temperature dramatically affects the decline in the concentration of vitamin C. Thus, we conclude that the effect of temperature on microorganisms similar to the effect of pressure, while the temperature destroys the vitamin C is stronger than the pressure.

### *3.3.6. Conclusions*

Effects of such factors as the pressure, temperature and processing time can be interpreted in the framework of the chemical reaction of the first order. The results obtained in the paper speak in favor of the applicability of the linear kinetics to describe the degradation of biological systems under the high pressure. The studied "multiphase" of kinetics is associated with the cooling of the specimen heated by the compression.

The made analysis the found parameters of the inactivation of *A*, *U* and *ΔV* of different organisms confirms the relationship with the inactivation of the protein denaturation. The microscopic mechanism of the pressure effect on microorganisms is determined by the competition between the contributions to the free energy of the inactivation of unfolding of the polar and non-polar groups inside the protein globule. The formation of the activated state is associated with the discovery of water ingress into the internal cavity of the protein.

It is established that the basic laws of the joint influence of the factors of high pressure, temperature and process duration on microorganisms and vitamin C are reproduced in the framework of the linear kinetics. When choosing the values of the process parameters (pressure, temperature, duration of the process), as well as at the development of new standards the averaged thermodynamic characteristics of microflora - preexponential factor *A*, the value of the activation barrier of the reaction of *U* and the volume change *ΔV* should be used.

It is shown that the deviation of the kinetics of microorganism inactivation from the dependence that characterizes the chemical reaction of the first order, is explained by uneven cooling of the specimen which is heated by the compression. These deviations increase with the pressure rise and the rate of its increase. The dependence of cooling time on the geometry of the compression chamber explains the dispersion of data from the various laboratory settings.

The coincidence of the obtained values of the activation barrier *U* for all studied organisms

# (B-II) THE EVOLUTION AND DEVELOPMENT PLANS FOR CAREER DEVELOPMENT

## 1. EVOLUTION OF PROFESIONAL AND ACADEMIC ACTIVITY

### 1.1 General framework

My professional activity started immediately after master graduation, since 1996, then continuing a natural evolution, both on teaching and research area. In this way I had the chance to work from the beginning of my career, with those who guided me during college. Step by step I knew very well the team that belonged to Machinery for Agriculture and Food Industry Department, from Faculty of Mechanical Engineering, collective which later became what is today the Faculty of Food and Tourism.

The development in the new faculty is entirely due to the team to which I belong, who knew how to combine professionalism and enthusiasm and gave great opportunities for new generations of students. I find myself totally in the spirit of ethical and moral principles of this dynamic team, and I want to support the development objectives of the new founded faculty. This is reflected in the career development plan, plan which will be presented in follows.

Through constant involvement, excellent relations with staff to which I belong to, transparency and openness to new, I intend to be one of the teachers that faculty can count on.

My professional prestige is a result of the professional training, published scientific papers, coordinated program studys, grants and projects, creating new specializations and new labs, founding new NGO units. Of course, there are many interference areas between the scientific, academic and professional components.

### 1.2. Step by step and on the basis of legal contest evolution within academic functions hierarchy

Until present, my academic career has developed gradually, from university assistant to university professor. Every didactic function was gained as a result of a public contest, as follows:

**October. 1996 - oct. 1998 - Laboratory Assistant**, Transilvania University of Braşov – Department of Machines for Agriculture and Food Industry

Didactical and research activities in the area of agri-food technology and equipment:

Equipment for vegetal products processing;

Operations in food industry;

Equipment and technology for grain milling and bakery.

**October. 1998- oct. 2001 – Assistant,** Transilvania University of Braşov –Department of Machines for Agriculture and Food Industry

Didactical and research activities in the area of agri-food technology and equipment:

Equipment for vegetal products processing;

Computer aided design applied in food industry;

Equipment and technology for grain milling and bakery.

**October. 2001- oct. 2007 – Lecturer, Transilvania University of Braşov –Department of Machines for Agriculture and Food Industry**

Didactical and research activities in the area of food technology:

Equipment for vegetal products processing;

Computer aided design applied in food industry;

Equipment and technology for milling and bakery.

**October. 2007 - oct 2014 - Associate Professor, Transilvania University of Braşov – Department of Machines for Agriculture and Food Industry**

Didactical and research activities in the area of food technology:

Equipment for vegetal products processing;

Computer aided design applied in food industry;

Finite Element Analyses;

Equipment and technology for milling and bakery;

Editor in chief of the JOURNAL OF ECOAGRITOURISM – ISSN 1844-8577 www.rosita.ro/jeat

.**October. 2014 - present – Professor, Transilvania University of Braşov – Department of Machines for Agriculture and Food Industry**

Didactical and research activities in the area of food technology:

Equipment for vegetal products processing;

Computer aided design applied in food industry;

Finite Element Analyses;

Equipment and technology for milling and bakery.

Editor in chief of the JOURNAL OF ECOAGRITOURISM – ISSN 1844-8577 www.rosita.ro/jeat

## 1.3 Completion of professional training

Completion of Professional Training was achieved by graduating stages:

**University:**

• 1990 - 1995, Faculty of Mechanical Engineering, specialization: Technological equipment for the preservation and processing of vegetable and livestock products;

After university:

• 1995 - 1996, Faculty of Mechanical Engineering, Graduate studies, specialization: Power tractor-agricultural machine system;

• 1997 - 2001, Faculty of Mechanical Engineering, PhD in Engineering Sciences.

The topic for the phD research paper it was: Research on optimization of drying grain and seed crops, maize and soya applications, under the leadership of Mr. Prof. Dr. Ing. Bratucu George.

**Postdoctoral stages:**

In the timeframe January 2002 - October 2002, I received a scholarship in the field of assisted design using finite element method at Technische Hochschule Rheinisch-Westfaelische Aachen, Germany.

In the timeframe 2003 – 2013, I participated in annually internships of 3-4 weeks: Institute of applied thermodynamics and fluid mechanics, Konstanz, Germany; University of Food Technologies in Plovdiv, Bulgaria; University of Thessaly, Volos, Greece; State Agricultural University in Kazakhstan, Almaty; State Technological Institute of St. Petersburg, Russia. With this occasion I had training sessions in applied engineering technologies in food. These are part of the fundamental basic training, continuously improved through complementary trainings and educational programs.

## 1.4 Involvement in student professional activity

Over 18-years of academic career, I have guided many students in developing and supporting the work of diploma or dissertation, with good and very good results. Foreign collaborations supported consistently made it possible for some coordinated students for diploma, to receive an internships to prepare the paper work at Rheinisch-Westfaelische Technische Hochschule Aachen, Germany or Institut für Angewandte or Thermo-und Fluiddynamik, Hochschule Konstanz, Germany. It is also an availability expressed for cooperation with University of Food Technology in Plovdiv, Bulgaria; University of Thessaly, Volos, Greece; Kazakh National Agrarian University; St. Petersburg State Technological Institute, Russia.

Also, a number of foreign students spent traineeships for diploma project at our faculty, with very good results; their work are published in scientific journals.

Practice with students in specialized institutions is also a current activity which contributes continuously to strengthen theoretical knowledges for students. Companies SC Vel Pitar SA Brasov and Nova Pan Brasov are already partners involved for over a decade in preparing students in the milling and baking areas.

## 1.5 Permanent publishing activity

As an academic career does not involve only teaching, in the 18 years of my academic activity I have constantly published 11 books, all of them ISBN edited and printed. Most of these works are now used as basis for new program study curricula that have been introduced in educational plans.

Also, scientific research domain, particularly concerned me since the beginning of my career, and had resulted in over 150 publications in journals and international conferences in Romania and abroad. A special interest in recent years had publication in ISI journals with impact factor above zero, so combining the scientific component with the professional one.

Since 2005, I am editor chief of the Journal of EcoAgroturism, ISSN: 1844-8577, edited by Transilvania University of Brasov. The journal is indexed in the database CABI International and Global Health and in the last 10 years more than 1000 scientific articles have been published.

Every year, participation in international scientific life led to engagement in major events, of which we can mention:

• Member of the editorial board of the journal "Journal of Agricultural Informatics" ISSN 2061-862X, Debrecen, Hungary;

• Member of the editorial board of the journal "Journal of food and packaging science technique and technologies" ISSN 1314-7420 (Print), University of Food Technologies in Plovdiv, Bulgaria;

• Member of the scientific committee of the magazine "Equipment and technology of food production", published by University of Economics and Trade Donetsk, Ukraine;

• Member of the scientific committee of the magazine "Ukrainian Food Journal", ISSN 2304-974X, Kiev, Ukraine;

## 1.6 Participation in national and international conferences events

In the 18 years of professional activity, I participated as a researcher in over 40 national and international conferences, among which we can mention: International conferences "Conat"; International Computer Science Conference, Microcad 2000 University of Miskolc, Hungary; "Management of rural and industrial environment in the context of European integration", Brasov, SMAT Conference, Craiova, International Congress on Information Technology in Agriculture, Food and Environment, Ege University, Izmir, Turkey; 6th national conference for environmental protection through biological and biotechnical means and the 3rd National Conference of Ecosanogenesis, Brasov; International conference "Challenges in Higher Education and research in the 21st century", Technical University of Sofia; International Conference on Sustainable Agriculture Information Systems, Agroenvironment and Food Technology - HAICTA; International Conference on Agricultural Economics, Rural Development and Informatics, AVA, Debrecen, Hungary; 31th International Congress ARA; BIOATLAS 2006 -2014; NEEFOOD congress, etc.

I have published more than 100 papers in conferences, many abroad, and I was included as member of organizing or scientific committee, for example:

• Member of the scientific committee of the conference HAICTA 2011 to 2013, Volos, Greece.

• Member of the scientific committee of the conference "Agricultural Informatics Conference" 2007-2013, Debrecen, Hungary;

• Member of the scientific committee of the conference "ABIFA 2013-2nd and WSEAS International Conference on Agricultural Science, Biotechnology, Food and Animal Science" Braşov 2013;

• Member of the scientific committee of the conference "40 years of MAFI department" Plovdiv, Bulgaria, 9-11 May, 2013;

• Member of the organizing committee of the Conference AVA Congress 2008;

• Secretary of conferences BIOATLAS 2006, 2008, 2010, 2012, 2014.

In 2015, in position of coordinator, I organized the third congress NEEFOOD in Brasov. www.neefood2015.rosita.ro. With this occasion a number of personalities in the field, came as invited speaker at Transilvania University of Brasov and the best articles presented at the congress were published in Elsevier journals with impact factor over 2.

## 1.7. Teaching in foreign university

In the timeframe 2003 – 2013, I participated in annually internships for 3-4 weeks at: Institute of applied thermodynamics and fluid mechanics, Konstanz, Germany; University of Food Technologies in Plovdiv, Bulgaria; University of Thessaly, Volos, Greece; State Agricultural University in Kazakhstan, Almaty; State Technological Institute of St. Petersburg, Russia. On these occasions, I held thematic presentations in the field of finite element analysis, applied in food, equipment and technologies in milling and bakery industry, IT applications in food sector, etc.

## 1.8. Accessing and implementing projects/grants, focused on professional component

The research activity that I conducted as a coordinator or team member in several contracts, demonstrated the ability to conduct research and development projects. Thus, I was director of contract for four projects won in national or international competitions:

- Research on increase seed germination capacity for cereal and technical plants through, controlling and monitoring of parameters of the drying process in maize and soya applications. Excellence project for young researchers, code 35, CEEX 2005-2007, Ministry of Education and Research, project no. 52/3 October 2005;

- Research for promotion of innovative techniques for drying grain of cereal seeds and technical plants by heating-cooling oscillating regimes, in order to obtain finished ecological products. Excellence project for young researchers, code 100, CEEX 2006-2008 Ministry of Education and Research project no. 139 / 10.03.2006;

- Studies and research on designing a variable geometry grain dryer for cereals in order to obtain finished ecological products. CNCSIS project, code AT 56, 2006-2008, Theme 2, no project A1 / GR 106 / 19.05.06;

- Nutritional labeling study in Black Sea Region Countries - NUTRILAB FP7 project - IRSES no. 318 946.

In these projects, I have worked with various universities in Germany, Bulgaria, Hungary, Greece, Russia, etc., and personalities belong to areas of the addressed topics.

## 1.9. Forming new entities from profesional component point of view

In the Transilvania University of Brasov, as a member of the Department of Agriculture and Food Industry Machines, I actively participated in the founding in 2007 of the new academic structures, Faculty of Food and Tourism, which I later served as Scientific Secretary for 4 years.

For the 4 new curricula established, I coordinated and coordinate in present the studies program Food Engineering, which was accredited in 2014 by the commission ARACIS.

Since January 2011, I founded the Association: Romanian Society for Information Technology in Agriculture, Food, Environment and Tourism, and from the position of president of the association, I assure support for conference and faculty journal through numerous hardware and software resources, or electronic publishing services. This entity is connected to the activities of the European Federation for Information Technology in Agriculture and

Environment (EFITA), with the 18 national bodies similar in other European countries. An important scientific research activity which is currently ongoing and were are involving teachers and graduates of faculty refers to Nutritional labeling study project in the Black Sea Region Countries - NUTRILAB FP7 project - IRSES no. 318,946, involving 12 partners from countries around the Black Sea.

# 2. FUTURE PLANS FOR THE DEVELOPMENT OF MY PROFESSIONAL, SCIENTIFIC AND ACADEMIC CAREER

## 2.1 Development of the professional career

For the next future I intend to continue the development of my professional career in the frame of interdisciplinary fields I have approached so far. This will be possible only by developing and strengthening my working relationships with colleagues from other universities, and participating in many activities organized on national and international level.

The developing of educational activity is based on a constant concern for improving of teaching methods, student involvement in learning activities, update information of taught courses, using resources from national and international environment. Directions I will follow to achieve this objective are:

• active involvement in all teaching activities of the department they belong - commissions license, accreditation of study programs etc;

• introduction of new curricula in the existing teaching plans that are more attuned to the realities of the open market and present academia. In order to achieve this I will develop the syllabus of the new courses and form new educational and research teams;

• coordination of work in specialized laboratories to ensure equipment functionality and theoretical support for smooth running of classes of applications;

• participation in annual stages at least two weeks in foreign universities, to ensure an exchange of experience and information beneficial to my career and for the institution that I work (department, college, university);

• diversification of interactive teaching methods based on collaborative creativity and educational partnership, including guest lecturers from the country and abroad;

• active involvement of students in the development of courses and teaching using methods applications center on discovery learning, team learning and group learning;

• publishing and updating courses that I teach. Thus, I have in mind for next year: editing the second edition of the monograph *Modern techniques for drying cereals and technical plants* that will complete the first edition of the numerous results of research in this area conducted after the phD thesis presentation; finish editing and publishing the course *Equipments and technology in bakery industry*; editing the second edition of the handbook of laboratory for discipline *Equipments and technology in bakery industry*;

• students involvement in relevant activities for faculty (eg: BIOATLAS conference where students have a special section, ROSITA symposiums organized in research projects), in this way facilitating the integration of higher-level of theoretical assimilated elements;

• encourage students to apply and get scholarships in foreign universities in order to benefit from international work environment and share this experience with their colleagues (there it is manifested availability of the NDSU - US and HTWG - Germany);

• continue to conduct courses and tests on e-learning platform;

• continuously improve all aspects of teaching processes within the study program IPA, where I am in charge.

Also, I will continue to apply for financing in projects that encourage the development of professionals, like long life learning (Erasmus, Grundtvig, etc), and also larger programs like the Development of Human Resources Operational Program and the Increase of Competiveness Operational Program.

## 2.2 Development of scientific career

Scientific research is essential for the development of an academic career. Scientific career implies a continuous involvement and interest for research, the fields of research being established according to personal interests in the science.

I intend to increase the quality of my research by:

*a. Developing/creating new laboratories.*

I also intend to develop or create new stands in the Eco-Biotechnologies and Equipment for Agriculture and Food Industry research laboratory.

For there is an intention to create soon a new facility in mushrooms growing/ research area in collaboration with Sankt Petersburg Institute.

*b. Publishing intentions.*

My intention is to continue to publish the results of my research in national and international journals. For the future I will try to publish papers in ISI journals with a relative influence factor above 1 and an impact factor above 2 (included in the cited 10 representative papers), and I intend to index Journal of EcoAgriTourism in ISI web of knowledge database.

Another priority is to increase the number of international team papers, in order to be accepted in ISI rated journals with high influence scores.

*c. Research results presented in national and international conferences.*

In the future I intend to participate at more conferences and scientific events. Especially, I intend to participate in conferences and scientific events attended by participants from other universities and other countries, or organized by prestigious scientific communities. I will prefer to participate to conferences for which the proceedings are ISI indexed or on list A or B.

For example it is considered:

- Organizing international congress NEEFOOD 2015;

- Participation in following editions of the conference "Agricultural Informatics Conference" in Debrecen, Hungary;

- Participation in events organized by EFITA - European Federation for Information Technology in Agriculture and Environment in 2015 and eventually organizing a symposium in Brasov in 2016, in the framework of the conference BIOATLAS 2016;

- Participation in specialized seminars organized by the main agents in the food area: Vel Pitar, Chr Hansen, Prodlacta, etc.

*d. Accessing projects that give precedence to the scientific aspects over the professional ones, through activities like:*

- Participation in the timeframe 21 April - 8 September 2015 to the consortium proposed by the University Kaposvar, Hungary, on a proposal for the program: *Water Innovation: Boosting its value for Europe, Sub-call: WATER-2b-2015: Integrated approaches to food security, low-carbon energy, sustainable water management and climate change mitigation*;
- Proposal for a project in timeframe 24 April - 11 June 2015, with title *Involvement of small rural farms and food manufacturing SME în the transparent, sector spanning agrifood process networks* în cadrul call-ului SFS-18-2015: "*Small farms but global markets: the role of small and family farms în food and nutrition security*";
- Participation to the consortium for project proposal H2020 with title Reducing agricultural waste through application of innovative technologies and development of novel products, coordinate by University of Kassel (Uni Kassel), Faculty for Organic Agricultural Sciences, Germany;
- re-application for project **Fre**sh **e**ating **pas**try **s**olution for vending machines: **FREEPASS,** (proposed in April 2014) **to the following call's HORIZON 2020;**
- proposal of new projects in the already formed consortium for NUTRILAB project;
- Proposal of a common joint towards research on visible infrared analysis of the drying process of vegetal materials sliced, together with Biosystems engineering department at the state University of North Dakota;

***Development of the academic career***

*a. Ascending in the academic hierarchy: Step-by-step and competition based process.*

Until now, I have ascended the academic hierarchy, all the way up from assistant to professor, without any shortcuts. All obtained academic functions have been the result of competition. Presently, I am attempting to obtain the right to function as PhD supervisor.

*b. Publishinging activity.*

For the future I will continue to publish manuals and monography, having special objectives valorization of international team collaboration.

Also, publishing in ISI Journal consists one of the main priority, as results in the same frame of international research collaboration. Another priority is to index the faculty's Journal in ISI web of knowlegde database.

*c. Participating and presenting lectures in national and international conferences.*

For the future I intend to participate and present lectures in more international conferences and workshops. Also, I will organize conferences and workshops on subjects and themes related to the area of agri-food engineering, inviting many personalities form abroad.

I consider that the constant participation in scientific events as a way of increasing my professional abilities, collaborating and exchanging ideas, all of which are very necessary in our globalized small world.

*d. Presenting lectures in foreign universities.*

For the future, I intend to continue and give more attention to presenting lectures in other universities, especially universities in other countries. Such an activity will be a good occasion to contact academics from abroad, and develop my abilities to work and teach in an international, multicultural environment.

*e. Involvement in student activity:*

Involvement in students' work can be achieved through:

- support given to students to encourage their participation in scientific events and/or in organizing social activities by using support from different NGO;

- coordinating and supervising licence works;

- recommending students for scholarships or other practical activities during faculty;

- organizing professional visits for students to various public or private institutions

For the future I will give more attention to involve students working on their BSC thesis in the MSC /doctoral projects; also I would like to organize meeting by inviting various experts – in different areas – to present lectures and talk to students, as "special guests".

Following my academic career, I will support myself by values as: involvement and responsibility, transparency, communication, commitment and not least teamwork. I believe that these values are represented in the faculty in which I operate and form the pillars that support the mission and vision of this institution. These values were those who contributed to the setup of the Faculty of Food and Tourism.

Career Development Plan is correlated with the vision and the faculty and of the department and I plan to successfully meet all activities under my responsibility.

The fundamental objective is to build an academic career and an excellent professional reputation, which will increase the prestige of the faculty and to provide it national and international visibility.

### 2.3. Conclusions

The experience and knowledge gained in my teaching and research activity in the field agrifood engineering, along with the entire activity developed at university levels have essentially contributed in defining my personality as professor and researcher and contributed to the national and international visibility.

This work and its results could and should represent the basis for developing a group focused on optimization of agrifood processes, new functional food, reducing waste in agriculture and food industry, low energy consumption equipment. The development of doctoral programs and of projects within this group could contribute to the main research topic of our R&D center: ***Eco-biotechnologies and equipment in agriculture and food.***

The activity and the plans for the future are fully in line with the Sustainable Energy Technologies (SET) Plan formulated by EU for the period 2014-2020 and with the Horizon 2020 priorities set within the pillar Societal Challenges: the rational use of resources, wastes recycling and advanced materials for energy saving and green energy production and use.

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27.04.2015 Prof. Dr. Ing. Liviu GACEU