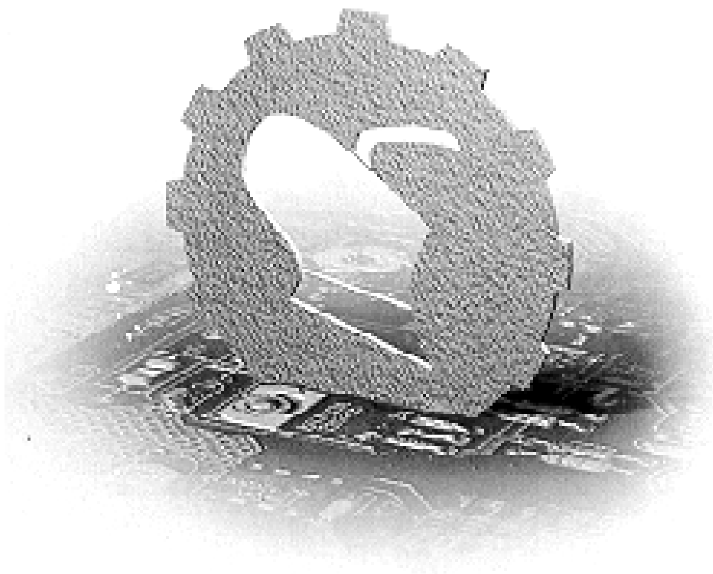
ISSN 0554-5587
UDK 631 (059)

ПОЉОПРИВРЕДНА ТЕХНИКА
AGRICULTURAL ENGINEERING

НАУЧНИ ЧАСОПИС
SCIENTIFIC JOURNAL



УНИВЕРЗИТЕТ У БЕОГРАДУ, ПОЉОПРИВРЕДНИ ФАКУЛТЕТ,
ИНСТИТУТ ЗА ПОЉОПРИВРЕДНУ ТЕХНИКУ
UNIVERSITY OF BELGRADE, FACULTY OF AGRICULTURE,
INSTITUTE OF AGRICULTURAL ENGINEERING

Година XXXVIII Број 2, 2013.
Year XXXVIII, No. 2, 2013.

Издавач *(Publisher)*
Универзитет у Београду, Пољопривредни факултет, Институт за пољопривредну технику, Београд-Земун
University of Belgrade, Faculty of Agriculture, Institute of Agricultural Engineering, Belgrade-Zemun

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11080 Belgrade-Zemun, str. Nemanjina No. 6, Tel. 2194-606, 2199-621, fax: 3163-317, 2193-659, e-mail: gogi@agrif.bg.ac.rs , Account: 840-1872666-79

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Техничка припрема ***(Technical editor)***

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Штампа ***(Printed by)***

"Академска издања" – Земун
Часопис излази четири пута годишње

Тираж ***(Circulation)***

350 примерака

Pretplata za 2014. godinu iznosi 2000 dinara za institucije, 500 dinara za pojedince i 100 dinara za studente po svakom broju časopisa.

Радови објављени у овом часопису индексирани су у базама ***(Abstracting and Indexing)***:

AGRIS i SCIndeks

Издавање часописа помогло ***(Publication supported by)***
Министарство просвете и науке Републике Србије

Na osnovu mišljenja Ministarstva za nauku i tehnologiju Republike Srbije po rešenju br. 413-00-606/96-01 od 24. 12. 1996. godine, časopis POLJOPRIVREDNA TEHNIKA je oslobođen plaćanja poreza na promet robe na malo.

S A D R Ž A J

C O N T E N T S

Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XXXVIII
Broj 2, 2013.
Strane: 1 – 11

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XXXVIII
No. 2, 2013.
pp: 1– 11

UDK: 631.147

Originalni naučni rad
Original scientific paper

SPECTROSCOPIC APPROACH OF WINTER WHEAT (*Triticum aestivum L.*) NUTRITION AND PEST CONTROL

Kornél D. Szalay[1*], József Deákvári[1], Ádám Csorba[1], Ferenc Firtha[2], Gábor Milics[3]

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Abstract: Laboratory reflectance spectroscopy is a routine evaluation technique in many scientific areas. The objective is to present the capabilities of a portable spectro-radiometer which can be used both for field and laboratory examinations. In this study an ASD FieldSpec 3 Max spectro-radiometer was used in two different application forms to analyze the reflected electromagnetic radiation in the wavelength range of 350 to 2500 nm. The study introduces some preliminary results of nutrient sensitive changes in winter wheat spectra and brings on the necessity of high resolution spectral testing of insect luring, repelling illuminants.

Key words: *spectroscopy, winter wheat, pest control*

INTRODUCTION

Spectroscopy studies the interaction between electromagnetic radiation and matter. The method of evaluating the spectral characteristics of different biotic or abiotic materials and surfaces originates in the laboratory spectroscopy, where it is generally used in physical and analytical chemistry hence atoms and molecules have unique spectra. Today the technological development has made possible to carry out high spectral resolution in-field analysis and airborne hyperspectral imaging and

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created new perspective for information management in site specific agricultural production [1, 2, 3].

In 2010 our Institute purchased an ASD FieldSpec 3 Max portable spectro-radiometer. The equipment can be widely used both in field and under laboratory circumstances. It is adequate to carry out independent, fast and precise evaluations in an economic way but also used to correct and validate simultaneous or near simultaneous airborne remote sensing data. This spectral sampling method results in the mean reflectance spectrum of the instantaneously scanned surface [4].

The device extends the range of the detectable visible light [5, 6, 7, 8] to NIR (near infrared) and the SWIR (shortwave infrared) region and covers the range of 350 to 2500 nm. Characteristic near infrared wavelengths can indicate changes in moisture content of vegetables [9]. Beyond the moisture content other relevant parameters can modify spectral characteristics [10], thus such wide spectral range can also increase the efficiency of computer vision based automatic fruit or crop inspection [11]. Though, the processing of these images is a very complex procedure [12]. In case the coordinates of in-field measurements are recorded the surficial spectrum can be fitted to the adequate pixel of a hyperspectral airborne image that is an important element of the subsequent evaluation processes. The number and the quality of in-field measurements determine the final accuracy of the airborne images.

The technology provides opportunity to obtain quantitative relationships between the environmental and physiological parameters of the vegetation [13, 14, 15, 16, 17], soil quality parameters [18, 19, 20] and the features of reflectance spectra (Fig. 1).

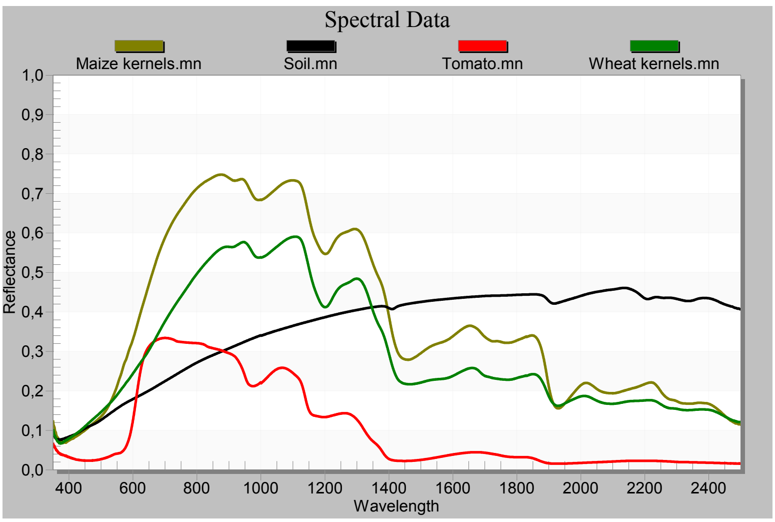


Figure 1. Distinctive spectral features of different samples

In this study we are introducing the technological basis of reflectance spectroscopy with preliminary results of segregating various nutrition levels in winter wheat production and a possible way to further increase the efficiency and/or selectivity of a new generation pest control system.

MATERIAL AND METHODS

For laboratory tests we constructed a light-isolated cabinet where disturbing environmental light is shielded. The ASD Field Spec®3 MAX portable spectro-radiometer (Fig. 2) and the laboratory cabinet are presented in Figure 14. Two methods of data acquisition are possible according to the size and physical parameters of the object to be tested. ProLamp (Fig. 3) is used to illuminate the object from a distance of 30-70 cm. Measurements of small object areas can be carried out with PlantProbe sensor-head (Fig. 4) which has internal light source. Technical parameters of the spectro-radiometer are summarized in Table 1.

Figure 2. ASD Field Spec®3 MAX

Figure 3. Laboratory cabinet

Figure 4. ProLamp light source

Figure 5. PlanProbe sensor-head

Table 1. Technical parameters of ASD Field Spec®3 MAX

	ASD Field Spec®3 MAX
Spectral range [nm]	*350 – 2500*
Spectral sampling band [nm]	*1.4 – 2*
Spectral bands	*2150*
Spatial pixels	*1*
Spectral depth [bit]	*16*
Image rate [image]	*Up to 100 ms*
FOV [degree]	*1, 8, 25*
Detectors	*Si and two InGaAs*

RESULTS AND DISCUSSION

Identifying different nutrition levels of winter wheat

Experiments were carried out to identify spectral differences of winter wheat treated with various nutrient dozes. 'Alföld 90' winter wheat variety was tested on agronomic replicated blocks (Fig. 6 and Fig. 7).

Figure 6. 'Alföld 90' winter wheat

Figure 7. Agronomic replicated blocks

Each replication had two variants: fertilized and unfertilized. Fertilized variants received 80 kg ha-1 nitrogen fertilizer. Samples were collected and analyzed in laboratory. The analysis of the protein (Fig 8) and the wet gluten content (Fig 9) approved the correlation with the amount of ammonium-nitrate fertilizer. As a result of the treatment all values decreased significantly. Protein content with nitrogen fertilizer (80 kg) and without (0 kg)

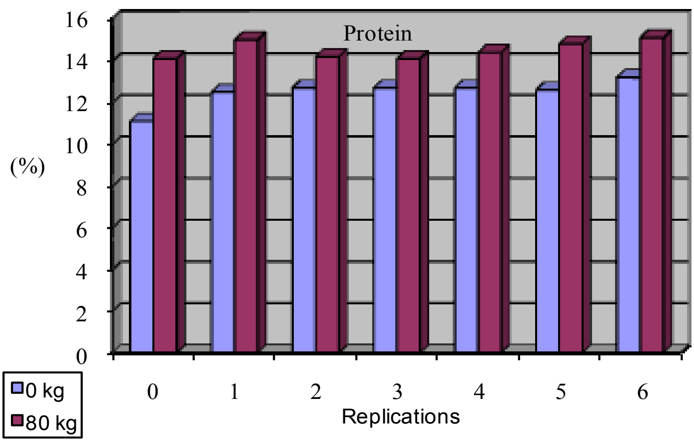


Figure 8: Yield with nitrogen fertilizer (80 kg) and without (0 kg)

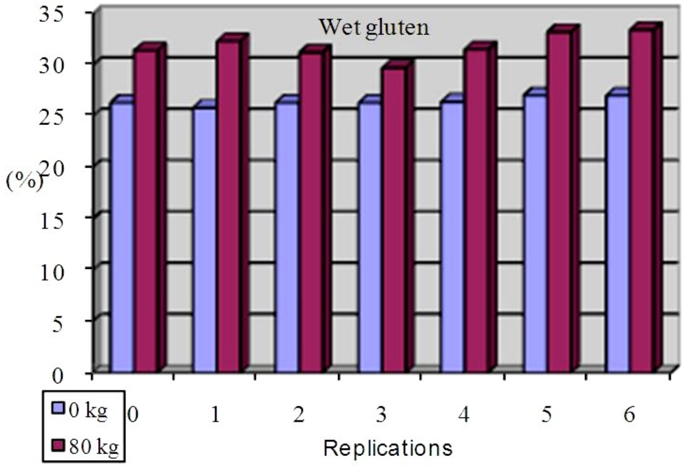
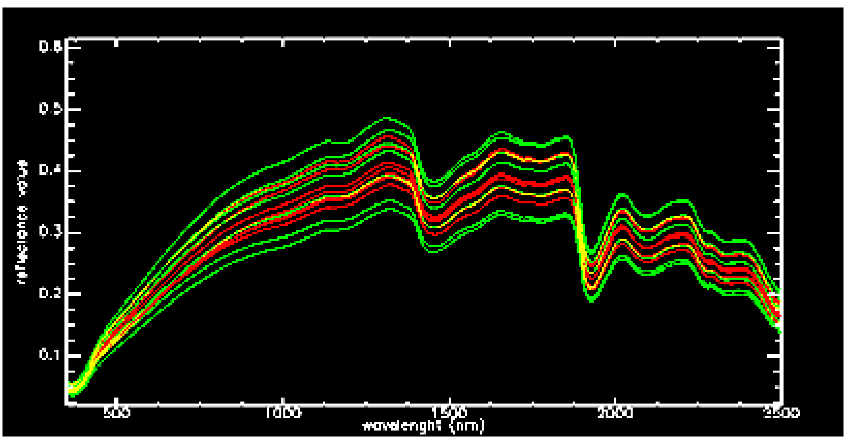


Figure 9: Wet gluten content with nitrogen fertilizer (80 kg) and without (0 kg)

Wheat ears were illuminated with ProLamp, kernel were tested with PlantProbe. Processing steps were carried out with ENVI software. We used continuum removal to normalize spectra. This made possible to compare the absorption features according to the common baseline (ITTVIS ENVI).

The mean reflectance spectra of the treatments were computed when evaluating the wheat ears and kernels by spectro-radiometry. Dashed line represents the nitrogen fertilized, while solid the not fertilized crops. Mean reflectance spectra of treatments are presented by Figure 10.

Normalized reflectance spectra with characteristic interval between 1700 nm and 1800 nm wavelength values were found in case of wheat ears and 500 to 800 nm at kernels (Fig 11).



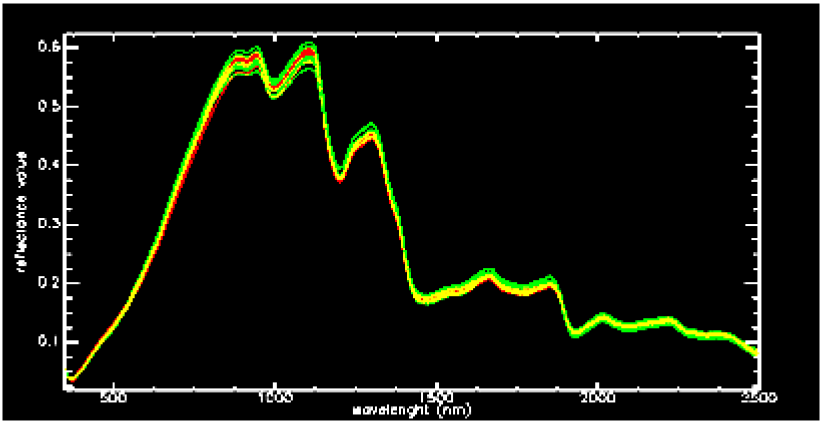


Figure 10. Normal reflectance curves of wheat ears (up) and kernels (down) with (80 kg - red) and without fertilizer (0 kg – green lines)

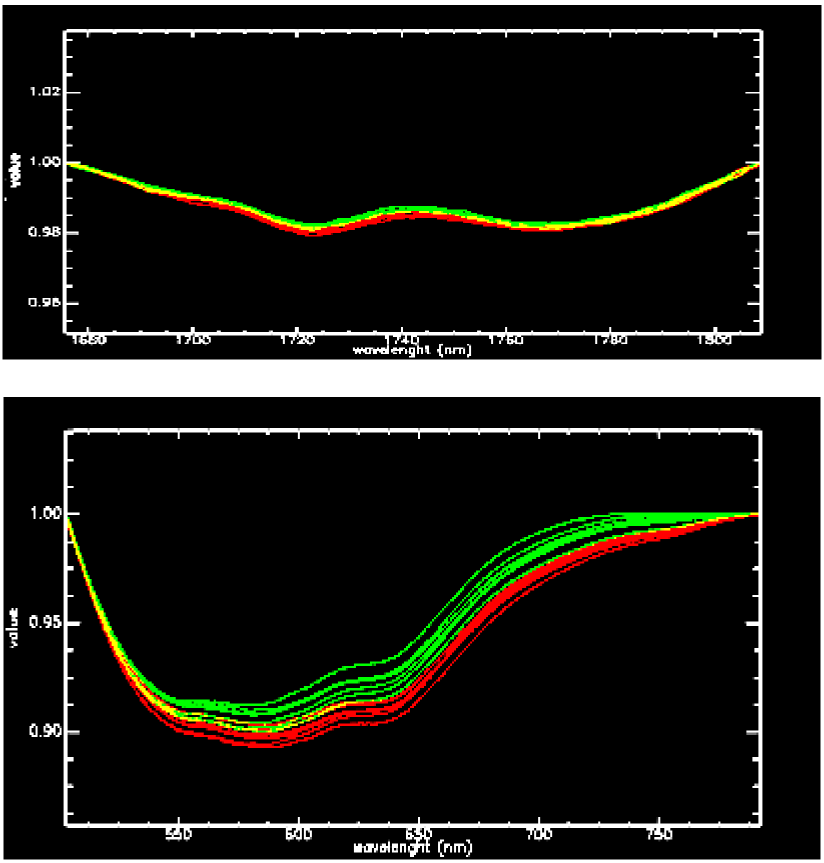


Figure 11. A decreasing trend is indicated in the spectra of nitrogen treated (80 kg - red) wheat ears (up) and kernels (down) compared to untreated ones (0 kg – green lines)

Differences in nitrogen treatment generated changes in spectral features of wheat ears and kernels. After normalizing the spectra we found two characteristic intervals in the wavelength range of 500 to 800 nm for wheat kernel and 1650 nm to 1800 nm for wheat ear samples. Both treatments show the same trend. After evaluating the most important parameters of the winter wheat (yield, protein, wet gluten content) with conventional laboratory technology the interrelation between spectra and nutrition application rate can be determined. Through calibration and validation process spectral instruments can contribute to better description and traction of nutrient supply and plant up-take.

Spectral evaluation of artificial illuminants

By the principle of pest's phototaxis and nocturnal habits the Shenzhen Fuwaysun Technology Co., Ltd. has developed a Solar Insect Killer (Fig. 12) - 1. solar cell, 2. power device with battery, 3. light bulb, 4. insect trap.

Figure 12. (FWS-SP05-12/2 type Solar Insect Killer at the MACFRUT 2011. exhibition)

Various illuminants are used to lure different insects into the trap which are very important elements of the system. There are two types, bulbs with wide and with narrow spectral characteristic. Nineteen narrow band illuminants are provided by the manufacturer (310 nm, 320 nm, 340 nm, 351 nm, 360 nm, 365 nm, 368 nm, 380 nm, 385 nm, 400 nm, 420 nm, 445 nm, 460 nm, 480 nm, 520 nm, 525 nm, 545 nm, 560 nm, 575 nm). The aim of our project was to evaluate the spectral distribution of each bulb in the wavelength range of 350-2500 nm.

In situ (Fig. 13) and ex situ measurements were made under laboratory circumstances (Fig. 14) - 1. Light bulb, 2. reference panel, 3. optical cable with 8° optic, 4. ASD FieldSpec 3 max - to determine the spectral feature of each illuminant.

The results showed that even the narrow band illuminants have several spectral peaks in the visible region and some bulbs have peaks in NIR range as well (Fig. 15 and 16).

Figure 13. In situ measuring method

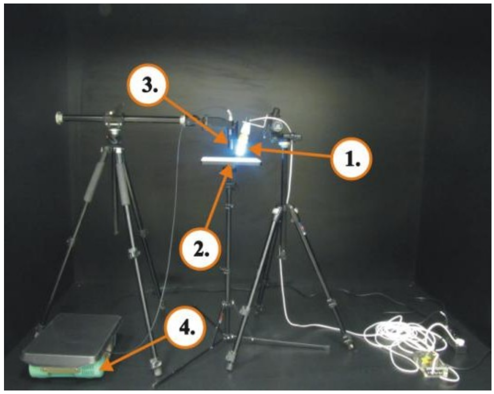


Figure 14. Measurement in laboratory cabinet

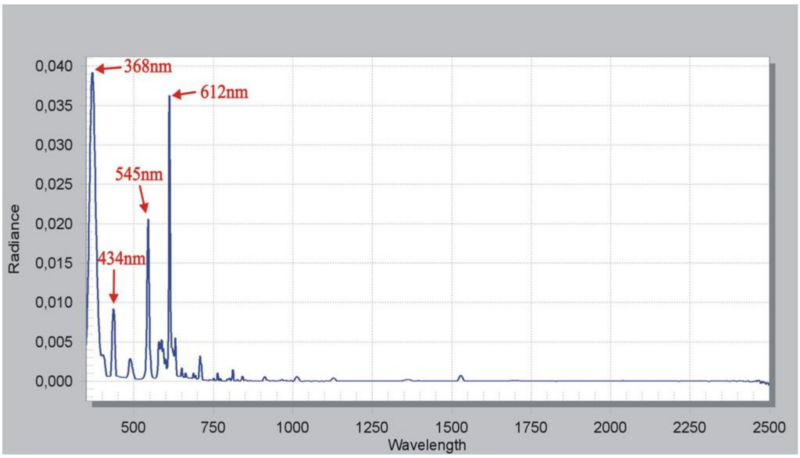


Figure 15. Narrow band illuminant 368 nm

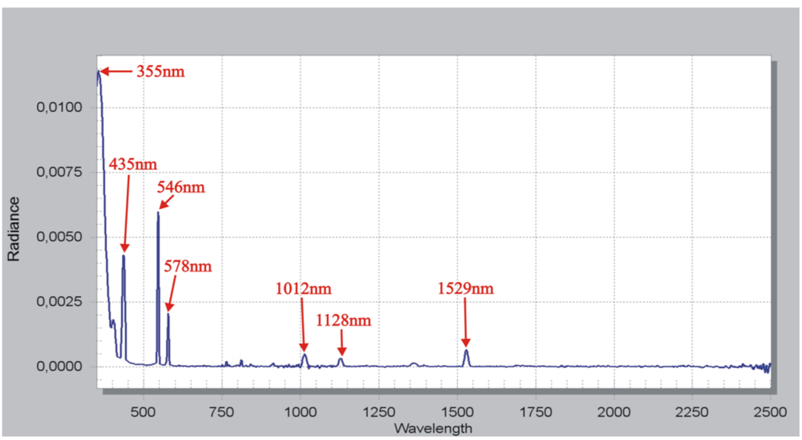


Figure 16. Narrow band illuminant 351 nm

The high resolution spectro-radiometer can enhance the specification of light sources. As insects have very fine and special sensitivity to EM radiation so a more precise selection (ex- or inclusion) of relevant spectral peaks can help even a species specific luring or repelling effect.

CONCLUSIONS

The application of the high resolution spectro-radiometer has been proved useful in two absolutely different application areas. We found two characteristic intervals in the wavelength range of 500 to 800 nm for wheat kernel samples and 1650 nm to 1800 nm for wheat ear samples where both treatments show the same trend. Different nitrogen fertilizer doses resulted in different quantity and quality parameters of the tested wheat variety. Differences also generated changes in spectral features of ears and kernels. Our measurements showed that even the narrow band illuminants have several spectral peaks. With the presented evaluation method the classification of illuminants can be facilitated and refined. A more precise selection of relevant spectral characteristic can further increase the luring or repelling effect of illuminants.

BIBLIOGRAPHY

[1] Papp, Z., Fenyvesi, L. 2007. Új távérzékelési módszer a mezőgazdaságban és a környezetgazdálkodásban *Mezőgazdasági Technika* 1: pp. 26-28.

[2] Fenyvesi, L. 2008. Characterization of the soil - plant condition with hyperspectral analysis of the leaf and land surface, *Cereal Research Communication*, (Supp 5) 659-663 pp.

[3] Késmárki-Galli, Sz., Papp, Z., Fenyvesi, L. 2008. Investigations of the agro-ecosystems with remote sensing *Cereal Research Communication* 36:(Supp 5) pp. 655-659.

[4] Virág, I., Szőke, Cs. 2011. Field and laboratory examinations of corn plants by means of hyperspectral imaging. *10 th Alps-Adria Scientific Workshop*. Növénytermelés. Opatija, Croatia 69-72 pp.

[5] Lágymányosi, A., Szabó, I. 2011. Investigation of chaff surface with imaging (In Hungarian). Fiatal Műszakiak Tudományos Ülésszaka XVI., *Kolozsvár Műszaki Tudományos Füzetek* 177-180 pp.

[6] Lágymányosi, A., Szabó, I. 2009. Calibration procedure for digital imaging, Synergy and Technical Development, Gödöllő, Hungary, 30. *Synergy 2009 CD-ROM Proceedings*

[7] Lágymányosi, A., Szabó, I. 2011. Imaging method for length estimation of the willow sclice. *Mechnaical engineering letters*, SzentIstván University Vol. 7. pp 53-60.HU ISSN 2060-3789

[8] Lágymányosi, A., Szabó, I. 2010. Investigation of chopped willow geometrical parameters with imaging. *CIGR Workshop on Image Analysis in Agriculture*, 26-27. August 2010, Budapest

[9] Fekete, A., Nagy, M., Kaszab, T. 2007. Estimation of Fruit Mass Loss by Optical Method. *Annual International Meeting of ASABE*, Minneapolis, Paper Number 076110. www.asabe org

[10] Erdeiné Késmárki-Gally, Sz., Fenyvesi, L., Papp, Z. 2009. Examination of soil and plant biotic and abiotic stress factors by thermal and hyperspectral remote sensing methods *Cereal Research Communication* 37:(513) p. 516.

[11] Cubero, S., Moltó, E., Gutiérrez, A., Aleixos, N., García-Navarrete, O., L., Juste, F., Blasco, J. 2010. Real-time Inspection of Fruit by Computer Vision on a Mobile Harvesting Platform under Field Conditions. *Progress in Agricultural Engineering Sciences* 6, 1–16 pp. DOI: 10.1556/Progress.6.2010.1

[12] Fekete, A., Nagy, M., Kaszab, T. 2007. Alma felületi jellemzőinek mérése képfeldolgozással. MTA-AMB XXXI. *Kutatásiés Fejlesztési Tanácskozás kiadványa*, Gödöllő.79-83.

[13] Erdélyi, É. 2009. Benefit and detriment of changing climate in crop production, In: *Workshop on Modeling and Measuring Aspects of some Environmental Issues in European Union and National Projects*, 2009, Novi Sad, Serbia

[14] Erdélyi, É., Horváth, L. 2006. Climate Change and Precipitation Needs of Winter Wheat, *Summer University on Information Technology in Agriculture and Rural Development*, Debrecen, 33-40 pp.

[15] Erdélyi, É., Boksai, D., Szenteleki, K., Hufnagel, L. 2009. The role of biomass in mitigation of global warming. *CIGR Symposium . 2009*.09.1-4., Rosario, Argentina

[16] Balla, I., Szentpétery, Zs., Jolánkai, M. 2011. The impact of precipitation on crop yield in a small-plot winter wheat (*Triticumaestivum L.*) trial series. *X Alps-Adria Scientific Workshop*. Növénytermelés. Opatija, Croatia 309-313 pp.

[17] Klupács, H. Tarnawa, Á., Balla, I., Jolánkai, M. 2010. Impact of water availability on winter wheat (*Triticumaestivum L.*) yield characteristics. *Agrokémiaés Talajtan* vol. 59 no. 1 (2010), 151-156 pp.

[18] Stefonovits, P., Micheli, E., Fenyvesi, L. 1989. Infrared reflectance of artificially prepared organo - mineral complexes. *International Agraphysics* 1989. 99-105 pp.

[19] Máthé, L., Pillinger, Gy., Kiss, P. 2010. Vályogtalaj mechanikai jellemzőinek vizsgálata a nedvességtartalom és ülepedettség függvényében. *XV. Fiatal Műszakiak Tudományos* Ülésszaka, Kolozsvár, Románia, 2010, pp. 201-204. ISSN 2067-6 808

[20] Tolner, I.T. 2011. Investigation of the effects of various acid treatments on the optical reflection spectra of a soil sample. *10 th Alps-Adria Scientific Workshop.* Növénytermelés. Opatija, Croatia 207-210 pp.

SPEKTROSKOPSKI PRISTUP ISHRANI I ZAŠTITI OZIME PŠENICE (*Triticum aestivum L.*)

Kornél D. Szalay[1], József Deákvári[1], Ádám Csorba[1], Ferenc Firtha[2], Gábor Milics[3]

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Sažetak: Laboratorijska refleksna spektroskopija je uobičajena tehnika evaluacije u mnogim naučnim oblastima. Cilj je da se predstave mogućnosti portabl spektroradiometra koji može da se koristi kako za poljska, tako i za laboratorijska ispitivanja. U ovom istraživanju upotrebljen je spektro-radiometar ASD FieldSpec 3 Max u dve različite aplikacione forme za analizu reflektovanog elektromagnetnog zračenja u opsegu talasnih dužina od 350 do 2500 nm. U radu su predstavljeni neki preliminarni rezultati osetljivih promena nutrijenata u spektru ozime pšenice i doprinos neophodnosti visoke rezolucije spektralnog testiranja svetlećih tela za privlačenje i odbijanje insekata.

Ključne reči: *spectroscopy, winter wheat, pest control*

Prijavljen: *Submitted*:	25.03.2013.
Ispravljen: *Revised*:	02.04.2013.
Prihvaćen: *Accepted*:	10.04.2013.

Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
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Scientific Journal
AGRICULTURAL ENGINEERING
Year XXXVIII
No. 2, 2013.
pp: 13 – 22

UDK: 631.51.01

Originalni naučni rad
Original scientific paper

SOIL MOISTURE INFLUENCE ON THE ENERGY OF AGRICULTURAL PROCESSES

Petru Cardei*, **Mihai Ludig**

National Institute of research – development for machines and installations designed to agriculture and food industry (INMA), Bucharest, Romania

Abstract: This article exposes the results related to one of the issues left open after a series of articles mentioned in the bibliography, which occurred in the years 2011-2013. A series of articles that were mentioned before reconsidered the workflow optimization problem of agricultural aggregates developing fundamental calculation in the 1950-1980s literature. Some open problems still arise from the theoretical and empirical reasoning. A solution to one of these problems is given in this article. The solution exposes an input mode of the soil moisture influence on the existence and quantification of possible optimal point in the space energy workflow of agricultural aggregates.

Key words: *soil, moisture, optimal points, influence, agriculture, processes*

INTRODUCTION

The importance of the working regime optimization issue of agricultural processes is not appropriate to be highlighted in this paper. The importance of this problem is exacerbated by the need to reduce fossil fuel consumption and pollutant emissions, but on the other hand, the need to increase food production and safety, generated in turn by rising of the global population.

In this context, anticipating less severity these phenomena, the optimal research from the last half of the twentieth century, opened a number of issues, solved in theory and using computation techniques within the reach during those years. After 1990, and especially in recent years, I reopened this issue, due to the identification of interesting and deeper ways. The main direction of these deeper studies was determined by more

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advanced computing compared to the one available at the time when the problem appeared. With the birth of computers, it enabled the use of numerical experiments (simulations) in computation and thus the use of very time consuming optimization techniques. In addition to these directions of study, a fundamental problem appeared not only in mathematical terms but also as a physical theory of optimal points existence. It is well known that in general the dynamic processes described by linear operators don't have critical points in operation and in this regard, it was quite clear that the classical models of the work processes of agricultural aggregates were less likely to naturally give optimal points as minimal - maximal results of functions that are natural for the following processes: force, power, energy, fuel, ability to work, or combinations thereof. Articles [1] - [6], [9], [10] include our efforts in the two fields: to deepen the computational study in the sense of natural optimizing based on the above objective function and finding physical causes that lead to nonlinearities in describing the concerned processes, generators of some optimal natural points (obtained as a result of minimizing or maximizing some of the aforementioned objective functions).

In [11], [12], [13] and [14], for example, such nonlinearities were introduced in some drag opposing components of agricultural machinery, without a precise physical link. Such coefficients were introduced without a physical interpretation but only to obtain optimal points that are deductible using classical mathematical analysis tools.

In [2], [3], [4], [5] and [6] we extended the calculation for classical optimization and for some aggregate types for which it was not developed. We constantly tried to develop a common method for all units, computing differences were only given by each specific work process. We also permanently tried expressing the methods in a classical language of discrete mechanical systems and continuum mechanics. All results related to the same problems are presented in [7] and [8].

Starting with [2], [3], [4], [5], [6] emerged the question of physical grounding nonlinearities introduced in optimal calculation, i.e. placing them in friction expressions and soil resistance to deformation, also possibly to power-take-off resistance. In [9] and [10], this nonlinear problem is treated as the main subject and the as possible effects. In these last works it is shown that expressions terms coefficients that express resistances of various types may depend on soil moisture and crop residues and other physical and chemical characteristics of the soil and vegetation.

This article gives many examples of modeling the influence of humidity on energy optimization of agricultural aggregates work processes.

MATERIAL AND METHODS

The material from which construction starts is introduced based on (1) or on [9], formulas (3). These formulas have been used for energy optimizing work processes listed in the bibliography. The list of the parameters involved in the models appear in Table 1. Description of soil moisture introduction method in nonlinear expressions of resistance is given in this article only for the friction formula between wheels and ground (tractor wheel and agricultural machinery wheel). The other extensions will undergo similar transformations. The formulas for nonlinear functions of soil friction and resistance to deformation are:

Table 1. Significance of the parameters of the mathematical models

Parameters	*Notation*	*Unit*
Function of friction between the tractor wheels and the ground	f	-
Function of sliding friction of the machine with the ground	μ	-
Function of soil deformation resistance	k	$N\cdot m^{-2}$
Coefficients defining the critical points of the function of friction f	f_0, f_1	-
Coefficients defining the critical points of the function of friction μ	μ_0, μ_1	-
Coefficients defining the critical points of the function of soil deformation resistance, k	k_0, k_1	$N\cdot m^{-2}$
Coefficients defining the critical points of friction and resistance functions, f, μ, k (speed significance)	$v_f, v_{f0}, v_{f1}, v_\mu, v_{\mu0}, v_{\mu1}, v_k, v_{k0}, v_{k1}$	$m\cdot s^{-1}$
Coefficients defining the critical points of friction and resistance functions, f, μ, k (moisture significance) in terms of soil moisture	$u_{f00}, u_{f01}, u_{f10}, u_{f11}, u_{v00}, u_{v01}, u_{v10}, u_{v11}$	-
Coefficients which produce the function critical point deviation cauzed by the moisture	$\delta, \delta_{f0}, \delta_{f1}, \delta_v, \delta_{v0}, \delta_{v1}$	-
Soil moisture influence function	W	$N\cdot m^{-2}$
Minimum and maximum values of the influence function	W_0, W_1	
Minimum and maximum soil moisture of influence function	u_0, u_1	-
Coefficient of amplitude of soil moisture influence function	α	-
Soil moisture	u	-

$$
\begin{aligned}
f(v) &= f_0 + 2\frac{f_1 - f_0}{v_f}v + \frac{f_0 - f_1}{v_f^2}v^2,\\
\mu(v) &= \mu_0 + 2\frac{\mu_1 - \mu_0}{v_\mu}v + \frac{\mu_0 - \mu_1}{v_\mu^2}v^2,\\
k(v) &= k_0 + 2\frac{k_1 - k_0}{v_k}v + \frac{k_0 - k_1}{v_k^2}v^2
\end{aligned}
\tag{1}
$$

or the formulas proposed in [9]:

$$
\begin{aligned}
f(v) &= f_1\left\{1 - \exp\left[-\frac{2v^3 - 3\left(v_{f1} + v_{f0}\right)v^2 + 6v_{f0}v_{f1}v}{v_{f0}^2\left(v_{f0} - 3v_{f1}\right)}\ln\left(1 - \frac{f_0}{f_1}\right)\right]\right\},\\
\mu(v) &= \mu_1\left\{1 - \exp\left[-\frac{2v^3 - 3\left(v_{\mu1} + v_{\mu0}\right)v^2 + 6v_{\mu0}v_{\mu1}v}{v_{\mu0}^2\left(v_{\mu0} - 3v_{\mu1}\right)}\ln\left(1 - \frac{\mu_0}{\mu_1}\right)\right]\right\},\\
k(v) &= k_1\left\{1 - \exp\left[-\frac{2v^3 - 3\left(v_{k1} + v_{k0}\right)v^2 + 6v_{k0}v_{k1}v}{v_{k0}^2\left(v_{k0} - 3v_{k1}\right)}\ln\left(1 - \frac{k_0}{k_1}\right)\right]\right\}
\end{aligned}
\tag{2}
$$

The method of introducing moisture dependence is simple: formula coefficients (1) or (2) all or a part of them, turn from constant to moisture functions. In order to introduce moisture in functions (1) and (2) a very simple formula for moisture influence is used:

$$W(u)=\frac{W_0+W_1}{2}+\frac{\alpha\cdot\left(W_1-W_0\right)}{2}\sin\left(\frac{3\pi u}{u_0+u_1+2\delta}\right) \tag{3}$$

The function W can be the same for all parameters involved in the formula of a friction function or different for each one. The form (3) of a function humidity influence function is not necessary. The authors can modify the model to achieve as fair as possible representation of reality using experimental data and the method of the smallest squares. Moisture influence function for each formula parameter (1) and (2) will be specified by moving the W function to index, in this article, the general form (3) being considered for all parameters.

RESULTS AND DISCUSSION

As a transformation example it will only be given the first formula in (1) and (2) the other formulas being similar. In the first stage, the first formula from (1) turns into:

$$f\left(v,u\right)=F_0\left(u\right)+2\frac{F_1\left(u\right)-F_0\left(u\right)}{V_f\left(u\right)}v+\frac{F_0\left(u\right)-F_1\left(u\right)}{V_f^2\left(u\right)}v^2 \tag{4}$$

where the constants are replaced by the moisture influence functions:

$$\begin{aligned}
F_0(u)&=\frac{f_{00}+f_{01}}{2}+\frac{\alpha\cdot\left(f_{01}-f_{00}\right)}{2}\sin\left(\frac{3\pi u}{u_{f00}+u_{f01}+2\delta_{f0}}\right),\\
F_1(u)&=\frac{f_{10}+f_{11}}{2}+\frac{\alpha\cdot\left(f_{11}-f_{10}\right)}{2}\sin\left(\frac{3\pi u}{u_{f10}+u_{f11}+2\delta_{f1}}\right),\\
V_f(u)&=\frac{v_{f0}+v_{f1}}{2}+\frac{\alpha\cdot\left(v_{f0}-v_{f1}\right)}{2}\sin\left(\frac{3\pi u}{u_{v10}+u_{v11}+2\delta_{v}}\right)
\end{aligned} \tag{5}$$

For the first nonlinear expression (2), instead of the last relation in (5) two similar relationships appear:

$$V_{f0}(u) = \frac{v_{f00} + v_{f01}}{2} + \frac{\alpha \cdot (v_{f00} - v_{f01})}{2} \sin\left(\frac{3\pi u}{u_{v00} + u_{v01} + 2\delta_{v0}}\right),$$
$$V_{f1}(u) = \frac{v_{f10} + v_{f11}}{2} + \frac{\alpha \cdot (v_{f10} - v_{f11})}{2} \sin\left(\frac{3\pi u}{u_{v10} + u_{v11} + 2\delta_{v1}}\right) \quad (6)$$

When the friction function expression relations (2) take the next form:

$$f(v,u) = F_1(u) \cdot$$
$$\cdot \left\{1 - \exp\left[-\frac{2v^3 - 3\left(V_{f1}(u) + V_{f0}(u)\right)v^2 + 6V_{f0}(u)V_{f1}(u)v}{V_{f0}^2(u)\left(V_{f0}(u) - 3V_{f1}(u)\right)} \ln\left(1 - \frac{F_0(u)}{F_1(u)}\right)\right]\right\} \quad (7)$$

The behavior of the friction function, modeled by (6) is plotted in Fig. 1, 2 and 3.

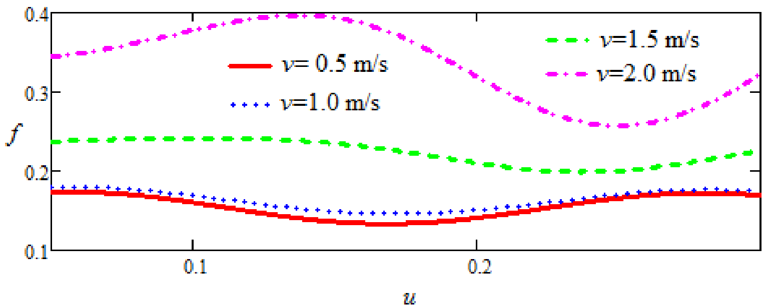

Figure 1. Dependence of f on the soil moisture, u for four values of speed, version (1)

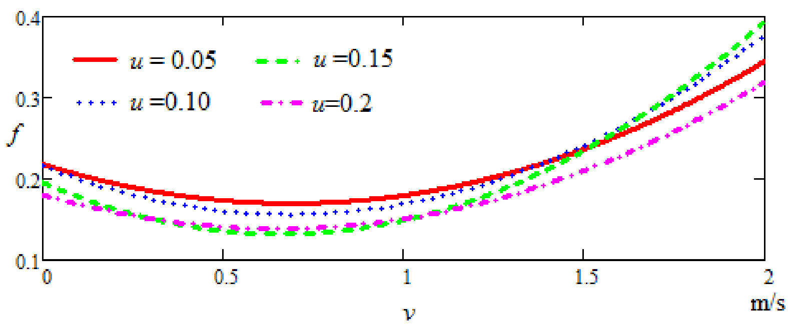

Figure 2. Dependence of f on the working speed for four moisture values, version (1)

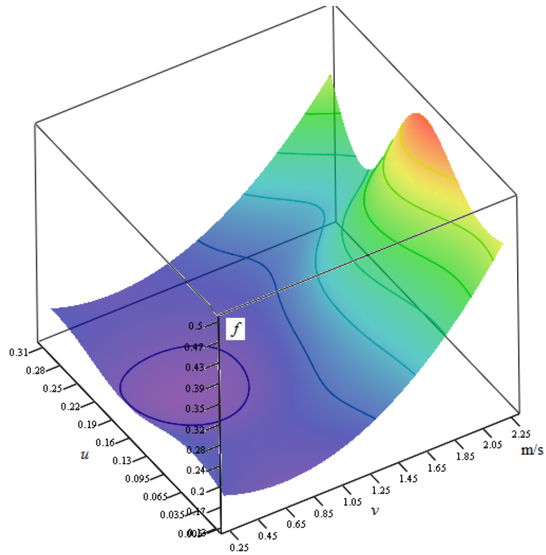

Figure 3. Dependence of friction function, f on the working speed and soil moisture, version (1)

The dependence of the friction function between the wheels and ground unit and/or the vegetation on soil moisture and working speed, shaped by function (7), is plotted in Fig. 4, 5 and 6.

It is noted that the variation of parameters defining the dependency of velocity for the friction function, relative to humidity, leads to changes in optimal points: their displacement and / or quantitative changes. In addition special qualitative phenomena can occur: the disappearance of optimal points or transformation of minimum points in maximum points.

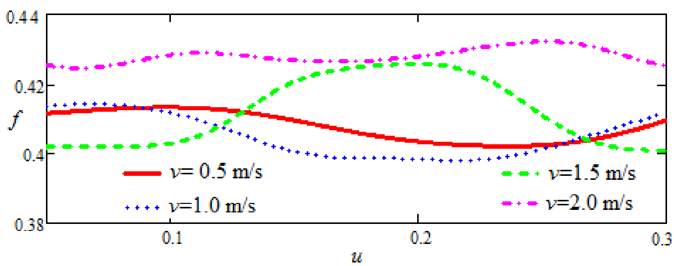

Figure 4. Dependence of f on the soil moisture for four values of working speed, version (2)

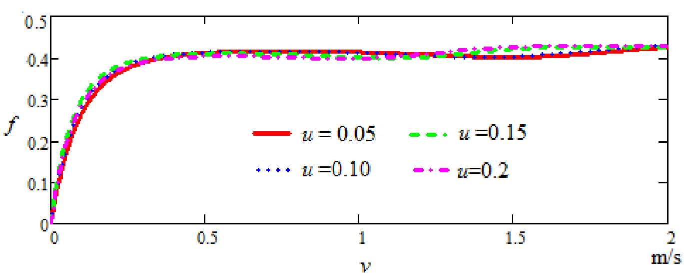

Figure 5. Dependence of f on the working speed for four moisture values, version (2)

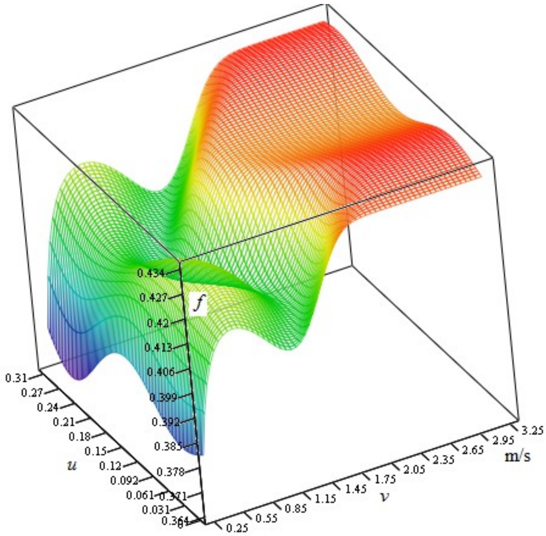

Figure 6. Variation of friction function on speed and soil moisture, version (2)

The above results were used in the optimization process as described in [2] and [10], for example. Optimization was performed for the work process of the U-650 M tractor - FP7 chisel plow unit. The results are concentrated in Table 2, for all the four objective functions that are used and described, for example, in [10]. Note that these results are superior to those from [2] and [10], because they contain an optimal information in addition: optimal humidity to achieve the optimal value for the objective process.

Table 2. Results of optimal calculus for the aggregate tractor U-650 M - plow PC7

Process parameters / *The objective function (optimization criteria)*	*Optimal values*						
	Working speed $[m \cdot s^{-1}]$	*Backing speed $[m \cdot s^{-1}]$*	*Travel speed $[m \cdot s^{-1}]$*	*Moisture*	*Energy consumption $[kWh \cdot ha^{-1}]$*	*Working capacity $[ha \cdot h^{-1}]$*	*Fuel consumption $[l \cdot ha^{-1}]$*
Energy consumption (minimal)	*0.975*	*0.967*	*0.971*	*0.207*	*149.166*	*0.149*	*14.064*
Working capacity (minimal)	*1.640*	*2.222*	*2.222*	*0.207*	*162.89*	*0.258*	*15.735*
Fuel consumption (minimal)	*0.987*	*0.963*	*0.966*	*0.205*	*149.177*	*0.151*	*14.063*
Global criteria (minimal value)	*1.944*	*5.983*	*4.559*	*0.062*	*161.567*	*0.318*	*15.718*

The models of agricultural aggregates workflow that perform such optimizations are very complicated. These models extend to include some a large number of parameters

(30-100 and more) and a large number of relationships, many of them non-linear (tens). For these reasons, this article cannot detail such a model. Mathematical models are constructed and used in the articles mentioned in the bibliography. Access to these items is free.

CONCLUSIONS

Nonlinear resistance functions in relation to the speed of travel, which contributes greatly to the existence and location of optimal points in space energy workflow of agricultural aggregates, depending on other parameters of the work process, among which one of the most important is soil humidity.

In this paper we presented a construction method of the dependence of moisture resistance functions (speed dependent) developed in previous works. The method and the results are just a proposal that needs addressing and improving within a wide circle of specialists. Improvement can be made only by major experimental studies, because functions of resistance depend on other parameters that characterize the physicochemical properties of the soil.

The use of friction and soil deformation resistance functions, allowed the insertion of an essential parameter for soil (moisture) in the set of parameters from the operation of agricultural aggregates energy optimization. The introduction in the calculation of this parameter was expected because the sphere of agricultural management concepts, optimal humidity favorable to various work processes in agriculture is an old and natural concept. The quantification and its influence in the work were the main contributions to the research from which the results were presented in this article.

From the two versions of the proposed strength functions formulas, the first is simpler, more stable, but in the case of aggregate dynamics study, it must be filled with a Heaviside factor type in speed, otherwise leading to abnormalities in the transient motion phase. For this reason, the second equation version of resistance function is more natural, in which, for zero speed, the resistance functions are canceled.

Therefore, the results presented in this article represent a link in the chain of results that follow the research conducted in the last two years and whose origins come from the optimal research of the twentieth century. But this research is not yet over.

The first direction is further optimized recalculation using the resistance functions proposed in this article and the influence estimation of the moisture parameter.

On the horizon, there are researches that must resume full optimization calculation in an ever more realistic way. This framework will be a high scientific level, that should include aggregate dynamics restrictions on the machine's traction limits, the topology of the work field. Furthermore, in this context the aggregate dynamics is not a simple one, addressed as in classical mechanics of material point motion. Aggregate dynamics is coupled with control functions developed by the operator, functions that give traction strength and direction of the field.

Objective functions (power, fuel consumption, work capacity) remain the same, but this time optimization parameters will not be numerical, but functions (speed) of certain parameters, form a functional space. Thus, the problem is transferred from the classical mathematical analysis in the functional analysis, more complex and with results that are difficult to interpret. This is the targeted direction at this time, direction in which the presented results in this article will surely be used.

BIBLIOGRAPHY

[1] Sfiru, R., Meca, A., Cârdei, P., Muraru, V., Mihailov, N., Atanasov, A. 2012. Optimizing Agricultural equipment choice by using databases. *INMATEH*, Vol. 37, 2/2012, p.p. 5-12.

[2] Cârdei, P., Meca, A., Kostandinov, G. 2012. Soil farm machinery mode of operation: from the optimization to the basis (1) . *INMATEH*, Vol. 37, 2/2012, p.p. 13-20.

[3] Cârdei, P., Kostandinov, G. 2012. Soil farm machinery mode of operation: from the optimization to the basis (2). *INMATEH*, Vol. 37, 2/2012, p.p. 21-28.

[4] Ştefanoiu, D.M., Cârdei, P., Vladuţ, V., Boruz, S., Savin, L., Fodor, M. 2012. Studies and researches on optimization of energetic of tractor –towed forage harvester combine aggregates. *INMATEH*, Vol. 37, 2/2012, p.p. 45-52.

[5] Cârdei, P., Sfiru, R., Ştefănoiu D.M., Bădescu, M., Boruz, S., Savin, L. 2012. Studies and researches on energetic optimization of fodder harvesting combines – unidimensional models. *INMATEH*, Vol. 38, 2/2012, p.p. 5-14.

[6] Ştefănoiu, D.M., Cârdei, P., Pirnă, I., Bădescu, M., Boruz, S., Atanasov, A. 2012. Studies and researches on energetic optimization of fodder harvesting combines – two dimensional models. *INMATEH*, Volume 38, 2/2012, p.p. 15-22.

[7] Stanciu, L., Cârdei, P., Voicu, E., Vartukapteinis, K. 2011. Studies on optimization of trailed corn harvesting combines working regimes. *INMATEH*, Vol. 33, 1/2011, p.p. 5-12.

[8] Naghy, M., Cârdei, P., Coţa, C., Fechete, L. 2011. Method of estimating the soil working regimes of machines used in horticulture. *INMATEH*, Vol. 35, 3/2011, p.p. 27-32.

[9] Cârdei, P., Alexiou, A., Bădescu, M., Sfîru, R., Muraru, V. 2013. New directions in exploring the optimization of agricultural aggregates working processes. *Proceedings of the union of Scientist, Ruse, Fifth Conference "Energy efficiency and Agricultural Engineering"*, ISSN 1311-9974, p.p. 163-168.

[10] Alexiou, A., Cârdei, P., Bădescu, M., Boruz, S. 2013. Optimum general problems of agricultural aggregates working processes. *Proceedings of the union of Scientist, Ruse, Fifth Conference "Energy efficiency and Agricultural Engineering"*, ISSN 1311-9974, p.p. 126-132.

[11] Letoşnev, N.N. 1959. *Agricultural Machinery*. State Agro-Forestry Publishing House, Bucharest.

[12] Dobrescu, C. 1981. Agricultural *aggregates parameter optimization in order to reduce energy consumption*. Agricultural Machinery Propaganda Editorial. Bucharest.

[13] Şandru, A., Bădescu, M., Şandru, L. 1982. *Reducing energy consumption through the rational use of agricultural aggregates*. Publishing Romanian Writing. Craiova.

[14] Şandru, A., Popescu, S., Cristea, I., Neculăiasa, V. 1983. *Operation of farm machinery*. Didactic and Pedagogical Publishing House. Bucharest.

UTICAJ VLAŽNOSTI ZEMLJIŠTA NA ENERGIJU PROCESA U POLJOPRIVREDI

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Sažetak: U ovom radu su prikazani rezultati istraživanja u jednoj oblasti koja je ostala otvorena i posle serije izvora pomenutih u literature, a dobijeni su u periodu 2011-2013. Pomenuti radovi razmatrali su ponovo optimizaciju toka radnih procesa poljoprivrednih agregata razvijajući fundamentalni obračun u periodu 1950 - 1980. Neki otvoreni problemi i dalje nastaju iz teorijskih i empirijskih razloga. Rešenje jednog od ovih problema je dato u ovom radu. Rešenje prikazuje unos uticaja vlage u zemljištu na postojanje i kvantifikaciju mogu
poljoprivrednih agregata.

Ključne reči: *zemljište, vlažnost, optimalne tačke, uticaj, poljoprivredni procesi*

Prijavljen: *Submitted*:	11.06.2013.
Ispravljen: *Revised*:	12.06.2013.
Prihvaćen: *Accepted*:	17.06.2013.

Univerzitet u Beogradu
Poljoprivredni fakultet
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Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XXXVIII
Broj 2, 2013.
Strane: 23 – 34

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XXXVIII
No. 2, 2013.
pp: 23 – 34

UDK: 621.039

Originalni naučni rad
Original scientific paper

3D DISCRETE ELEMENT MODEL OF SILO DISCHARGE

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Abstract: Silos are used by food industry, agriculture, mining and pharmaceutical industries for storing granular materials. The outflow properties of silos depend on the properties of the stored material and on the silo design. For this reason this has long been a subject of interest to both researchers and process engineers. In this paper a new numerical model for modeling silo discharge is proposed. This model was made by Discrete Element Method. We used this method because all of the analytical models are not able to describe the process in non-stationary case but DEM is suitable for describe the whole discharge process. Relying on previous models we established a new numerical model of silo discharge.

Key words: *silo, discharge, silo discharge, discrete element method.*

INTRODUCTION

Silos are used by food industry, agriculture, mining and pharmaceutical industries for storing granular materials. The outflow properties of silos depend on the properties of the stored material and on the silo design. For this reason this has long been a subject of interest to both researchers and process engineers [14]. The geometry and the surface conditions of the bin and the properties of the stored material define the flow pattern. In general the silos are classified in two different types: mass flow and funnel flow (Figure 1) [10].

In a mass flow silo all of the granular material moves when the silo is discharged, the material that enters the silo first is discharged first (this is a “first in, first out”

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Financial support from TÁMOP 4.2.1.B-11/2/KMR-2011-0003 and the Bolyai Scholarship of the Hungarian Academy of Sciences is gratefully acknowledged by Istvan Oldal Ph.D.

behavior). In a funnel flow design the movement of the material is confined to the vertical region in the center of the silo, the material that enters first is discharged last [10]. In case of a funnel flow silo stagnant zones are near the silo walls, where the particles flow slowly or there are stagnant. In extreme cases the silo may not empty completely under the force of gravity.

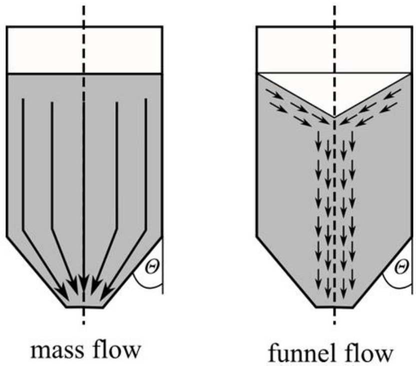


Figure 1. Flow patterns

The flow pattern depends on the properties of the granular material (e.g.: internal friction coefficient) the half angle of the bin and the wall friction coefficient. A lot of studies of granular materials have been described the flow mode of silos. By using the continuum model by Jenike [10], it is possible to define the flow pattern for a given system. The model of Jenike was validated against experimental data to determine a series of design charts (Figure 2). These design charts were verified by others methods, e.g.: DEM [13].

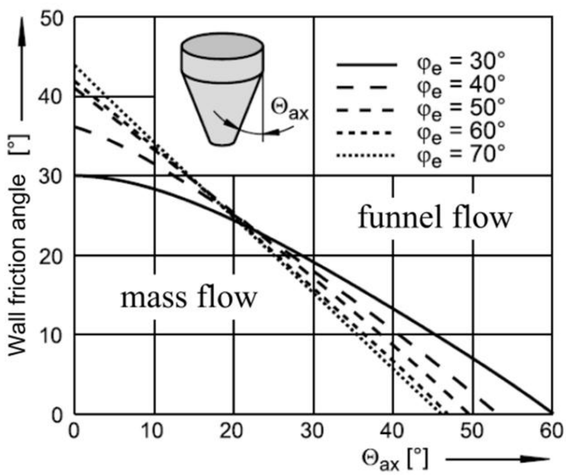


Figure 2. Bin design chart based on theory of Jenike [10]

The discharge rate of granular materials differs from the liquids (Figure 3). In case of fluids the discharge rate and the velocity are changing by the fluid level but in case of granular materials the discharge rate and the flowing velocity is independent of the filling level of silo, therefore constant [16].

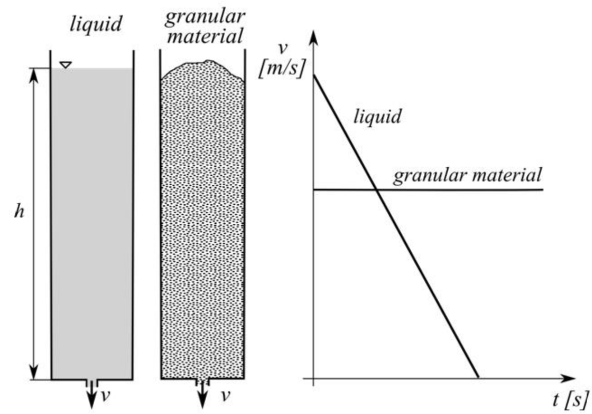


Figure 3. The flowing velocity meanwhile in the filling level

One of the first studies of granular flow in silos was based on a continuum model by Janssen [10]. His analysis showed that the pressure on the bottom of the bin is independent of the filling level. Therefore Janssen's theory predicts that the discharge rate is independent for the filling level. Significant efforts have been made since Janssen's work to determine the discharge rate of a silo using experiments. Thus several theories were forming to determinate the discharge rate of silos:

- For cohesionless granular materials:
  - Hagen model [9],
  - Beverloo model [1],
  - British model [2],
  - Crewdson model[15],
  - Williams model [21],
  - Zanker model [22],
  - Gjacev-Keller model [6]
  - Oldal model [16].
- For cohesive granular materials:
  - Janssen model [10],
  - Johanson model [21],
  - Tomas model [15],
  - Carleton model [3].

From the above the Beverloo's empirical and the Oldal's analytical model can be used in particular circumstances. Other models are empirical and these are unable to explain the physical process causing the phenomena (the constant flowing velocity and constant discharge rate in the same time) and unable to determine the discharge rate. The

Oldal model was developed for the outflow process, based on the assumption that the constant discharge rate of silos is caused by the formation and collapse of arches in the bin. This model explains the constant flowing velocity and the constant discharge rate also [16]:

$$W = \frac{\pi\sqrt{2g}}{6} \cdot \sqrt{\delta} \cdot \rho_h \cdot \left(d - d_p\right)^{\frac{5}{2}}. \tag{1}$$

where:
W [kg·s^{-1}] - discharge rate,
δ [-] - shape coefficient of arch,
ρ_h [kg·m^{-3}] - density of the bulk material,
g [m·s^{-2}] - gravitational acceleration,
d [m] - outlet size,
d_p [m] - particle size.

The difference between the empirical models and Oldal's model is that this model doesn't use empirical constants for describing the outflow. The δ constant is derived from the physical description of the discharge process. This model predicts the constant discharge rate and also the non-constant velocity distribution. Still this analytical model is unable to determine the discharge rate in the case of a mass flow silo.

In this paper a new numerical model for modeling the silo discharge is proposed. This model was made by Discrete Element Method. Our work is based on laboratory outflow experiments and simulations. We were making simulations and outflow measurements with wheat. To validate the numerical model, we created model silos with different cone angles. The aim of our work was a creation of a numerical model for silo discharge which can explain the constant flowing velocity and the constant discharge rate, therefore the phenomenon and to validate that the micromechanical parameters of wheat which validated for mixed flow dryer [12] are suitable for modeling silo discharge.

MATERIAL AND METHODS

The Discrete Element Method (DEM) is a numerical technique for modeling the static and dynamic mechanical properties of the granular materials. The method is based on the simulation of the motion of granular materials as separate particles and involves the movement of all particles and detection their collision with other particles and with their environment [4]. DEM is commonly used in many fields of engineering such as in the pharmaceutical, mining, food industries or agriculture. In agriculture this is commonly used to define the behavior and motion of granular materials in dryers or in silos and hoppers, such as flow patterns, segregations, and discharge rate. The method is continually developed and the experimental studies are also now gone on.

When DEM is used then the equations of motion on single particles are solved by a simulation circle. To describe the movement of the single particles Newton's second law of motion and the general rotational dynamics equation are repeatedly used. The contact forces and the moments are calculated based on the displacement of the particles in every time steps:

$$\underline{\underline{M}}^i(t)\cdot\underline{a}^i(t)=\underline{f}^i(t,\underline{u}^i(t),\underline{v}^i(t)). \qquad (2)$$

where:

$\underline{\underline{M}}$	[kg, kg·m^2]	- block diagonal matrix of mass and inertia,
t	[s]	- time,
$\underline{a}$	[m·s^{-2}, 1·s^{-2}]	- acceleration vector,
$\underline{f}$	[N, Nm]	- load vector,
$\underline{u}$	[m]	- position vector,
$\underline{v}$	[m·s^{-1}, 1·s^{-1}]	- velocity vector,
i	[-]	- index that is assumed the number of particles.

The equation of the whole granular material:

$$\underline{\underline{M}}(t)\cdot\underline{a}(t)=\underline{f}(t,\underline{u}(t),\underline{v}(t)). \qquad (3)$$

The behavior of the particles and the interaction between particles depend on the geometry and the micromechanical properties of the particles and their contacts [17]. The main problem is the determination of the micromechanical parameters (the calibration of the model). Because of the possibilities of errors in the simulations, we always have to compare the simulations with experimental results.

DEM has been used by different authors to study the outflow properties of silos such as pressure distribution [7], [8] flow patterns [13], [8], flow velocity [8], and segregation processes [13].

All simulations were undertaken using EDEM Academic 2.4 (2012) discrete element software. To modeling the outflow of wheat was used the Hertz-Mindlin no slip contact model with the following micromechanical parameters for the description of the interaction between particles:

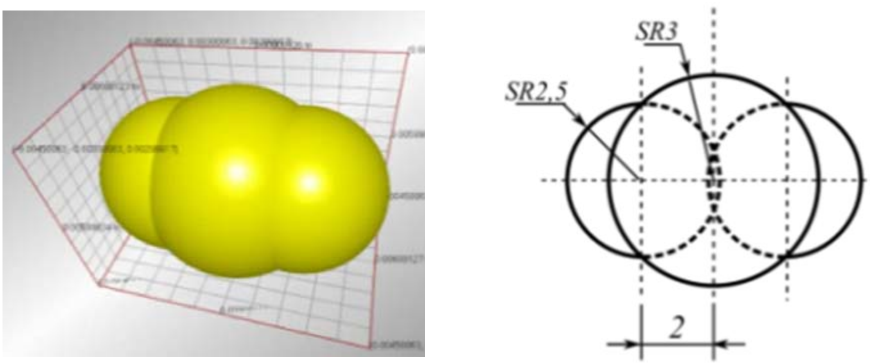
- Poisson's ratio (v): defined as the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force.
- Shear modulus (G): defined as the ratio of shear stress to the shear strain, where the shear stress is the components of stress at a point that act parallel to the plane in which they lie and shear strain is the components of a strain at a point that produce changes in shape of a body without a volumetric change.
- Density (ρ): defined as the "weight" per unit volume.
- Coefficient of restitution (C_r): the ratio of speed of separation to speed of approach in a collision.
- Coefficient of static friction (μ_0).
- Coefficient of rolling friction (μ_r).

The Hertz-Mindlin no slip contact model uses a spring-dashpot model to describe interaction of the particles. This contact model is elastic and non-linear and takes into account viscous and frictional damping. This contact model was used to simulate particle-particle and particle-wall contacts [20]. The micromechanical parameters have an influence on normal- and tangential forces and moment between the interacting particles. These micromechanical parameters and the particle model for wheat were determined in a mixed flow dryer by [12].

Table 1. Micromechanical parameters of wheat by [12]

Material	ν [-]	G [MPa]	ρ [kg·m^{-3}]	C_{rw} [-]	C_{rs} [-]	μ_{0w} [-]	μ_{0s} [-]	μ_{rw} [m]	μ_{rs} [m]
Wheat	0,4	$3{,}58\cdot10^{8}$	1460	0,5	0,6	0,3	0,25	0,01	0,01
Steel	0,3	$8\cdot10^{10}$	7500	0,5	-	0,25	-	0,01	0,01

The particle model has been created as the clump of three spheres, having radiuses 3 mm and 2,5 mm respectively. The distance between the centers of the spheres on the edges was 2 mm (Figure 4).



a. b.

Figure 4. Particle model of a grain of wheat [12]

We used in present wok two groups of geometrical models. In case of first group the geometrical model was a cylinder with a diameter of 200 mm and conical bin with outlet diameter of 60 mm and the cone half angle 30° and 60°. In case of second group the geometrical model was a cylinder with a diameter of 105 mm and conical bin with outlet diameter of 35 mm and the cone half angle 30° and 60°. In all cases a virtual volume was created, which was the same shape and in the same position with the geometrical models.

In the simulation process the first step was the generation of all of the particles, these were generated randomly in the virtual volume. The generated particles were allowed to fall under gravity; this step was the filling of silo. During the filling process the outlet of the silo was closed. The next step was the emptying of the silo. When the particles reach a static state then the outlet of the silo was opened and all of the particles were discharged. To the end of the filling process the bulk reaches a static state (his energy of motion is about zero). On the Figure 5 the particles were painted according to their vertical velocity. Vertical velocity of the blue particles is minimal and the vertical velocity of red particles is maximal.

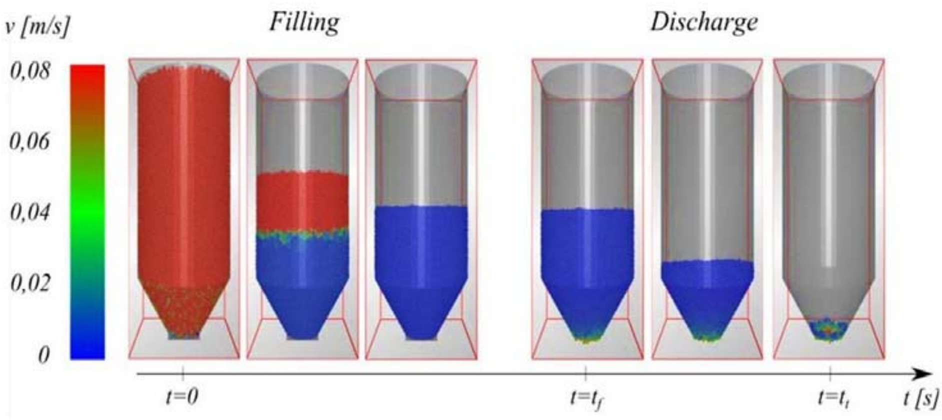
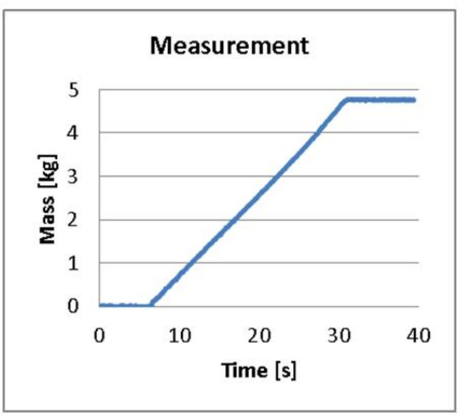


Figure 5. The steps of simulation process

To validate the numerical model, we were creating model silos with same dimensions with the geometrical models. The mass of the discharged wheat was measured by three load cells. The measurements were repeated five times in case of every model silo. The goal of the measurements was the determination of the amount of outflowing wheat as a function in time. The mass change functions were determined by also the simulations and these were compared with the measurement results. The aim of the experiments was the validation of DEM model.

RESULTS AND DISCUSSION

Based on the results of experiments the mass of the discharged material in function of time can see on Chart 1/a. As we expected the mass-change functions are linear in all cases. This means, that the discharge rate is constant, since this is the slope of the linear. Consequently the discharge rate is independent of the filling level of silo.



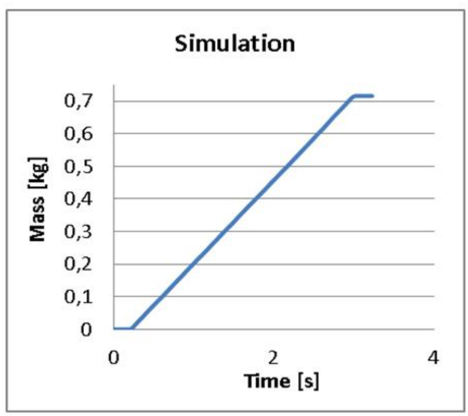


Chart 1. Measured and simulated mass-time values

Similarly to the experiments we determined the mass-change functions based on the simulation results. In case of all simulation the mass-change functions are also linear (Chart 1/b). This means that the new numerical model is suitable for right modeling the physical phenomenon.

Based on the mass-times values the discharge rate was determined in all cases. Then the simulation results were compared with measurements. The difference between our model and measurements is less than 5% in case of a silo with 60 mm outlet diameter by both bins.

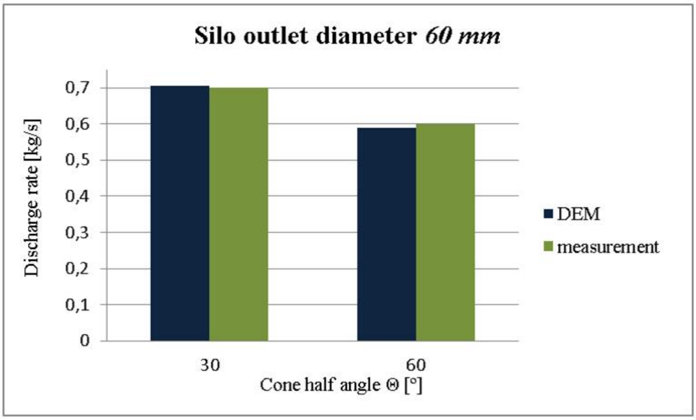


Chart 2. Discharge rates in case of a silo with 60 mm outlet diameter

In case of *35 mm* outlet diameter the difference of the discharge rates is larger by both bins (between 10 and 15%) (Figure 7). The reason of the larger difference is the particle model. The particle model of [12] is a slightly bigger as a real grain of wheat, but this is suitable for determine the velocity distribution in a mixed flow dryer and also suitable for the discharge simulation in case of a silo with 60 mm outlet diameter (the computational requirement can reduce with this particle model).

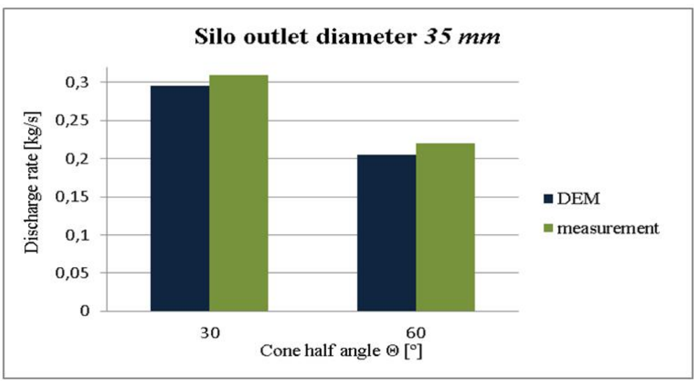
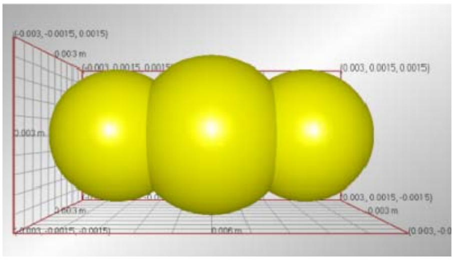
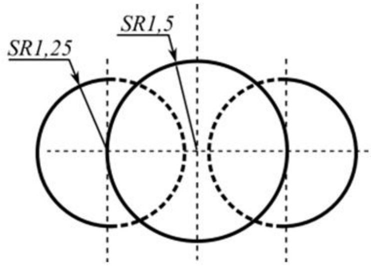


Chart 3. Discharge rates in case of a silo with 35 mm outlet diameter

However this particle model is not suitable for the silo model with outlet diameter 35 mm, because the bigger wheat particles caught on each other above the outlet. For this reason the discharge rate is less than the real. We had to create a new particle model, which is a better likeness the real grain of wheat. The new particle model has been created well as the clump of three spheres, having radiuses 1,5 mm and 1,25 mm respectively. The distance between the center of the spheres on the edges was 1,5 mm (Figure 8).



a.



b.

Figure 6. The new particle model of wheat

To this new particle model we had to define also the adequate density of particles:

Table 2. Micromechanical parameters to new particle model

Material	ν [-]	G [MPa]	ρ [$kg \cdot m^{-3}$]	C_{rw} [-]	C_{rs} [-]	μ_{0w} [-]	μ_{0s} [-]	μ_{rw} [m]	μ_{rs} [m]
Wheat	0,4	$3,58 \cdot 10^{8}$	1430	0,5	0,6	0,3	0,25	0,01	0,01
Steel	0,3	$8 \cdot 10^{10}$	7500	0,5	-	0,25	-	0,01	0,01

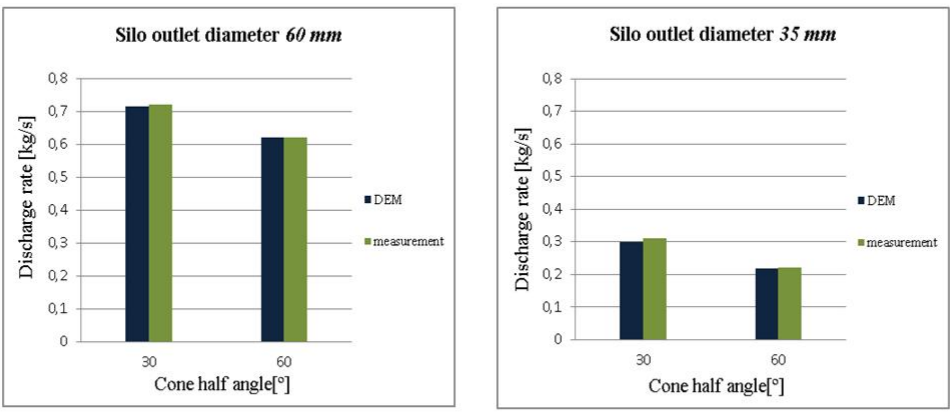


Chart 4. The discharge rates with the new particle model

With the new particle model and micromechanical parameters the difference between experiments and simulations is less than 5% in all cases. So the discharge of wheat can be on a suitable manner modeled.

CONCLUSIONS

We created a new numerical model for silo discharge of wheat which is suitable for description the outflow process with an adequate accuracy. With the numerical model the whole discharge process can be described, still in case of an emptying bin. One of the analytical models is not able to describe the process in this non-stationary case.

The particle model and the micromechanical parameters of wheat which are validated for a mixed flow dryer are suitable for modeling also the silo discharge. With these parameters can reduce the computational requirements because this particle model is a slightly bigger as a real grain of wheat. However we can't use these parameters in all cases because if the outlet diameter of the silo less than 35 mm than the particles caught on each other. For this reason we made a new particle model and we determined for this new micromechanical parameters. We validated these parameters with outflow experiments.

Consequently if a discrete element model for wheat is created in which the flowing dimensions are 35 mm then it is necessary to use our new particle model with the adequate micromechanical parameters.

BIBLIOGRAPHY

[1] Beverloo, R. 1961. The flow of granular solids through orifices. *Chemical Engineering Science* 15 (262), p.p. 260-269.

[2] British Standard Summaries: BS5502: Part 74: 1991. *Building and Structures for Agriculture*. Design and Construction of Bins & Silos for Combinable Crops.

[3] Carleton, A.J. 1972. The effect of Fluid-Drag Forces on the Discharge of Free Flowing Solids from Hoppers. *Powder Technology*, Volume 6, p. 91-96.

[4] Cundall, P; Strack, O. 1979. *A discrete numerical model for granular assemblies.* Geotechnique.

[5] Enstand, G. 1975. On the theory of arching in mass flow hoppers. *Chem. Eng. Sci.* Vol. 30, p.p. 1273-1283.

[6] Gjacev, L.,V., Keller, H. 1984. Grundlagen einer Theorie zum Schuettgutausfluss aus Bunkern und einige Ergebnisse ihrer experimentellen Ueberpruefung. *Wissenschaftliche Zeitschrift der Hochschule für Architektur und Bauwesen Weimar*, Vol. 30, p.p. 269-272.

[7] Goda, T.J., Ebert, F. 2005. Three-dimensional discrete element simulations in hoppers and silos. *Powder Technology* 158, 2005, p. 58-68.

[8] Gonzalez-Montanello, C., Ramírez, A., Fuentes, J.M., Ayuga, F. 2012. Numerical effects derived from en masse filling of agricultural silos in DEM simulations. *Computers and Electronics in Agriculture* 81, 2012, p. 113-123.

[9] Hagen, E. 1852. Druck und Bewegung des trockenen Sandes. *Bericht über die zur Bekanntmachung geeigneten Verhandlungen der Königlich Preußischen Akademie der Wissenschaften zu Berlin* 1852, p. 35-42.

[10] Janssen, H.A. 1895. Versuche über Getreidedruck in Silozellen. *Zeitschrift des Vereines der Deutschen Inegniuere* 39, 1895, p.p. 1045-1049.

[11] Jenike, A.W. 1987. A theory of flow of particulate solids in converging and diverging channels based on a conical yield function, *Powder Technology* 50 (3), p.p. 229-236.

[12] Keppler, I., Kocsis, L., Oldal, I., Farkas, I., Csatár, A. 2012. Grain velocity distribution in a mixed flow dryer. *Advanced Powder Technology* 23, 2012, p. 824-832.

[13] Ketterhagen, W.R., Curtis, J.S., Wassgren, C.R., Kong, A., Narayan, P.J., Hancock, B.C. 2007. Granular segregation in discharging cylindrical hoppers: A discrete element and experimental study. *Chemical Engineering Science* 62, 2007, p. 6423-6439.

[14] Langston, P.A., Tüzün, U., Heyes, D.M. 1995. Discrete element simulation of granular flow in 2D and 3D hoppers: dependence of discharge rate and wall stress on particle interactions. *Chemical Engineering Science* 50 (6), 1995, p. 967–987.

[15] Martens, M.1998. *Silo-Handbuch*., Ernst & Sohn, Berlin.

[16] Oldal, I., Keppler, I., Csizmadia, B., Fenyvesi, L. 2012. Outflow properties of silos: The effect of arching. *Advanced Powder Technology* 23, 2012, p. 290-297.

[17] Raji, A. O; Favier, J. F. 2004. Model for deformation in agricultural and food particular materials under bulk compressive loading using discrete element method - theory, model development and validation. *Journal of Agricultural Engineering Research*, 2004, p. 359-371.

[18] Scheibe, M. 1997. *Die Fördercharakteristik einer Zellenradschleuse unter Berücksichtigung der Wechselwirkung von Silo Austragsorgan.* Dissertation, Fakultät für Maschinenbau, Technischen Universität Bergakademie, Freiberg.

[19] Schulze, D. 1991. *Untersuchungen zur gegenseitigen Beeinflussung von Silo und Austragorgan.* Dissertation, Technischen Universität Carolo-Wilhelmina zu Braunschweig.

[20] Tsuji Y., Tanaka T., Ishida T. 1992. Lagrangian numerical simulation of plug flow of cohesionless particles in a horizontal pipe. *Powder Technology* 71, p. 239-250.

[21] Woodcock, C. R; Mason, J. S. 1987. *Bulk solids handling.* Leonard Hill, Glasgow and London.

[22] Zanker, A. 1975. Estimating the flow of solids through openings. *Process Engineering (July)*, p.p. 66–67.

3D MODEL PRAŽNJENJA SILOSA KORIŠĆENJEM METODA DISKRETNIH ELEMENATA

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Sažetak: Silosi se koriste u prehrambenoj industriji, poljoprivredi, rudarstvu i farmaceutskoj industriji za skladištenje granulastih materijala. Pražnjenje silosa zavisi od osobina skladištenog materijala i konstrukcije silosa. Iz ovog razloga je pražnjenje uvek bilo značajno kako za istraživače, tako i za procesne inženjere. U ovom radu je predložen novi numerički model za projektovanje pražnjenja silosa. Ovaj model je napravljen korisćenjem Metoda Diskretnih Elemenata. Koristili smo ovaj metod zato što svi analitički modeli nisu u stanju da opišu proces u nestacionarnom slučaju, a MDE je

pogodan za opisivanje kompletnog procesa pražnjenja silosa. Oslanjajući se na prethodni model uspeli smo da uspostavimo novi numerički model pražnjenja silosa.

Ključne reči: *silos, pražnjenje, pražnjenje silosa, metod diskretnih elemenata.*

Prijavljen: *Submitted*:	31.05.2013.
Ispravljen: *Revised*:	11.06.2.13.
Prihvaćen: *Accepted*:	21.06.2013.

Univerzitet u Beogradu
Poljoprivredni fakultet
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Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XXXVIII
Broj 2, 2013.
Strane: 35 – 44

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XXXVIII
No. 2, 2013.
pp: 35 – 44

UDK: 620.92:523

Originalni naučni rad
Original scientific paper

GAINS OBTAINED IN HYBRID SYSTEMS OF ENERGY GENERATION SOLAR PHOTOVOLTAIC AND WIND POWER FOR RURAL ELECTRIFICATION WITH THE USE OF FUZZY LOGIC CONTROLLERS BASED

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Abstract: This paper presents the gains from the application of fuzzy logic control in a hybrid power generation wind-photovoltaic for small rural. The use of alternative and renewable energy has been increasingly discussed in all sectors of society. The interest in these sources of energy, alternative and renewable, is of fundamental importance, both in terms of the shortage, as the price of oil, and the environmental issues involved in the use of renewables. The variability in the intensity of wind and solar energy can be circumvented by complementation between a source and one or more stability set by the generation system. When using a fuzzy control system, is expected to reach the point of maximum power generation, transferring substantially all the energy generated to load and / or batteries when their use is not immediate. The operation of the fuzzy controller was simulated using the MATLAB® software, through the *Fuzzy Logical Toolbox*. It was

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found through simulations that this model can be used efficiently in hybrid power generation, providing better utilization of alternative energy sources.

Key words: *fuzzy logic, photovoltaic solar energy, wind energy, rural electrification.*

INTRODUCTION

Global warming, fossil fuel depletion, the growth of large new economies, and the latent risks of terrorism and international conflict are weaving an uncomfortable stranglehold on the world's energy outlook.[1]

The sun as a source of heat and electricity is one of the most promising sources of energy to meet the energy crises of this millennium, since there are several technologies available for the utilization of this energy source. Energy from the sun is responsible for numerous natural phenomena that occur on this planet, including the formation of zones of high pressure responsible for the flow of wind, for example.[2]

There are various energy alternatives, which may be non-renewable options such as clean coal, nuclear, and renewable options such as hydroelectric, biomass / biofuels, geothermal, thermal energy conversion, wave, tidal, wind, solar, and other .[3]

Figure 1 shows a comparison between booked renewable and nonrenewable energy. Total recoverable reserves are shown for non-renewable resources. The annual potential is shown for renewables. The volume of each bead is the total quantity of energy involved.[1,3]

About 1 to 2 per cent of the energy coming from the sun is converted into wind energy. That is about 50 to 100 times more than the energy converted into biomass by all plants on earth.[4]

Solar and wind are renewable and non-polluting, and is optional alternative resources for power generation. Many countries, with wind speeds averaging in the range of 5 to 10 ms^{-1}, are using systems conversion of wind energy into electrical energy (wind generators), in an effort to minimize their dependence on fossil fuels that are not renewable.[5]

Currently thousands of photovoltaic systems in regions with average daily solar radiation in the range 3-6 $kWhm^{-2}$, are installed around the world, providing small powers, independent applications across individual systems or in isolated regions.[6]

Secondly, a common drawback for wind and solar energy resides in dependence on climatic variations. Both forms of energy, regardless if used, would have to be oversized to become reliable, resulting in a total cost much higher. However, a combination of solar and wind power generation system in a hybrid individual can mitigate the fluctuations of these forms of energy, increasing global energy production and significantly reducing the need for energy storage. Due to this combination, the overall expenditure for autonomous systems can be drastically reduced to a large number of cases.[7]

Mathematical models implemented in computer programs have shown significant results in nonlinear systems and complexes in several areas, including the control theory model for recognition and decision analysis. These programs are able to resolve issues that the classical models, as a rule, are not able to do so. They are called intelligent systems, among which stand out the Neural Networks and Fuzzy Logic.[8]

Information vague, uncertain, qualitative, verbal communications, ability to learn and formulate strategies of decision making are human characteristics. Therefore, the fuzzy theory is often referred to as "smart", due to the fact simulate human intelligence.[9]

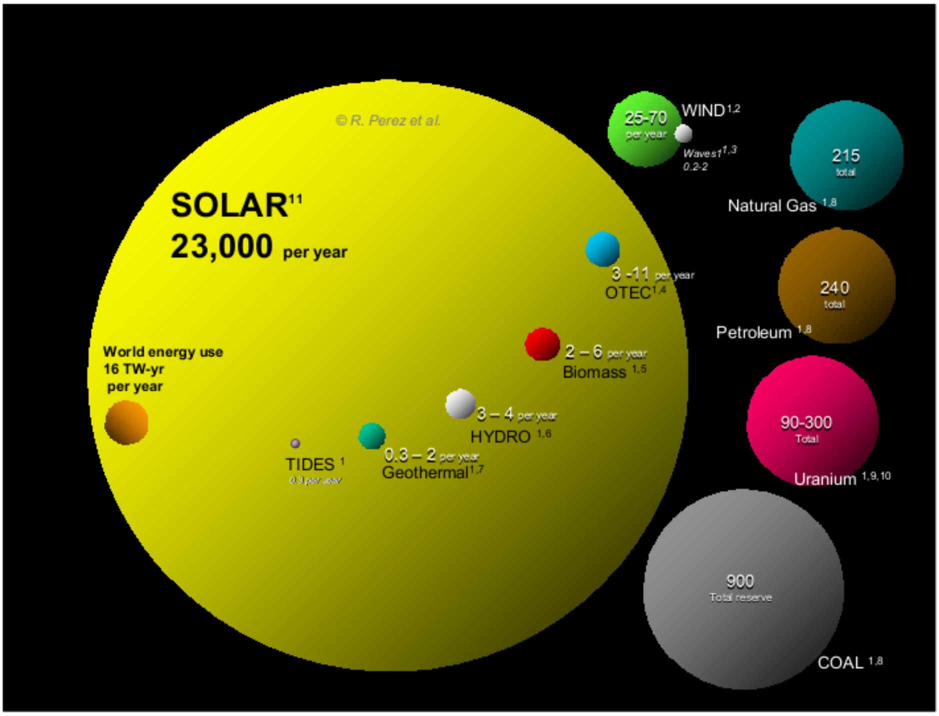

Figure 1. Comparing finite and renewable planetary energy reserves (Terawatt - years). Total recoverable reserves are shown for the finite resources. Yearly potential is shown for the renewables [1,3]

In this context, this paper aims to describe how the use of fuzzy logic for controlling a hybrid power generation wind-photovoltaic small in the energy supply required by a resident of a rural property, you can make the most energy to produce electricity.

MATERIAL AND METHODS

The work was developed in the Laboratory of Rural Empowerment, Lageado Experimental Farm, located in Botucatu, Brazil, with geographical location defined by coordinates: 22°51' South Latitude (S) and 48°26' West Longitude (W) and an average elevation of 786 meters above the sea level. The monthly average wind speed at 10 m height is 3,1 ms^{-1} and solar global monthly average daily rate is 4772 Whm^{-2} .[10]

To generate electricity from solar energy using three photovoltaic modules I-100 Isofoton the rated power of 100Wp each, totaling 300Wp. [11,12]

For the generation of electricity from wind energy available on site, we used a wind turbine AIR-X model of rural SOUTHWEST WINDPOWER rated power of 400W and has an internal charge controller. This turbine was mounted on a tower 14 meters high.[12]

The aero-generator and the photovoltaic modules that constitute the hybrid system can be seen in Figure 2.

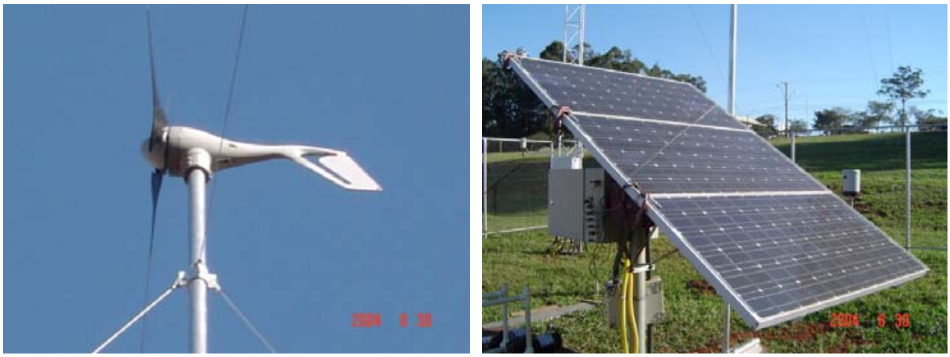

Figure 2. wind turbine and photovoltaic hybrid system

Meteorological data and electrical data

Tables 1 and 2 are examples of weather data collected and calculated [12,13,14].

Table 1. Characteristics of wind speed and wind power from 01/07 to 31/07/2005

Day / Month	Daily Average Wind Speed (ms^{-1})	Total Wind Energy Available Daily (Wh)
1/7	3,5	2,2
2/7	2,6	19,5
3/7	4,5	420,5
4/7	2,8	4,7
...	...	...
28/7	0,0	0,0
29/7	3,0	29,7
30/7	2,6	111,2
31/7	2,1	22,5

It is observed that there is a direct and proportional to the wind speed at the wind energy available. This is due to the intermittent characteristic of wind, gusts and other factors that cause not all will generate wind energy. Another important condition which can limit wind generation is that the battery is charged. If so, then the turbine automatically stops working. This fact is one of the justifications for the use of more batteries and management through a fuzzy controller.

Examples of data from electricity generation and performance of the hybrid system will be the period September 2004 to August 2005, are shown in Table 3. [12,14]

Table 2. Characteristics of solar irradiance and solar energy from 01/07 to 31/07/2005

Day / Month	*Daily Average Solar Irradiance ($W.m^{-2}$)*	*Total Solar Energy Available Daily (Wh)*
1/7	*610,3*	*13.293,2*
2/7	*582,8*	*12.693,1*
3/7	*275,3*	*5.698,0*
4/7	*164,0*	*3.600,8*
...	...	...
28/7	*463,8*	*10.770,5*
29/7	*626,1*	*14.426,3*
30/7	*626,2*	*14.427,4*
31/7	*617,2*	*13.886,4*

Table 3. Summary of electricity generation by wind-PV hybrid system in the period from 01/07 to 31/07/2005

Day / Month	*Solar + Wind Available (Wh)*	*Total Daily Energy Generated by Hybrid System (Wh)*	*Efficiency Hybrid System (%)*
1/7	*13.295,4*	*1.066,6*	*8,0*
2/7	*12.712,7*	*1.064,4*	*8,4*
3/7	*6.118,5*	*511,9*	*8,4*
4/7	*3.605,4*	*343,0*	*9,5*
...	...	...	...
28/7	*10.770,5*	*844,7*	*7,8*
29/7	*14.456,0*	*1.169,0*	*8,1*
30/7	*14.538,7*	*1.048,2*	*7,2*
31/7	*13.909,0*	*1.095,3*	*7,9*

To simulate the energy gain by the proposed system was regarded as a condition, the higher throughput of the system during the period of data collection which was from September 2004 to August 2005. Analyzing data from the cited period arrives to the highest value of daily income that was 12.8% and was verified on 22/12/2004.

Modeling of fuzzy controller for hybrid system

The modeling strategy for the controller is shown in Figure 3.

In MATLAB® software through the *Toolbox Fuzzy Logical*, was held to build the fuzzy inference system.

The same software defined the membership functions associated with input variables (Wind Speed, Solar Radiation and Charge Battery - A, B and C) and output variable (Charge Battery Bank) fuzzy controller. The map of rules was drawn up identifying all its details and features, and will assist in identifying the decisions to be taken during the operation of the process.

The final step consisted in performing the defuzzification which was translated into a discrete value the result of linguistic variable output controller that was inferred by fuzzy rules. Generally speaking, this process is nothing more than an inverse transformation that translates the output of fuzzy domain to the discrete domain.

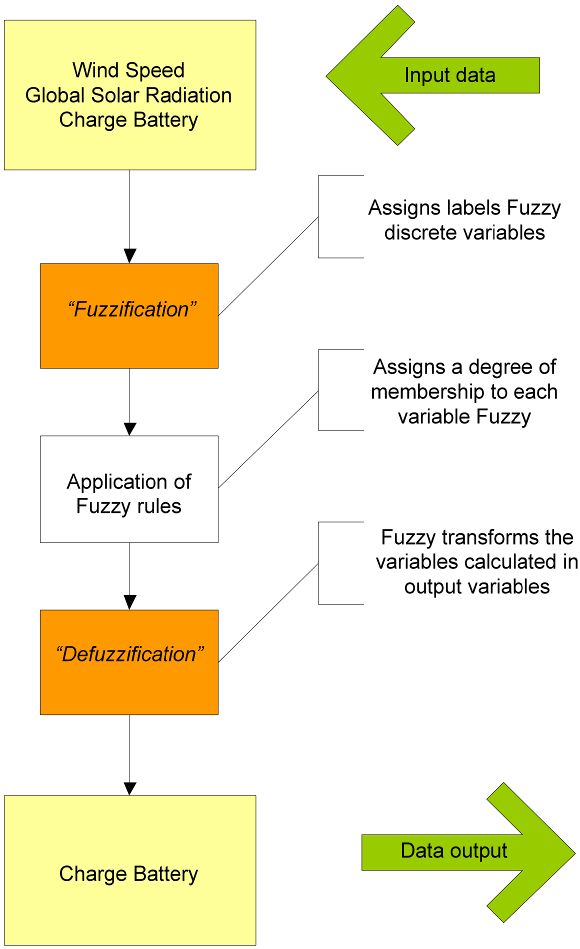

Figure 3. Fuzzy model for a control system for energy generation hybrid solar-photovoltaic and wind

RESULTS AND DISCUSSION

As a result of the proposed fuzzy control system, has been gaining energy generated using the control that enables the use of efficient alternative energy sources (solar photovoltaic and wind) and also manage the storage of energy not used by the loads, using a battery bank. Also as a result, has been the development of a methodology to design a controller using fuzzy logic system to manage a hybrid power generation.

Table 4 is presented, for the period September 2004 to August 2005, the generation of electricity with and without using fuzzy controller, and the energy gain and percentage of gain when using the fuzzy controller. [14]

Table 4. Summary of electricity generation by wind-PV hybrid system with and without fuzzy controller, from September 2004 to August 2005 and the gain and percentage gain when using the fuzzy controlled

Day / Month	Total Daily Energy Generated by Hybrid System (Wh)	Energy Generated by the Hybrid System with Fuzzy (Wh)	Gain of Energy (Wh)	Percentage Gain (%)
Sep/04	25.533	38.190	12.657	33,1
Oct/04	27.884	41.968	14.083	33,6
Nov/04	27.370	40.188	12.818	31,9
Dec/04	27.249	41.353	14.104	34,1
Jan/05	26.441	36.740	10.300	28,0
Feb/05	27.541	41.678	14.137	33,9
Mar/05	27.815	43.130	15.315	35,5
Apr/05	29.901	44.322	14.421	32,5
May/05	30.276	41.201	10.925	26,5
Jun/05	29.598	39.685	10.087	25,4
Jul/05	30.391	46.029	15.638	34,0
Aug/05	30.732	43.777	13.045	29,8
Annual	340.731	498.262	157.530	31,6

Considering the total analyzed period, the total energy generated in the period is 341 kWh to 498 kWh, something around 157 KWh of energy gain generated in the period, representing 31.6% gain. This gain can be seen in Figure 4.

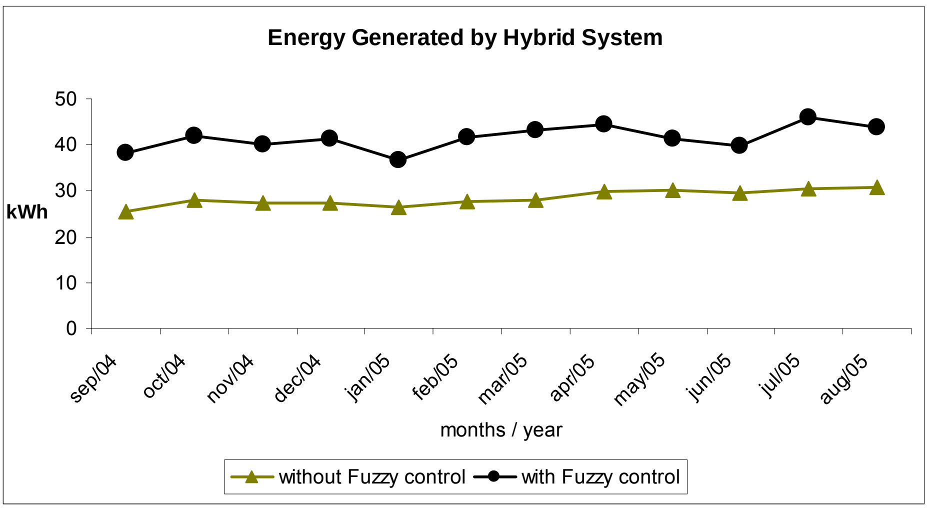

Figure 4. Energy generated without the Fuzzy controller and Energy generated by the Fuzzy controller

CONCLUSIONS

Considering the various factors that influence the efficiency of generation hybrid (solar-photovoltaic and wind), using a fuzzy control system for managing and using additional batteries, represents a significant increase in use of renewable energy.

The great advantage of using fuzzy theory is the ability to model and manipulate mathematically vague, imprecise and intermittent nature of human language, and that are provided by experts, not mathematicians, to characterize the processes studied.

This manipulation can be done easily from the junction of variables chosen to model mathematically the proposed system, when the implication of independent variables is set dependent on a set of linguistic rules based on knowledge from experts.

The gain in power generation was estimated at 31.6% in the analyzed period and suggests that beyond simply using alternative sources of energy, we can also optimize its use, extracting the maximum energy available.

What we could see is that the fuzzy control, which is one of the most widely used parts of the theory of fuzzy sets, enables control and manage a hybrid power generation satisfactorily.

BIBLIOGRAPHY

[1] Perez, R., Perez, M. 2009. A fundamental look at energy reserves for the planet. *Iea Shc Solar Update Newsletter*, Ottawa, v. 50, n. , p.2-3.

[2] Tolmasquim, M.T. 2003. *Fontes Renováveis de Energia no Brasil*. 2003. Rio de Janeiro: Interciência.

[3] Perez, R., Zweibel, K., Hoff, T.E. 2012. Solar power generation in the US: Too expensive, or a bargain? *Energy Policy*, Amsterdan, v. 39, n. , p.7290-7297.

[4] DWIA - Danish Wind Industry Association. 2013. *Where does Wind Energy come From*? DWIA. Available through: http://www.motiva.fi/myllarin_tuulivoima/windpower web/en/tour/wres/index.htm. Accessed date: 02. Apr. 2013.

[5] Bellarmine, T. G. 1996. Wind energy for the 1990s and beyond. 1996. *Energy Conversion and Management*. v.12, n.37, p.1741-52.

[6] Mahmoud, M. 1990. Experience results and techno-economic feasibility of using photovoltaic generators instead of diesel motors for water pumping from rural desert wells in Jordan. *IEE Proceedings*, v.137, n.6, p.391-4.

[7] Bagul, A.D. 1996. Sizing of a stand-alone hybrid wind-photovoltaic system using a three-event probability density approximation. *Solar Energy*, v4, n.56, p.323-35.

[8] Souza, O.T.L. 2004. *Desenvolvimento de um modelo fuzzy para determinação do calor latente com aplicação em sistemas de irrigação*. Botucatu: Faculdade de Ciências Agronômicas, Universidade Estadual Paulista.

[9] Mcneill, D., Freiberger, P. 1994. *Fuzzy Logic*. 1 ed. New York: Touchstone and Colophon.

[10] Silva, C.D. 2000. *Avaliação do Potencial das Energias Solar e Eólica para Acionamento de Pequenos Sistemas de Bombeamento na Fazenda Lageado*. Botucatu: Faculdade de Ciências Agronômicas, Universidade Estadual Paulista.

[11] Fiorentino, J.J. 2004. *Análise do Desempenho de um Conjunto de Módulos Fotovoltaicos Aplicados Para Energização Rural*. Botucatu: Faculdade de Ciências Agronômicas, Universidade Estadual Paulista.

[12] Siqueira, J.A.C. 2005. *Desempenho de um sistema híbrido eólico-fotovoltaico de pequeno porte para energização rural*. 2005. Botucatu: Faculdade de Ciências Agronômicas, Universidade Estadual Paulista.

[13] Gabriel Filho, L. R. A. 2007. *Análise e modelagem geométrica da potência gerada por um sistema híbrido Solar Fotovoltaico Eólico*. Botucatu: Faculdade de Ciências Agronômicas, Universidade Estadual Paulista.

[14] Caneppele, F.L. 2007. *Desenvolvimento de um modelo fuzzy para otimização da energia gerada por um sistema híbrido (solar- fotovoltaico e eólico)*. Botucatu: Faculdade de Ciências Agronômicas, Universidade Estadual Paulista.

DOBICI DOBIJENI U HIBRIDNIM SISTEMIMA ZA PROIZVODNJU STRUJE U POLJOPRIVREDNIM OBJEKTIMA IZ SOLARNE ENERGIJE I ENERGIJE VETRA KORIŠĆENJEM KONTROLERA NEPRECIZNE LOGIKE

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Sažetak: Ovaj rad prezentuje dobitke dobnijene korišćenjem kontrolera neprecizne logike u hibridnim sistemima za proizvodnju struje iz solarne energije i energije vetra za male poljoprivredne objekte. Korišćenje alternativnih i obnovljivih izvora energije se sve više primenjuje u svim oblastima društva. Razumevanje alternativnih i obnovljivih izvora energije je od fundamentalnog značaja, kako u pogledu ograničenja kao što je cena nafte, tako i u pogledu uticaja na životnu sredinu. Variranje u intenzitetu vetra i solarnoj energiji se može izbeći putem dopunjavanja između izvora i jednog ili više stabilnih uređaja podešenih od strane generatora. Kad se koristi kontroler neprecizne logike očekivano je da sistem postigne tačku maksimalne proizvodnje struje i da postepeno prebaci svu proizvedenu energiju ili potrošačima ili baterijama tokom perioda niske potrošnje. Rad kontrolera neprecizne logike je simuliran korišćenjem programa MATLAB® kroz *Fuzzy Logical Toolbox*. Kroz simulaciju je utvrđeno da se ovaj model

može uspešno koristiti u hibridnoj proizvodnji struje kao i da pruža mogućnost za bolje korišćenje alternativnih izvora energije.

Ključne reči: *neprecizna logika, solarna energija, energija vetra, elektrifikacija poljoprivrenih objekata*

Prijavljen: *Submitted*:	26.04.2013.
Ispravljen: *Revised*:	10.06.2013.
Prihvaćen: *Accepted*:	22.06.2013.

Univerzitet u Beogradu
Poljoprivredni fakultet
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Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XXXVIII
Broj 2, 2013.
Strane: 45 – 53

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XXXVIII
No. 2, 2013.
pp: 45 – 53

UDK: 631.4

Originalni naučni rad
Original scientific paper

VARIABLE RATE CONTROL SYSTEM DESIGNED FOR SPINNER DISC FERTILIZER SPREADER – "PreFer"

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Abstract: The objectives of this study were: development of fertilizer rate control system which allows applying of granular fertilizer at variable rates, adopting it into a commercial granular fertilizer spreader, and then investigation and evaluation of its performances. A control program in C++ software environment, using the Raisonance 8051 IDE tool was developed. The system was tested in laboratory conditions. Each of rollers released fertilizers almost equally at different application rates. The system can easily be attached to local made spreaders with some mechanical modification. Further tests are needed to verify systems performance in field conditions.

Key words: *precision agriculture, spinner disc fertilizer spreader, variable rate fertilizer application*

INTRODUCTION

During the past few decades, in order to increase the productivity and profitability, agriculture-related studies have been directed toward the introduction of new high–yield and pest-resistant varieties as well as finding the best ways to use agricultural inputs more effectively due to the recent focus on environmental concerns [8].

Modern agricultural systems, along with preserving the quality of world's environmental sources, must increase the productivity and profitability for farmers.

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The authors would like to thank the Ege University Research Fund (projects 2002 ZRF 023, and 014) and Türkay Agricultural Machinery, LLC for their support.

Limiting profit margins and strategic planning for farm production system has become more important and difficult. To find the best solution for the complex problems they are facing, farmers have to consider the integrated approach in production. Integrated agriculture management is dynamic, as opposed to being limited to certain rule-structures.

To be succeed in this dynamic environment, farm managers have to mine data and process it so that data can be converted to knowledge and/or existing knowledge can be used in the decision-making stage and the consequent application. In this case, the agricultural data, its quantity and quality, its sources and the process of converting it to knowledge are of importance [11]. The critical point is that the necessary information would be generated, accessed and utilized only by using ICT. Parallel to this necessity and thanks to the recent advancements in information technologies, technology has secured a place in agriculture.

Variability that exists in growing conditions (soil, crop, disease etc.) has to be considered while managing through a new approach called "Precision Agriculture" and its related technologies (GIS, GPS, VRT). Precision Agriculture is an approach for producing food and fiber in a sustainable way by assigning information technologies. Precision agriculture approach has made a deep impact on the world's agriculture, and although the principals of this trend are the same, the tools and machines should be modified, based on the country and also each farm's conditions.

Many studies in the past were conducted to develop prototype variable rate applicators. Some of them focused on applying fertilizers. Sensor-based or map-based variable rate technologies have also been considered. When using sensor-based technology, sensors are employed in order to determine the amount of fertilizer requirement for a particular location and then actuators vary the input rate based on the fertilizer needs. Map-based technology uses digital maps endowed with location data. The map is generated by analyzing the data obtained by soil-sampling, yield-mapping, etc. [11].

Spinner disc type spreaders are common, due to the fact that they are simple in design and user-friendly; and also that they are cheap and require little maintenance while field work rates are high [5, 10, 12, 7, 9]. Earlier studies on variable rate granular fertilizer application were performed by Fulton *et al*. (2001) [6]., who modified a granular spreader truck equipped with a commercially available controller and a GPS system. The controller varied the speed of the belt hydraulically and fertilizer was supplied to the two discs by an apron belt.

Cerri *et al*. (2002) [4] designed and built a system for variable rate lime application. The system included a computer to obtain the coordinate information from GPS and to look up prescription map in order to find the exact rate to instant location, and then send signals to step motor to control the fertilizer flow.

Recently, some researchers have focused on electromechanical control system. There are also commercial products in the world market that have such a system. But, there is no similar system on the spreaders produced by national companies. Akdemir *et al.* (2007) [1] developed a variable rate controller for centrifugal fertilizer spreader. They employed step-motors to control the fertilizer application rate by varying the outlet area of windows at the bottom of the spreader hopper. Step motors were connected to the rate control levers of spreader.

The objectives of this study included designing a system (considering country-specific conditions) which allows applying granular fertilizer at variable rate by employing rollers and building the VRT attachment, then testing and evaluating it in laboratory condition.

MATERIAL AND METHODS

In this study, commercially manufactured spinner disc granular fertilizer spreader was used. The spreader was a mounted type (Fig. 1). The machine was supplied by local agricultural machine and tool manufacturer. In performance test of prototype and calibration of metering units, Calcium Ammonium Nitrate (26% CAN) and composite 20.20.20 fertilizer were used as test materials.

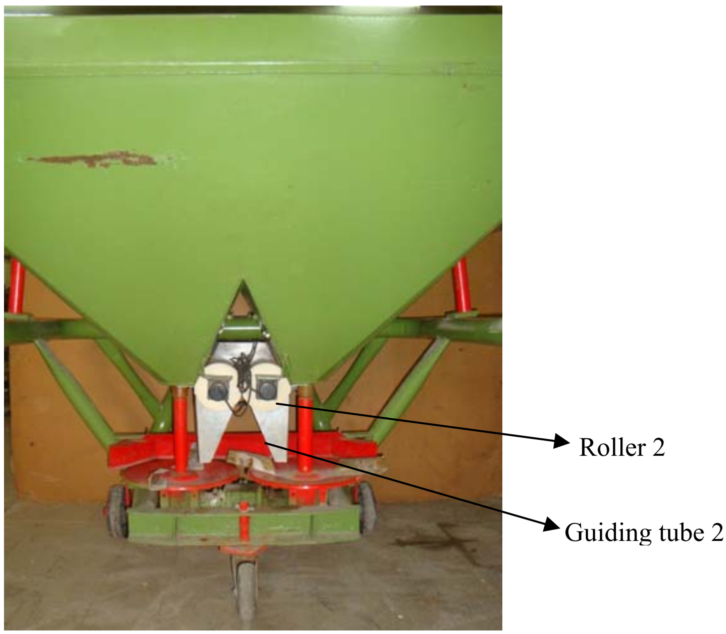

Figure 1. Rollers on spinner disc fertilizer applicator

During the performance tests of designed variable rate control system, electronic balances (Sartorius BL610, with a range of 610 g and 0.01g precision; Tamtest TTS 2010 with a range of 50 kg, and 20 g precision) were used in weight measurement.

RESULTS AND DISCUSSION

Metering efficiency of rollers was determined at different rotation speeds using two fertilizers (CAN and Composite) in laboratory condition. The physical properties of the fertilizers used in the tests are tabulated in Table 1.

Table 1. Physical properties of fertilizers

Properties	Fertilizer	
	20:20:0 Compose	26% CAN
Volume Weight	956.44 kg m^{-3}	988.74 kg m^{-3}
Moisture	4.24%	3.11%
Sieze range	% fertilizer	
> 3.15 mm	25.90	0
3.15 - 2.50 mm	37.79	32.88
2.50 - 2 mm	23.87	52.64
2-1 - 60 mm	7.24	6.09
1.60 - 1 mm	3.16	5.01
1 - 0.8 mm	0.51	2.21
< 0.8 mm	1.50	1.15

Quadratic functions (1) written below were developed for each roller for metering different fertilizers (Table 2). The coefficients of determination (R^2) of the functions are greater than 98%, except one. Although the equations developed for dosage were found the same, they release different amount of fertilizers. This case is valid for (both) fertilizer types. These differences occurred due to the friction forces on bearings. Preliminary tests showed that mixing agitators failed in properly feeding the rollers. As a result, the agitators were redesigned and manufactured.

$$W = as^2 + bs + c \tag{1}$$

where:
W [g] - flow rate,
s [min^{-1}] - revolution of metering roller,
a, b, c [-] - regression coefficients.

Table 2. Data belong to flow functions.

Fertilizer / Roller	1. Metering Roller				2. Metering Roller			
	a	b	c	R^2	a	b	c	R^2
26% CAN	0.73535	177.8408	242.556	0.9950	0.89884	206.8403	737.28	0.9802
20.20.20 Compose	0.6951	162.1907	1120.57	0.9876	0.70012	147.3279	110.454	0.9604

As seen in Figure 2 and 3, the relationship between the dosage and revolution of the rollers was parabolic. Hence, the revolution ranges of rollers were delimited considering the top points of curves and the practical fertilizer application rate. In practical conditions, fertilizer application in the field is not achieved in a single operation and at each application the fertilizer rate is no more than 400–500 kg ha^{-1}. As a conclusion, the maximum application rate of 400 kg ha^{-1} was chosen and calibration data were reanalyzed (Table 3). The analyses resulted in linear functions with high R^2, and they were used in control algorithm (Fig. 4 and 5). Function was defined as below:

$$s_i = dw_i + e \tag{2}$$

where:
s_i [min^{-1}] - metering roller revolution,
w_i [g] - flow rate,
d, e [-] - coefficients.

It was found that there was a difference between two rollers while pouring the same amount. Roller 2 poured more than roller 1 under the same conditions (Table 4). In calcium ammonium nitrate metered at 200 kg ha^{-1} rate, the difference was almost 4 kg (0.02%). As the rate increases, the difference became smaller; it reached to 50 kg (11%). On the other hand, the difference was high in composite fertilizer as compared to ammonium. It increased dramatically when the composite fertilizer was used.

Table 3. Data belong to linear flow function.

Fertilizer / Roller	1. Metering Roller			2. Metering Roller		
	d	e	R^2	d	e	R^2
26% CAN	0.0099	-11.6116	0.9514	0.0083	-5.42	0.9545
20.20.0 Compose	0.0105	-1.7194	0.9709	0.0106	-6.21	0.9618

Table 4. Data belong to dosage tests.

Fertilizer	Calcium Ammonium Nitrate			Compose 20.20.20		
Test Rate	Metering Roller 1 (g 10 s^{-1})	Metering Roller 2 (g 10 s^{-1})	Application Rate (kg ha^{-1})	Metering Roller 1 (g 10 s^{-1})	Metering Roller 2 (g 10 s^{-1})	Application Rate (kg ha^{-1})
200 kg ha^{-1}	2982	2382	198.468	2842	3311	227.661
	2781	2273	186.998	2890	3298	228.956
	2864	2369	193.621	2882	3333	229.955
300 kg ha^{-1}	4226	4218	312.428	4349	5089	349.206
	4261	4156	311.429	4353	4940	343.841
	4012	3942	294.298	4450	4967	348.429
450 kg ha^{-1}	6754	6811	501.905	6863	7779	541.754
	7319	7402	544.677	6465	7244	507.233
	6688	6741	496.873	6430	7275	507.085

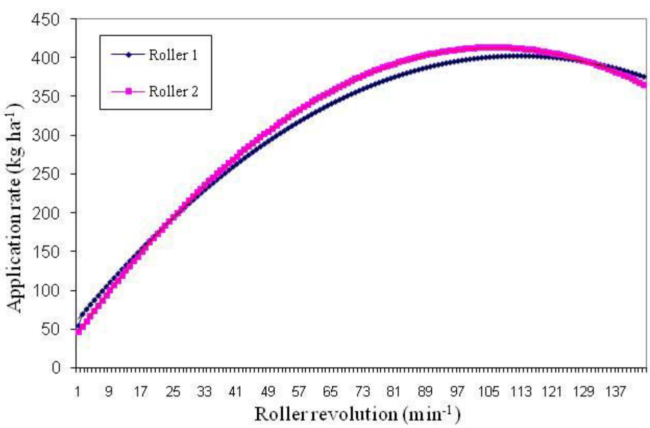

Figure 2. Dosage efficiency of rollers in 26% CAN application (kg ha^{-1})

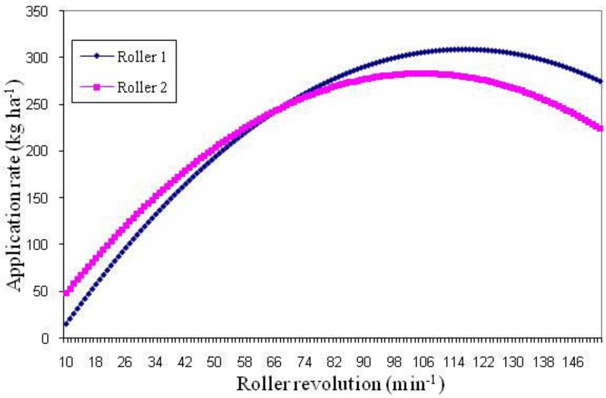

Figure 3. Dosage efficiency of rollers in 20:20:0 Composite application (kg ha^{-1})

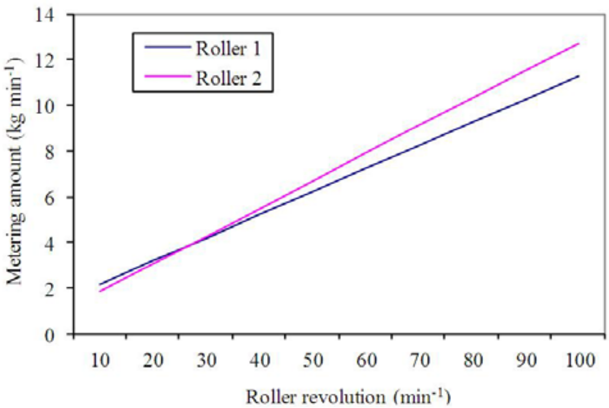

Figure 4. Calcium ammonium nitrate metering function (Roller 1 and 2)

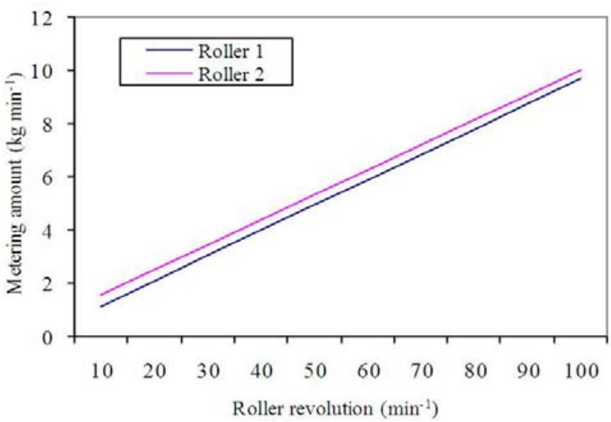

Figure 5. Composite fertilizer (20:20:0) metering function (Roller 1 and 2)

A prototype of variable rate fertilizer spreader using a frame of commercially available spinner disc fertilizer spreader was developed considering the country-specific conditions in this study. The machine was mechanically modified and equipped with metering rollers, an electronic control unit, a speed control unit, and a DGPS module. Each roller can be controlled individually and this helps in the use of only one roller, as it is the case for applying fertilizers to the field's border.

As expected, the dosage efficiency showed variations depending upon the physical properties of the fertilizers used in the study. Beside them, filling efficiency was another important phenomenon for rollers in terms of metering. So, the dosage amount of rollers in certain revolutions for composite fertilizer (with a different volume weight, granule size and shape) differed from that of calcium ammonium nitrate: The amount for calcium ammonium nitrate is less than that of composite fertilizer (Fig. 6 and 7). In the light of these contributions, it is necessary to generate flow functions for different types of fertilizers.

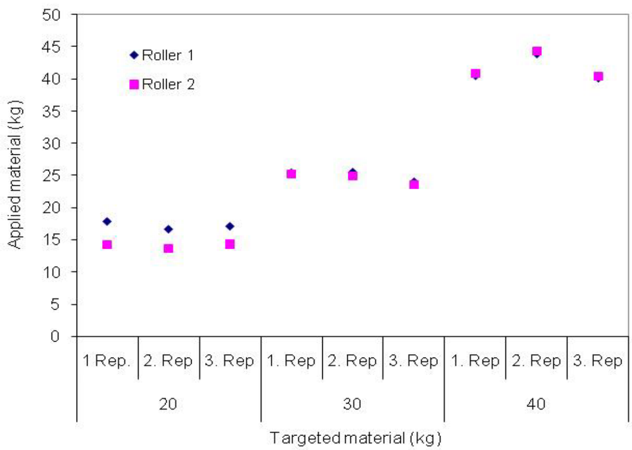

Figure 6. CAN dosage test (Roller 1 and 2)

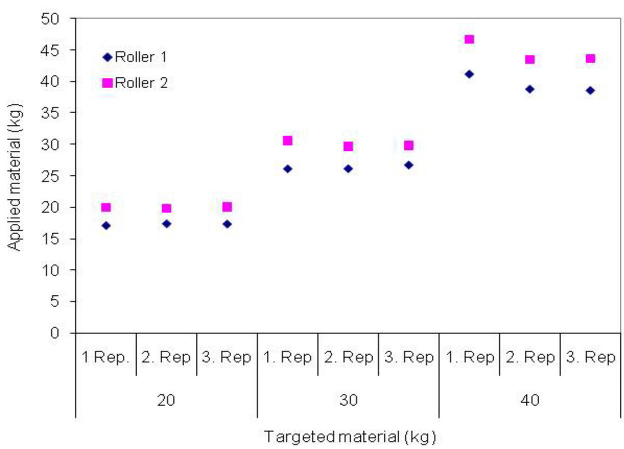

Figure 7. Composite dosage test (Roller 1 and 2)

As seen in Figures 6 and 7, the relationship between the dosage and revolution of the rollers was parabolic. This means that the dosage amount peaks and then decreases due to the filling efficiency of rollers as the rpm increases. Hence, the revolution ranges of rollers should be delimited considering the peak points of curves. This negative effect of rollers due to speed and fertilizer were eliminated in the software by modifying the dosage functions so that rollers release the corresponded rate to the entered rate to control the unit precisely up to 400 kg ha^{-1}, but there were small variations beyond this rate.

CONCLUSIONS

In this study, a variable rate fertilizer system was developed which allows releasing the target fertilizer rate to match the crop and soil requirements and places the fertilizer as accurately as possible in the fertilized zone. A control program in C++ software environment, using the Raisonance 8051 IDE tool, was developed. The results of the study revealed that the system can be attached to local made spreaders with some mechanical modification to adjust fertilizer application rate effectively. Quadratic functions were developed for each roller for metering different fertilizers. The coefficients of determination (R^2) of the functions are greater than 98%. Further developments are intended for practical use. Experimental tests are planned in field conditions to investigate the performance of the system, optimize settings, and to verify if any modifications are required before the system can be used in farm conditions.

BIBLIOGRAPHY

[1] Akdemir,B., Sağlam, N., Bellitürk K., Aydogdu, B. 2007. Development a variable rate controller for centrifugal fertiliser (Design the system), *4th Intenrational Symposium on Intelligent information technology in Agriculture*, 26-29 October 2007, Beijing, China.

[2] ASAE S358.2. 2003. *Moisture measurement*. St. Joseph, Mich. ASAE Organization, USA.

[3] ASAE S281.3. 2004. *Capacity designation of fertilizer and pesticide hoppers and containers*. St. Joseph, Mich. ASAE Organization, USA.

[4] Cerri, D.G.P., Balastreire, L.A., Amaral, J.R. 2002. Development of a variable rate lime application system. In: Proceedings of the *World Congress of Computers in Agriculture and Natural Resources*, Brazil, p.p. 238-243

[5] Çarman, K. 1988. Santrifüjlü Kimyasal Gübre Dağıtma Makinalarında Bazı Yapısal Özelliklerin Dağılım Düzgünlüğüne Etkisi Üzerine Bir Araştırma. *Doktora Tezi*. Selçuk Üniversitesi, Fen Bilimleri Enstitüsü, p: 151.

[6] Fulton, J.P., Shearer, S.A., Stombaugh, T.S., Higgins, S.F. 2001. Pattern assessment of a spinner disc variable-rate fertilizer spreader. In: *ASAE Annual International Meeting* California. pp: 20.

[7] Grift, T.E., Kweon, G. 2006. Development of a uniformity controlled granular fertilizer spreader. In: *2006 ASABE Annual International Meeting*. Portland, Oregon. pp: 14.

[8] Lal, R. 2008. Soils and world food security. *Soil and Tillage Research* 102, 1-4.

[9] Önal, İ. 2006. Ekim, Bakım, Gübreleme Makinaları. Ege Üniversitesi, *Ziraat Fakültesi Yayınları*, No: 490, İzmir. p: 606.

[10] Taşer, Ö.F. 1988. Diskli Gübre Dağıtma Makinalarında Farklı Tip Kanat Profillerinin Gübre Dağılım Desenine Etkileri. *Doktora Tezi*. Ankara Üniversitesi, Fen Bilimleri Enstitüsü. p: 108.

[11] Tekin, A.B. 2005. Değişken Düzeyli Uygulamaya Yönelik Mineral Gübre Dağıtma Makina Tasarımı Üzerine Bir Araştırma. *Doktora Tezi*. Ege Üniversitesi, Fen Bilimleri Enstitüsü, p:135.

[12] Yıldıran, Y. 2002. Diskli Gübre Dağıtma Makinalarında Dağılım Düzgünlüklerinin İyileştirilmesi Üzerine Bir Araştırma. *Doktora tezi*. Atatürk Üniversitesi, Fen Bilimleri Enstitüsü

SISTEM KONTROLE PROMENLJIVIH NORMI ZA DISKOSNI RASIPAČ ĐUBRIVA – "PreFer"

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Sažetak: Ciljevi ove studije bili su: razvoj sistema kontrole norme đubrenja koji omogućava primenu granuliranog đubriva sa promenljivim normama đubrenja, njegovu primenu sa komercijalnim rasipačem granuliranog đubriva i zatim ispitivanje i ocena njegovih performansi. Razvijen je program kontrole u C++ softverskom okruženju, koristeći alat Raisonance 8051 IDE. Sistem je testiran u laboratorijskim uslovima. Svaki od valjaka je pri različitim normama aplikacije skoro podjednako oslobađao đubrivo. Sistem se može lako ugraditi na lokalno pravljene rasipače uz neke mehaničke modifikacije. Dalja ispitivanja su potrebna da bi se potvrdile performanse sistema u poljskim uslovima.

Ključne reči*: precizna poljoprivreda, diskosni rasipač đubriva, promenljive norme đubrenja*

Prijavljen: *Submitted*: 31.05.2013.
Ispravljen: *Revised*:
Prihvaćen: *Accepted*: 10.06.2013.

Univerzitet u Beogradu
Poljoprivredni fakultet
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Broj 2, 2013.
Strane: 55 – 69

University of Belgrade
Faculty of Agriculture
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Scientific Journal
AGRICULTURAL ENGINEERING
Year XXXVIII
No. 2, 2013.
pp: 55 – 69

UDK: 631.536

Originalni naučni rad
Original scientific paper

AERODYNAMIC AND SOLIDS CIRCULATION RATES IN SPOUTED BED DRYING OF CARDAMOM (Part 1)

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Abstract: Two dimensional spouted bed units with flexible bed dimensions were used with draft tubes to study spouting pressure drop and minimum spouting velocity, solids circulation rate and average cycle time. The data were collected while varying slant angle, draft tube height, separation distance and height of bed using cardamom. The variables which affect the spouting pressure drop and airflow through the beds are discussed. Empirical correlations were developed following the principles of dimensional analysis and similitude. The developed correlations were in accordance with the collected data. The article has been divided into two parts where the first part includes the analysis for spouting pressure drop and minimum spouting velocity and the second parts includes the solids circulation rate and average cycle time.

Key words: *Spouting pressure drop, minimum spouting velocity, solids circulation rate, average cycle time, dimensional analysis, Elettaria cardamomum, Conical-Cylindrical Spouted Bed (CSB), curing chambers, rectangular orifices*

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The authors are grateful for the financial support provided by Canadian International Development Agency (CIDA) and Natural Sciences and Engineering Research Council (NSERC) of Canada.

INTRODUCTION

Drying is one of the most important processes as it affects the quality of the final product. Cardamom commonly known as the 'queen of spices' is a valuable spice obtained from the seeds of *Elettaria cardamomum*. It is grown in the coastal regions of India and several other countries. In order to preserve for longer period of time and also to enhance its aromatic flavor, fresh green cardamom is subjected to drying process. Several drying processes are used for this purpose, most commonly sun drying and cardamom curing chambers; however these traditional techniques have lower efficiency and also negatively affect the quality of the final product [1].

Spouted bed is a dynamic fluid-solid system which has a wide range of applications for processing of heat-sensitive coarse particles, such as grains and cereals [2]. Two-Dimensional Spouted Bed (2DSB) is a modified form of the Conical-Cylindrical Spouted Bed (CSB). It has a rectangular bed cross-section and vertical plane walls. The process of spouting in a 2DSB is the same as that in a conical-cylindrical spouted bed [3]. The spouting air enters the bed through a slot located at the center of the bottom of bed and runs parallel to the length of the bed. The insertion of draft tube above the air entry slot in the bed, parallel to the length, provides two independent down comers, one on each side of the spout. As the draft tube is fixed in the bed for a required separation distance, a rectangular orifice is formed on the side of spout in each down comer [4, 5].

The flow of grains through these orifices should be governed partially by bulk solids flows [6]. The air flowing through the entry slot has to pick the grains coming from the orifice, accelerate and convey them over the separation distance to the top of the bed and overcome air loss through grain voids via the rectangular orifices to the down comers for smooth operation of the bed. Since the spouting fluid has to overcome the forces of inertia, gravity, friction and fluid viscosity, spouting pressure drop occurs during the operation. A systematic cyclic pattern of solids movement are stabilized in a steady state operation [7].

Basically, spouting pressure drop, minimum spouting velocity are some of the major parameters which shape-up the systematic operation of a slotted 2DSB with draft tube and they are very important from the design and scaling point of view [8]. These parameters are being considered for the development of mathematic models based on dimensional analysis and similitude principles for a batch type slotted 2DSB with draft tube [9-11]. The addition of a draft tube has been proven to act as a beneficial constraint which helps in terms of a better definition of both the gas distribution and the solids motion pattern during various processes such as drying [12], coal gasification, combustion, [13, 14] pyrolysis of hydrocarbons [11] and production of pharmaceuticals [15, 16].

Draft tube installed above the air entry slot in a spouted bed leads to better grain circulation, reduced pressure drop, lower air velocity requirements and increased maximum spoutable bed height [17-19], Moreover, Law *et al*. (1986)[20] stated that spouting pressure drop was higher at the minimum superficial velocity than at superficial velocities greater than the minimum spouting velocity. When the draft tube is present in a bed of given dimensions, spouting pressure drop and airflow through the bed vary when either slant angle, spout diameter and separation distance is changed. This happens due to variation of normal distance. Barroso and Massarani (1984)[21] also developed spouting pressure drop and minimum spouting velocity equations for soybeans and rice as a function of separation distance. Since their equations do not fully account for the particle and spouting fluid properties and bed geometry, they cannot be applied with confidence to other bed geometries.

The objective of this research was to investigate the factors influencing the spouting characteristics of spouted bed with draft tube; taking into account grain particle parameters in order to provide a sound basis for the design of commercially viable units.

MATERIAL AND METHODS

Theory and model development: In a two-dimensional spouted bed with draft tube, the air passing through the bed has to accelerate as well as convey the grains coming from the rectangular orifices in the vertical direction for the stable operation of bed. In this situation, the total pressure drop at the bottom of the bed varies with the size of orifice, size of air inlet, height of draft tube, the ratio of solids to air, type of solids to be spouted, fluid properties and other bed geometry. For a given bed geometry, the spouting air flow through the bed varies with slant angle, draft tube height, normal distance, width of bed, length of bed, height of bed, particle properties and fluid properties.

Since the system of spouting in this configuration is very complex in comparison to conventional CSBs, a dimensional analysis scheme was employed. The relevant variables for 2DSB dynamics (i.e., spouting pressure drop, minimum spouting velocity, solids circulation rate and average cycle time) are listed in Tab. 1 with the following assumptions:

- Bulk solids consist of particles which are small in comparison to the bed dimensions that they can be considered to be a continuous mass.
- Bulk solids have the same mechanical properties in any direction inside the bed.
- The rate of flow of grains through the orifice is independent of bed height because normal distance is always less than the bed height.
- Frictional forces between particles in down comers and the column walls are negligible compared to other forces.
- Grains are uniform in shape and free flowing.
- The void fraction in the down comer is uniform and is approximately equal to that of a loose packed bed.
- The particles move through the down comers in a plug flow manner.
- Grains are linearly distributed over the entrainment zone and are picked up by air uniformly.
- Solids velocity in the down comer is much lower than fluid velocity and may therefore be neglected.
- Air compressibility is neglected due to the relatively low pressures involved.
- Resistance to air flows through the down comers are higher than in the spout.
- The effects produced by broken seeds, foreign materials and bed shrinkage are not incorporated in the mathematical model.

It should be noted that all the variables in Tab. 1. constitute a unique set. They were chosen because they appeared convenient for the experimental and analytical phases of study.

Table 1. The pertinent variables for the mathematical modeling of fluid and particle dynamics in the 2DSB with draft tube

Symbol	Variable	Unit
P_s	Spouting pressure drop	Pa
U_f	Minimum spouting velocity	$m \cdot s^{-1}$
ρ_ϕ	Dry air density	$kg \cdot m^{-3}$
μ	Absolute viscosity	$kg \cdot m^{-1} s^{-1}$
g	Acceleration due to gravity	$m \cdot s^{-2}$
V_p	Average particle velocity	$m \cdot s^{-1}$
Q_p	Volumetric flow rate of grains	$m^3 \cdot s^{-1}$
S_p	Solids circulation rate	$kg \cdot s^{-1}$
M_p	Mass of grains in the spouted bed	kg
t_c	Average cycle time	s
d_p	Geometric diameter of particle	m
ϕ	Sphericity	--
ρ_β	Bulk density of grains	$kg \cdot m^{-3}$
ρ_π	Particle density of grains	$kg \cdot m^{-3}$
E_v	Bed voidage	---
W_b	Width of spouted bed	m
W_d	Width of a down-comer of spouted bed	m
L_b	Length of spouted bed	m
H_b	Depth of grains in spouted bed	m
H_t	Height of draft tube	m
D_i	Diameter of air entry slot	m
θ_σ	Slant angle	--
D_s	Diameter of draft tube or spout	m
W_o	Normal distance	m

Table 2. Repeating variables for the mathematical models and variables representing mass, length and time

Symbol	P_s	U_f	S_p	t_c	
ρ_ϕ	-	+	+	-	
g	+	+	+	-	
S_p	-	-	-	+	
M_p	-	-	-	+	
d_p	-	+	-	+	
ρ_π	+	-	-	-	
H_t	+	-	-	-	
W_o	-	-	+	+	
	L	H_t	d_p	W_o	d_p
	M	$\rho_\pi H_\tau^3$	$\rho_\phi \delta_\pi^3$	$\rho_\phi \Omega o^3$	M_p
	T	$(H_t/g)^{1/2}$	$(d_p/g)^{1/2}$	$(W_o/g)^{1/2}$	S_p/M_p

+ = Variable in the theoretical model,
- = Variable not in the theoretical model

Buckingham (1914) [22] stated that if there is a dimensionally homogeneous equation relating '*n*' quantities defined in terms of '*r*' reference dimensions, then the equation may be reduced to a relationship between (*n-r*) independent Dimensionless

Products (DPs or PI) provided that the members of the reference set be themselves chosen so as to be independent of one another. Hence, the fundamental basis for Buckingham's PI theorem is that a valid physical equation must be dimensionless, or to reduce to like dimensions on both sides of the equality sign. Tab. 2 reveals that there can be three reference dimensions of MLT selected on the basis of ease of use, influence, independence from one another and literature data on spouted beds and granular flow through orifices. In view of this, the selected repeating variables for spouting pressure drop, minimum spouting velocity are given in Tab. 2 along with the variables representing the MLT reference dimensions.

Spouting pressure drop theory indicates that the airflow through the bed is not fixed constants but are functions of other variables. For a given bed geometry, the spouting air flow through the bed varies with slant angle, normal distance, width of bed, length of bed, height of bed, height of draft tube, particle properties and fluid properties. The variables that are important for the analysis of air and solids dynamics were selected. A list of variables for the mathematical modeling of 2DSBs with draft tube is given in Table 1. It should be noted that not all of these variables are necessarily important for each operational phase of spouted beds.

The normal distance (W_o) of the orifice was calculated from relationship of separation distance (H_E) and slant angle (θ_s): $W_o = H_E \cos\theta_s$

Spouting pressure drop: In the dimensional matrix, let the first variable be the dependent variable, let the second variable be that which is easiest to regulate experimentally [23]. Let the third variable be that which is next easiest to regulate experimentally and so on. In this way, the pertinent variables proposed in Tab. 1 for the modeling of spouting pressure drop were arranged and then reproduced.

$$F\,(P_s,\ U_f,\ \rho_f,\ \mu,\ g,\ Q_p,\ d_p,\ \rho_p,\ \phi,\ E_v,\ W_o, D_s,\ \theta_s,\ L_b,\ H_b,\ W_i,\ D_i,\ W_b,\ H_t)=0 \qquad (1)$$

Taking the independent variables from Eq. 1 and using the repeating variables for the MLT reference dimensions given in Tab. 2, the following dimensionless *PI* numbers were generated for the *Ps* in Eq. 2:

$$F\,[P_s/g\rho_p H_t,\ U_f^2/gH_t,\ \mu^2/g\rho_f 2d_p^{\,3}, Q_p/Q_f,\ d_p/H_t,\ \rho_p\text{-}\rho_f/\rho_f, \phi,\ E_v,\ W_o/H_t,\ D_s/H_t,\ \theta_s,\ L_b/H_t,\ H_b/H_t,,\ W_b/H_t,\ D_s/D_i]=0 \qquad (2)$$

The dimensional numbers can be transformed in to some well known dimensionless numbers in order to simplify the relationship for spouting pressure drop. The number of dimensionless terms should however remain the same after transformation; otherwise, the new products do not form a complete set. The transformed numbers which were used in the analysis of data for establishing the following relation for spouting pressure drop are shown:

$$F[P_s/g\rho_p H_t, Fr, Ar, Q_p/Q_f,\ d_p/H_t,\ \rho_p\text{-}\rho_f/\rho_f,\ \phi,\ E_v,\ W_o/H_t,\ D_s/d_p,\ \theta_s,\ L_b/W_o,\ H_b/H_t, W_b/W_o,\ D_s/D_i]=0 \qquad (3)$$

where, *Fr* and *Ar* are Froude number and Archimedes number, respectively.

Minimum spouting velocity: However, this is not a unique set, since other groups of fifteen independent products could be formed from the *PI* numbers given in Eq. 3 by multiplication or division. It should be noted that this procedure of theoretical development of spouting pressure drop was also applied to the minimum spouting velocity regardless of number of pertinent variables and the following dimensionless numbers were obtained:

$$F\,[U_f^2/gd_p,\ \mu^2/g\rho_f^2 d_p^3,\ \rho_p\text{-}\rho_f/\rho_f,\ \phi,\ E_v,\ W_o/d_p,\ D_s/d_p,\ \theta_s,\ H_b/d_p,\ L_b/d_p,\ W_b/d_p,\ H_t/d_p]=0 \tag{4}$$

The dimensionless products of Eq. 4 were transformed into the following dimensionless products for establishing the relation for superficial spouting velocity through the spouted bed at the minimum spouting conditions:

$$F\,[Ar,\ \rho_p\text{-}\rho_f/\rho_f,\ \phi,\ E_v,\ W_o/L_b,\ D_s/W_o,\ \theta_s,\ W_b/H_t,\ d_p/W_i,\ W_b/W_o,\ H_t/H_b]=0 \tag{5}$$

Experimental methods and procedures: The spouted bed drier used for the study (Fig. 1) consists of a motor-blower assembly, heating chamber, hot air delivery duct, temperature controller, plenum chamber and spouted bed chamber. The equipment was fitted with an energy meter. The motor-blower assembly is built-in type, run by three phase electric supply and has provision to adjust the airflow rate at suction side. The heater is connected to the suction side of the blower, which is made in cylindrical shape, with a heating coil of 2kW capacity connected in series. A temperature controller is provided to control the temperature of the inlet hot air. A ball valve is fitted in between the hot air delivery duct and spouted bed to keep the cardamom capsules at minimum spouting condition by adjusting the airflow rate.

The mechanical design of two-dimensional spouted bed was primarily aimed to permit variation of bed length, bed width, slant angles, air entry slots, separation distance and draft tube height. A rectangular frame with four support legs was made from angle iron and it was made in such a way to accommodate the spouted bed-drying chamber. The drying chamber was made of 0.01m thick plexiglass to visualize the material flow pattern. The sides of the bed were constructed using plexiglass and reinforced with screws at specified intervals. The width sides of the bed were rigidly fixed. The length sides of the unit can be clamped on the width sides of the bed. The unit can accommodate different slanting on the length sides. The unit was built with 0.50 m width, 0.15 m length and 1.2 m height. The unit can handle a maximum capacity of five kilogram of cardamom excluding the fountain portion.

The spout pressure measuring taps were positioned starting at 0.01 m and at intervals of 0.10 m from the bottom of the bed throughout the height. The spout pressure taps were fixed on one width side of the bed. The spouting pressure drop was measured using a U-tube manometer. The down comer pressure measuring taps were installed on the length side of the bed above the slanting base at an interval of 0.10 m. To eliminate potential stagnation zones, the slanting base plates were inclined at 45° and 60°. A parabolic deflector made of metal sheet was mounted above the draft tube to limit the spout height and aid the material circulation by directing the particles from the spout to the down comer. The circular air inlet nozzle was covered with wire mesh, which helped to distribute the air uniformly. Two guide ways were provided on either side of the down comer in order to maintain the cyclic movement of the material and also to obtain uniform dried product. A door-like structure was made on the width side of the bed to feed the material directly into the chamber. A shutter was provided on each side at the bottom of the bed in order to ease the discharge of the material.

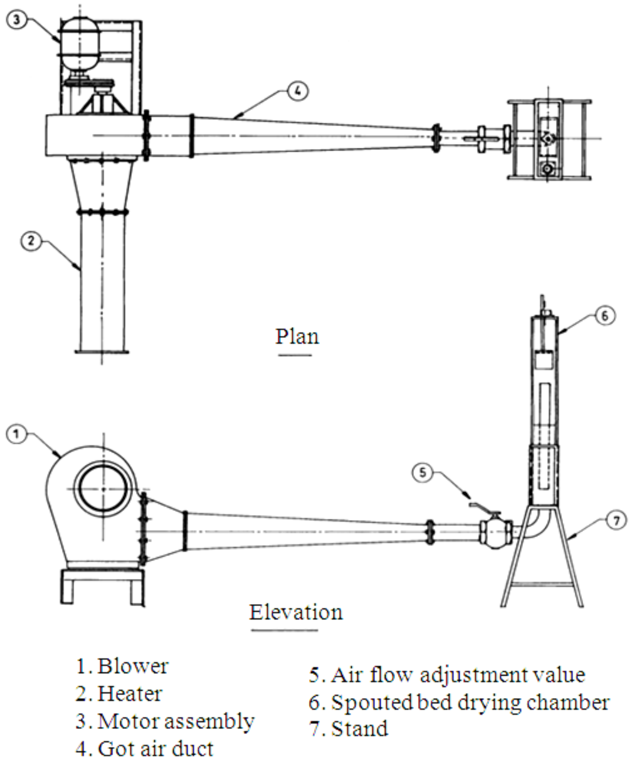


Figure 1. Schematic diagram of spouted bed dryer

The thermocouples were inserted at various points on one side of the bed to measure the down comer temperature. An energy meter was provided to measure the number of units of energy for each experiment. The two sided slanted base inclined at 45° and 60° to the side walls connected to a circular air entry slot which was covered with wire mesh to prevent the cardamom capsules going down. A draft tube was installed centrally above the air entry slot. Thermocouples for recording bed temperature were positioned centrally in both down comers and an additional thermocouple was embedded into the external and internal sides of a down comer wall along the plexiglass to monitor heat losses. Temperatures at all measuring points were recorded by a digital thermometer with an accuracy of ±0.1°C. Air velocity was monitored by a thermal anemometer accurate to ±3 %. Inlet and outlet air humidities were monitored continuously by a Humidity meter with the least count of ±0.1%.

RESULTS AND DISCUSSION

The data on grain aerodynamics from the experiments on slant angle, separation distance, draft tube height, variation of bed height of cardamom were pooled and then used to generate the *PI* terms in the models proposed for spouting pressure drop, minimum spouting velocity. The PI terms were then linearized by the natural logarithm transformation. The data were analyzed by full model regression using the M-STAT. A number of alternative models were created by multiplying or dividing *PI* terms, while maintaining both the independence of these terms and the total number of terms in each original formulation. The models were evaluated using the following criteria: the R^2 statistic, standard error, level of significance (α), residual characteristics and the number of terms in the model. The final selected models describing the dynamic phenomena of two-dimensional spouted bed with draft tube have been presented in the following sub-sections.

Spouting pressure drop: The variation of spouting pressure drop with change in variables is given in Figs. 2 and 3. From the figures it is clear that increased slant angles produced a positive effect on spouting pressure drop in all the spouting conditions. Spouting pressure drop increased from 117-333 Pa with an increase in slant angle from 45-60°. The spouting pressure drop was increased from 225-333 Pa while the slant angle changed from 45-60° under the spouting conditions of 40°C air temperature, 7.5 cm separation distance, 60 cm draft tube height with tempering period of 30 min. Possible cause for this trend may be due to the fact that higher air flow rates were required to keep the material in spouting conditions at 45° slant angle than at 60° slant angle and hence the air velocity at the fountain was also more at 45° than at 60° slant angle.

The effect of separation distance on the spouting drop associated with spouted bed drying of cardamom has been shown in Figs. 2 and 3. The data shows that the spouting pressure drop increased with separation distance and the similar effects were reported for small scale CSB's [19] for two dimensional spouted beds [2, 20]. This increase in spouting pressure may be attributed to the higher number of cardamom capsules entering the spout and at the same time spouting air pushing the grains towards the down comer sides to keep the spout open. In these experiments, the highest-pressure drop of 333 Pa was produced when the separation distance was increased from 5-7.5 cm.

The spouting pressure drop data collected in this study indicated that the spouting pressure drop increased as the draft tube height increased from 40-60 cm (Figs. 2 and 3). This increase in spouting pressure drop might be due to dissipation of energy from the air, which is more when the draft tube height is increased. It may be concluded that the spouting pressure drop at the minimum spouting conditions was most affected by separation distance followed by slant angle.

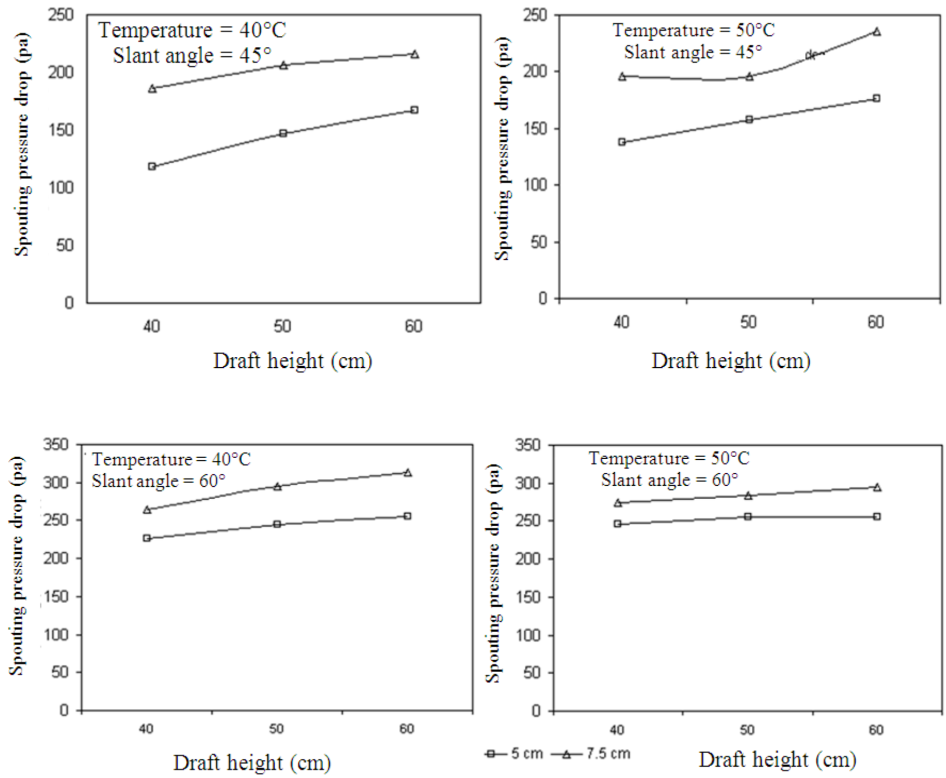
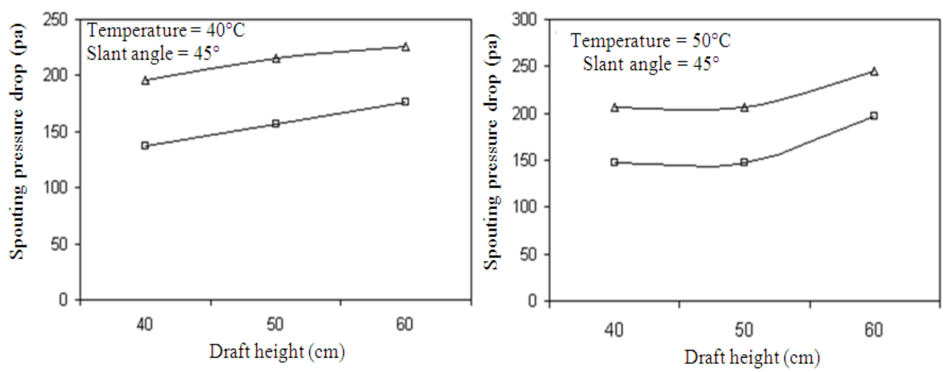


Figure 2. Effect of draft height (H_f) on spouting pressure drop at indicated separation distances for cardamom



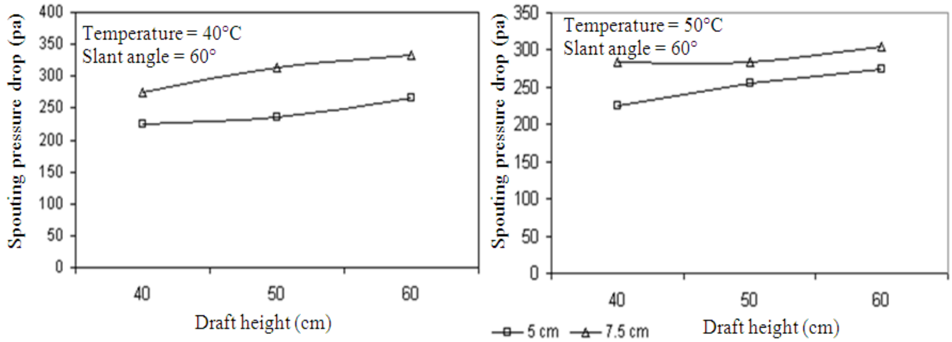


Figure 3. Effect of draft height (H_t) on spouting pressure drop at indicated separation distances with tempering period for 30 min for cardamom

The model developed for the spouting pressure drop is Eq. 6:

$$P_{s\,/}\,g\,P_p\,H_t = (U_f^2/g\,H_t)^{-0.4512}\,(d_p/H_t)^{0.1595}\,(W_o/H_t)^{0.501}\,(H_bW_b/H_tW_o)^{0.0019}\,(\theta_s)^{1.56} \qquad (6)$$

The model has R^2 = 93.44%, standard error of estimate =0.0274, α = 0.0001. The residuals exhibited a random distribution when plotted against predicted values of spouting pressure drop (Fig. 4b). A plot of observed versus predicted values for the selected model of spouting pressure drop has been shown in Fig. 4a. The estimates from the model deviated, on average, by ±2% from the collected data.

Minimum spouting velocity: The airflow monitored in the air supply conduit during the studies was divided by the cross-sectional area of the spouted bed to get the superficial velocity. Some superficial velocity data through two-dimensional spouted bed have been presented in Fig. 5 and 6. From these data, it could be inferred that the superficial velocity through beds increased as the separation distance increased from 5-7.5 cm. Similar results have been reported by Buchanan and Wilson (1965)[17] and Claflin and Fane (2009)[19] for Conical-cylindrical spouted beds and Law *et al.* (1986)[20] for small scale two dimensional spouted beds and Kalwar and Raghavan (1993)[24] for pilot scale two dimensional spouted beds. This increase of superficial velocity might be due to the combined effects of:

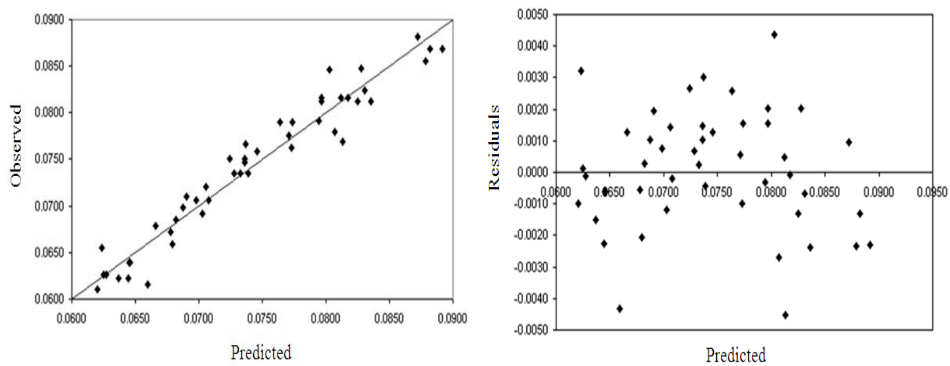
1. large number of grains entering the spout,
2. more jet air being dispersed into the down comer at larger separation distances, and
3. physical characteristics of grains leading to higher air flow rates through the spouted beds.

The superficial velocity of air through the beds also increased as the draft tube height increased from 40-60 cm for all the spouting conditions. This increase was due to higher cross-sectional area of the spout causing higher airflow requirements for transporting an increased number of capsules through the spout and to preserve stable dynamic conditions. This trend was supported by Law *et al.* (1986)[20] for small scale two dimensional spouted beds with flat bottoms, for rice beds with a slant angle of 45° by Khoe and Brakel (1983) [8] and for wheat beds with a slant angle of 60° in a conical-cylindrical spouted beds geometry by Claflin and Fane (2009)[19].

Figures 5 and 6 show the differences in superficial velocity due to slant angles. The required airflow rates were higher at a slant angle of 45° than at 60° under the same separation distance and draft tube height. The result was supported by the findings of Thorley *et al*. (1959) [25] for Conical-cylindrical spouted beds when slant angle was changed from 45-60°. It was concluded that the superficial velocity through two-dimensional spouted beds increased with separation distance and draft tube height. However, the superficial velocity decreased when the slant angle was shifted from 45°-60° for cardamom used in this study.

The mathematical model obtained from the superficial air velocity through the bed has been given below:

$$U_f/(gH_t)^{0.5} = (P_s/g\rho_p H_t)^{-0.2339} (d_p/H_t)^{0.3606} (W_o/H_t)^{0.0821} (H_b W_b/H_t W_o)^{0.0641} (Q_p/Q_f)^{-0.604} (\Theta_s)^{-0.4802} \quad (7)$$



(a) (b)

Figure 4. (a) Comparison of measured spouting pressure drop with predicted spouting pressure drop by Eq. 6 (b) Residual plot for spouting pressure drop model Eq. 6

The model has R^2 =95.63%, SE = 0.0197 and α = 0.0001. The plot of residuals against the predicted values of superficial velocity showed randomness of residuals (Fig. 7a and 7b). Hence, the developed model accounted for most of the variation found in the collected data. Using Eq. 7, the predicted values of superficial velocity were generated and compared with the entire observed values of superficial velocity. This comparison indicated that the Eq. 7 predicted with an average error of ±1.5% from the observed values.

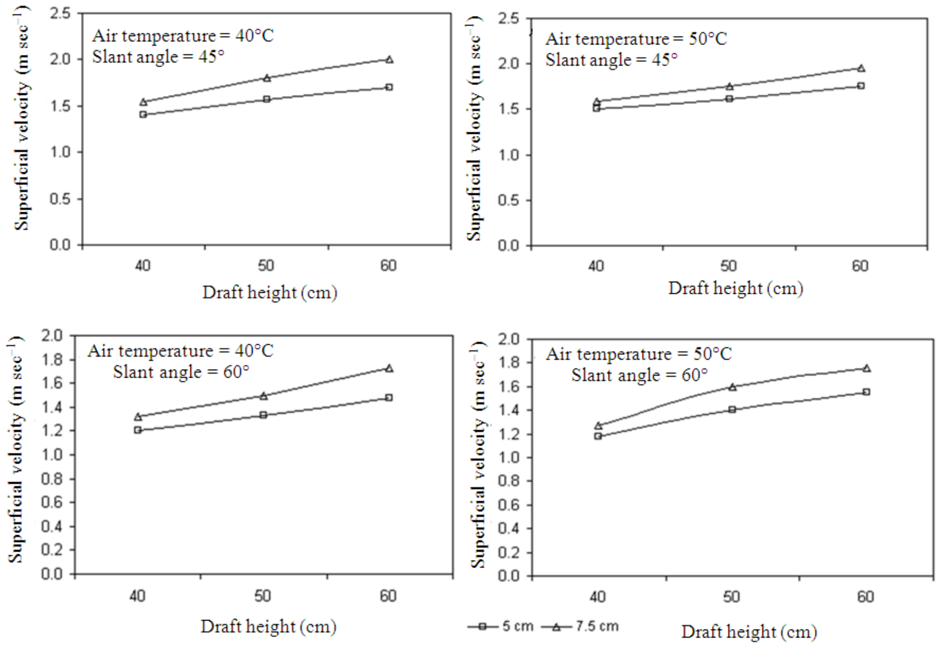


Figure 5. Effect of draft height (H_t) on superficial velocity for cardamom

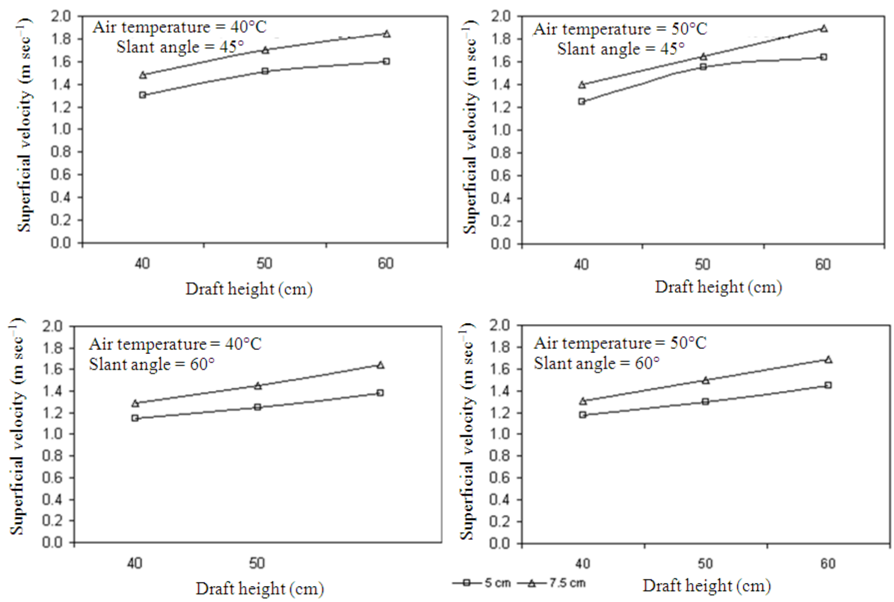


Figure 6. Effect of draft height (H_t) on superficial velocity with tempering for 30 min for cardamom

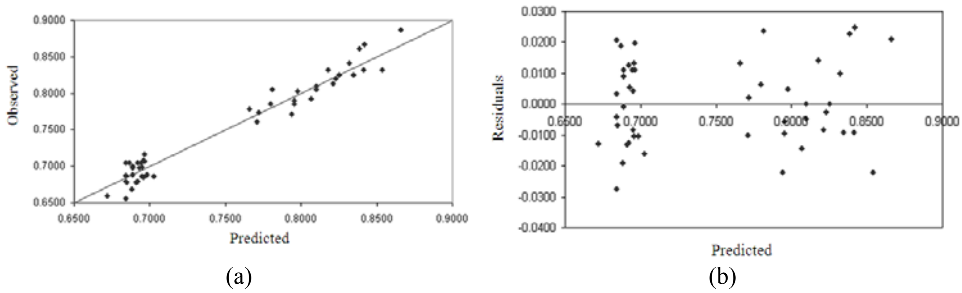


Figure 7. (a) Comparison of measured minimum spouting velocity with predicted minimum spouting velocity by Eq. 7 (b) Residual plot for minimum spouting velocity model, Eq. 7

CONCLUSIONS

Spouting pressure drop increases as the separation distance and slant angle increase. It also increases as the draft tube height increases. Minimum spouting velocity increases as the separation distance and draft tube height increase and as the slant angle decreases. The insertion of draft tube to form a tube in two-dimensional spouted bed proved very effective in controlling pressure drop, air flow and to operate in plug flow manner. Hence, the two-dimensional spouted bed with draft tube can satisfy drying requirements in practice. Empirical correlations are presented for spouting pressure drop and minimum spouting velocity. The comparison of these developed models with the experimental data indicated quite close agreement.

BIBLIOGRAPHY

[1] Mande, S., Kumar, A., Kishore, V. 1999. A study of large-cardamom curing chambers in Sikkim. *Biomass and Bioenergy*, 1999. 16(6): p. 463-473.

[2] Kalwar, M., Raghavan, G., Mujumdar, A. 1992. Spouting of two-dimensional beds with draft plates. *The Canadian Journal of Chemical Engineering*, 1992. 70(5): p. 887-894.

[3] Arsenijević, Z.L., Grbavčić Z.B., Garić-Grulović R.V. 2004. Drying of suspensions in the draft tube spouted bed. *Canadian Journal of Chemical Engineering*, 2004. 82(3): p. 450-464.

[4] Hattori, H., Morimoto, T., Yamaguchi, M., Onezawa, T., Arai, C. 2001. Drying of Porous Solid Particles in Various-Shaped Spouted Bed with a Draft-Tube. *Journal of chemical engineering of Japan*, 2001. 34(12): p. 1549-1552.

[5] Ijichi, K., Miyauchi, M., Uemura, Y., Hatate, Y. 1998. Characteristics of Flow Behavior in Semi-Cylindrical Spouted Bed with Draft Tube. *Journal of chemical engineering of Japan*, 1998. 31(5): p. 677-682.

[6] Ishikura, T., Nagashima, H., Ide, M. 2003. Hydrodynamics of a spouted bed with a porous draft tube containing a small amount of finer particles. *Powder technology*, 2003. 131(1): p. 56-65.

[7] Ji, H., Tsutsumi, A., Yoshida, K. 1998. Solid Circulation in a Spouted Bed with a Draft Tube. *Journal of chemical engineering of Japan*, 1998. 31(5): p. 842-845.

[8] Khoe, G., Brakel, V.J. 1983. Drying characteristics of a draft tube spouted bed. *The Canadian Journal of Chemical Engineering*, 1983. 61(3): p. 411-418.

[9] Osorio-Revilla, G., Elías-Serrano, R., Gallardo-Velázquez, T. 2004. Drying of Liquid Feedstocks in a Spout-Fluid-Bed with Draft-Tube Submerged in Inert Solids: Hydrodynamics and Drying Performance. *The Canadian Journal of Chemical Engineering*, 2004. 82(1): p. 142-147.

[10] Osorio-Revilla, G., López-Suárez, G., Gallardo-Velázquez, T. 2004. Simultaneous Drying and Cleaning of Guava Seeds in a Spout-Fluid Bed with Draft Tube. *The Canadian Journal of Chemical Engineering*, 2004. 82(1): p. 148-153.

[11] Stocker, R.K., Eng, J.H., Svrcek, W.Y., Behie, L.A. 1989. Ultrapyrolysis of propane in a spouted-bed reactor with a draft tube. *AIChE Journal*, 1989. 35(10): p. 1617-1624.

[12] Tulasidas, T.N., Kudra, T., Raghavan, G.S.V., Mujumdar, A.S. 1993. Effect of bed height on simultaneous heat and mass transfer in a two-dimensional spouted bed dryer. *International communications in heat and mass transfer*, 1993. 20(1): p. 79-88.

[13] Konduri, R.K., Altwicker, E.R., Morgan M. 1995. Atmospheric spouted bed combustion: the role of hydrodynamics in emissions generation and control. *The Canadian Journal of Chemical Engineering*, 1995. 73(5): p. 744-754.

[14] Konduri, R.K., Altwicker, E.R., Morgan, M.H. 1999. Design and scale-up of a spouted-bed combustor. *Chemical Engineering Science*, 1999. 54(2): p. 185-204.

[15] Fukumori, Y., Ichikawa, H. 1997. Microencapsulation of Pharmaceuticals by Fluidized Bed Process-Apparatus, Material and Particulate Designs. *Journal-Society Of Powder Technology*, 1997. 34: p. 536-544.

[16] Littman, H., Morgan, M, Morgan, C. 1997. A New Computer Controlled Wurster-Type Particle Coating Apparatus. In: *AIChE Symposium Series*. 1997. New York, NY: *American Institute of Chemical Engineers*, 1971-c2002.

[17] Buchanan, R., Wilson, B. 1965. The fluid-lift solids recirculator. *Mech. Chem. Eng. Trans,* 1965. 1(1): p. 117-124.

[18] Khoe, G., Brakel, V.J. 1980. A draft tube spouted bed as small scale grain dryer. In: *IE Chem. Symp*. 1980. *Dublin International Conference on Solids Separation Processes*.

[19] Claflin, J., Fane, A. 2009. Spouting with a porous draft-tube. *The Canadian Journal of Chemical Engineering*, 2009. 61(3): p. 356-363.

[20] Law-Kwet-Cheong, L., Malhotra, K., Mujumdar, A. 1986. Some aerodynamic and solids circulation measurements in a slotted spouted bed of grains. *Powder technology*, 1986. 46(2): p. 141-148.

[21] Barroso, M.A.S., Massarani, G. 1984. Grain Drying in Non–conventional Spouted Bed. In: *XII ENEMP1984*: Maringa (Brazil).

[22] Buckingham, E. 1914. On physically similar systems; illustrations of the use of dimensional equations. *Physical Review*, 1914. 4(4): p. 345-376.

[23] Isaacson, E.S.Q., Isaacson, M.S.Q. 1975. *Dimensional methods in engineering and physics: reference sets and the possibilities of their extension*. Wiley.

[24] Kalwar, M., Raghavan, G. 1993. Batch drying of shelled corn in two-dimensional spouted beds with draft plates. *Drying Technology*, 1993. 11(2): p. 339-354.

[25] Thorley, B., Saunby, J.B., Mathur, K.B., Osberg, G.L. 1959. An analysis of air and solid flow in a spouted wheat bed. *The Canadian Journal of Chemical Engineering*, 1959. 37(5): p. 184-192.

STEPENI AERODINAMIKE I PROTOKA ČVRSTE MATERIJE U ODVODNIM KANALIMA ZA SUŠENJE KARDAMOMA (1. deo)

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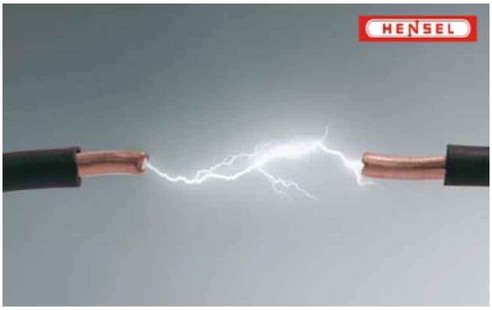
Sažetak: Za proučavanje pada pritiska u odvodnom kanalu, minimalne brzine odvođenja materijala, stepena cirkulacije čvrstog materijala i prosečnog vremena ciklusa korišćene su dvodimenzionalne jedinice odvodnih kanala sa fleksibilnim dimenzijama. Podaci su prikupljani variranjem ugla nagiba, visine pripremnog kanala, rastojanja pri separaciji i visine kanala. Analizirane su veličine koje utiču na pad pritiska u odvodnom kanalu i protok kroz kanal. Razvijene su empirijske zavisnosti korišćenjem simulacije i dimenzione analize. Razvijene zavisnosti su bile u skladu sa prikupljenim podacima. Rad je podeljen u dva dela pri čemu se prvi deo bavi analizom pada pritiska u odvodnom kanalu i minimalnom brzinom odvođenja a drugi deo stepenom protoka čvrste materije i prosečnim vremenom ciklusa.

Ključne reči: *Pad pritiska pri odvodjenju materijala, minimalna brzina odvodjenja, stepen protoka čvrste materije, prosečno vreme ciklusa, dimenziona analiza, Elettaria cardamomum, konično-cilindrični kanal za odvodjenje (CSB), komore za konzervaciju, pravougaoni otvori*

Prijavljen: *Submitted*:	04.05.2013.
Ispravljen: *Revised*:	11.06.2013.
Prihvaćen: *Accepted*:	24.06.2013.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Народна библиотека Србије, Београд

631(059)

ПОЉОПРИВРЕДНА техника : научни часопис = Agricultural engineering : scientific journal / главни и одговорни уредник Горан Тописировић. – Год. 1, бр. 1 (1963)- . - Београд; Земун : Институт за пољопривредну технику, 1963- (Београд : Штампарија ”Академска издања”) . – 25 cm

Тромесечно. – Прекид у излажењу
од 1987-1997. године
ISSN 0554-5587 = Пољопривредна техника
COBISS.SR-ID 16398594