Strojniški vestnik - Journal of Mechanical Engineering 53(2007)1, 48-58
UDK - UDC 631.365:681.5
Strokovni članek - Speciality paper (1.04)

Optimizacija neprekinjenega postopka sušenja v težnostnih sušilnicah

Optimization of the Performance of the Continuous-Drying Process in Gravity Dryers

Neven Voća - Tajana Krička - Vanja Janušić
(University of Zagreb, Croatia)

V prihodnosti pričakujemo razvoj tehnologije in izvedbo tehnoloških načrtov; seveda pa bo obseg njihove uporabe določen tudi z dejanskimi možnostmi, potrebami in delovnimi razmerami. Na vseh področjih človeške dejavnosti, tudi na področju kmetijstva, nastajajo načrti in napovedi za prihodnji razvoj. Na podlagi znanja, ki je bilo doslej uporabljeno v postopku osuševanja v gravitacijskih sušilnicah, in dosegljivih podatkov o medsebojni odvisnosti velikega števila parametrov, ta prispevek predlaga način optimizacije posameznih sklopov postopka osuševanja.

Celoten postopek optimizacije sušenja v gravitacijskih sušilnicah moramo razviti v posameznih stopnjah, upoštevajoč posamezne funkcionalne sklope. Vsaka stopnja vpliva na izboljšanje celotnega postopka in vse stopnje skupaj vodijo v optimizacijo delovanja sistema. Dodatna prednost predlaganega postopka je v tem, da ga lahko izvedemo postopoma. Z optimizacijo sušenja dosežemo večjo stabilnost delovanja sušilnic, zmanjšanje porabe energije in boljšo kakovost zrn.

(Ključne besede: sušenje, optimiranje, statična lastnost, učinkovitost, mikroprocesorsko krmiljenje)

Technology and technological expectations are expected to develop with time; however, opportunities, needs and working conditions affect the extent of their usage. Predictions are made in all areas of human activity, and this includes the agricultural sector. Using the know-how so far applied during the drying process in gravity dryers, together with the available data on the interdependencies of a large number of parameters, this paper suggests how a system for drying could be organized by optimising the functional ensembles.

A comprehensive method for drying-process optimization in gravity dryers can be built in several steps from several functional ensembles. Each step improves the process, and together they represent the complete system for performance optimization. An additional property is the possibility of realizing each step. The drying-process optimization results in the stabilisation of the dryer functions, a decrease in the specific energy consumption, and better kernel quality.

(Keywords: drying process, optimization, static properties, performance, microprocessor controller)

0 UVOD

Visoke cene energije in drugi problemi, povezani z naftnim trgom, so v zadnjem desetletju spodbudili vrsto znanstvenih raziskav na področju energetike. Na primer, priča smo bili intenzivnemu raziskovanju sušenja kmetijskih pridelkov, ki je razkrilo, da je kar 40% vseh stroškov porabljenih za to opravilo [1].

Vsi lahko kvarljivi pridelki morajo biti konzervirani. Konzerviranje je postopek popolne

0 INTRODUCTION

High energy costs and problems in the oil market have resulted in many scientific investigations in the field of energetics over the past ten years. As an example, intensive investigations have been carried out in the field of drying agricultural products, and it was determined that 40% of the overall energy costs are spent during this process [1].

All easily perishable products have to be preserved. This term refers to the final operation of comodstranitve prisotnih mikroorganizmov ali vsaj ustavitev njihove rasti in razmnoževanja. Ta postopek omogoči hrambo izdelka za določeno časovno obdobje, ko izdelek ostane nespremenjen, in tako omogoči njegovo uporabo ne glede na čas in kraj njegove pridelave. Namen konzerviranja je torej ohranitev primarnih značilnosti izdelka in podaljšanje njegovega roka trajanja [2].

Na podlagi dosegljivih podatkov o žitaricah je bilo ugotovljeno, da je osuševanje postopek, ki ga določa medsebojno vplivanje številnih parametrov. Kakovost osuševanja je odvisna od fizikalnih značilnosti ozračja, v katerem poteka osuševanje, fizičnih ter kemijskih značilnosti poljščine in debeline plasti, skozi katero prehaja voda; slednja pa je odvisna od značilnosti sušilnice. Hitrost sušenja je odvisna od vseh omenjenih dejavnikov, katerih učinke lahko opazujemo z vidika kinetike osuševalnega postopka, pa tudi s tehnološkega vidika, tj. glede na kakovost osušenega pridelka [3].

Na zbirnem mestu imajo koruzna zrna delež vlage večji od ravnovesnega stanja, ki je najbolj primerno za shranjevanje. Zaradi tega je postopek osuševanja le nadaljevanje in dokončanje spontanega zorenja zrna, ki se ne more zgoditi po naravni poti. Da bi podaljšali dobo skladiščenja zrna, mora biti postopek osuševanja osredotočen na konzerviranje zrna in na ustvarjanje primernih okoliščin. Namen osuševanja je odstranitev odvečne vsebnosti vode, tj. ohranitev le deleža vode, ki je potrebna za mirujoč obstoj [4].

Hitrost in kakovost sušenja zrna sta odvisni od postopka sušenja. Na primer, pri spontanem sušenju je temperatura zraka skoraj enaka temperaturi zrn, zaradi česar je sušenje zelo počasno. Ko pa pri postopku sušenja uporabljamo vroč zrak, se hitrost sušenja poveča. V tem primeru povečana temperatura zraka povzroči zmanjšanje vlage v zrnih in povečana razlika med vlažnostjo zrna ter vlažnostjo zraka pospeši sušenje ([5] in [6]).

Učinkovitost sušenja je odvisna od parametrov, ki se navezujejo na značilnosti zraka, tj. od toplotne intenzivnosti, hitrosti zračnega toka, relativne vlažnosti, pa tudi od načina izgradnje sušilnice ter temperature zrn. Slednja je, kot funkcija temperature zraka, najbolj pomemben in najbolj občutljiv parameter v postopku sušenja. Največje dovoljene temperature zrn, ki so odvisne od namena uporabe zrn, določajo tudi temperaturo zraka, uporabljeno v postopku sušenja. To pomeni,

pletely removing the micro-organisms that are present, or at least stopping their growth and multiplication. This process ensures the product is preserved without any changes during a specific period of time and therefore ensures that it can be used, no matter when and where it was produced. Hence, the aim of the preservation is to maintain the product's primary properties and to prolong its useful lifetime [2].

According to the available data on plants for cereal finishing, it was determined that the drying process involves the multiple interconnections of parameters. The quality of the drying process itself depends on the physical properties of the atmosphere the drying is being conducted in, on the physical and chemical properties of the product, and on the thickness of the layer the water is diffusing through. The last of these properties depends on the properties of the dryer. The velocity of the drying process depends on the above-mentioned parameters, whose effects can be observed in terms of the drying-process kinetics, and from the technological point of view, i.e., the quality of the dried product [3].

At the collection point the corn kernel has a higher moisture content than at equilibrium point, which is a desirable property for storing. This is why the drying process is only a continuation and finishing of the spontaneous ripening of the kernel, which cannot be carried out naturally. In order to store the kernel for a longer period the drying process has to be focused on kernel preservation and on providing the necessary related conditions. The aim of the drying process is to remove the redundant water content, i.e., to retain only the water content necessary for dormant life [4].

The velocity and quality of the kernel-drying process depend on the drying procedure. For instance, the air temperature during the spontaneous drying process is almost equal to the kernel temperature, which leads to a very slow drying rate. When heated air is used in the drying process, the drying rate is faster, i.e., an increased air temperature leads to a decrease in the kernel's moisture content, and so a greater difference in the moisture contents of the kernel and the air speeds up the drying process ([5] and [6]).

The drying efficiency depends on a few parameters associated with the air, i.e., its thermal intensity, flow velocity and relative humidity, as well as the dryer construction and the temperature of the kernel. The last of these is, as a function of the air temperature, the most important and the most sensitive parameter in the drying process. The maximum allowed temperatures of the kernel, which again depend on the purpose, limit the air temperatures that can be used in the drying process. This da se zmogljivosti sušilnice na more povečati s preprostim povečanjem temperature zraka, saj bi v tem primeru sušenje zrna poškodovalo. Za postopek sušenja velja, da je osuševanje bolj izrazito pri višji temperaturi in boljšem prenosu toplote iz zraka na sušeni pridelek. Še več, pomemben parameter sušenja je tudi hitrost prehajanja vode v razdalji med jedrom in površino pridelka ([3], [7] in [8]).

Zrna so običajno v sušilnico dostavljena z različnih krajev. Zato imajo različna zrna različne deleže vlage, pripadajo različnim sortam in hibridom, a so v sušilnici pomešana in skupaj osušena. Ker se zrna razlikujejo glede na morfološko strukturo in pripadajoča razmerja, se tudi v postopku sušenja različno obnašajo. Hitrost sprostitve odvečne vode, ki ustvari higroskopično ravnovesje, se spreminja glede na vrsto hibrida (v primeru koruznih zrn znaša 14 %). Glede na prehajanje vode skozi zrna je najbolj problematičen semenski mešiček in Katić [9] je ugotovil, da je debelina semenskega mešička obratno sorazmerna (r=0,83) s hitrostjo sušenja. Razmerja v zrnih vplivajo na postopek sušenja tudi z ustvarjanjem odpornosti proti zračnemu toku. Sušenje lahko zmanjša prostornino zrn za 40 %, zaradi česar se spremeni poroznost kupa zrn v sušilnici, kar še dodatno poveča odpornost proti zračnemu toku [9].

Ob izhodu iz sušilnice imajo zato zrna različne deleže vlage. V preteklih desetih letih so se razlike med vlago osušenih zrn še dodatno povečale zaradi slabih gradenj sušilnic, tako da se je razpon deleža vode lahko povečal tudi do 11 %. V takšni situaciji je skoraj nemogoče organizirati dolgotrajno skladiščenje zrn, zato je treba uvesti nove tehnologije osuševanja.

Ko govorimo o postopku sušenja, je poleg dejavnikov, kakor sta kakovost zrn in zmogljivost sušilnice pomemben tudi dejavnik porabe energije na kilogram vode, ki izhlapi iz zrn. Teoretično je energija potrebna za izparevanje vode enaka specifični entalpiji nasičene pare pri tlaku, ki ustreza temperaturi izparevanja ([11] do [13]).

Namen tega prispevka je, na podlagi najnovejšega znanja in sodobnih tehnik, predlagati nov način organizacije sistema neprekinjenega sušenja v navpičnih gravitacijskih sušilnicah.

1 RAZISKOVALNA METODOLOGIJA

Za potrebe nadzora neprekinjenega sušenja zrna smo upoštevali le posamezne odvisnosti med

means that the capacity of the dryer cannot be increased simply by increasing the air temperature, because this would lead to a drying process that has detrimental effects on the dried kernel. For the drying regime, the higher the temperature and the better the air-to-product heat transfer, the more intensive is the resulting drying process. Moreover, an important parameter in the drying process is the rate of water fluctuation from the centre of the product to its surface ([3], [7] and [8]).

The kernels that are dried in a dryer are usually being supplied from different places. Consequently, these kernels have different moisture contents and are of different varieties and hybrids, which are then mixed and dried when entering the dryer. Because the kernels differ in morphological structure and proportions, they behave differently in the drying process. The rate of release of the redundant water content until the hygroscopic equilibrium is achieved differs depending on the hybrid (for the corn kernel this means 14%). The pericarp is the major problem in terms of the water flow through the kernel, and Katić (1985) established that its thickness is inversely related (r=0.83) to the velocity of the drying process. Kernel proportions also affect the drying process by providing a resistance to the air flow. The drying process can decrease the kernel's volume by 40%, which changes the pile porosity in the dryer and subsequently leads to a greater resistance to the flow of air [9].

Accordingly, these exceptional kernels have a different moisture content when exiting the dryer. In the past ten years the differences in kernel moisture after the drying process were even more obvious because of poor dryer constructions, which caused variations in the water content of up to 11% [10]. The long-term storage of such kernels is almost impossible to achieve, so there is a need for the introduction of new drying technologies.

When speaking of the drying process, besides parameters such as kernel quality and dryer capacity, the specific energy consumption per kilogramme of water evaporated from the kernel is also an important parameter. Theoretically, the energy that is necessary for the evaporation of the water is equal to the specific enthalpy of saturated steam at the pressure that corresponds to the evaporation temperature ([11] to [13]).

The aim of this paper is to propose a new way of organising a system of continuous drying in vertical gravity dryers, based on the latest knowledge and modern techniques.

1 RESEARCH METHODOLOGY

For the purposes of monitoring the continuous kernel drying, single dependencies dvema ali tremi spremenljivkami, drugim pa smo določili stalne vrednosti in tako preprečili njihovo učinkovanje.

Kakovostni nadzor parametrov postopka sušenja zrn je osnova za zadovoljivo neprekinjeno sušenje, saj omogoča potrebno kakovost zrn ob izhodu iz sušilnice. Za sušenje množice zrn je potrebno, da spremenimo nekatere dejavnike, npr. temperaturo osuševalnega zraka ali hitrost prezračevanja. V gravitacijskih sušilnicah so zrna izpostavljena enakim razmeram, zato so na svoji poti proti izhodu iz sušilnice lahko izpostavljena načrtovanim parametrom. Če spremenimo enega izmed dejavnikov in pri tem želimo, da rezultat osuševalnega postopka ostane nespremenjen, moramo spremeniti tudi preostale dejavnike. To je osnovno vodilo optimizacije sušenja, s katerim želimo doseči:

- najboljšo mogočo kakovost zrn,
- najmanjši čas sušenja ali največjo zmogljivost sušilnice,
- najamanjšo porabo energije.

Doseganje največje zmogljivosti sušilnice in najmanjše porabe energije je težavna naloga. Za doseganje najboljše mogoče kakovosti zrn pa je potrebno temeljito poznavanje obnašanja zrn v različnih razmerah. Poznati moramo vse dejavnike, ki vplivajo na kakovost zrn. Te dejavnike lahko izrazimo v obliki:

- preglednic ali diagramov ustaljenih odvisnosti med spremenljivkami;
- krivulj dejavnikov, ki kažejo ustaljene odvisnosti;
- matematičnih izrazov, s katerimi dobimo približne vrednosti odvisnosti spremenljivk;
- preglednic in diagramov, ki kažejo odvisnosti spremenljivk od časa;
- diferencialnih enačb sistemov, posebej tistih, ki izrazijo približne vrednosti odvisnosti določenih spremenljivk od časa ter drugih spremenljivk.

Zaradi velikega števila podatkov je treba voditi njihovo klasifikacijo glede na tip in potencialno rabo podatkov. Sam postopek osuševanja pa lahko opazujemo z uporabo ustaljenih ali dinamičnih značilnosti, odvisno od tega, ali čas definiramo kot dejavnik naše raziskave.

1.1 Ustaljene lastnosti

Naši predlogi za izboljšano gradnjo gravitacijskih sušilnic se nanašajo tudi na določitev številnih meril, potrebnih za boljše delovanje

between two to three variables were taken into consideration, while others were kept at constant values and their effects were eliminated.

Qualitative monitoring of the parameters of the kernel-drying process is the basis for satisfactory continuous drying because it ensures the required quality of the kernel when it exits the dryer. The batch-drying process requires the parameters, e.g., the drying-air temperature or the ventilation speed, to be changed. In gravity dryers the kernel is exposed to the same conditions in order to be exposed to the programmed parameters on its journey to the dryer's exit. If one of the parameters is being modified, and the result of the drying process is expected to remain unchanged, the other parameters need to be modified, too. This is the basis for the drying-process optimization, in order to achieve:

- the best kernel quality,
- the minimum drying period or maximum dryer capacity,
- the minimum energy consumption.

Achieving the maximum dryer capacity and the minimum energy consumption is a difficult problem. However, obtaining the best kernel quality requires a comprehensive knowledge of kernel behaviour in different conditions. All the parameters that affect the kernel quality need to be known. These parameters are expressed in the form of:

- tables or diagrams of the static dependencies between variables,
- parameter curves showing static dependencies,
- mathematical expressions, used for an approximation of the variables' dependencies,
- tables or diagrams expressing the variables' dependence on time,
- differential equations of the systems, especially those which approximate a particular variable's dependence on time and other variables.

Because of the large amount of data it is necessary to carry out their classification from the data-type and the potential-application points of view. The drying process itself can be observed by using either static or dynamic properties, depending on whether time is taken into consideration as a parameter.

1.1 Static properties

The present proposals for improving the gravity dryers' construction also refer to establishing numerous criteria for better operation of the dryer, sušilnice, kar pa je spet povezano s kakovostjo izdelka, najmanjšimi stroški izdelave sušilnice in njenimi tehničnimi rešitvami, ki naj omogočijo najmanjšo porabo energije in časa. Razpon spremenljivk postopka in "delovno polje" določimo z izbiro določenega tipa konstrukcije in zmogljivosti sušilnice, v kateri je večina postopkov optimiziranih. Diagrami odvisnosti določenih spremenljivk znotraj določenih delovnih polj kažejo ustaljene lastnosti. Izbira avtomatičnega upravljanja ali avtomatiziranega vodenja temelji na teh lastnostih. Poleg tega so pogosto določeni tudi pomembni podatki o vrednostih tretje spremenljivke. V primeru večje vrednosti določene spremenljivke ali parametra je ustaljena lastnost izražena kot krivulja parametra. Ko v izračunih uporabljamo ustaljene lastnosti, je koristno, da odvisnosti med spremenljivkami pokažemo z matematičnimi izrazi.

1.2. Dinamične lastnosti

Dinamične lastnosti določijo obnašanje spremenljivk v času. Ko govorimo o sušilnicah, je primerno, da določimo njihovo dinamično obnašanje in ga predstavimo v obliki prehodnih lastnosti ali kot odziv na skočno funkcijo. Tovrstni časovni diagrami kažejo potencialne pojave odziva neke spremenljivke v času, ko druga spremenljivka skokovito spremeni svojo vrednost. Te podatke uporabimo, ko določamo čas in način obnašanja določene spremenljivke, ki smo jo spremenili zato, da bi lahko predvideli obnašanje druge spremenljivke.

Dinamično obnašanje izrazimo matematično v obliki diferencialnih enačb. Vendar pa moramo, pred določitvijo postopka z uporabo diferencialnih enačb, nastaviti toliko enačb, kolikor je spremenljivk. Da bi lahko uporabljali te enačbe na določenih predmetih, morajo koeficienti enačb ustrezati izbranemu predmetu. V našem primeru morajo ustrezati sušilnici.

Pregled rezultatov osuševanja je prikazan z dvema diferencialnima enačbama. V praksi smo enačbi preizkusili z uporabo določenega osušitvenega modela, ki smo ga kasneje uporabili tudi za določitev koeficientov enačb. Numerične rešitve teh enačb, in posledično tudi vrednosti spremenljivk, se niso znatno spreminjale. Vendar se je ta sistem diferencialnih enačb nanašal na zelo preprost model in veliko parametrov ter podmen smo zanemarili. Zato lahko ta pregled osuševalnega postopka uporabljamo le v nekaterih splošnih

which again refer to the quality of the existing product, to the minimum dryer-production costs and to the plant's technical solutions with a minimum energy and time consumption. The range of the process variables and the "working field" are determined by choosing the dryer's construction and capacity type, in which the majority of processes are optimal. Diagrams showing the dependence of particular variables within estimated working fields are known as static properties. The selection of automatic manipulation or automatic conduction is based upon these properties. In addition to that, important data regarding the values of the third variable are often specified. In the case of a higher value of a particular variable or parameter, the static property is expressed as parameter curves. When using static properties in calculations it is useful to express dependencies between variables with mathematical expressions.

1.2. Dynamic properties

The dynamic properties define the behaviour of the variables with time. When speaking of dryer-type plants it is convenient to determine the dynamic behaviour and to present it in the form of transitive properties or as a response to the leap. Time diagrams of this kind indicate the potential occurrence of one variable's response when the other variable changes its value by leaps. This data is used when determining the time and conduction modus of particular variables, which were changed in order to predict the behaviour of the latter.

The dynamic behaviour is mathematically expressed in the form of differential equations. However, before determining a process using differential equations it is necessary to set up as many equations as there are variables. In order to use these equations on a specific object, the equation coefficients have to correspond with this object. In this case they have to correspond to the dryer.

An overview of the drying-process results is presented with two differential equations. In practise they were tested by using a certain drying model, which was again used to determine the equation coefficients. Numerical solutions of these equations, and consequently the variables' values, did not differ significantly. However, this system of differential equations was related to a very simple model and a lot of parameters and hypotheses were omitted. Accordingly, this drying process overview can be analizah, ne moremo pa ga uporabljati za potrebe delovanja določene sušilnice.

2 REZULTATI IN RAZPRAVA

Iz izkušenj upravljanja osuševalnega postopka v težnostnih sušilnicah in ob upoštevanju medsebojnih vplivov velikega števila spremenljivk v prispevku predlagamo optimizacijo sistema znotraj posameznih funkcionalnih enot, ki vključujejo meritve in signalizacijo, upravljanje, avtomatsko krmiljenje, ustavitvene ukrepe in vodenje.

2.1 Meritve in signalizacija

Meritve določenih spremenljivk ponujajo vpogled v način poteka postopka. Tako sledimo stalno spreminjajočim se spremenljivkam pa tudi mejnim in kritičnim spremenljivkam.

Prve se nanašajo na vlago v vstopnih zrnih, temperaturo vročega zraka po končanem segrevanju, temperature posameznih predelov osuševalnega zraka, hitrost zračnega toka ali znižanje zračnega tlaka v sušilnici, temperaturo zraka v sušilnici in v hladilniku, temperaturo zrn ob izpustu iz sušilnice, fluktuacijo zrn v sušilnici, porabo goriva, temperaturo in vlažnost okolja ter vlažnost izhodnega zraka.

Mejne in kritične spremenljivke se nanašajo na zasedenost sušilnice, dovod vlažnih zrn, najvišjo temperaturo v sušilnici, stanje motornih naprav itn.

2.2 Upravljanje

Sklop upravljalnih naprav omogoči neposredno ali posredno vplivanje na osnovne spremenljivke postopka in s tem popravke postopka. Upravljanje izvajamo na tri načine: ročno, ročno na daljavo in avtomatsko. Spremenljivke, ki jih upravljamo, vključujejo mešanje vročega in zunanjega zraka, mešanje vročega in povratnega zraka, delovanje ventilacije (hitrost osuševalnega zraka in delovanje zapore za zrna) in hitrost zrn, ki potujejo skozi sušilnico.

2.3 Avtomatsko krmiljenje

Z združitvijo meritvenih in upravljalskih funkcij z učinkovito negativno povratno zvezo je mogoče ustvariti krmilne zanke, ki pomagajo ohraniti

used in some analyses, but it is not applicable when operating a specific dryer.

2 RESULTS AND DISCUSSION

Using the experience of managing the drying process in gravity dryers, and based on the interdependencies of a great number of variables, this paper suggests organising the system for the purpose of its optimization through functional units, which include measurement and signalization, managing, automatic control, blocking effects and conduction.

2.1 Measurement and signalization

The measurement of particular variables gives an insight into the way the process is being run. The continuously changeable variables, the borderline and the critical variables are monitored.

The first relates to the moisture of the entering kernel, the hot-air temperature after the heating process, the section drying-air temperatures, the air-flow velocity or the air-pressure decrease in the dryer, the air temperature in the dryer and the cooler, the temperature of the exiting kernel, the kernel fluctuation in the dryer, the fuel consumption, the environmental temperature and the humidity, and the exiting air's humidity.

The borderline and critical variables relate to the dryer's occupancy, the delivery of humid kernels, the maximum air temperature in the dryer, the condition of the motor device, etc.

2.2 Managing

The group of managing devices enables a direct or indirect effect on the fundamental process variables and therefore ensures the process corrections. It is carried out in three steps, i.e., manually, remote manually, and automatically. The variables that are being managed include the hot- and outer-air mixing, the hot- and recurrent-air mixing, the ventilator operation (the velocity of the drying air, and the working of the kernel excluder) and the kernel velocity when passing through the dryer.

2.3 Automatic control

By integrating the measuring and managing functions with a meaningful negative recurrent conjunction it is possible to deliver controlling circuits vrednosti spremenljivk v določenih mejah. S tem preprečimo motnje, ki bi jih lahko povzročile nenadzorovane spremembe omenjenih spremenljivk, kar pomeni, da z omenjenim postopkom zmanjšamo število spremenljivk, ki bi lahko povzročile prekinitev osuševalnega postopka. Krmilne funkcije izvajamo z naslednjimi sklopi opreme:

- posameznimi krmilnimi zankami s stabilnimi vrednostmi;
- posameznimi krmilnimi zankami z nastavljenimi vrednostmi;
- industrijskim krmilnikom, ki združuje vse merjene in krmilne spremenljivke in vodi postopek.

2.4 Ustavitveni ukrepi

Ko se sprožijo signali, ki opozarjajo na mejne in kritične vrednosti, se sprožijo določeni ustavitveni ukrepi za postopek. Ti so prilagojeni dogodkom v sušilnici in v sosednjih prostorih: povečanje temperature v sušilnici nad predpisano, premajhen dotok vlažnih zrn, motnje v postopku ogrevanja ali prekinitev delovanja katerihkoli bistvenih rabljenih naprav.

2.5 Vodenje

Postopek vodenja vključuje ustaljeno in dinamično sinhronizacijo spremenljivk ali parametrov, tako da lahko kljub nekaterim nenadzorovanim spremembam ohranimo nespremenjene rezultate postopka in stalno kakovost pridelka.

Ta postopek nadzoruje inteligentni industrijski krmilnik, čigar nastavitve moramo prilagoditi tovrstnemu opravilu (upoštevati moramo odvisnosti med spremenljivkami ter tehnološke in ekonomske kriterije). Krmilnik mora biti zmožen sprejeti več tipov podatkov, ki v obliki preglednic in diagramov izražajo ustaljene in dinamične lastnosti. Krmilnik izvaja tudi obdelavo podatkov, tako da podatke lahko prepozna kot matematične funkcije, ki jih nato preoblikuje v enačbe. Drugi tip podatkov so matematični izrazi. Tretji tip podatkov so posamezni podatki, ki določajo parametre postopka kakor na primer vrsta sušenega blaga, cena goriva itn. Nazadnje mora krmilnik sprejeti še podatke o določenem postopku, pridobljene od naprav za merjenje in signaliziranje, hkrati s podatki o vrednostih in spremembah nenadzorovanih spremenljivk.

Ob uporabi vseh navedenih podatkov, krmilnik nenehno izvaja izračune, ki pomenijo temelj

that can help in maintaining the variables' values within set margins. This ensures the elimination of interferences caused by uncontrolled changes to these values, i.e., this leads to a decrease in the number of variables that can cause an interception of the drying process. The control functions are accomplished through a few levels of plant equipping:

- single control circuits with stable values,
- single control circuits with externally set values,
- an industrial controller that unites all the measured and controlling variables and operates the process.

2.4 Blocking effects

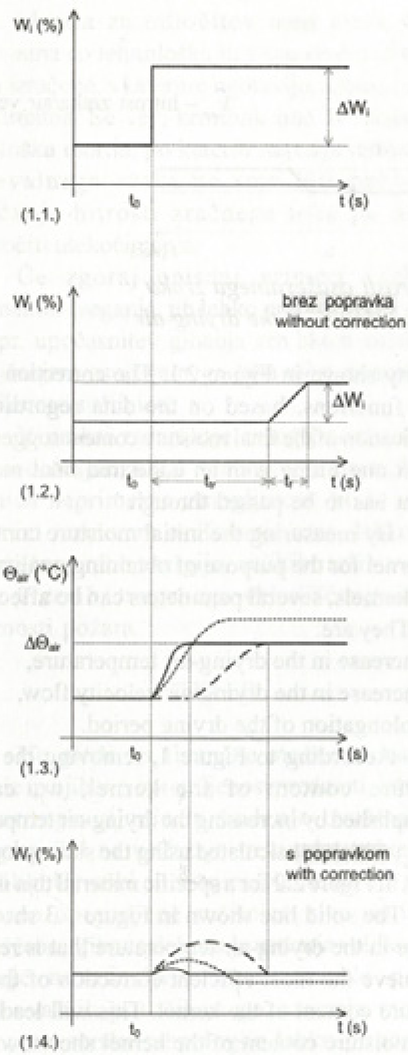
When borderline and critical values are being signalled, the critical values activate certain blocking effects in the process. They are specified by the dryer's and attached buildings' solutions: exceeding the prescribed dryer temperature, the shortage of humid kernel inflow, the interferences with the burner functions and the ending of the vital device functions in the plant.

2.5 Conduction

The conduction procedure involves the static and dynamic synchronization of process variables or parameters, so that constant process results and constant product quality are preserved in spite of uncontrolled changes.

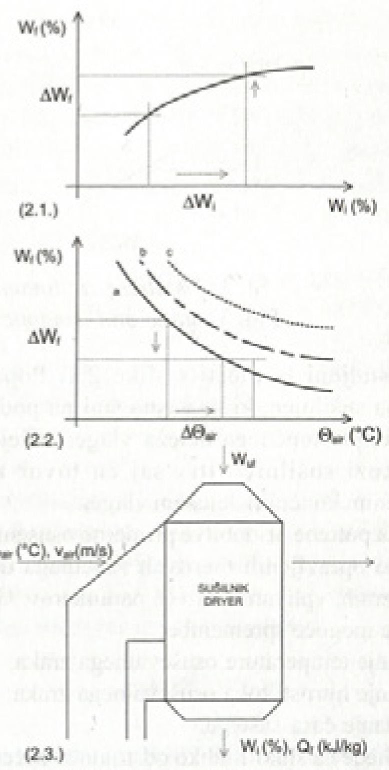
This procedure is supervised by an intelligent industrial controller, which needs to be set up for this kind of operation (i.e., the dependencies between the variables and the technological and economic criteria need to be entered). The controller has to be able to accept a few types of data that contain the static and dynamic properties in the form of tables and diagrams. Data processing is also conducted by the controller so it can recognize them as mathematical functions, which are then transformed into equations. The second types of data are previously arranged mathematical expressions. The third forms are single data, which specify the process parameters such as the type of the drying material, the fuel price, etc. Finally, the controller has to accept the actual process data that are obtained from the measuring and signalling equipment, together with data relating to the values and changes of unmonitored variables.

Using all the above-mentioned data, the controller continuously performs calculations, which



Sl. 1. *Dinamične lastnosti*

Fig. 1. *Dynamic properties*



w_i začetni delež vlage v zrnih/initial moisture content of kernel

w_f končni delež vlage v zrnih/final moisture content of kernel

Θ_{air} temperatura zraka pri osuševalnem postopku/air temperature of drying process

t čas sušenja/drying period

t_{tr} čas prenosa pri osuševalnem postopku/transport period of drying process

Q_f poraba energije/energy consumption

Sl. 2. *Ustaljene lastnosti*

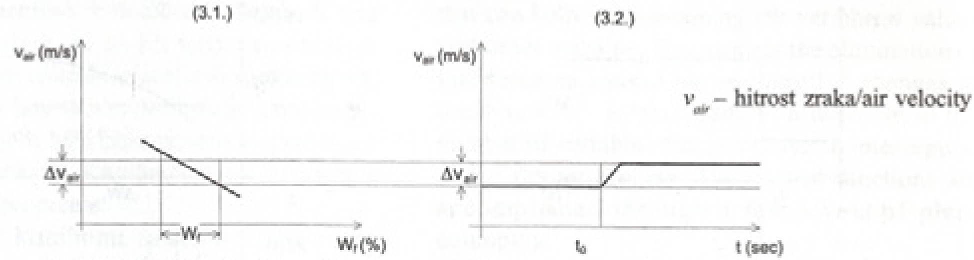
Fig. 2. *Static properties*

za nadzor spremenljivk in njihovo spreminjanje glede na vrednosti in čas. Še več, izračuni vsebujejo merila za optimalno krmiljenje postopka, ki pa jih lahko tudi spremenimo in jih prilagodimo želeni odvisnosti med kakovostjo osušenega pridelka, zmogljivostjo in porabo energije.

Slike 1, 2 in 3 prikazujejo delovanje krmilnika. Glede na sliko 1.1 se v primeru, ko se začetni delež vlage v zrnih (w_i) poveča med postopkom stabilnega sušenja, drugi parametri pa ohranijo nespremenjene vrednosti, končni delež vlage v zrnih (w_f) poveča po preteku določenega časa prenosa (t_{tr}) (sl. 2.3). To povečanje se pokaže postopoma (sl. 1.2) in z določeno časovno stalnico, t_f. Končna sprememba končnega deleža vlage bo

represent the basis for variables' monitoring and their variation with value and time. Furthermore, the calculations include the conduction criteria for an optimal process, which can then be altered and consequently balanced to a desired dependence between the dried material's quality, capacity and energy consumption.

Figures 1, 2 and 3 show a controller-functioning system. According to Figure 1.1., if the initial kernel moisture content (w_i) is increased during a stabilized drying process, while other parameters retain the same values, the final kernel moisture content (w_f) will be increased after a certain transport period (t_{tr}) (Fig. 2.3). This increase will manifest itself gradually (Fig. 1.2) with a particular time constant, t_f. The final change of the final moisture content will be equal to the static



Sl. 3. *Ustaljene in dinamične lastnosti hitrosti osuševalnega zraka*
Fig. 3. *Static and dynamic properties of the velocity of the drying air*

enaka ustaljeni lastnosti s slike 2.1. Popravki delovanja sušilnice, ki so zasnovani na podatkih o spremembi končnega deleža vlage, kažejo, da mora skozi sušilnico iti vsaj en tovor zrn z nezaželenim končnim deležem vlage.

Za potrebe pridobitve primerno osušenih zrn lahko, po opravljenih meritvah začetnega deleža vlage v zrnih, vplivamo na več parametrov. Gre za naslednje mogoče spremembe:
- povečanje temperature osuševalnega zraka,
- povečanje hitrosti toka osuševalnega zraka,
- podaljšanje časa sušenja.

Glede na sliko 1 lahko odstranitev začetnega deleža vlage v zrnu, w_i, dosežemo s povečanjem temperature osuševalnega zraka za vredno st Θ_{air}, ki jo za določen osuševani pridelek izračunamo z ustaljenimi lastnostmi s slike 2.2. Polna črta na sliki 1.3 kaže spremembo temperature osuševalnega zraka, ki je potrebna za doseganje kar najbolj učinkovite poprave končnega deleža vlage v zrnih. Po popravku bomo dobili končni delež vlage zrn, ki jo prikazuje polna črta na sliki 1.4. Če do temperaturnih sprememb pride kasneje, kakor to prikazuje prekinjena črta na sliki 1.3, bo končni delež vlage v zrnih vsebovala večjo napako, ki bo trajala dlje časa kakor napaka iz prvega primera (prekinjena črta na sl. 1.4). Do nezadovoljivega rezultata bo prišlo tudi v primeru, ko se temperatura premočno poveča. V tem primeru bo imela napaka končnega deleža vlage v zrnih nasprotni predznak (pikčasti črti v sl. 1.3 in 1.4). Če predpostavimo, da je povečanje hitrosti toka osuševalnega zraka kompenzacijska spremenljivka, lahko ustaljeno lastnost (sl. 3.1) uporabimo v izračunih, ki posledično vplivajo na spremembo hitrosti zraka za vrednost Δv_{air}. Zdaj tudi ugotovimo, da imajo dinamične lastnosti temperaturne spremembe in hitrosti spremembe zračnega toka podobne časovne stalnice. To pomeni, da bo končno delovanje podobno, takšno, kakršnega prikazuje polna krivulja na sliki 1.4.

property shown in Figure 2.1. The correction of the dryer functions, based on the data regarding the modification of the final moisture content suggests that at least one filling with an undesired final moisture content has to be passed through.

By measuring the initial moisture content of the kernel for the purpose of obtaining qualitatively dried kernels, several parameters can be affected on time. They are:
- an increase in the drying-air temperature,
- an increase in the drying-air velocity flow,
- a prolongation of the drying period.

According to Figure 1, removing the initial moisture content of the kernel, w_i, can be accomplished by increasing the drying-air temperature by Θ_{air}, which is calculated using the static properties shown in Figure 2.2 for a specific material that is being dried. The solid line shown in Figure 1.3 shows the change in the drying-air temperature that is required to achieve the most efficient correction of the final moisture content of the kernel. This will lead to the final moisture content of the kernel shown with the solid line in Figure 1.4. If the temperature changes begin later, as shown with the dashed line in Figure 1.3, the final moisture content of the kernel will have a greater error and will exist for longer than in the first case (the dashed line in Fig. 1.4.). An unsatisfactory result will also be achieved if there is a large effect on the temperature increase. In this case the final moisture content of the kernel will take an error of the opposite sign (the dotted lines shown in Figs. 1.3. and 1.4.). If an increase in the velocity of the drying air flow is considered as a compensating variable, then the static property (Fig. 3.1.) can be used in calculations, which subsequently affects the change in the air velocity by Δv_{air}. Furthermore, it is clear that the dynamic properties of the temperature change and the velocity of the air-flow change have similar time constants. This means that the final functioning will be similar, as shown in the solid curve in Figure 1.4.

Merila za odločitev med tema dvema funkcijama so tehnološka in ekonomska. Krmilnik izvaja izračune, s katerimi ugotavlja, katera možnost je optimalna. Še več, krmilnik ima že nastavljena tehnološka merila, po katerih najvišja temperatura osuševalnega zraka ne sme biti presežena, povečanje hitrosti zračnega toka pa ne sme povzročiti utekočinjenja.

Če zgoraj opisani primeri vsebujejo kakršnakoli tveganja, jih lahko preprečimo z ukrepi, kot npr. upočasnitev gibanja zrn skozi sušilnico s podaljšanjem osuševalnega časa ali z zmanjšanjem zmogljivosti sušilnice.

V praksi manjšanje zmogljivost sušilnice sicer ni običajno; kljub temu pa v primeru, ko ima sušilnica neprimerno zmogljivost, ki ne ustreza naravnim razmeram osuševanja zrna, lahko pride do povečane rabe energije, velikih razlik v deležu vlage v zrnih, tveganega skladiščenja in celo nevarnosti požara.

The criteria for choosing between these two functions are technological and economic. The controller performs calculations to determine which of them is optimal. Moreover, it has already set technological criteria, i.e., that the maximum drying-air temperature cannot be exceeded, and that the increase in the velocity of the air flow must not cause a fluidization process.

If there is any hazard in the above-mentioned situations, there are some measures that need to be taken, such as slowing down the kernel's movement through the dryer by prolonging the drying period or by decreasing its capacity.

In practice it is not common to decrease the capacity of a dryer; however, if the dryer has an inadequate capacity, which does not match the kernel's natural conditions, i.e., its drying possibilities, this leads to an increase in energy consumption, large differences in the kernel's moisture content, unsafe storage and a possible fire hazard.

3 SKLEP

Ne glede na finančne možnosti lastnikov sušilnic in njihovo opremljenost predmeti, izbrani za nadzor, upravljanje in vodenje osuševalnega postopka, žal ne ustrezajo trenutnim zahtevam v Republiki Hrvaški ali v tujini. Ne le, da niti najbolj moderno opremljene sušilnice niso optimalno izkoriščene, njihovo delovanje ustvarja velike stroške in daje nezanesljive rezultate. Na podlagi raziskovalnih poročil in poznavanja moderne mikroprocesorske tehnologije lahko priporočimo rabo zgoraj opisane rešitve, tj. namestitev krmilnikov, ki bodo krožno izvajali potrebne izračune. Ti izračuni so temelj za upravljanje s spremenljivkami, ki se v določenem obdobju spremenijo, kar vodi v optimizacijo osuševalnega postopka v gravitacijskih sušilnicah.

Dodatna prednost opisanega predloga je v tem, da je mogoče tehnična dela in finančne vložke investitorja izvesti postopno. Rezultati predlagane rešitve so izboljšano in poenoteno delovanje sušilnice, manjša poraba energije in boljša kakovost osušenih zrn.

3 CONCLUSION

Plants designated for process monitoring, managing and conducting, unfortunately, do not meet the present solutions in the Republic of Croatia nor abroad, no matter what the financial potentials of the dryer's owner are or what equipment is available. Indeed, even the most modern equipped dryers are not only non-optimised, but in fact represent high costs and unreliable results. Based on such reports and knowledge regarding the modern achievements of microprocessor technology, it is advisable to introduce the above given solution, i.e., to introduce controllers that will perform calculations cyclically. These are a basis for managing the variables, so that they are modified by their value during a certain period, which consequently leads to optimization of the drying process in gravity dryers.

An additional property of the proposed solution is the possibility to realize in phases the technical equipment and the financial possibilities of the investor. The results are better and uniform dryer functions with lower energy consumption and a better kernel quality.

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Naslov avtorjev: mag. Neven Voća
prof. dr. Tajana Krička
Vanja Janušić
Univerza v Zagrebu
Fakulteta za kmetijstvo
Svetošimunska 25
10 000 Zagreb, Hrvaška
nvoca@agr.hr

Authors' Address: Mag. Neven Voća
Prof. Dr. Tajana Krička
Vanja Janušić
University of Zagreb
Faculty of Agriculture
Svetošimunska 25
10 000 Zagreb, Croatia
nvoca@agr.hr

Prejeto: 13.3.2006
Received:

Sprejeto: 22.6.2006
Accepted:

Odprto za diskusijo: 1 leto
Open for discussion: 1 year